STUDIES ON NEONATAL CALF DIARRHOEA

by

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Introduction and Review of the Literature

Diarrhoea in the bovine neonatal animal has been a preoccupation of the cattle industry for many years. Its causes and incidence have been the subject of study throughout the world (Smith, T. and Little, 1922; Gribanov, Russia, 1937; Ottosen, Denmark, 1959; U.S.A., A.R.S., 1965). Several surveys which have been carried out in Great Britain (Lovell and Hill, 1940; Withers, 1952-53; Leech, Macrae and Menzies, 1968) investigating the incidence and causes of calf mortality, have suggested that septicaemia and diarrhoea in which Escherichia coli have been implicated, are the conditions which beset to the greatest extent, the well being of the newborn calf.

Although new approaches are constantly being made leading towards a better understanding of the aetiology, pathogenesis, and prophylaxis of neonatal calf diarrhoea, the disease profile described by Jordan (1933) regarding calf diseases and particularly 'white scours' remains, despite 36 years of investigation and the introduction of new and more sophisticated therapeutic methods, much the same.

In an attempt to assess the significance of E.coli in neonatal calf disease and death, (Gay, 1965) divided the syndrome on clinical and bacteriological grounds into three forms:-

(a) The septicaemic form of coli-bacillosis (Colisepticaemia)

The death of the calf, is associated with an E.coli bacteraemia, a single strain being isolated in pure culture from the internal organs.

(b) The enteric form

This is part of the syndrome of the scouring calf. Death, when it occurs, appears to result from severe metabolic acidosis and cardiac failure, caused by fluid and electrolyte loss (Fisher, 1965 and Fisher & McEwan, 1967).

(c) The third form of the condition considered by Gay was the enteric toxaemic form. In this condition there is no bacteraemia and death is associated with the proliferation of certain strains of E.coli in the small intestine. The clinical signs of collapse and rapid death are attributed to toxaemia.

Of the three syndromes mentioned above, colisepticaemia is the best understood. It may be that the reason for the more thorough study of this pathological condition is the ease with which the condition can be reproduced in colostrum deprived calves. The significance of colostrum in the outcome of colisepticaemia, and its beneficial effects to the calf in the diarrhoeic syndrome, will be referred to later in this review.

The aetiology and pathogenesis of the diarrhoeic syndrome in the newborn calf have yet to be explained. Factors such as bacterial and viral agents, husbandry, nutrition of the calf and dam, have all been suggested as possible primary and secondary causes of the condition.

Jensen (1893, 1913) presented evidence establishing the possible aetiological significance of E.coli in calf diarrhoea, and since then an association has been demonstrated between these gram negative

bacteria and disease in the newborn of other species, including man, pig and sheep (Stock and Shuman, 1956; Stulberg, Zuelzer, 1956; Sojka, 1965; Moon, Sorensen, Sautter, 1966; Nielsen, Moon, Rae, 1968; Kohler and Cross, 1969; Smith, H.W. and Halls, 1967). Subsequent studies concerning the significance of E.coli in the development of neonatal calf diarrhoea, although prolific, have been inconclusive.

Carpenter and Woods (1924) found that the number of E.coli in the upper intestine was much greater in calves suffering from diarrhoea than in normal calves. Smith, T. and Orcutt (1925) arrived at similar conclusions. On the other hand Smith, H.W. (1962) concluded that neither E.coli nor other bacteria were concerned in the causation of diarrhoea, and he supported his conclusions with the following evidence:-

1. The absence of incriminating serological findings in affected calves.
2. The diversity of the phage types of E.coli found in the small intestine of the diarrhoeic calves.
3. The finding of the same serotypes in both healthy and affected calves.
4. The changes in the predominant phage types of E.coli occurring in the faeces of diarrhoeic calves during the scouring period.
5. The negative results in most of the transmission experiments.

Alternatively he suggested that bacteria might aggravate the primary condition, and in further studying this possibility he suggested that

the metabolic products of certain strains of E.coli were capable of producing diarrhoea in young calves and pigs (Smith, H.W. and Halls 1967a, 1967b).

Glantz, Dunne, Heist and Hokanson (1959) produced evidence that certain strains of E.coli were capable of producing diarrhoea in both calves infected experimentally and in calves living in contact with the infected ones. In these experiments, as well as in other reports, the ability to reproduce the condition and the fate of the animals affected were dependent on whether or not they had received colostrum. For example, Glantz et al, (1959) reported that when 19 colostrum-deprived calves were infected orally with E.coli strain 56 (8: K: NM), 17 had diarrhoea and 13 died; this particular strain being isolated from the faeces and organs of the dead animals. When the same strain was given orally to 5 colostrum fed calves all had diarrhoea, but only two died.

Roy, Palmer, Shillam, Ingram and Wood (1955) reported that when stocking the same calf house, the incidence of diarrhoea and death increased as the period of continuous occupation increased. They believed this to be due to a build up and natural selection of a particularly virulent strain of E.coli, conditioned by the calves' lack of antibody against the strain.

More recently, the study of the possible role that substances such as endotoxin and enterotoxin may play in the pathogenesis of diarrhoea has received increased attention. Both these substances have been considered by different authors when attempting to explain the pathogenesis of E.coli diarrhoea.

Since first isolated (Boivin, 1935) endotoxin has been called by several names including:- somatic antigen, toxic antigen, tumour necrotising substance and Schwartzman toxin. It is a phospho lipid-polysaccharide-protein complex (Gilbert, 1960) produced mainly by gram negative bacteria. Its toxic properties are generally similar regardless of the specific bacterial source of the endotoxin. The primary effects produced by endotoxin in man and different animal species have been repeatedly investigated. Studies comparing the effects of endotoxin with the effects of other organic products in the human subject and other animal species have also been reported. Bennett (1964) stated 'Few areas of research exceed the field of endotoxin in evoking the overwhelming desire of an investigator to take his findings and mould a hypothetical analogy'.

Stetson (1951) emphasised the analogy between the reaction of normal rabbits to endotoxin, and the delayed type hypersensitivity to tuberculin shown by tuberculous rabbits. He suggested that the reaction to endotoxin was also allergic and that it arose from past infections of the rabbits by gram negative bacteria. However, Braude (1964), experimenting with human tuberculous subjects, reported distinctly different reactions to the injection of tuberculin and to that of endotoxin. He found that the skin at the site where endotoxin was injected showed a form of injury typical of a hypersensitive skin reaction (The Arthus phenomenon). This prompted Braude and his co-workers to think about endotoxic shock as an anaphylactic reaction. Their subsequent work in search of the antibodies responsible for such a reaction supported their view. They found that almost every animal had natural antibodies against endotoxin. They reported, however, that the relationship between antibodies and endotoxin was a very peculiar one. It appeared that antibody could either potentiate

or inhibit the pathologic effect of endotoxin. They suggested as a possible answer that the outcome of the condition would be decided by the relative proportions of endotoxin to antibody 'if the amount of antibody exceeds the amount of endotoxin, it protects; if it does not, it may add to the toxicity.' It may be interesting to correlate their hypothesis with the findings reported later in this review regarding the augmented susceptibility of hypogammaglobulinaemic calves to E.coli invasions.

The similarity between endotoxic and anaphylactic shock in dogs was pointed out by Weil and Spink (1957). One of the main observations of these authors was that of a release of histamine into the bloodstream. The response to histamine varies in the different animal species, but it simulates the response to endotoxin and anaphylactic shock. In the dog, for example, it affects the muscle fibres of the hepatic veins giving rise to hepatic congestion. In cattle and sheep, the lung and the respiratory tract seem to be the target organs. Rats appear to be more resistant to the effects of endotoxin, but large doses will overcome such resistance. In this animal species, the shock is characterised by a constriction of the intestinal veins and haemorrhages throughout the intestine. Although intestinal haemorrhages are not a common picture in the enteric form of colibacillosis in calves, (Jarrett, 1954), Osborne (1967) reported severe haemorrhagic enteritis and abomastitis in calves experimentally infected with E.coli and its products. He successfully produced the condition by feeding E.coli cultures obtained from outbreaks of diarrhoea to colostrum-deprived and colostrum-fed calves. The main clinical sign showed by these animals was a profuse, watery, and, on occasions, bloody diarrhoea. When cell-free cultures

and whole cell cultures from the same serotypes used to produce diarrhoea were injected intravenously into calves, they produced an endotoxic-like syndrome. He described the clinical signs observed as follows:- fever, hyperpnoea, dyspnoea, coughing, respiratory grunting, cold extremities, severe diarrhoea, marked depression and death. He suggested that E.coli endotoxin, or the absorption of E.coli and a substance intimately associated with the viability of the organism, were the cause of severe gastro-enteritis in calves. It is unfortunate that the immune globulin levels of the calves were not reported, but the fact that E.coli was isolated from the internal organs of almost every calf would suggest that the majority of these animals, although stated to have been fed colostrum, were hypogammaglobulinaemic. Thus, they were highly susceptible to a possibly very virulent strain of E.coli, which not only exerted its pathogenic effect through endotoxin but also through its ability to invade.

Thomlinson and Buxton (1962-1963) having shown that in pigs and in guinea pigs, lesions similar to those which occur in natural E.coli infection also develop in anaphylactic shock, postulated that E.coli endotoxin exerts its effect through anaphylactic shock. They found that the anaphylactic shock was dependent on the immunological status of the animal. At the same time they reported that the development of gastro-enteritis was correlated to the duration of the shock.

Wray and Thomlinson (1969a and 1969b) showed a similar relationship between the duration of anaphylactic shock and the development of gastro-intestinal lesions in calves. They concluded that the gastro-intestinal

lesions observed in these calves, which could account for diarrhoea, could develop as a result of anaphylactic reaction to endotoxin. These authors produced the condition in calves by injecting and feeding soft agar culture fluid prepared from E.coli serotype 078-K80, a serotype which has been regarded as a septicaemic strain (Sojka, 1965; Rees, 1958). When comparing the effects between a soft agar culture fluid from E.coli and a phenol extracted endotoxin, they produced the same syndromes when injected intravenously into calves. By giving a large dose of the soft agar culture fluid to one-day old calves, mild shock with marked lesions of enteritis developed. They concluded that the soft agar culture fluid contained appreciable amounts of free endotoxin, biologically active. This is in accordance with findings previously reported by Marsh and Crutchley (1967).

de la Fuente and Fisher (1969), have witnessed similar results in a small number of calves by injecting intravenously the cell-free fluid from soft agar cultures of E.coli isolated from calves suffering from severe diarrhoea. Besides the onset of a marked respiratory distress, a striking finding in these animals was the vast amounts of fluid faeces passed in a relatively short period of time. The water and electrolyte content of the faeces was not significantly different from that found in dying diarrhoeic calves infected naturally.

Lovell (1955) injected calves intravenously with dialysed supernatant fluid obtained from mucoid strains of E.coli treated with trichloracetic acid. The calves showed a marked reaction, death occurring within an hour or two after the injection. He suggested that the diarrhoea in the young calf may not be caused by a local infection but by the toxic products of E.coli.

Gay, McKay and Barnum (1964b) reported a form of colibacillosis mainly affecting calves under 48-hours old. They referred to the condition as an enteric toxaemic form of colibacillosis. They reported a massive proliferatio of a certain mucoid strain of E.coli in the lower and middle portion of the small intestine. The failure to isolate E.coli from the different organs of the animal affected was indicative of the absence of bacteraemia. The condition was characterised by a sudden onset, marked depression, collapse, extreme prostration and complete loss of muscle tone. Diarrhoea was not a constant finding. In the terminal stage the pulse was weakened and the respiratory movements were shallow and infrequent. Death occurred within 6-16 hours of the onset. Although no pathology was reported, the clinical signs observed by Gay et al are similar to those reported by other workers observing endotoxic shock in calves.

Whether endotoxin exerts its pathological effects by virtue of some intrinsic pharmacological activity, or whether the reactions to the endotoxin are mediated by immunological or hypersensitive phenomena is still a matter of speculation. The striking similarities between the endotoxic shock and the shock produced by foreign antigen in hypersensitised animals makes it tempting to consider that endotoxin is only 'toxic' to the hypersensitised animal. However, the fact that newborn unsensitised rabbits and rats (Spievak, 1964) are susceptible to the lethal effect of endotoxin does not lend support to this hypothesis.

Recently Smith and Halls (1967a) have put forward the suggestion that certain E.coli strains have the property of producing a toxic substance, different from endotoxin, which is capable under special circumstances of producing diarrhoea in calves and pigs.

The ligated intestinal loop technique introduced by De and Chatterje (1953) to determine the enteropathogenecity of vibrio cholera and its products (De, Ghose and Sen, 1960; Sack and Carpenter, 1969 (a) and (b)) has been successfully applied to determine the enteropathogenecity of E.coli in human and in other animal species (De, Bhattacharya and Sarkar, 1956; Taylor, Maltby and Payne, 1958; Namioka and Murata, 1962; Moon, Sorensen and Sautter, 1966; Gitter, 1967; Smith, H.W. and Halls, 1967 (a) and (b); Truszczynski, Pilaszek and Glasgow, 1968; Koheler and Cross, 1969).

In an attempt to determine the enteropathogenicity of E.coli Smith and Halls (1967a) applied the ligated loop technique to different animal species. The experimental animals used were: pigs 7-12 weeks old, calves 3-7 days old, lambs 7-30 days old, adult sheep, rats, broiler chickens and guinea pigs. The authors tested a great number of strains of E.coli. Those tested in pigs were obtained from pigs suffering from neonatal and post-weaning diarrhoea, bowel oedema, and the condition described as 'non-infective diarrhoea' by Smith, H.W. and Jones (1963). In calves, the strains tested came from animals suffering from bacteraemia and diarrhoea and in lambs, too, the strains investigated were isolated from lambs affected with diarrhoea and bacteraemia. Strains isolated from healthy human beings and from cases of neonatal diarrhoea in human infants were also investigated. Their investigations yielded the following very interesting findings. The strains of E.coli tested could be differentiated into those which dilated the ligated intestinal segments of the different animal species inoculated and those which did not. This is in accordance with the original work of De, et al. (1956) who, using rabbit intestine, applied this property of dilation to classify E.coli

strains isolated from human subjects as pathogenic and non-pathogenic. Moon, et al. (1966) arrived at similar findings applying the technique in pigs.

Smith, H.W. and Halls (1967a) found that the dose of E.coli injected and the region of the intestine in which these tests were performed had an important influence in the results. It was found that the anterior segments of the small intestine were the most susceptible and such susceptibility gradually decreased posteriorly. When estimating the number of viable E.coli present in the dilated and non-dilated segments, the authors found no significant difference in the number of pathogenic and non-pathogenic strains that proliferated in the intestinal loops. Moon, et al. (1966) reported similar findings, and thus it appeared that the mere number of E.coli organisms was not the cause of dilatation.

Of a total of 138 strains of E.coli obtained by Smith, H.W. and Halls (1967a) from diarrhoeic and septicaemic calves, only 7 produced dilatation of the intestinal loops. None of the strains obtained from calves that had died from septicaemia dilated the loops. To study the correlation between the ability of E.coli strains to dilate the intestinal loop and to produce diarrhoea, the authors inoculated calves orally with the enteropathogenic strains. The animals used had all received colostrum and were stated to have absorbed an adequate amount of immune globulins as estimated by the zinc sulphate turbidity test, although the actual readings of turbidity were not given. The enteropathogenic strains were fed to calves 6-20 hours old. Such animals were extremely susceptible to the oral infection and developed severe diarrhoea 9-22 hours after the infection. The severity of the

diarrhoea and the symptoms varied according to the strain inoculated. When fed to older calves, the same strains failed to produce any signs of ill health, even in some colostrum-deprived animals. None of the strains that failed to dilate the intestinal loops produced diarrhoea when given orally to calves. A very similar picture was found in lambs. In pigs, most of the E.coli strains isolated from cases of neonatal diarrhoea and post-weaning diarrhoea and bowel oedema produced dilation and none of the strains isolated from cases of non-infective diarrhoea behaved in this manner.

A striking finding reported by Smith, H.W. and Halls (1967a) in the animals which developed diarrhoea when orally inoculated with enteropathogenic strains was the massive proliferation of the E.coli in the small intestine. Very much lower numbers were found in the small intestine of calves inoculated with non-enteropathogenic strains. No organisms were isolated from the spleen and liver of the animals affected. The strains appeared to have some host specificity. This was shown by the fact that when calves were inoculated with three different strains, one from a calf and two from pigs which had proved good dilators of the ligated intestine, only the strain obtained from calves proliferated in the intestine. The inhibition of the pig strain was not due to colicine produced by the bovine strain, nor was it due to the presence of a latent bacteriophage in the bovine strain.

The confirmation of the inability of the E.coli strains obtained from cases of non-infective diarrhoea in pigs (Smith, H.W. and Jones, 1963) to produce dilatation when injected into the intestine, prompted Smith, H.W. and Halls (1967a) to suggest that the same situation prevailed in the calf

/and that only a very small proportion of the cases of diarrhoea seen in calves can be attributed to E.coli, most of them being non-infective in origin. Subsequent work by Smith, H.W., and Halls (1967b), Nielsen, et al. (1968), Kohler (1968) and Kohler and Cross (1969) has shown that cell-free culture of enteropathogenic strains retained their ability to dilate the intestinal loops of newborn pigs and 2-day old calves. These findings suggest that a toxin or a group of toxins produced by the enteropathogenic strains is responsible for the accumulation of fluid in the ligated loops. Smith, H.W., and Halls (1967b) called such a toxic material 'enterotoxin.'

E.coli enterotoxin, although it has not yet been characterised chemically and its biological properties need to be investigated further, appears to be distinct from endotoxin. Smith, H.W., and Halls (1967) clearly demonstrated differences by studying the effect of endotoxin and enterotoxin obtained from enterotoxic strains of E.coli. They found that when they injected cell-free soft agar culture of enterotoxic strains into mice all the mice survived, but when the animals were injected with cell-free fluid from the same cultures treated ultrasonically prior to filtration, five out of the eleven mice died. These authors also prepared endotoxin by three different methods from enteropathogenic strains, and failed to produce dilatation when injecting the endotoxin from these strains into the intestinal loops. They also found that enterotoxin obtained from different animal species behaved differently from one another when injected into the ligated intestine. This would suggest that the reaction responsible for the dilatation is a highly specific and localised one. The reports of Smith, H.W., and Halls (1967b) on the variable susceptibility of the different parts of the intestine to

enterotoxin and the fact that only very young calves are susceptible would further support this view.

It is perhaps relevant to this discussion to note some of the striking similarities between E.coli enterotoxin and vibrio cholertoxin. Both these substances are produced by Gram negative bacteria, they both behave in similar manner when tested in ligated intestinal loops, both appear to exert their pathological effects in the presence of an apparently normal intestinal epithelium and the main general effect of these substances on the physiological integrity of the animals or man affected is the excessive loss of fluid and electrolytes through diarrhoea (Watten, Morgan, Songkhlia, Vanikati and Phillips, 1959). Another similarity is that, in order for both substances to be produced, it is essential first that a massive proliferation of the bacteria responsible for their production takes place. In the case of E.coli enterotoxin, it is essential for E.coli to be able to proliferate and remain in the confined susceptible area of the small intestine (Smith, H.W. and Halls, 1967a).

However, there are some dissimilarities. The vibrio cholera toxin appears to be less specific in that successful experiments have been performed in dogs, rabbits, mice and other animal species. This toxic product of vibrio cholera is certainly capable of affecting adult as well as young humans, and thus the degree of physiological maturity of the intestine would appear to have no effect on the outcome of the disease. Although in pigs E.coli enterotoxin may exert its toxic effect in newborn and in adult pigs (Nielsen and Sautter, 1968; Moon, Sorensen and Sautter, 1966), it is effective only in very young calves (Smith, H.W., and Halls, 1967a).

The possible involvement of viruses as primary or secondary agents in neonatal calf diarrhoea cannot be disregarded. However, this is still very much open to question. Light and Hodes (1943 and 1959) recovered a virus from stools of infants in an outbreak of diarrhoea and successfully produced diarrhoea when giving it to young calves. Other viruses, such as the one responsible for 'virus diarrhoea' in adult cattle, have been reported to cause diarrhoea in newborn calves (Bacon, York, Gillespie and Mitchell, 1954). Dalton (1965) reported having seen an outbreak of mucosal disease in newborn calves, where the animals were suffering from severe diarrhoea. However, no attempt was made to isolate the virus.

In a recent paper, Lambert, Fernelius and Cheville (1969) reported that calves born under normal and specific pathogen-free (S.P.F.) conditions were severely affected with diarrhoea when exposed to the Bovine Viral Diarrhoea virus (B.V.D.) One of eight colostrum-fed and four of thirteen (S.P.F.)colostrum-deprived calves died from neonatal enteritis attributed to B.V.D. Of the 23 animals exposed to the virus, all had diarrhoea for several days.

A seasonal variation in the incidence of mortality and calf diarrhoea has been consistently reported in several surveys conducted in Great Britain (Jordan, 1933; Lovell and Hill, 1940; Withers, 1952-1953; Macrae, et al., 1968). Greater losses have been recorded during the winter months and such seasonal variation has been ascribed to the effect of colder and more inclement conditions during the winter (Withers, 1952-1953). However, controlled experiments do not seem to support such a hypothesis. Roy, Shillam and Palmer (1955) reported successfully rearing dairy calves out-of-doors during the winter months

and came to the conclusion that adverse weather bore no relation to the production of scours. Similar results were reported by Hofmann and Schwark (1958). It is interesting to note that a cold environment does not appear to affect the absorption of immune globulin in the newborn calf (Selman, 1969).

Nutrition of the newborn calf has also been considered when searching for an explanation to calf diarrhoea. This issue is a field of controversy like most of the other issues attempting to elucidate the aetiology and pathogenesis of the diarrhoeic syndrome. One aspect regarding the nutrition of the newborn calf which is clear and widely accepted is the importance of feeding colostrum.

While studying the significance of colostrum to the newborn calf, Smith, T., and Little (1922) clearly showed its benefits in preventing colisepticaemia. They kept two groups of calves under the same conditions, ten being fed colostrum while twelve were colostrum deprived. All of the colostrum-fed calves survived, but nine of the colostrum-deprived calves died and E.coli was isolated from the different organs of the animals that succumbed.

The beneficial action of colostrum was further confirmed in a series of experiments by Aschaffenburg, Bartlett, Kon, Terry, Thompson, Walker, Briggs, Cotchin and Lovell (1949a). These workers compared the performance and survival of calves fed whole colostrum, different fractions of colostrum, and a colostrum substitute supplemented with vitamins A, C and nicotinic acid. The performance of the calves was assessed by providing numerical values for each of three main factors; namely, (a) changes in live weight, (b) changes in body

temperature, (c) incidence of diarrhoea. There was no significant difference in performance among the groups fed whole colostrum, the non-fatty fraction of colostrum and reconstituted colostrum. Statistically, there was a significant difference in the performance between the groups of calves fed the clear fatty portion of colostrum and those fed reconstituted colostrum, and an even higher significant difference between calves fed the fatty fraction of colostrum and those fed whole colostrum or the non-fatty fraction. Those calves fed whole colostrum and the non-fatty fraction showed the best performance. The mean performance of the calves in the vitamin supplemented group was poorer than in any of the other groups. In a later experiment, Aschaffenburg, et al. (1949b) and Aschaffenburg, et al. (1950) concluded that the non-fatty fraction of colostrum had a high protective power, small amounts being sufficient to prevent death from colisepticaemia. The essential protective factor was associated with the immune lactoglobulin fraction.

Smith, H.W. and Halls (1968) inoculated four selected strains of E.coli orally into calves whose blood was devoid of immune globulin and to calves whose blood contained immune globulin, as judged by the zinc sulphate turbidity test. They found that the blood and tissues of those calves deprived of immune globulin were readily invaded by the strains that had the ability to grow in immune globulin deprived serum. The calves became ill after about 15 hours and death followed shortly afterwards. When the same E.coli strains were given to calves whose blood contained immune globulin, no adverse effects were produced. The same results were obtained when injecting the strains intravenously.

It is now widely accepted that the lactoglobulin which is found in high concentrations in the mammary gland of the bovine at calving time is derived from the serum gamma globulin (Howe, 1921; Orcutt and Howe, 1922; Garner and Crawley, 1958, and Larsen, 1958). Immune lactoglobulin is the source of passive immunity for the newborn calf, and it is absorbed unchanged through the intestinal wall (Jameson, Alvarez Tostado and Sortor, 1942; Hansen and Phillip, 1947; Smith, E.L. and Holm, 1948; Johnson and Pierce, 1959; Pierce, 1961 and 1962; Balfour and Comline, 1962).

The factors that influence the degree of absorption and the mechanism of absorption itself are not clear as yet. There also seems to be some disagreement concerning the length of time that such an absorptive mechanism remains patent. Fey (1962) fed colostrum to calves 24 hours after birth and found that they were capable of absorbing lactoglobulin, becoming 'normal gammaglobulinaemic.' However, he did not quantify his observation and the meaning of this term is difficult to interpret since such a wide variation exists in the serum immune globulin concentrations of newborn calves (Fisher, Selman, McEwan and de la Fuente, 1968; Smith, H.W., 1962; Smith, H.W., O'Neil and Simmons, 1967; Kruse, 1969; Selman, 1969).

Smith, V. and Erwin (1959) infused colostrum into the duodenum of five calves of varying ages and followed the intestinal absorption of globulins from the colostrum by electrophoretic studies performed on the serum of the calves infused. All the calves were deprived of colostrum prior to treatment. The ages of the experimental calves were: Calf A - 6 hrs.; B - 18 hrs.; C, D and E - 48 to 60 hrs.

The serum protein patterns obtained for calves A and B were

very similar, both exhibited increasing amounts of gamma globulins, while calves C, D and E did not show any absorption, as indicated by the absence of the curve corresponding to the gamma fraction in the electrophoretic pattern. They suggested from their results that the permeability of the intestinal wall of the young calf to colostrum globulin was transitory. Although it would appear from the findings of Smith, V. and Erwin (1959) that the permeability of the intestinal wall to protein may still be patent at 18 hours after birth, it would be wrong to generalise on the findings obtained in one calf.

Recent and more extensive studies reported by Fisher, et al. (1968) have demonstrated that the percentage of calves with medium and high immune globulin levels when colostrum is fed by bucket is higher in those calves fed within 6 hours post partum. Selman (1969), under strictly controlled and standardised conditions, produced evidence which demonstrated that the rate of absorption of immune globulin decreases continuously from birth in Ayrshire calves. It is possible, therefore, that any situation that could interfere with early feeding of colostrum to the newborn calf might result in a low serum globulin concentration.

Yet another possible influence on immune globulin absorption was demonstrated by Selman (1969). He showed that muzzled calves left with their mothers and allowed to suckle their dam only at 6 and 12 hours post partum had significantly higher immune globulin levels than calves kept away from their dams at all times, except during feeding from the dam at 6 and 12 hours post partum. There was no significant difference in the amount of colostrum ingested

by both groups of calves. Thus, this interesting experiment strongly suggested that 'mothering' enhances the absorption of immune globulin from the calf intestine. This latest evidence could well explain some of the variations in the serum immune globulin concentration of newborn calves.

Kruse (1969) concluded that the reasons for the wide variation in the serum immune globulin concentration of newborn calves were:

1. Variations in the time of first feeding colostrum after birth
2. Variations in the immune globulin concentration of the colostrum given
3. Variations in the amount of colostrum given

The increasing interest in the immune globulin status of the newborn calf has undoubtedly arisen from the reports of Fey and Margadant (1961). These authors performed electrophoretic examinations on the plasma of 149 calves which died from septicaemia and found that 92.6% were hypogammaglobulinaemic or agammaglobulinaemic. These calves were all stated to have been fed colostrum on the first day of life. The calves which survived showed higher immune globulin concentrations, and these concentrations of immune globulin were regarded by Fey and Margadant (1961) as an important factor in combating colisepticaemia. They suggested that E.coli septicaemia developed when hypogammaglobulinaemic calves came into contact with certain strains of E.coli immediately after birth.

Gay, et al. (1965) found a similar picture in 178 bought-in market calves. These investigators, by using the zinc sulphate turbidity test, as described by McEwan (1968), were able to estimate indirectly

the immune globulin concentrations of newborn calves. Their findings demonstrated that 53 calves (29.8%) were agamma- or hypogammaglobulinaemic as shown by the turbidity test which gave a reading of less than 10, and a further 18.5% possessed low immune globulin levels, that is, colorimeter readings of less than 20. 17.4% of the calves died; 11.2% from septicaemia and 6.2% from other causes, mainly neonatal diarrhoea. All but one of the deaths from septicaemia occurred in calves with the readings below 10, and the majority occurred in calves with readings of below 2. There was some evidence from these studies that the mortality from the enteric form of colibacillosis was also related to the levels of immune globulin present in the serum of newborn calves.

A marked seasonal variation in the immune globulin concentrations of newborn calves in the West of Scotland has been measured by Gay, et al. (1965), Fisher, et al. (1968). Less obvious seasonal variations were detected in the immune globulin levels of calves in England by Smith, H.W., O'Neil and Simmons (1967), and by Gregorovic, Skusek and Batis (1968) in Yugoslavia. High average serum immune globulin levels were detected in the summer months of the year, and low average levels were obtained in the early months of the year.

The seasonal variation is inversely related to mortality, and it can be modified by the alteration of the managemental procedures (Selman, 1969). The seasonal variation in mortality appears to be a constant feature. Since first recorded by Jordan (1933), it has also been observed by Withers (1952-53), Lovell and Hill (1940), and Leech, et al. (1968).

These findings are increasingly suggestive of a close relationship

between immune globulin levels and the calf's probabilities of survival under adverse conditions. Not only is the passive immunity essential to protect the newborn calf from the septicaemic stage of the infection, but it also appears to play an important role in the prevention of the enteric form of colibacillosis.

Fisher, et al. (1968), studying over 500 calves, made the following observations.

(a) Very low immune globulin concentrations in the serum of newborn calves are consistent with a liability to death from septicaemia.

(b) Newborn calves with low and medium immune globulin levels are liable to die from diarrhoea. High immune globulin serum concentrations in calves are consistent with survival.

Thus, by knowing the immune globulin status of the newborn calf, it is possible to predict to a certain extent the fate of such a calf.

Post-colostral diets and methods of feeding the newborn calf have also been suggested as potential causes of diarrhoea. Withers (1952-53) noted that the incidence of diarrhoea appeared to be higher in those herds where milk was fed by bucket than in the herds where cows were allowed to suck. Claims were made by Inglis (1960) and Cowie (1964) as to the beneficial effects of suckling as a method of reducing the incidence of calf diarrhoea. Factors such as quantity of milk ingested, composition of the milk, the rate of ingestion, have all been implicated as contributing to the onset of diarrhoea. Ingestion of large quantities of milk and overloading of the abomasum as a consequence of pail feeding

was suggested by Blaxter and Wood (1953) as a cause of diarrhoea. In contrast, Ingham, Meade and Berry (1930) concluded that feeding too little milk often leads to diarrhoea. Walker (1950), studying the behaviour of newborn calves, noted that the time spent suckling varied. However, he found that calves would often suck more milk than they would consume if fed from a bucket. These calves, although they ingested greater quantities of milk than those fed by bucket, showed no signs of diarrhoea. Selman (1969) in his detailed study of the behaviour of the newborn calf, reported that the number of suckling spells during the first eight hours post partum varied from one to four. He also found that calves usually ingested colostrum to the extent of 7 per cent of their bodyweight within the first few hours of life. The ingestion of large quantities of colostrum did not seem to produce any serious adverse effects. Furthermore, he advised that a very large initial volume of colostrum (7% of the calf's bodyweight) should be given as one of the measures to assure high immune globulin concentrations in the calf.

Dalton (1965) found that feeding calves on Oster milk 11 (Glaxo Laboratories Limited) three times a day instead of twice daily had no effect on the incidence or severity of calf diarrhoea.

Mylrea (1966c), while examining the role of overfeeding young calves as a possible cause of disturbance in the normal functioning ofthe digestive tract, came to the conclusion that overfeeding had few adverse effects. He studied the effect of overfeeding in intact calves and in calves fitted with a reentrant cannula in the small intestine. The age of the animals used in his experiments varied from 9 to 38 days. The calves were first kept on a restricted diet of milk, fed by bucket equivalent to 5% of their bodyweight per day

during 6 days and immediately after this period were fed milk ad libatum for the same length of time. Although ingesting greater quantities of milk during the first day that milk was fed ad libatum, the calves seemed to exercise a control of their total milk intake in subsequent days. The results obtained in four intact calves showed a marked change in the amount, appearance, and fat content of the faeces passed by these animals during the first period of feeding ad libatum. Although the total amount of faeces passed during this period was increased, there was little change in the dry matter percentage of the faeces. On changing back to the restricted regime, the percentage of faecal fat declined and there was also a decline in the total faecal output. Subsequent changes to feeding ad libatum had little effect on the amount of faeces passed and the total fat content of the excreta. The results obtained by these experiments performed in the calves with re-entrant cannula clearly demonstated that the small intestine was capable of absorbing the greater intakes of reducing substances, nitrogen and lipids that entered this organ when milk was fed ad libatum. Mylrea concluded that the small intestine of a calf has sufficient digestive and absorptive capacity to handle the substances derived from a large quantity of whole milk.

Blaxter and Wood (1953) suggested that the inhibition of clot formation in the abomasum could lead to uncontrollable scours. Thus, a deficient or unbalanced composition of a diet could well result in diarrhoea. Reduction of casein or the substitution of this substance with gelatine were suggested by these authors as

causes of diarrhoea. They thought that diarrhoea was triggered off by a primary dysfunction of the small intestine leading to undigested feed residues reaching the lower part of the intestine. The bacteria normally present in this part of the digestive tract would then have a suitable environment to feed and multiply actively and possibly invade higher regions of the intestine yielding large amounts of their metabolic products. As a consequence, a build up of the osomotic pressure in the lumen of the intestine would result followed by the secretion of water and electrolytes which eventually would be 'explosively discharged from the colon.'

Kastelic Bentley and Phillips (1950) reported that milk substitutes with low levels of calcium or high levels of sodium would not clot with rennet consequently resulting in diarrhoea.

Owen, Jacobson, Allen and Homeyer (1958) found no adverse effects when feeding curd inhibited diets. These authors also reported that milk fat (3%) had a costive action. Such findings agreed with previous reports by Gullickson, Fontaine and Fitch (1949), who reported a lower incidence of diarrhoea in calves fed on diets containing butter oil.

Dalton (1965) comparing the performance among calves fed on a milk substitute and calves fed on milk found that the incidence of diarrhoea was greater in calves fed with milk substitute.

Shillam, Roy and Ingram (1962) produced evidence indicating that the denaturation of whey proteins would result in diarrhoea. They stated that such denaturation could be brought about by the processing of skimmed milk at high temperatures when producing milk substitutes. They investigated the effect of different types

of milk substitute diets and whole milk, the diets being synthetic milk, synthetic milk without glucose, fresh separated milk plus glucose, fresh separated milk, whole milk plus supplementary vitamins A and D, and whole milk. The term synthetic milk was applied to a diet, based on spray-dried skim milk powder, to which the different components, such as glucose, water, margarine, etc., were added, depending on the treatment in question. The group of calves was formed by allocating a calf to each type of diet, the calves were all kept in a calf house, and a new group would occupy the calf house every 10 or 13 days.

They reported the following findings. The results obtained indicated that as the period of occupation of the calf house increased, so did the mortality in all the groups. There was a marked difference in the mortality rate observed by those calves belonging to the groups fed the synthetic milk and those calves fed whole milk. Nine (60%) out of fifteen animals fed the synthetic milk died. The animals that were fed on synthetic milk without glucose showed a mortality of 53.3%. The mortality recorded for the calves fed on fresh separated milk was 13.3%, and that for the calves given fresh separated milk containing glucose, 33%. Five of the fifteen calves fed whole milk died (33%). The group fed whole milk plus supplementation with vitamin A and D had a mortality of 26.6% - four animals died. The overall mortality for the groups of calves fed 'synthetic' milk was 56%, as compared with 26.6% mortality observed in groups fed non 'synthetic' milk.

Shillam, et al. (1962) mentioned in their communication that

the calves were given similar passive immunity. However, the intestinal absorption of immune globulins from the pooled colostrum was assumed, since no values were reported for the serum immune globulin concentrations.

Nutrition of the dam before and after parturition has been suggested as a contributory factor in calf diarrhoea (Shanks, 1950; Fraser, 1959; Mackintosh, 1953; Withers, 1953; Inglis, 1960). However, little experimental evidence exists to support these suggestions.

One aspect of the cows' nutrition which has received a more detailed investigation is the concentration of vitamin A in its diet, and the effect of these concentrations on the levels of vitamin A in colostrum. Perhaps the well-recognised function of vitamin A as an 'anti-infection' vitamin, and its role in the structure of the epithelial surfaces (Mellanby and Green, 1929; Rubin and De Ritter, 1953; Keil and O'Neil, 1961; Irving and Richards, 1956; Follis, 1958) has contributed towards a more detailed study of the effects that different concentrations of vitamin A in the food and colostrum of cows may have on the outcome of calf diarrhoea.

Stewart and McCallum (1938a and 1938b) reported that calves which received colostrum with low vitamin A concentrations were more susceptible to diarrhoea than calves fed with colostrum containing high vitamin A concentrations. Other workers have also studied the effect of vitamin A supplementation in the diet of the dam and calf and its repercussion in the subsequent performance of the calf. Spielman, Eaton, Loosli and Turk (1949) found that the incidence of scours was lower in calves from dams supplemented with vitamin A 30 days prior to parturition. Jacobson, Converse and Moore (1949)

reported that calves supplemented with vitamin A suffered less severely from diarrhoea than those not given the supplement.

In contrast to the findings previously mentioned, several groups of workers have considered vitamin A supplementation irrelevant to the incidence of neonatal calf diarrhoea. Nevens and Kendall (1947) concluded that supplements containing vitamins A, C, D, niacin and nicotinic acid were of no value when given to calves that had been fed colostrum. Hibbs and Krauss (1947) reported similar findings. Aschaffenburg, Bartlett, Sears, Thompson, Ingram, Lovell and Wood (1953) further stressed the importance of colostrum when they produced experimental evidence demonstrating that vitamin A had no effect in reducing diarrhoea in colostrum-deprived calves. Whilsts studying the composition of colostrum, Selman (1969) questioned the work suggesting that vitamin A was the protective factor against neonatal diarrhoea. He found a wide individual variation in the vitamin A concentration of colostrum. He also reported a marked seasonal variation, the lowest levels being observed in the winter months. Although this seasonal variation in vitamin A concentration coincides with the seasonal variation in the serum immune globulin concentration of newborn calves (Gay, et al., 1965; Fisher, et al., 1968), Selman (1969) found no correlation between the immune lactoglobulin and vitamin A concentration of colostrum. Thus, it is not unlikely that the colostrum with high vitamin A concentration used in previous experiments was fed to calves which, because of the seasonal management, had also acquired high immune globulin levels. By the same token, those calves which were fed low vitamin A colostrum were more likely to have been

born during the late winter months, and this is just the time when due to winter management low serum immune globulin levels occur. It would appear that the occurrence of lowest colostrum vitamin A levels at the time of highest calf mortality might be purely coincidental, but further studies are needed to confirm this possibility. Little is known about the effect of other vitamins on the outcome of calf diarrhoea.

Clearly, the diarrhoeic syndrome in the bovine neonate is an extremely complex problem. It results from a physiological failure of the intestinal tract, which in a specific instance may be of single aetiology being brought about by a known agent, biological or otherwise. It can also be triggered off or exacerbated by a combination of factors. It is the interaction of environmental, biological and managemental factors which make this condition such a complex malady and such a difficult syndrome to define, study and reproduce experimentally.

Attempts to produce an effective therapy against calf diarrhoea have been numerous and varied. Some of them have been applied and claimed to be beneficial by subjective assessment of the results without the support of control animals. Few have discriminated the different conditions under which diarrhoea may occur, and even fewer have taken into consideration the immunological status of the animals being treated. Thus, it is difficult in such circumstances to evaluate the true benefit of any previour therapeutic procedures. Nevertheless, the work performed in this field cannot be disregarded, and indeed some of the investigations have contributed considerably to a better understanding of the situation.

In general, the different therapies that have been used in an attempt to control neonatal diarrhoea may be divided into:

1. Anti-bacterial agents (a) Antibiotics
   (b) Sulphonamides
   (c) Nitrofurans
2. Water and electrolyte therapy
3. Blood and blood derivatives
4. Vaccines and immune sera
5. Corticoids and antihistamines
6. Anticholinergic agents
7. Astringents, adsorbents and other treatments

Of the different therapeutic methods previously mentioned, the use of anti-bacterial drugs and fluid and electrolyte replacements have been studied in some detail. The observations made by Thorp and Shigley (1942), Thorp (1943), Thorp, et al. (1944) on the therapeutic value of different sulphonamides in calf diarrhoea cannot be properly assessed since no control groups were used. However, it does appear that the use of sulphonamides effectively reduced the number of E.coli present in the small intestine of the animals affected. Wise and Anderson (1943) reported that calves affected with diarrhoea which received sulphathalidine by mouth had a lower mortality rate than the untreated group of diarrhoeic calves. Udall (1949) found that oral administration of phthalysulphathiazole prevented death in the treated calves, while the control group had a mortality rate of 50%. Voelker and Jacobson (1953) found that the oral administration of penicillin had no effect on the incidence of

diarrhoea in newborn calves. Studies investigating the efficiency of other antibiotics, such as streptomycin, chlortetracycline, and oxytetracyclines, in the treatment of calf diarrhoea have been reported by Henderson and McKay (1949), Fox (1952), Kastelic, Bentley and Phillips (1950), Bortree, Sook, Chang and Dawdy (1952). However, all these reports failed to give information regarding control animals, hence the difficulty in assessing the true value of such antibiotics. Roy, Palmer, Shillam, Ingram and Wood (1955) reported an increase in bodyweight and a lower incidence of mortality in colostrum-deprived calves treated with daily doses of 238 mgms. of aureomycin by mouth. Of the twenty treated animals, only two died (10%), compared with four dead in the group of ten controls (40%). In 1958 the same authors, comparing the performance of colostrum-deprived calves given chlortetracycline and penicillin, found that all of the eight animals in the control group died (100%), three of ten animals died when treated daily orally with 250 mgms. of chlortetracycline for the first five days of life (30%), whilst in the penicillin-treated group, eight out of ten animals died (80%). The authors also demonstrated an increased resistance to chlortetracycline and penicillin of E.coli isolated from the intestine of the animals which had received these antibiotics. E.coli appeared to develop an even higher resistance when both antibiotics were given together. These investigations are amongst the few to be found in the literature that have been performed on completely susceptible colostrum-deprived calves.

Henry and Blackburn (1957) used the synthetic nitrofuran furamazone. They divided 87 calves under a week of age into two

groups; a control group of 24 animals and another group of 63 animals which each received one tablet containing 1 gm. of furamazone twice daily until it showed signs of improvement. The animals in the control group were mixed with the treated animals and all other conditions were exactly the same for both groups apart from therapy. All animals treated were scouring. 21 (87.5%) of the 24 untreated animals died, whereas only 3 (4.7%) of the treated group of 63 died, only one being due to enteritis.

Osborne and Watson (1965) reported successfully preventing death from E.coli 'enteritis' in experimentally infected calves by the oral administration of furaltadone (6 mg. per 1 lb. bodyweight). No deaths were recorded during the first three weeks of life in a group of 13 calves treated with furaltadone, whereas 8 of the 13 calves (60%) kept as controls died during the same period.

Dalton, Fisher and McIntyre (1960) reported an extensive study on the effect of different antibiotics and sulphonamides in the treatment and prophylaxis of calf diarrhoea. Groups were made up of ten calves, one group of which served as the control. The drugs were administered to the animals orally and parenterally, and the value of the drugs was assessed by judging beneficial effects in the performance of the animals treated. The following criteria were used to compare the performance of the different groups: the number of calves which died in each group, the number of calves which became affected with diarrhoea during the experimental period, the severity of diarrhoea in the calves of the different groups and changes in bodyweight. A special statistical analysis was applied

to determine significant differences in the incidence of diarrhoea and death between the treated and the control groups in each experiment. The drugs compared were: streptomycin, neomycin, oxytetracycline, chlortetracycline, penicillin, chloromycetin and phthalylsulphathiazole, given orally; and streptomycin and oxytretracycline, given intramuscularly.

The results obtained in their experiments led the authors to believe that although a number of the antibiotics tested significantly reduced the incidence of mortality and diarrhoea, none of the antibiotics studied could be expected to control diarrhoea in calves in all circumstances. The fact that oxytetracycline produced only a slightly significant result on one occasion and chlorotetracycline failed to produce any beneficial effect in another are an example. It is interesting to note that the experiment in which oxytetracycline administered orally produced only a slight beneficial effect was performed during the summer (3.6.58). In this experiment none of the animals in the control group died. It is at this time of the year that calves have been shown to be better protected against infection as suggested by their immune globulin levels. Hence, it is possible to suggest that in this circumstance the true protective factor is the level of immune globulin present in the young calf and any benefit derived from the antibiotic is only secondary. The experiment, where chlorotetracycline given orally did not appear to have any value in preventing death and diarrhoea, was performed in February. In this particular study the death rate was high in the three groups studied, in fact it is the experiment which shows

the highest mortality rate in the series. In this case, such mortality and the incidence of diarrhoea could well be a reflection of a very low immune globulin level in these calves. The fact that a poorer result was obtained when applying the antibiotic in the early months of the year (Experiment No. 5, Dalton et al, 1960), than when applying it in exactly the same manner in the summer months (Experiment No. 4, Dalton et al., 1960) further supports the view that the immunological status of the animals to be treated must be known in order to obtain a better assessment of the effects of the antibiotic therapy in question. The authors did not perform any sensitivity tests prior to the antibiotic treatments in question. The higher incidence in mortality during the winter months, referred to previously in this review, was also noted by these workers. 38% of their control animals died during the early months of the year, as compared with 13% during June and July, and 20% in October and November.

The work of Smith and Crabb (1960) has shown that chemotherapy can significantly reduce the number of E.coli in the faeces. It was thought possible by Dalton et al, (1960) that this factor alone could account for the reduced incidence of diarrhoea in treated calves. In this respect these authors reported that streptomycin and oxytetracycline were ineffective when given parenterally, because they are not excreted into the lumen of the intestine and do not come in contact with the organisms.

Resistance to antibiotics by E.coli has been suggested as the reason for the failure of these substances to control diarrhoea. Dalton, Fisher, McIntyre (1960), Dalton (1965), McKay, Ruhnke and

Barnum (1965), Smith, H.W. and Crabb (1956), Smith, H.W. (1958). Evidence has been brought forward demonstrating that resistance to antibiotics has increased considerably. McKay et al, (1965) reported that the percentage of strains of E.coli resistant to streptomycin recorded in 1957 was 60% but had increased to 90% in 1963. The resistance to tetracycline had risen to 90%, and the resistance to neomycin had risen from 10% in 1957 to 50% in 1963. In the same period chloramphenicol had changed from 8% to 22%. Their results showed that 10% of the strains of E.coli tested were resistant to furozalidone, but further resistance to this chemotherapeutic did not appear to be developing.

Smith, H.W. and Crabb (1960) observed that the proportion of strains reistant to streptomycin, oxytetracycline and chlorotetracycline was higher in 1955 than in similar surveys carried out during the years 1950-53. They showed that the E.coli population of the calf's intestine could change from an antibiotic sensitive one to an antibiotic resistant one within 24-48 hours of an antibiotic being given. Smith, H.W. (1960) stated that the efficiency of antibiotics in eliminating sensitive strains of E.coli is matched by the extreme speed with which resistant strains may replace them during chemotherapy.

Some of this resistance to antibiotics has been shown to be infectious. Since first described by Ochiai, Yamanaka, Kimura and Sawada in 1959, it has been recognised by other workers. Datta (1962), and Smith, H.W. (1966) have been able to transfer resistance from resistant strains of the Enterobacteraceae family to sensitive recipients of the same family. Walton (1968) stated that it was apparent that

transfer of drug resistance determinants was the most common method of acquiring drug resistance in the family Enterobacteraceae, and when this type of resistance is associated with intestinal infection then treatment of the condition with antibiotics becomes difficult or impossible.

The use of vaccines and hyperimmune sera has been advised as a prophylactic and therapeutic method against calf diarrhoea (MacDonald and Oakley, 1961; Roy, 1959; Gay, McKay and Barnum, 1964 (a) and (b)). The administration of whole sera from the dam or another calf in the herd has also been suggested as a beneficial therapeutic method. However, the results are controversial and some have been disappointing (Juld, 1958; Gay, 1962; Sellers, Smith and Pook, 1962).

Watt (1965) strongly recommended the intravenous administration of homologous plasma prior to the administration of electrolytes. The results obtained from treating newborn calves affected with coliform-septicaemia indicated a significantly higher mortality rate amongst the calves treated with electrolytes alone, as compared with those treated with plasma and electrolytes.

Claims have been made for the beneficial effects of anti-cholinergic drugs in the treatment of neonatal calf diarrhoea, but no control calves have been included. A short experiment is reported in this thesis concerning the results obtained when the drug 'Pamine' (an anti-cholinergic agent) was given to diarrhoeic calves.

The use of corticosteroids has been advised in the treatment of endotoxic shock (Little, 1961; Rosen, 1961). If endotoxin is in any way involved in the pathogenesis of neonatal calf diarrhoea

it seems reasonable to suggest that their application may be useful in the treatment of the diarrhoeic syndrome, but once again no controlled studies have been made.

Many reports of astringents, adsorbents and other miscellaneous treatments of calf diarrhoea are difficult to evaluate because control groups have not been included and the rationale behind the therapy has often been impossible to ascertain. In addition, 'shot gun' therapies have been used and it is impossible to determine which component of the therapy may have had a significantly beneficial effect.

The excessive loss of body fluids and electrolytes and subsequent dehydration has been regarded as an outstanding feature of calf diarrhoea. The severity of this dehydration depends on the relative quantities of water and electrolytes lost by the diarrhoeic animal, mainly in the faeces and otherchannels of excretion and the amount administered orally and/or parenterally. Blaxter and Wood (1953) drew attention to the apparent water and electrolyte losses suffered by diarrhoeic calves. In a limited number of calves (2) they showed that the weight of the material lost from the bowel by diarrhoeic animals was more than forty times the normal excretion, the increased weight being due mainly to increased secretion of water accompanied by a considerable loss of electrolytes, particularly sodium and potassium. Consequently the diarrhoeic calves would quickly fall into a negative water and electrolyte balance. Such losses would no doubt have repercussions on the body fluid and electrolyte concentrations. In this respect McSherry and Grinyer (1954) studied the changes in acid-base balance in electrolyte concentrations in

the serum of calves suffering from diarrhoea, and found that the most constant feature was a metabolic acidosis and a decline in the serum bicarbonate concentration. Eight of the eighteen animals studied had a pH below 7.3. Serum sodium, potassium, and chloride concentrations, varied, some values were found above, and some below, the normal concentrations. However this variation could be accounted for by the animals probably suffering from varying degrees of diarrhoea, and having different management previous to or during the onset of diarrhoea. It could be assumed that the dehydration which occurs in the diarrhoeic calf would lead to a reduction in the plasma volume and a rise in the packed cell volume (P.C.V.), but an interesting finding in the reports of these authors is that very few of the calves showed an increase in P.C.V.

Roy, Shillam, Hawkins, and Lang (1958) observed the changes in the serum electrolyte levels that occurred in calves suffering from localised infection of E.coli and from E.coli septicaemia. The values they obtained for the sodium and potassium electrolyte concentrations of normal newborn calves were 135 m.eq/litre for sodium and 5.9m.eq/litre for potassium and these are lower than those reported by McSherry and Grinyer (1954) of 142.1 m.eq/litre for sodium and 5.3 m.eq/litre for potassium. Roy et al., found that the changes in serum electrolytes varied according to the period of time during which the animals were diarrhoeic. In those calves with an increasing duration of scouring a greater fall in the mean serum sodium values occurred. For instance, in animals recovering from six or more days of diarrhoea, the lowest level was reached on the ninth day of life with a mean value of

127 m.eq/litre. Thereafter, the values rose to nearly normal by the end of the third week. The mean serum potassium levels in normal animals fell gradually from birth until the end of the experimental period. However, with an increasing duration of scouring the potassium levels showed a slight increase during the first four to twelve days of life reaching mean values of 6.5 m.eq/litre in calves scouring for more than seven days.

An interesting finding by Roy et al was the different serum electrolyte concentrations in animals that died from septicaemia as compared with those that died from the effects of diarrhoea. Animals dying from septicaemia showed a fall in serum sodium which was not significantly different from that shown in diarrhoeic calves that recovered. The levels of serum potassium were usually normal or slightly raised, but again within the values observed in recovering diarrhoeic calves. Similarly those calves whose deaths were associated with a localised intestinal infection with E.coli showed a fall in serum sodium comparable to that of calves surviving after profuse scouring, and to those dying from E.coli septicaemia. However, the serum potassium concentrations of the calves which died from localised infection were significantly elevated with a mean of 7.1 m.eq/litre. Values as high as 12.5 m.eq/litre were obtained in some of these animals during the ten hours preceding death. In view of these findings, the authors concluded that this abnormally high rise in serum potassium concentration could well be the cause of death.

Abnormally high levels of serum potassium have been demonstrated by Bergman and Sellers (1953) and (1954) to cause cardiac arrest and

death from heart failure. Fisher (1965) was of the opinion that death in calf diarrhoea was due to circulatory failure in which, of the three components of the circulation: the heart, the containing vessels, and the circulating fluid; the primary failure was of the heart. He produced conclusive evidence regarding the difference in the concentrations of serum electrolytes between surviving and dying diarrhoeic calves. He found that those animals dying had significantly higher levels of potassium and showed a more severe metabolic acidosis. Urea concentrations were also significantly higher in those animals dying than in those which recovered, but the values for sodium chloride and plasma volume were not significantly different. It was suggested that the more severe metabolic acidosis of dying calves might stimulate increased reabsorption of potassium by the kidney in exchange for hydrogen ions. Further increase in plasma potassium and blood urea in dying calves could however result from renal failure secondary to cardiac failure rather than from a deficiency in plasma volume.

In a later publication, Fisher and McEwan (1967) studied the effects of the acidosis of calf diarrhoea on the potassium content of cardiac muscle. They found that there was a significantly higher content of potassium in the muscle of normal calves as compared with diarrhoeic dying calves. However, when acidosis was induced in healthy newborn calves by the constant infusion of hydrochloric acid there was no significant difference in the potassium content of the heart in the animals dying from diarrhoea as compared with those dying following the acid infusion. Furthermore, the cardiac arrhythmias which had been detected in animals dying from diarrhoea (Fisher, 1965) were also present in the animals which died after the infusion of

acid. The authors suggested that supportive therapy should be directed at attempting to overcome the acidosis and might comprise of alkaline solutions such as isotonic sodium bicarbonate. In an attempt to drive potassium into the myocardial cells, the administration of solutions containing potassium was also suggested, where evidence of cardiac failure or of secondary renal failure was absent.

Dalton, Fisher, and McIntyre (1965) also investigated the effects of neonatal calf diarrhoea and the concentrations of the different plasma electrolytes. They divided the animals studied into different groups according to the number of days in which the animals showed diarrhoea. The animals suffering from diarrhoea showed a marked loss in bodyweight, this increasing in proportion to the number of days for which animals were affected with diarrhoea. The animals which did not suffer from diarrhoea tended to gain weight. There was no significant difference in the mean haematocrit values found in the diarrhoeic and in the non-diarrhoeic calves. Their findings regarding the different serum electrolyte concentrations mainly showed hypoelectrolytaemia, and no cases of hyperelectrolytaemia were recorded. Their values were very similar to those previously reported by Roy et al. (1958).

Following these findings several reports have been made of attempts to use different electrolyte therapies to reverse or counteract the changes that occur in neonatal calf diarrhoea. McSherry et al (1954) in Canada reported to have successfully treated diarrhoea with a balanced electrolyte solution containing 144 m.eq/litre of sodium, 103 m.eq/litre of chloride, 10 m.eq/litre of potassium, 5 m.eq/litre of calcium and 3 m.eq/litre of magnesium.

Radostits (1965) advocated the administration of saline solution to calves suffering from diarrhoea, the solution being given by a stomach tube in varying volumes depending on the degree of the condition. Volumes of up to 4000 cc. could be administered if divided into two or three administrations during the day.

Watt (1965) considered the administrations of homologous plasma to be of the utmost importance if subsequent electrolyte therapy was to be effective. The intravenous injection of plasma was considered to expand the depleted plasma volume of diarrhoeic individuals improving the general circulation and providing a more efficient vehicle for the distribution of the electrolyte solution to be administered. The intake of milk was stopped during the first 24 hours of treatment, and between 400 and 800 ml. of plasma were administered intravenously, followed by intravenous injection of the balance isotonic electrolyte solution. The total volume of the electrolytes to be administered was obtained on the basis of the packed cell volume values recorded immediately prior to treatment. The electrolyte solution was injected slowly alternating over a period of 24 hours with intravenous glucose. If by this time the animal had not improved the procedure was repeated. Adopting this method of therapy, the author compared its effects with other therapies in the treatment of newborn calves living in herds with long histories of high mortality from 'coliform septicaemia'. The types of herds from which the calves were obtained were beef and dairy herd stock, and therapies compared were: antibiotics only, chosen on the basis of bacterial sensitivity tests, the antibiotic administered being that which

possessed the greatest *in vitro* bacterial sensitivity; electrolytes only, in the form of Darrows solution; plasma and electrolytes (Darrows solution) and plasma electrolytes and antibiotics. A total of 135 calves were treated, 50 with antibiotics, 13 with electrolytes and antibiotics. Table I illustrates the results obtained during these trials.

The results showed that the highest mortality rate (78%) was recorded in the group of calves treated with antibiotics only. The lowest mortality was obtained in the group of calves treated with plasma and electrolytes (7.5%). The group treated with plasma, electrolytes, and antibiotics had a mortality rate of 10%, and the group treated with electrolytes only had a mortality rate of 46.15%. In the light of these findings, the author concluded that it was possible to treat an outbreak of scour in calves by using plasma and electrolyte solutions only, there being no significant additional improvement in survival rates from the inclusion of antibiotic therapy.

Although the results certainly suggest beneficial effects from plasma and electrolytes, it is unfortunate that more precise data regarding the conditions treated were not given. At one point Watt mentions coliformsepticaemia as being the condition from which the animals were suffering; yet if this was the case it is difficult to see how the administration of electrolytes could be of benefit, since the septicaemic form of colibacillosis is not usually characterised by severe diarrhoea (Roy *et al*, 1958; Smith, 1962; and Gay, 1965). In such cases, the amount of plasma injected into these calves would also provide them with probably sufficient immune globulins to

TABLE I

COMPARISON OF FOUR TYPES OF THERAPY IN CLINICAL OUTBREAKS OF NEONATAL DIARRHOEA WITH ASSOCIATED COLIFORM INFECTION

				Number of Calves Treated (Deaths in parentheses)			
Farm	Type of management	Total number of calves at risk	Number of scouring calves	Antibiotics only	Electrolytes only	Plasma + electrolytes	Plasma + electrolytes & antibiotics
1	Double-suckled bought-in calves (Dairy cross)	36	22	10 (7)	4 (2)	0	6 (0)
2	Naturally reared calves (Beef cross)	65	47	14 (14)	6 (4)	14 (2)	13 (1)
3	Bucket-fed market calves (Dairy bulls)	40	14	0	0	12 (0)	2 (0)
4	Naturally reared calves (Housed beef-cross)	16	12	6 (4)	3 (0)	3 (0)	0
5	Naturally reared calves (Beef cross)	12	4	0	0	2 (0)	2 (2)
6	Bucket-fed market calves(Mixed origin)	36	34	20 (14)	0	7 (1)	7 (0)
7	Naturally reared	14	(0)	0	0	2 (0)	0
Total		219	135	50 (39)	13 (6)	40 (3)	30 (3)
Percentage				78	46.15	7.5	10.0

Results reported by Watt (1965)

protect them against septicaemia, and this alone could be expected to have reduced mortality considerably. On the other hand, if the majority of animals were suffering from diarrhoea the administration of adequately large quantities of fluid and electrolytes would have been of value, but the volumes of electrolytes injected by the author would appear to have been quite inadequate to achieve this. For example, the stated regime of treatment for one calf was 800 ml. of homologous plasma, 1500 ml. of Darrow's solution and 1000 ml. of 5% glucose over a period of 24 hours, i.e. a total of 3,300 ml. Since milk was withheld from the animal the net fluid intake under these conditions was no different from the intake of fluid which would have been provided by the normal feeding of milk over that period, although Watt suggested that packed cell volumes may be of assistance in obtaining an approximate assessment of the degree of dehydration, the accurate computation of a suitable fluid replacement from an isolated value is open to question since the actual values for normal newborn calves vary considerably (Dalton et al, 1965; Roy et al., 1958). Furthermore, Dalton et al. (1965) and McSherry et al. (1954) reported that only a very few calves affected with diarrhoea showed significant changes in their haematocrit values.

This introduction and review of the literature covering colibacillosis and calf diarrhoea clearly demonstrates that many problems remain to be solved.

High serum immune globulin concentrations in newborn calves are consistent with survival while very low or negligible concentrations are liable to produce a very high mortality from colisepticaemia. Between

these extremes lies a percentage of calves with serum immune globulin concentrations which are sufficient to prevent colisepticaemic death but are insufficient on all occasions to prevent diarrhoeic death.

The studies to follow were performed in order to ascertain how different management procedures, carried out on farms, influence the serum immune globulin concentration of newborn calves, and consequently affect the incidence of death from E.coli septicaemia and neonatal diarrhoea. A limited number of therapeutic experiments were also conducted in order to ascertain the efficacy of some drugs in controlling diarrhoea in calves of known serum immune globulin concentrations, that is in calves unlikely to die of colisepticaemia but very likely to die from diarrhoea.

PART 2

STUDIES ON THE INFLUENCE OF SOME ENVIRONMENTAL THERAPEUTIC AND MANAGEMENTAL FACTORS ON THE SEVERITY OF DIARRHOEA AND SURVIVAL OF NEWBORN CALVES OF KNOWN SERUM IMMUNE GLOBULIN CONCENTRATION

Section I

The Serum Immune Globulin Concentration of New-born Heifer Calves

A Farm Survey

INTRODUCTION

The review of the literature has revealed that several factors have been stated to influence the outcome of E.coli septicaemia and neonatal calf diarrhoea. Amongst such factors the serum immune globulin levels would appear to be of prime importance. The significance of the immunological status of the newborn calf in the prevention of death from E.coli septicaemia is well established (Smith, T. and Little, 1922, Glantz et al, 1959, Fey and Margadant, 1961, Smith, H.W. and Halls, 1968).

However the importance of the passively acquired immune globulins, in relation to the outcome of diarrhoea, has only recently been suggested, (Gay et al, 1965, Fisher et al, 1968).

Studies performed by Fey and Margadant, 1961, demonstrated that a large number of calves remained hypogammaglobulinaemic despite the fact that they received colostrum. Further investigations looking into the immunological status of the newborn calf have been reported by Gay et al, 1965; and Fisher et al, 1968. A wide individual and a marked seasonal variation in the serum immune globulin concentration of newborn calves was found by these workers. They also found that the serum immune globulin levels, were inversely related to mortality from E.coli septicaemia and diarrhoea. These investigations, which extended for a period of several years, were all performed on bull calves bought through local markets around Glasgow. Except for the Farm survey reported by Smith et al (1967) investigating the serum immune globulin concentration of newborn calves in England, nothing is known about such levels in newborn heifers kept on farms in the West of Scotland.

A farm survey was performed in order to investigate the serum

immune globulin concentration of newborn diary heifer calves kept on farms in the West of Scotland, in order that a comparison could be made with the previous results obtained from bull calves in the same area. The managemental procedures prevailing in the different farms regarding the place of birth of the calves investigated, and how and when colostrum was fed after birth, were carefully recorded. It was then feasible to establish any possible correlation between the effects of early calf management and serum immune globulin concentrations. The incidence of mortality from E.coli septicaemia and diarrhoea during the first month of life was also recorded, so that the effects of different serum immune globulin concentration on the outcome of E.coli septicaemia and neonatal calf diarrhoea in calves kept under different methods of management could be further investigated.

MATERIALS AND METHODS

With the co-operation of local veterinary surgeons, a total of 47 dairy farms were visited at least once weekly during the months of February, March, April, May and June, 1968. This covered the period from when all calves were born inside until the majority of calves were born outside in the field. The farmers were asked to record as accurately as possible the time, place and date of birth, the time elapsed after birth before colostrum was fed, and whether the calf was or not removed from its dam. In order to facilitate the recording of this data, pretyped forms were left with the farmers and collected by the author on the day of sampling, further notes as to the state of health of the calves sampled were made by the author on the say of sampling. The form used is illustrated in Fig. 1. No attempt was made at the time of the survey to influence the management procedures followed by the farmers.

Sampling of Animals

A blood sample was obtained from the jugular vein of all heifer calves born during the previous week, but not younger than 48 hours. Since the farms were visited weekly, all the animals sampled were seven days of age or younger. Only heifer calves were included in this survey because it was impossible to record the progress of the bull calves. Most of the bull calves were born and left the farm within seven days of birth and therefore were not available for sampling at the time of each visit. The blood samples were taken back to the laboratory, allowed to clot and the serum was separated. The immune globulin concentrations were then estimated.

Name of Farm	Calf Identification	
Date	Born	
	Bled	
Sex		
Breed		
When born	(a) Exact (b) If at night estimated	
When removed from Dam		
Had it suckled		
When was colostrum fed		
How much colostrum taken by calf		
Living at one month		
State of health		
Any illness over first month		
$ZnSO_4$		

Fig. 1

Form used to record the data of individual calves during this survey.

Estimation of the Serum Immune Globulin Concentration by the Zinc Sulphate Turbidity Test

The method described by McEwan (1969) using the zinc sulphate turbidity test was used throughout this work to measure the serum immune globulin concentration of newborn calves.

A solution of zinc sulphate (208 mgms. $ZnSO_4$, 1 litre of water) was prepared in a volumetric flask using carbon dioxide-free distilled water. Two matched colorimeter tubes were then taken and 6 ml. of distilled water were placed into the first (control) and 6 ml. of the zinc sulphate solution were placed into the second (test tube). A sample of 0.1 ml. of the serum under test was then delivered into each tube. The tubes were then shaken and allowed to stand for 30 minutes at room temperature. After this time had lapsed, the turbidity in the tubes was read by an E.E.L. Colorimeter (Evans Electroselenium, Halstead, England). The degree of turbidity registered in the dial of the apparatus was recorded as zinc sulphate turbidity units. Using an Ilford blue-green filter No. 623, a 'blank' consisting of a colorimeter tube containing distilled water, was used to set the instrument at zero. The samples to be read were inserted in turn, i.e. first the sample and then the control, and their turbidities recorded. The actual values were then obtained by subtracting the control tube turbidity value from the value of the test tube.

Antibiotic Sensitivity Tests

A faecal swab was obtained from the rectum of the calves from which blood samples were taken. The specimens were taken back to the laboratory and streaked evenly, over the surface of a 5% blood agar plate. Immediately afterwards the disc containing the antibiotics

to be tested were applied to the contaminated plate with sterile forceps. The plates were then incubated at 37°C for 24 hours and examined. The discs used were MULTO DISKS, 30-12 L. (Oxoid Laboratories Limited, London, England).

Clinical Examination

A brief clinical examination, mainly directed towards recording the demeanour of the calves bled, and whether or not they were diarrhoeic, was performed on the day of sampling. Thereafter, the progress of the calves was closely followed for a period of four weeks so that the mortality during this period of time in these calves could be ascertained. If any animals died, the farmer was asked to telephone the Veterinary Hospital; the carcass was then brought immediately to the Veterinary Hospital where a necropsy was performed. Unfortunately, some farms omitted to notify deaths immediately, the information being given at the next visit. Therefore, it was not always possible to carry out an autopsy as to determine the precise cause of death; such was the case with 5 calves.

Necropsy and Bacteriological Procedures

Samples obtained from the spleen and kidney of the dead animals, were cultured in blood agar and McConkey agar. A diagnosis of death from septicaemia was made if E.coli was cultured from both organs. Additional macroscopic lesions, such as marked splegnomegaly, petechiae and haemorrhages on the surface of the spleen, enlargement of the carpal and tarsal joints, together with an increase in fluid and fibrin in these joints, were considered as supportive evidence of septicaemia. A diagnosis of death from diarrhoea was based on

the clinical history of the animal, the presence of large amounts of fluid contents, particularly in the caecum and colon, a dry carcass, the failure to isolate E.coli from the internal organs of the animals and the absence of any other specific lesions.

Statistical Methods

The deviations from the mean of the parameter analysed were recorded as standard deviations. Student's 'T' test has been used to determine the statistical significance of the difference between mean values of the different parameters analysed in different groups. These statistical methods were used throughout this thesis (Bishop 1966).

Results

A total of 327 heifer calves were included in this investigation.

Seasonal Variation

A monthly variation in the average serum immune globulin concentrations of these heifer calves was obtained. Figure 2 illustrates the mean monthly immune globulin values obtained in the heifer calves surveyed.

When comparing the mean monthly values of the calves surveyed, with the immune globulin values reported by Gay et al. (1965) and Fisher et al. (1968) for market bull calves born during the same months in previous years, the results were very similar. This is illustrated in Figure 3.

The marked seasonal variation in the serum immune globulin concentration reported by Gay et al. (1965) and Fisher et al. (1968) in market bull calves was also evident in this survey. The mean monthly values are not significantly different between the heifer calves surveyed and the market bull calves sampled the previous years. The values are illustrated in Table II.

Fig. 2.

Average Monthly Immune Globulin Levels (Z.S.T. units) of new-born Heifer Calves

Farm Survey 1968

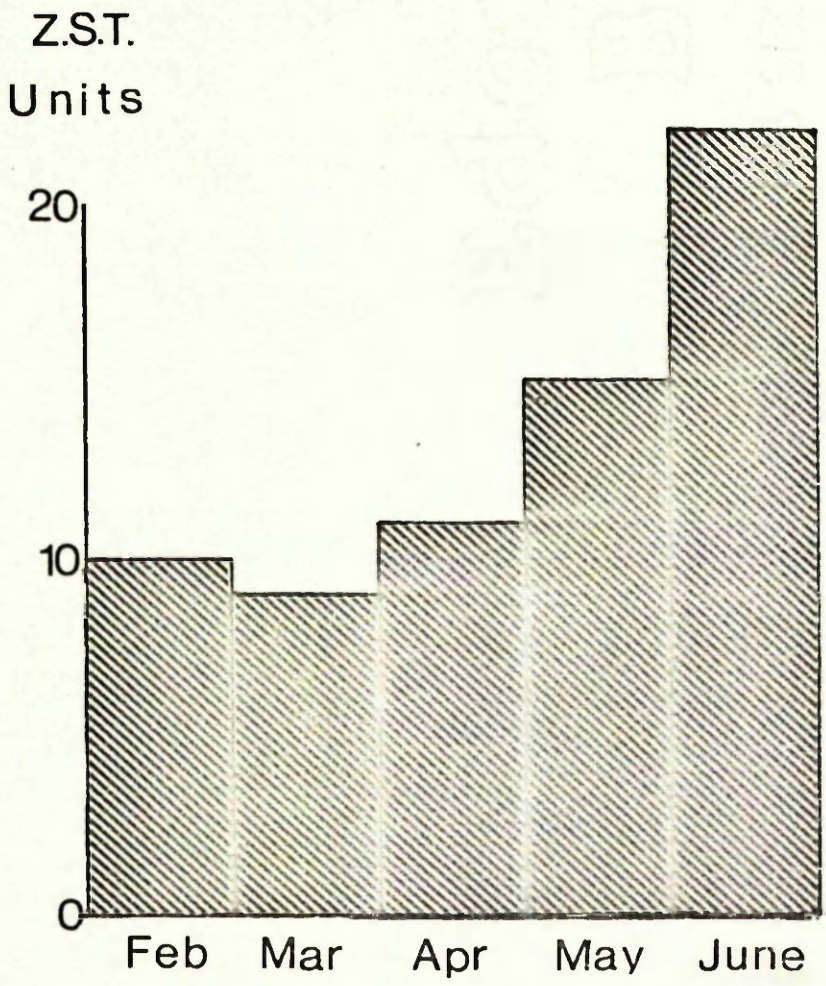


Fig. 3.

The Average Monthly Immune Globulin Levels (Z.S.T. Units)

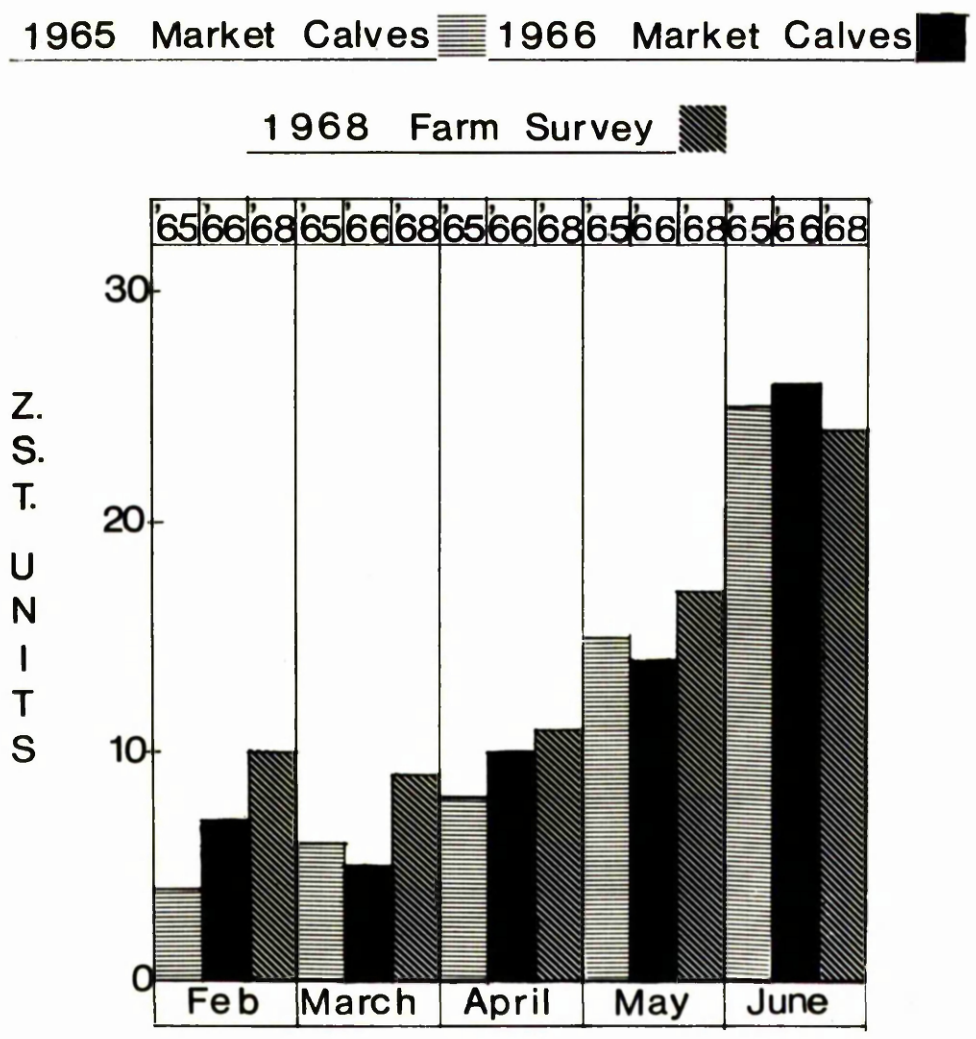


TABLE II

The mean monthly serum immune globulin concentrations of the heifers surveyed in 1968, compared with the mean serum immune globulin concentrations of market bull calves samples in previous years.

	FEBRUARY		MARCH		APRIL		MAY		JUNE	
	No. of calves sampled	Mean Z.S.T. S.D.	No. of calves sampled	Mean Z.S.T. S.D.	No. of calves sampled	Mean Z.S.T. S.D.	No. of calves sampled	Mean Z.S.T. S.D.	No. of calves sampled	Mean Z.S.T. S.D.
Heifer calves Farm Survey 1968	23	9.8 ± 6.4	114	9.1 ± 6.4	82	10.6 ± 7	87	17.4 ± 11	22	23.4 ± 10
Market Bull Calves 1966*	74	7.2 ± 4.4	24	4.7 ± 4.2	40	9.8 ± 5	73	13.7 ± 7	22	25.4 ± 8
Market Bull Calves 1965 *	20	4.3 ± 7.2	20	6.2 ± 4.5	59	8.2 ± 3.6	117	15 ± 4.5	72	24.4 ± 7.5

* Values obtained from the results reported by Fisher, Selman, McEwan and de la Fuente (1968) and McEwan (1968).

Effect of Place of Birth on Serum Immune Globulin Concentration

The place of birth appeared to influence the serum immune globulin concentration of the newborn calf.

Table III shows the immune globulin values obtained from calves born in different places.

TABLE III

The Serum Immune Globulin Concentration (Z.S.T. Units) of Calves Born in Different Places

Place of Birth	No. Calves Samples	Mean Serum Immune Globulin Concentration (Z.S.T. Units)	S.D.	Significance
Byre Born (a)	194	9.0	±5.8	a & b, $p = <0.01$
Box Born (b)	64	12.0	±7.9	b & c, $p = <0.001$
Field Born (c)	69	24.4	±7.9	a & c, $p = <0.001$

It can be seen from these results that by far the highest values were seen in calves born in the field (mean 24.4 ± 7.9). The lowest values were observed in those calves born in the byre (9.0 ± 5.8). Box-born calves showed an intermediate value (12.0 ± 7.9). The difference in the mean values amongst the three groups is statistically significant, $p < 0.01$ between the byre-born and the box-born calves. The value of 'p' for the difference of means between box-born calves and field-born calves is more significant, p 0.001. The same value was obtained when comparing the means of the byre-born and field-born calves, $p < 0.001$.

Mortality

When analysing the mortality, which in this survey was mainly due to E.coli septicaemia and diarrhoea, an overall mortality of 11% was obtained, a figure similar to that reported by Withers in 1952 for heifer calves in this area. The values are shown in Table IV as is the division of such mortality according to the place of birth.

TABLE IV

Mortality

Total Calves Sampled		Total Deaths	Mortality.
327		36	11%
Mortality According to Place of Birth			
Byre Born	194	29	15%
Box Born	64	5	8%
Field Born	69	2	3%

It can be observed that the mortality holds a very close inverse relationship with the serum immune globulin levels shown in Table III and that the animals born in the byre (lowest immune globulin levels) had the highest mortality rate (15%). The calves born in the field (highest immune globulin levels) had the lowest mortality rate (3%). The box-born calves had a mortality rate of 8% (intermediate immune globulin levels).

Effect of Time of First Feeding on Immune Globulin Levels

Other factors apart from place of birth clearly influenced the serum immune globulin levels of the calves. Time of first feeding colostrum after birth had such influence.

TABLE V

Immune Globulin Concentrations of Byre-Born Calves Separated on Time of First Feed

	No. Calves Sampled	Mean Serum Immune Globulin Concentration (Z.S.T. Units)	S.D.	Significance
Calves fed at less than 6 hours post partum	76	10.7	±6.6	$p < 0.001$
Calves fed later than 6 hours post partum	88	6.7	±4.5	

Table V shows the values for the byre-born calves which were fed before six hours post partum and those fed later than six hours. A statistically significant higher immune globulin concentration was found in those animals fed within six hours post partum ($p < 0.001$) than in those fed six hours after parturition.

Effect of Leaving the Calf with its Dam on Immune Globulin Levels

The number of calves born inside during the months of March and April was sufficiently large as to enable a comparison to be made, between those calves left with their dams and those removed from their dams.

The results which illustrate the beneficial effect of leaving the calf with its dam for a period of at least twelve hours are given in Table VI. For this purpose the calves were divided into two groups. One group included those animals which were left with their dams for more than twelve hours; the other includes the animals which were removed from their mothers immediately after birth or when found.

TABLE VI

Average Immune Globulin Concentrations Depending on Time Left with Dam
(All Calves Born Inside)

	No.	Average Z.S.T. Units	Significance
March			
Calves left with dams more than 12 hours	16	12.7 ± 7.9	p = <0.05
Calves separated at birth or when found	96	8.3 ± 5.7	
April			
Calves left with dams more than 12 hours	17	16.2 ± 9	p = <0.05
Calves separated at birth or when found	69	9.4 ± 5.9	

Significantly higher ($p = <0.05$) immune globulin concentrations were found in those calves left with their dams for more than twelve hours.

Discussion

The seasonal variation in the serum immune globulin concentration of newborn market bull calves, previously reported by Gay et al, 1965, and Fisher et al, 1968, was also apparent in the present survey. The results reported herein clearly indicate that such seasonal variation also exists amongst heifer calves retained in farms. Although an exact comparison cannot be made with the results previously reported by Smith, H.W., et al, 1967 regarding the immune globulin concentration of home bred newborn calves due to a difference in the analytical methods used, it would appear that the seasonal variation encountered in the West of Scotland is more distinct than that seen in England. It is interesting to note that the seasonal variation in mortality is also less marked in England

than it is in Scotland (Lovell and Hill, 1940; Withers, 1952-1953).

The close correlation between low serum immune globulin concentrations and death from E.coli septicaemia and neonatal diarrhoea, and high serum immune globulin levels and survival in newborn calves, suggested by Gay et al, 1965, and Fisher et al, 1968, was confirmed by this survey. Those calves with the lowest serum immune globulin concentration (9.0 ± 5.8 Z.S.T. units) showed the highest mortality, 15%. Those with the highest serum immune globulin concentrations (24.4 ± 7.9 Z.S.T. units) showed the lowest mortality, 3%. The calves with intermediate serum immune globulin concentrations (12.0 ± 7.9 Z.S.T. units) had a mortality rate of 8%. Different methods of management prevailing at parturition have been suggested by Selman (1969) as being responsible for the wide individual and in fact the seasonal variation of serum immune globulin concentrations. The findings obtained in this survey would agree with this view, as shown in the results, a statistically significant difference in the serum immune globulin concentration was found in calves born under different methods of management; those calves born in the byre had a significantly lower serum immune globulin concentration (9.0 ± 5.8 Z.S.T. units) than those born in boxes (12.0 ± 7.9 Z.S.T. units) and than those born in the field (24.4. ± 7.9 Z.S.T. units). These values as mentioned previously are inversely related to the incidence of mortality. The observation made by Leech et al (1968) is relevant to this discussion; these workers found that the calf's chance of survival was closely related to its place of birth. The present results, however, would suggest that the calf's chance of survival was closely related to its serum immune globulin concentration, and that such concentration is influenced by the place of birth.

Other factors, such as time of first feeding colostrum after birth, and allowing the calf to remain with its dam for 12 hours had a significant influence in the serum immune globulin concentrations of the newborn calves.

A higher serum immune globulin concentration was found in those calves left with their mothers than in those removed from them. Significantly higher serum concentrations were also found amongst calves fed colostrum within six hours post partum. This is in agreement with the findings of Kruss, 1969 and Selman, 1969, who found that the calf's ability to absorb immune lacto globulin decreases rapidly after birth.

The findings mentioned above, would indicate that the higher serum immune globulin concentrations found in the field-born and some box-born calves, are due to the fact that under these circumstances the newborn calf has a greater chance of sucking colostrum at an early age. However, there are exceptions, and other factors such as the shape and volume of the udder of the dam, mothering ability and strength of the calf at birth (Selman 1969) may influence the end result, even if the calf is left with its dam for more than 12 hours.

Since no detailed bacteriological studies were performed during the survey, it could be argued that calves born under different methods of management may have been unequally exposed to the effects of E. coli and that the population and build up of bacteria may have differed from farm to farm. Furthermore, within each farm those calves born in the field would be exposed to a considerably smaller challenge of bacteria, than those born in the byre. A similar situation could be argued to exist between those calves born in clean calving boxes

and those born in the byre, and this could have been responsible for the difference in mortality. Although this situation could certainly have existed and, as reported in the following investigations, could have explained the higher mortality observed in individual farms, the results obtained during the survey produced further evidence supporting the close relationship between high serum immune globulin concentrations and survival and low immune globulin concentrations and death from E.coli septicaemia and neonatal diarrhoea.

Section II

Farm Investigation into the Effects of Different Methods of Management in the Serum Immune Globulin Concentration of New-born Calves; and its possible Correlation with mortality from Septicaemia and Neonatal Diarrhoea

INTRODUCTION

The results reported in the previous section, stressed the importance of the different methods of management in relation to the eventual serum immune globulin levels observed in newborn calves. The following investigations on individual farms, were undertaken in order to assess further the relationship between the newborn calf's serum immune globulin concentration, the methods of management and husbandry prevailing on the farm, and the incidence of death from E.coli septicaemia and diarrhoea. The last investigation in this section, describes how a change in management can influence the serum immune globulin concentrations of newborn calves and its effects on the death rate from E.coli septicaemia and diarrhoea.

MATERIALS AND METHODS

These were the same as the ones described for the previous section. A brief account of the management, husbandry and other relevant details are given at the beginning of each investigation.

INVESTIGATION NO. 1.

The Effect of Poor Management at Parturition, Poor Housing and Poor Stockmanship on the Serum Immune Globulin Concentrations of Calves and Subsequent Progress of the Calves - Farm E.

The calves born on this farm were born in the byre, and removed from the cow when found. They were bucket fed two pints of their dams' colostrum at the next herd milking. When removed from the byre, the calves were housed in a converted stable among other calves of varying ages. The stable was bedded with straw which was never cleaned out; therefore the animals were living on a bed of urine and faeces impregnated straw. The incidence of diarrhoea was 100%. Apart from treating the sick animal with oral tetracyclines, no attempt was made by the stockman to improve the hygienic conditions of the sick animals. The farmer himself took little interest in the calves, and the byreman who was responsible for looking after the calves was not very interested in the animals, since he was about to leave the farming industry.

Results

Table VII illustrates the mean and standard deviation of the immune globulin values found in this farm. The mean serum immune globulin concentration (5.7 $\pm$ 5.3 Z.S.T. units) is significantly lower ($p < 0.001$) than the mean obtained for the other byre-born calves in this survey (9.0 $\pm$ 5.8 Z.S.T. units). The mortality observed in this farm was 28% as compared with the overall mortality of 11% found in the survey, and the mortality of 15% found amongst the byre-born calves of the other farms.

TABLE VII

Z.S.T. Values from Byre-Born Calves in Farm 'E'

Calf No.	Z.S.T. Units.
1	1.25
2	1.5
3	2.75
4	2.25
5	3.75
6	8.0
7	6.25
8	8.75
9	5.25
10	10.00
11	1.75
12	22
13	2
14	5
Mean	5.75
S.D.	± 5.3

Mortality

Number of Animals that Died	Percentage of Mortality
4	28.5%

Discussion

It is clear from the serum immune globulin concentrations obtained in these calves on Farm E that the majority (57%) were potentially susceptible to E.coli septicaemia (McEwan 1968) (refer to Table No. XI) and all of them were susceptible to diarrhoeic death.

Thus, it is not at all surprising to find under the circumstances the mortality previously mentioned. The statement made by H.W. Smith (1962) would certainly apply to this farm. "... It must be appreciated that most present day methods of rearing calves are harshly artificial and the question that may rightly be asked is not why do calves so reared become ill, but rather how do most of them survive?"

Since a detailed bacteriological study of the different serotypes present at the time of the investigation was not made, it cannot be ascertained whether or not a known pathogenic strain was present.

The significantly lower degree of protection observed in these calves plus the obvious continuous build up of infection and the lack of interest by the farmer and his byreman would explain the higher mortality observed in this farm.

INVESTIGATION NO. 2.

The Effect of Good Nursing, but Poor Hygiene and Management at Parturition on the Serum Immune Globulin Concentrations of Newborn Calves and Subsequent Progress to One Month of Age - Farm 'C'.

On this farm neonatal calf diarrhoea had been a problem for the last three years and practically every calf born on the farm was expected to suffer from the condition. The hygienic conditions were very poor, particularly those concerning the birth and the rearing of calves. Although a large herd of 110 Ayrshire cows was kept, no provision was made for calving boxes, calf houses or calf cubicles. The calves were born in the byre, removed when found and kept in a provisional stall amongst other calves of up to one month of age. This provisional accommodation occupied one end of a very poorly illuminated and ventilated byre. The animals were crammed together and if too many were born at the same time, further provisional accommodation was provided in other byres. When the animals reached two or three months of age, they were placed together in a large loose-box. Amongst these detrimental conditions, there was one procedure which, according to the person in charge of the calves, was always followed; this was, to feed the calves their mother's colostrum as soon as possible after birth. Two to three pints of colostrum were fed by bucket usually within six hours post partum. The person who looked after the calves was the wife of the farmer who was very interested in their progress and proud of the fact that although she had been treating almost every calf that had been born during the past three years, mortality was very low. This person would spend any amount of time persuading a calf to drink its milk and would make several attempts

to feed the sick animals if necessary. Different chemo-therapeutic drugs had been used and although some had appeared to be effective when first tried, they were soon replaced by a different one. At the time of the survey the calves were being treated with tetracycline and streptomycin.

Results

The results obtained when analysing the data from this farm showed two relevant findings which may account for the low mortality rate which was said to exist by the owner and confirmed by the survey.

TABLE VIII

The Serum Immune Globulin Concentrations of Byre-Born Calves in Farm 'C' Compared with Other Byre-Born Calves in the Survey

Byre-Born Calves	No. Calves Sampled	Mean Serum Immune Globulin Concentration (Z.S.T. Units)	S.D.	Significance
Farm 'C'	7	16.6	±4.0	$p < 0.001$
Other Farms	187	9.0	±5.8	

Mortality

Farm 'C' - 0% Other Farms - 15%

Table VIII illustrates the mean immune globulin concentrations of byre-born calves on Farm 'C' as compared with the mean levels of byre-born calves on other farms. Mortality is also shown.

It can be seen from the figures shown in Table VIII that the mean serum immune globulin concentration found on this farm is significantly higher ($p < 0.001$) than the mean for the rest of the byre-born calves in this survey. There were no deaths recorded during the period of the survey.

Discussion

It can be suggested that although the animals were kept in very poor housing conditions, subject to the constant re-infection of bacteria, including E.coli, prevailing in the environment, the serum immune globulin concentration of most of the animals born on this farm was sufficiently high to certainly prevent death from colisepticaemia and to render these calves less susceptible to diarrhoeic death. This, plus the good nursing carried out by the person in charge of the calves at the critical time, during illness, no doubt contributed to the result of no mortality. It could be argued that the chemotherapeutics used may have also played a part in the lower mortality observed on this farm. However, the fact that various therapeutic agents had been tried for a number of years and the problem remained for all practical purposes the same, together with the fact that over 90% of the rectal swabs cultured in McConkey agar from the calves in this farm were not sensitive to the drugs used, would not support this argument. The higher serum immune globulin levels observed in these calves can be attributed to the special attention given to the early feeding of colostrum.

INVESTIGATION NO. 3.

Effect of Bad Management at Parturition, but Good Housing and Stockmanship on the Serum Immune Globulin Concentrations and Survival of Newborn Calves - Farm 'D'.

This farm was one of the few farms visited in the survey which had calving boxes. The accommodation for calves, stirks and cows was excellent. The byres were kept clean and the younger stock was housed according to age in separate buildings. There had been the occasional dead calf in the two years prior to the survey, and diarrhoea, when it occurred in calves, was claimed to have been successfully treated with antibiotics. The situation had deteriorated at the time of the survey, and the incidence of death and the number of calves suffering from diarrhoea had increased considerably without any apparent reason during the past year. Although the calves were born in boxes, this practice was followed for the benefit of the cow. When possible, the cows were taken into the boxes one or two days before the assumed date of parturition. The boxes were cleaned and bedded generously with straw. Once the cow had calved, she was immediately removed from the box, on most occasions before she had a chance to lick or groom her calf. The calf was fed colostrum from a bucket at the next milking time. If there was no great demand for the calving box, the newborn calf was left there for two or three days, after which it was removed and placed in an individual cubicle in another byre used specifically to house young calves and followers. The calves remained in individual cubicles for eight to ten weeks. The sick animals were being treated with antibiotics and sulphonamides.

Results

Table IX illustrates the mean serum immune globulin concentration of calves on Farm 'D' and their mortality.

TABLE IX

The Serum Immune Globulin Concentration of Box-Born Calves on Farm 'D' Compared with Other Box-Born Calves in the Survey

Box-Born Calves	No. of Calves Sampled	Mean Serum Immune Globulin Concentration (Z.S.T. Units)	S.D.	Significance
Farm 'D'	18	4.3	±2.3	$p < 0.01$
Other Farms	46	12.7	8	

Mortality

Farm 'D' - 16% Other Farms - 4.3%

No. of calves 3.

A statistically significant ($p = 0.01$) lower serum immune globulin concentration was observed in calves born on Farm 'D' than calves born under similar circumstances in other farms. In fact, the mean serum immune globulin value obtained for these calves is lower than the mean value obtained for the byre-born calves in the survey. The mortality on this farm was higher (16%) than the overall average mortality (11%) observed on the farms included in the survey. All the calves that died on this farm were immediately reported. Bacteriological examination performed in specimens obtained from the spleen and kidney of the dead animals revealed that all the calves had died from colisepticaemia.

Discussion

It was not surprising to find that all the animals which died on this farm did so from septicaemia. This would be expected in view of the fact that the majority of calves possessed insufficient serum immune globulin concentrations to properly protect them from septicaemia.

It has been shown in Table III that those animals born in boxes had medium immune globulin levels. However, because of the particular managemental procedure followed by this farm at parturition, such concentrations were not attained. Removing the cow from the box immediately after calving deprived the calves of the chance of sucking and other benefits derived from leaving the calf with its mother for a longer period of time.

The calves produced under these circumstances were demonstrably susceptible to the fatal effects of colisepticaemia and diarrhoea. It is relevant that although the mean serum immune globulin concentration of the calves born on Farm 'D' (4.3 ± 2.3 Z.S.T. units) is not significantly different from the mean serum immune globulin levels obtained on Farm 'E' (5.75 ± 5.3 Z.S.T. units), the mortality is higher under the worse hygienic conditions prevailing on Farm 'E'. It is suggested that because of the excellent hygienic conditions observed on Farm 'D', losses did not reach more drastic proportions. It could well be that directing the efforts of management towards increasing the serum immune globulin levels in the calves would be sufficient to eradicate or considerably decrease the mortality. After the survey had been completed, a change in management, as described below was advised in order to achieve this purpose. It

is realised that the data which is presented below represents the findings on one farm and thus is limited. However, it is reported with the intention of illustrating how a simple change in management can influence the serum immune globulin concentrations of newborn calves and hence the incidence of mortality and neonatal diarrhoea.

All but one of the managemental procedures prevailing during the survey, as well as the sampling procedures, of calves and recording of data were adhered to while undertaking this later investigation.

Change in Management

The byreman was asked to leave the calf with its mother for at least 12 hours, preferably 24 hours. He was to observe the calf and cow repeatedly during the first 3 hours after birth. If during that time the calf had not suckled, he would ensure that the calf did so at 3 hours post partum. When the cow and calf were separated, the calf was put in the individual cubicle and fed cow's milk. The calves were observed closely by the byreman and any evidence of diarrhoea and sickness was recorded. Studies were continued for 9 months after the survey was completed.

Results

Figure 4 illustrates the immune globulin values of the heifer calves born on Farm 'D' during the survey (January to July, 1968) and the values obtained in calves born on the same farm after the change in management had been adopted. These values are summarised in Table X.

Fig. 4.

The Serum Immune Globulin Concentrations of new-born Calves Born in Farm D Under Two Different Methods of Management i.e. Left with and Removed from their Mothers

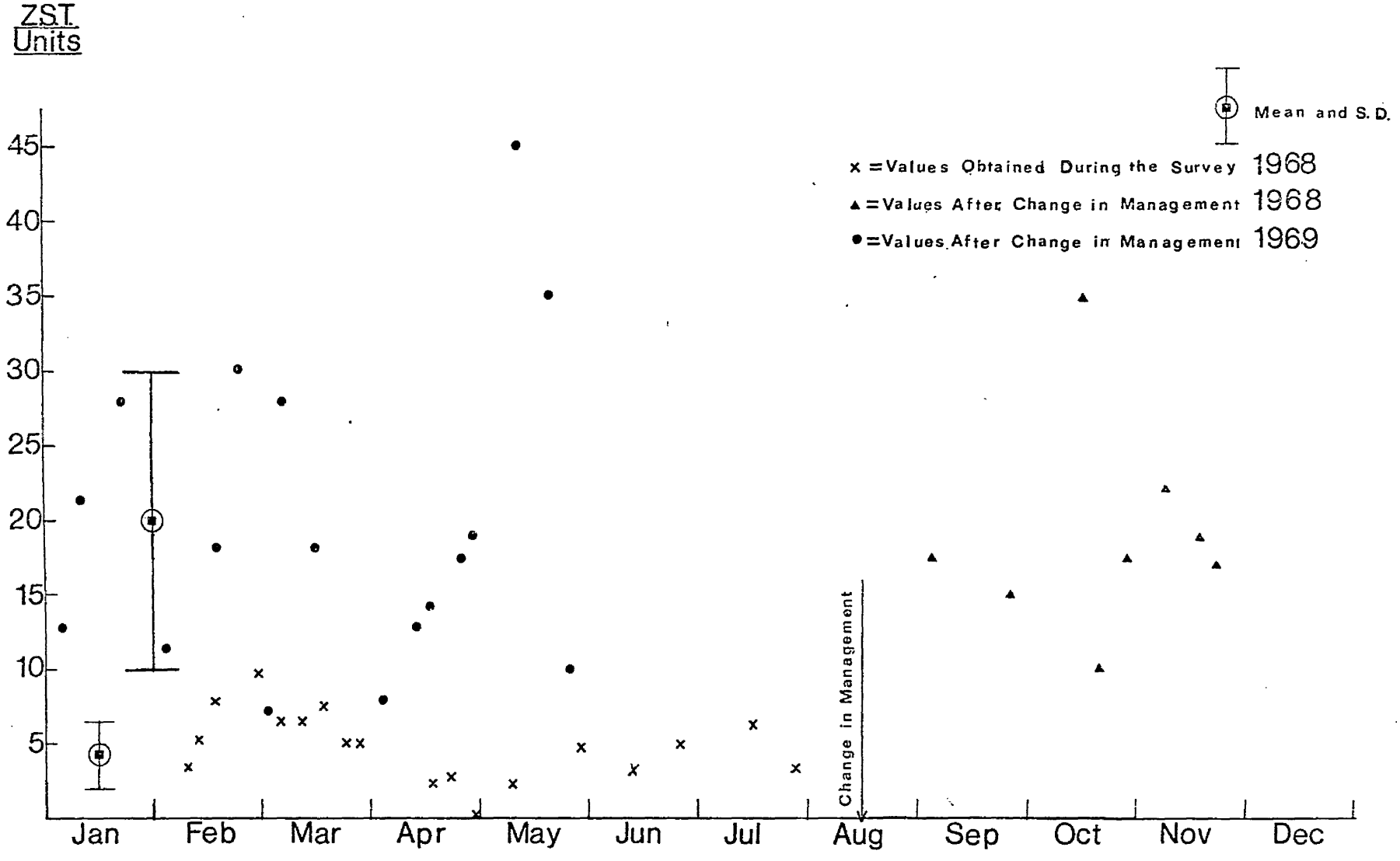


TABLE X

The serum immune globulin concentration of calves born in Farm 'D' before and after change in management

	No. of calves sampled	Mean serum immune globulin concentrations Z.S.T. Units	S.D.	Significance	Mortali
Calves born during the survey	18	4.3	± 2.3	p = 0.001	15%
Calves born after the change in management was adopted	25	20.0	± 9.8		0%

Significantly higher serum immune globulin concentrations were recorded immediately after the new system had been adopted, and although there is a variation in the individual values, the mean serum immune globulin concentration of the calves born during the nine months after the management was changed is significantly higher. There were no deaths recorded during this period; only two animals suffered from diarrhoea and were treated, as compared with 90% of diarrhoeic and treated animals during the survey period.

Discussion

It is interesting to note that under these circumstances the marked seasonal variation reported in Figure 3 disappears. This would strongly support the view of Selman (1969) who regards the seasonal variation in the serum immune globulin concentration of newborn calves as a result of the managemental procedures prevailing in the West of Scotland. It also appears from these results that increasing the passive immunity of the calves born under these circumstances was sufficient to reduce the incidence of diarrhoea and certainly to prevent mortality. It must be emphasised that there was no other change made in the management of the calves; that is to say, they were fed exactly the same diet as the animals previously born on this farm, which showed a significantly higher mortality. It is thus unlikely that a dietetic factor other than that described was playing a primary role in this outbreak of neonatal diarrhoea. The calves were fed by the same person and no particular measures were taken concerning disinfection of pens or pails.

Section III

Experimental Studies Into The Effects of Environmental Temperature and Some Therapeutic Agents on the Outcome of Neonatal Calf Diarrhoea in Calves of Known Serum Immune Globulin Concentration

Introduction

The results of the investigations reported in sections I and II have stressed the importance of the passive immunological status of the newborn calf in the prevention of neonatal disease. The serum immune globulin concentrations of newborn calves may influence considerably the final outcome of *E. coli* septicaemia and neonatal diarrhoea. The failure to consider this fact would leave open to question the validity of the majority of previous therapeutic trials performed in order to assess their benefifical effect in preventing death from these conditions. (McSherry and Grinyer, 1954; Henry and Blackburn, 1957; Dalton *et al*, 1960; Osborne and Watson, 1965; Radostis, 1965; Watt, 1965; Dickson, 1969).

The following experiments have been designed in such a way, as to minimize as much as it is possible, the effects of the variations observed in the serum immune globulin concentration of newborn calves. Thus newborn calves with similar serum immune globulin levels have been used as experimental animals.

In experiment number 3, the performance of a group of newborn calves with significantly higher serum immune globulin concentrations is compared with the performance of treated and control calves with lower serum immune globulin concentrations.

MATERIALS AND METHODS

Experimental Animals

108 bull calves were used for these experiments. The animals were purchased through a dealer, who obtained the animals from different

local markets. The breeds of calves used were mainly Ayrshire and Ayrshire crosses. Although the exact age of the animals could not be obtained accurately, it is customary for the farmers in this region of Scotland to send their newborn calves to the market as soon as possible after birth, certainly within a week of birth. It is feasible to assume, therefore, that the animals used in these experiments were under a week old.

A variable number of calves was bought weekly by the dealer and the animals were transported from the markets to his premises. Here, the animals were mixed and kept together in a large box. On occasion over fifty calves were housed in this box, and never were there less than twenty animals. The calves were usually kept overnight before the majority of them were sent to different farms or to the slaughterhouse. This procedure was repeated weekly, and the total turnover of calves amounted to several hundred in a month.

This concentration of calves lent itself ideally for the sampling procedures designed in order to make the following study possible.

On the evening of the day on which the calves were bought by the dealer, a brief examination of the animals available was performed once they were all accommodated in the calf box. Animals which were obviously ill, recumbent or diarrhoeic were marked and excluded from the group as possible experimental animals. However, no attempt was made to separate the sick animals from the group. The majority of calves were tagged with a market number. When this was not the case, the animals were numbered with a coloured crayon for the purpose of

later identification.

Blood Sampling

A blood sample was obtained from the jugular vein of all the suitable calves available. The samples were marked, and taken back to the laboratory. Here they were allowed to stand and clot. Serum was then removed and its immune globulin concentration was immediately measured.

Estimation of the Serum Immune Globulin Concentration

This was performed, following the method mentioned in Section I.

Selection of Experimental Animals

The zinc sulphate values obtained from all the calves sampled were compared. A selection was made of those animals which showed similar low serum immune globulin concentrations. All those calves which showed readings of less than five turbidity units were excluded. The rationale behind this procedure was that by doing so the calves liable to die from E.coli septicaemia would be excluded, thus allowing a more precise selection of calves susceptible only to the diarrhoeic syndrome. The value of a zinc sulphate turbidity reading of five units used in eliminating calves liable to die from E.coli septicaemia was extracted from the data reported by McEwan (1968). His findings are illustrated in Table XI.

Animals with immune globulin levels over 25 were also excluded, since as reported by Gay et al. (1965) such calves were most unlikely to die from diarrhoea even under adverse conditions. Calves with

TABLE XI

IMMUNE GLOBULIN CONCENTRATION (ZST. UNITS) IN 50 CALVES WHICH DIED FROM SEPTICAEMIA

Calf No.	Zinc Sulphate Turbidity Units	Survival (days)	Calf No.	Zinc Sulphate Turbidity Units	Survival (days)
1	0.25	4	26	2.5	1
2	0	3	27	0.5	3
3	6.0	14	28	0.6	5
4	1.75	11	29	0.2	6
5	2.5	4	30	0.6	6
6	2.5	8	31	0.1	3
7	0.25	14	32	1.9	8
8	3.0	11	33	1.7	3
9	2.0	3	34	1.3	2
10	1.5	4	35	2.3	2
11	6.0	4	36	0.9	5
12	12.0	4	37	2.6	1
13	8.5	12	38	1.8	5
14	0.5	4	39	1.2	8
15	2.0	9	40	0	2
16	2.25	4	41	0.1	2
17	0	3	42	1.5	7
18	0	3	43	1.7	5
19	8.5	5	44	0	3
20	2.5	3	45	4.4	5
21	2.5	2	46	1.8	5
22	5.25	9	47	0.4	2
23	1.75	3	48	1.1	2
24	0.5	2	49	0.9	3
25	2.0	7	50	0.25	2

$ZnSO_4$ turbidity mean $\pm$ S.D. = 2.1 ± 2.4

Table extracted from: A.D. McEwan Ph.D. Thesis (1968) with the kind permission of the author.

serum immune globulin concentrations between the values of 5 and 25 were thus selected, and preferably whenever possible with values between 6 and 15.

Once this screening was performed the suitable experimental calves were brought to the Veterinary Hospital the following morning.

All these experiments were performed during the late and early months of the year (December to March), for two reasons:

(a) It was at this time when a greater number of hypogammaglobulinaemic calves were found.

(b) At this time the incidence and death from diarrhoea has been found to be highest.

It must be emphasised however, that although a greater number of hypogammaglobulinaemic animals were seen at this time of the year, a large proportion of these were agamma-globulinaemic or possessed such low levels that the danger of dying from septicaemia was considerable. Because of this finding and because of the need to obtain groups with similar low immune globulin levels, 906 newborn calves had to be sampled in order to obtain sufficient numbers of calves for these experiments.

Accommodation of Experimental Animals

The calves were kept in a calf house divided into several cubicles by means of tubular steel bar fences. Four or five animals were placed in each cubicle. A thick bed of straw was provided at the beginning of the experiment, and fresh straw was thrown into the cubicles when the bedding became too moist and dirty, but

the cubicles were not cleaned or disinfected during the experimental period.

Weighing of the Animals

On arrival at the Veterinary Hospital the animals were weighted on 'Avery' cattle scales which were accurate to the nearest half pound. Further weighting of the experimental animals was carried out on alternate days in the morning two or three hours after feeding.

Feeding of Experimental Animals

All calves were fed three to four pints of bulked cows' milk twice daily. No attempt was made to force the animals to drink all of their allocated feed. The animals were fed from a bucket, and the same pail was used to feed several animals.

Clinical Examination of Calves

The rectal temperature, pulse rate, respiratory rate, and the demeanour of the animals was recorded twice daily, in the morning and in the afternoon. A subjective assessment of the degree of diarrhoea was performed by qualifying the consistency of the excreta obtained on examination as follows:

(a) Normal faeces (-) They were passed in small amounts, well formed, firm and pasty in consistency, sometimes covered with a layer of clear mucous. They were pale brown to light yellow in colour. On many occasions it was difficult to induce defaecation in animals passing this type of stool, even when stimulating the rectum by the insertion of the protected finger.

(b) Diarrhoea (+) These were passed in larger amounts but still would hold their shape when falling to the straw bed.

(c) Diarrhoea (++) The fluid content of this type of stool was much greater; the animals defaecated readily when stimulated and only a small proportion of the material excreted was retained on the surface of the straw bedding when falling, the remainder draining through the straw. The faeces were of a yellow-green or creamy-white colour and had an offensive smell. The hind legs and perineal region of these animals were usually stained badly with faecal material.

(d) Diarrhoea (+++) The faeces classified as such were extremely watery. When excreted, large amounts of fluid material were explosively discharged from the rectum and practially nothing remained on the surface of the straw bedding. The animals would often strain after defaecation. In a number of recumbent animals this very fluid fetid material would dribble from their rectums.

EXPERIMENT NO. 1.

The Effect of Ambient Temperature on the Severity of Diarrhoea in Neonatal Calves of Known Serum Immune Globulin Concentrations

Introduction

Previous studies, reported in the review of the literature, undertaken in order to assess the possible effect of temperature on the outcome of neonatal calf diarrhoea have yielded controversial results. In view of this, an experiment was designed to evaluate the influence of a warm and a cold environment on the outcome of diarrhoea in calves with known serum immune globulin levels. The methods of sampling and general experimental procedures mentioned in the section of methodology were adhered to while undertaking these investigations.

Materials and Methods

A group of sixteen calves with similar immune globulin concentrations was selected from a total of 56 animals. These sixteen calves were then divided into two groups of eight, by the following procedure. Pairs of calves showing the same or very similar immune globulin levels were selected, allocating one calf to Group A and one to Group B. When the two groups were formed, one of the groups was selected at random to occupy the pens kept at an average of $60^{\circ}F$ (highest recorded was $62^{\circ}F$ and the lowest recorded was $57^{\circ}F$). The temperature in the cold pens varied to a great extent, the average temperature recorded was $44^{\circ}F$ (highest, $46^{\circ}F$ and lowest $30^{\circ}F$). Thus, of the two calf houses, one was above and one below the lower limit of optimal temperature ($52^{\circ}F$) suggested by Jimenez and Blaxter (1962) for calf houses.

Apart from the difference in temperature all other conditions of management were exactly the same for both groups. The same stockman fed both groups of calves and no attempt was made to disinfect the pails used for feeding nor did the stockman take any special precautions while going from one calf house to another. The animals were under observation for a maximum of fifteen days. The individual clinical records of these calves are included in Appendix

Results

Table XII illustrates the serum immune globulin concentrations of the calves at the beginning of the experiment as evaluated by the zinc sulphate turbidity test, the number of days in which the animals showed diarrhoea and the fate of the calves. It can be observed from Table XII that there was no significant difference in the mean serum immune globulin concentrations of the calves studied in this experiment. All the animals in this study suffered from diarrhoea and except for calf No. 72 in Group 'B' every one of them passed a +++3 diarrhoea for at least two consecutive days. The mean time of survival in days was greater for the animals housed under cold environment (Group 'B') 9.2 days compared to 6.0 days for the animals housed in the warm pens (Group 'A'). However, the mean number of days in which a +++3 diarrhoea was recorded was similar for both groups; that is 3.25 in Group 'B' and 3.37 for Group 'A'.

There was no significant difference in the mortality rate between the calves that were kept in cold pens as compared with those kept in a warm environment. In each group only one calf survived;

that is, there was a mortality of 87.5%.

Discussion

It is interesting to note that the only survivors in both groups, calf No. 76 in Group 'A' and calf No. 72 in Group 'B' had the highest immune globulin levels recorded amongst the sixteen calves. In both animals the zinc sulphate reading was significantly higher than the mean values obtained for both groups. It would appear from the results obtained in the experiment that animals with low serum immune globulin concentration are equally susceptible to the fatal effects of diarrhoea regardless of the environmental temperature.

TABLE XII

The effect of temperature in the incidence and severity of diarrhoea

Calf No.	Z.S.T. Units	Diarrhoea	Fate	Body Weight in pounds at the beginning of experiment	Body Weight in pounds at the end of experiment
GROUP 'A' Housed in a warm environment - Temperature kept at 60°F					
64	6.25	+++(3)	D(4)	72	67
69	8.00	+++(4) ++(2)	D(8)	60	53
71	8.50	+++(4) ++(2)	D(9)	88	82
75	7.75	+++(3)	D(5)	69	61
76	23.75	+++(3)	S	62	61
78	5.0	+++(3)	D(4)	65	60
80	9.75	+++(4) ++(4)	D(12)	79	68
82	6.25	+++(3) ++(4)	D(7)	60	51
Mean	9.46 ± 5.9	+++(3.37)	(6)	69.30	62.87
MORTALITY 87.5%					
GROUP 'B' Housed in a cold environment - Temperature 44°F					
72	19.25	++(5)	S	78	79
90	10.25	+++(3) ++(4)	D(11)	86	71
93	6.5	+++(3) ++(2)	D(9)	76	68
94	9.75	+++(3) ++(8)	D(13)	67	56
96	6.50	+++(4) ++(1)	D(7)	66	54
99	8.75	+++(4) ++(2)	D(9)	67	59
101	6.75	+++(5) ++(3)	D(10)	75	67
102	6.75	+++(4) ++(1)	D(6)	79	73
Mean	9.31 ± 4.29	(3.25)	(9.2)	74.25	65.87
MORTALITY 87.5%					

The number of +'s marked under the heading of diarrhoea indicates the severity of diarrhoea, the number in brackets immediately after indicates the number of days in which that degree of diarrhoea was observed. D = Died, the number immediately after in brackets, indicates the day of the experiment in which the animals died. S = Survived.

EXPERIMENTS NO. 2A and 2B

The Efficacy of Furazolidone and Chloramphenicol Among Calves of Known Low Serum Immune Globulin Concentrations in the Treatment of Neonatal Calf Diarrhoea.

Introduction

The use of antibiotics and other chemotherapeutics has been claimed to be of benefit in controlling neonatal calf diarrhoea (Dalton, Fisher and McIntyre, 1960; Henry and Blackburn, 1957; Osborne and Watson, 1965). However, these and other reports lack information regarding the immunological status of the animals treated. This status, as demonstrated previously in the literature review, can under certain circumstances alter the final outcome of the condition, therefore modifying any conclusions which could be drawn concerning drug efficacy. In view of the drastic increase in the prevalence and emergence of resistant strains of E.coli, a number of drugs, in particular antibiotics which are widely used in the prevention and treatment of neonatal calf diarrhoea, are obviously not contributing at all to the solution of the problem and their use is thus not justified. Some of the findings in the previous investigations reported herein clearly support this fact. However, the wise application of the results obtained from the use of extensive and regular antibiotic sensitivity testings could positively benefit the situation. Such results have revealed that there are some chemotherapeutics to which resistance does not seem to develop to the same degree. The regular use of the sensitivity tests has yielded information as to which are the more active chemotherapeutics in vitro against the intestinal flora of the animals being investigated.

By discriminating between the different chemotherapeutics

available on the basis of *in vitro* sensitivities, the reports of Mackay *et al.* (1965), the report of the Edinburgh and West of Scotland College of Agriculture, 1968, and Smith H.W., 1960, would suggest that furazolidone and chloramphenicol are the drugs of choice if any benefits were to be expected at the present time from dosage with antibacterial agents in the treatment of neonatal calf diarrhoea. Mackay *et al*, (1965), for example, reported that only 10% of the *E.coli* strains tested were resistant to furazolidone. Furthermore, resistance to this drug did not seem to be developing to the same degree as with some antibiotics. Although resistance to chloramphenicol had increased 14% in six years, it was, of the antibiotics commonly used against neonatal diarrhoea, the one to which fewer strains were resistant. Only 22% of the *E.coli* strains isolated were resistant to this drug as compared with 90% resistance against tetracycline and streptomycin and 50% against neomycin. The data reported by the Edinburgh and East of Scotland College of Agriculture supported this finding in that these two drugs were found to be the ones to which a smaller percentage of *E.coli* strains were resistant. The percentage of resistant strains of *E.coli* to furazolidone was 27% and that to chloramphenicol was 40%. The results obtained from the sensitivity tests carried out while performing the farm survey previously reported in this thesis are summarised below. It can be seen that these findings strongly support those of the studies previously mentioned.

TABLE XIII

in vitro Drug Sensitivities - Farm Survey

Drug	Resistance Per Cent
Chloramphenicol	29%
Streptomycin	93%
Tetracyclines	91%
Furazolidone	10.0%
Neomycin	34%

As a consequence of these findings, experiments were carried out testing the efficacy of chloramphenicol and furazolidone in the treatment of diarrhoeic calves of known low serum immune globulin concentrations.

Experiment 2A - Animals Treated with Furazolidone

Materials and Methods

Two groups each consisting of twelve calves, were formed by allocating calves of similar serum immune globulin concentrations to each group. Once this allocation was performed, one group was selected at random to serve as the control group and the other was to be treated with furazolidone. A rectal swab was obtained from every experimental calf and a sensitivity test was performed. The intestinal flora of all the animals treated was shown in vitro to be sensitive to furazolidone. The animals were all kept together in the same calf house, mixed in groups of five. The animals were examined clinically twice daily, following the system previously mentioned.

Treatment

The animals treated received 510 gms per day of Neftin* orally. The treatment was instituted after the calf was seen to pass a +++3 diarrhoea, and it was continued until the calf had recovered or died. The experimental period lasted 15 days.

Results

Table XIV illustrates the serum immune globulin concentrations of the experimental calves, their bodyweight in pounds at the beginning of the experiment and at death or at the end of the experimental period. The severity of the diarrhoea and the number of days on which any particular degree of diarrhoea was detected is

* Smith, Kline and French Laboratories Ltd., England

TABLE XIV

The Efficacy of Furazalidone in the Treatment of Neonatal Calf Diarrhoea in Calves of Known Serum Immune Globulin Concentrations

Calf No.	Serum Immune Globulin Concentration (Z.S.T. Units)	Diarrhoea	Fate	Bodyweight in pounds at the beginning of Experiment	Bodyweight in pounds at the end of Experiment	Total Gain or Loss of Bodyweight at the end of Experiment
Treated Group						
506	4.00	+++ (2)	D (3)	78	74	- 4
511	7.75	+++ (1) ++ (7)	S	67	64	- 3
515	6.25	+++ (1) ++ (6)	S	71	65	- 6
518	10.0	+++ (3) ++ (4)	D (11)	66	56	- 10
521	22.0	+++ (1)	S	60	64	+ 4
528	9.5	+++ (2) ++ (5)	D (10)	72	68	- 4
537	6.0	+++ (2)	D (4)	63	61	- 2
532	5.5	+++ (2)	D (5)	60	57	- 3
585	14.25	+++ (2) ++ (2)	D (6)	70	62	- 8
592	6.75	+++ (2)	D (4)	64	52	- 8
594	15.00	+++ (2)	S	79	84	+ 5
595	11.25	+++ (2)	S	88	91	+ 3
Mean S.D. ± 5.1	9.9	+++ (1.8) ++ (4.3)		69.8	66.5	
MORTALITY 49%						
Control Group						

509	7.25	++ (9)	S	60	54	- 6
507	12.75	+++ (2)	D (5)	56	52	- 4
516	6.0	++ (5)	D (5)	55	51	- 4
517	11.25	+++ (4)	D (7)	63	52	- 11
522	13.50	+++ (2) ++ (3)	D (9)	80	76	- 4
527	8.25	+++ (1) ++ (2)	S	55	56	+ 1
530	24.00	+++ (1) ++ (4)	S	74	70	- 4
531	5.75	+++ (2)	D (7)	70	64	- 4
540	6.25	+++ (2) ++ (4)	S	83	84	+ 1
582	12.00	++ (5)	D (6)	58	50	- 8
587	7.00	+++ (3) ++ (1)	D (6)	52	48	- 4
596	5.25	+++ (1) ++ (4)	D (6)	60	55	- 5
Mean	9.9	+++ (1.5)		63.8	59.3	
	S.D. ± 5.2	++ (5)				
MORTALITY 66%						

The number of +'s marked under the heading of diarrhoea indicates the severity of diarrhoea, the number in brackets immediately after indicates the number of days in which that degree of diarrhoea was observed. D = Died, the number immediately after in brackets indicates the day of the experiment in which the animals died. S = Survived.

also reported.

The mean serum immune globulin concentration was not significantly different between the two groups. Although all the calves included in the experiment suffered from diarrhoea, the death rate was higher in the control group. Five of the animals belonging to the treated group survived (41%), as compared with only four of the control animals (34%). The mean number of days in which surviving calves from both groups suffered from +++3 diarrhoea was not significantly different. There was, however, a difference in the mean number of days during which calves suffered from ++2 diarrhoea, the mean being higher in the control group, five days as compared with three days in the treated group. The total weight gain of the five survivors in the treated group was 3 pounds, as compared with a loss of eight pounds in the total weight of the four survivors belonging to the control group.

The mean surviving period for the animals that succumbed was five days for the calves serving as controls and six days for the treated calves, day 1 being the first day of the experiment. The number of times during which dying calves passed +++3 diarrhoea before dying was variable in both groups.

Discussion

Although the oral administration of furazolidone to susceptible newborn calves of known serum immune globulin concentrations appeared to be of some small benefit in the treatment of neonatal calf diarrhoea, the results obtained under the circumstances are not as impressive as those reported by Osborne and Watson (1965 and Henry and Blackburn (1957). In both these investigations, however, the nitrofurans

were used as a prophylactic measure rather than as treatment, since the administration of the drugs was commenced from the first day of the experiments regardless of the clinical conditions of the animals. Furthermore, the results reported by Osborne and Watson (1965) are even more difficult to interpret, since these authors included beef and dairy calves in their investigations without considering the effects that the different methods of management prevailing in dairy and beef herds may have on the acquisition of passive immunity. It is relevant to note that during the present investigation, the calves with the highest immune globulin concentrations in both groups survived.

Experiment No. 2B - The Efficacy of the Parenteral Administration of Chloramphenicol in the Treatment of Neonatal Calf Diarrhoea in Calves of Known Serum Immune Globulin Concentrations.

Materials and Methods

With the exception of treatment, the methods followed while undertaking this experiment were identical to those reported in Experiment 2A.

Administration of Therapy

The calves allocated to the treatment group were given intramuscularly 500 mgms of Chloramphenicol daily (Intramycetin, Parke-Davis). The animals were treated immediately after a +++3 diarrhoea was detected and remained under treatment until they recovered or died.

Results

Table XV illustrates the mean serum immune globulin concentration of the calves used in this experiment, the incidence of diarrhoea, the bodyweights of the experimental calves at the beginning and at the

end of the experiments and the fate of such calves. The mortality found during the experiment is also illustrated.

As it can be seen from the figures in Table XIV, the mean serum immune globulin concentration of both groups of calves does not differ significantly. In both groups an identical high mortality of 80% was recorded, two animals surviving in each group. The change in total bodyweight observed in the survivors from the treated group was negative; a total loss of nine pounds was seen in this group. The survivors from the control group, however, only lost a total of two pounds. The mean number of days which the calves that died survived was very similar in both groups, 8.1 days for the animals in the treated group and 7.8 days for the animals in the control group. All the experimental calves suffered from diarrhoea, and the incidence of the condition was not significantly different between the two groups.

Discussion

The poor results obtained in this experiment by the intramuscular administration of Chloramphenicol in the prevention of calf diarrhoea, when compared with the results obtained by Dalton et al. (1960), could perhaps be partly explained by the fact that the intramuscular application of this drug is probably more effective in preventing the septicaemic form of colibacillosis; and although the drug is excreted in the bile, thus reaching the intestinal lumen, the quantities excreted might not be sufficient to prevent the local proliferation of E.coli in the intestine. Since the calves used in this experiment were already passively protected against septicaemia, any possible beneficial

effect of the antibiotic against colisepticaemia would not, therefore, be detectable.

In other studies, including that of Dalton, et al. (1960) claiming beneficial effects of antibiotics in neonatal calf disease, it is possible that the lack of knowledge of the immunological status of such calves meant that the claimed beneficial action was due to the antibiotic preventing deaths from septicaemia, but not necessarily reducing the incidence of diarrhoea and thus preventing death from this condition.

In this experiment once again the calves with the higher serum immune globulin concentrations were the survivors in both groups.

TABLE XV

The Efficacy of the Parenteral Administration of Chloramphenicol in the Treatment of Neonatal Calf Diarrhoea in Calves of Known Serum Immune Globulin Concentrations

Calf No.	Serum Immune Globulin Concentrations (Z.S.T. Units)	Diarrhoea	Fate	Bodyweight in pounds at the beginning of Experiment	Bodyweight in pounds at the end of Experiment	Total Gain or Loss of Bodyweight at the end of Experiment
Treated Group						
365	15.25	+++ (7) ++ (2)	S	85	77	- 8
371	8.75	+++ (3) ++ (2)	D (9)	88	82	- 6
375	8.25	+++ (4)	D (6)	69	61	- 8
376	24.00	+++ (4)	S	62	61	- 1
382	6.5	++ (2) +++ (3)	D (7)	59	51	- 8
390	9.5	+++ (3) ++ (5)	D (11)	86	71	- 15
394	9.5	+++ (4) ++ (2)	D (12)	67	56	- 9
396	7.75	+++ (3) ++ (2)	D (7)	66	54	- 12
391	7.25	+++ (3) ++ (2)	D (6)	70	63	- 7
455	9.0	+++ (3)	D (7)	68	62	- 6
Mean	10.5			72	63.8	
	S.D.± 5.0					
MORTALITY 80%						
Control Group						

364	6.25	+++ (3)	D (3)	72	69	- 3
369	8.50	+++ (4)	D (8)	60	54	- 6
378	5.50	+++ (3)	D (4)	65	60	- 5
399	7.25	+++ (3) ++ (2)	D (9)	67	59	- 3
301	6.25	+++ (5) ++ (5)	D (12)	84	70	- 14
380	10.00	+++ (4) ++ (2)	D (12)	79	74	- 5
393	7.25	+++ (3) ++ (2)	D (9)	67	62	- 5
372	20.00	+++ (6) ++ (1)	S	78	79	+ 1
466	4.50	+++ (2) ++ (2)	D (6)	83	78	- 5
469	16.00	+++ (1) ++ (2)	S	70	67	- 3
Mean	9.2			72.5	67.2	
S.D.	± 4.74					
MORTALITY	80%					

The number of +'s marked under the heading of diarrhoea indicates the severity of diarrhoea, the number in brackets immediately after indicates the number of days in which that degree of diarrhoea was observed. D = Died, the number immediately after in brackets indicates the day of the experiment in which the animals died. S = Survived.

EXPERIMENT NO. 3.

The Effect of the Prophylactic Use of Furazolidone in Calves with Low Serum Immune Globulin Concentrations on the Incidence and Severity of Neonatal Calf Diarrhoea, Compared with the Effect of High Serum Immune Globulin Concentrations

Introduction

The results obtained in Experiment No. 2A suggested that the oral administration of furazolidone may be of some slight value in the treatment of neonatal calf diarrhoea. The beneficial effects of the drug could perhaps in the light of the findings reported by Henry and Blackburn (1957) and Osborne and Watson (1965) be enhanced if it was used as a prophylactic measure. It was the object of this study to ascertain such beneficial effects.

At the same time a group formed with calves possessing significantly higher serum immune globulin concentrations was included in this study, in order to evaluate further the possible protective value of high serum immune globulin concentrations.

Materials and Methods

Three groups of calves were used in this investigation. Two groups consisted of five calves each, and one was made up of six calves. The two groups of five animals included calves of similar immune globulin levels. Group 'A', served as control, while the calves in Group 'B', received 510 mgms per day of Neftin orally from the day that the experiment began. Group 'C' was formed by calves which had a significantly higher serum immune globulin concentration than the calves in the other two groups. All the animals were of

similar age (3 ± 2 days); they were all kept together in the same calf pens and fed bulked cows' milk. The methods of clinical examination were the same as those mentioned in previous experiments.

Results

Table No. XVI shows the serum immune globulin levels of the experimental animals, the number of diarrhoeic periods recorded, the fate of the animals and the change in bodyweight.

There was no significant difference in the death rate between the low serum immune globulin control group and the low serum immune globulin prophylactically treated group. Two animals survived in each group. Of the survivors in the treated group, one calf (No. 30) was never diarrhoeic and at the end of the experimental period had gained four pounds. Calf No. 32 passed severe diarrhoea only one day, but an increased faecal excretion was recorded during three consecutive days. This calf did not gain any weight. In the lower immune globulin control group both survivors went through the experiment without showing a severe diarrhoea. However, a moderate diarrhoea was recorded on several occasions from both calves. Calf No. 25 gained one pound and calf No. 33 showed no change in bodyweight by the end of the experiment. In contrast, no deaths were recorded in the control group formed by calves which possessed high serum immune globulin levels. Four of the six calves in the group showed severe diarrhoea at least on one occasion and all showed a moderate diarrhoea during one or more days.

Two animals gained weight, three lost weight and one showed no change. However, at the end of the experimental period all the calves in this

group, except for calf No. 36, were passing well-formed faeces; they were drinking their milk avidly; and they appeared bright and playful. Although every attempt has been made to exclude on the basis of serum immune globulin concentrations calves liable to die from colisepticaemia, this purpose could not always be achieved. In these experiments, one calf (No. 17) died from colisepticaemia. However, if this calf is excluded from the experiment, the valid conclusions are unaltered.

Discussion

The data in Table XVI clearly indicated how the serum immune globulin levels of a group of calves influenced the outcome of the results obtained when assessing the value of a particular therapy against calf diarrhoea. It can also be deduced from the results obtained that in this particular case the animals with higher serum immune globulin concentrations were better protected against the effects of diarrhoea, than those animals with lower serum immune globulin levels that were treated prophylactically with Neftin, a chemotherapeutic to which the intestinal flora of the animals treated had been proved sensitive *in vitro*.

TABLE XVI

The effect of Furazolidone and high (Ig) levels in the incidence and severity of diarrhoea

Calf No.	Z.S.T. Units	Diarrhoea	Fate	Body Weight in pounds at the beginning of experiment	Body Weight in pounds at the end of experiment
Treated Group					
17	4.25	++ (1) Se	D (1)	72	72 - 0
18	5.75	+++ (2) ++ (1)	D (6)	62	57 - 5
30	5.25	-	S	75	79 + 4
21	5.5	+++ (2)	D (4)	65	61 - 4
32	5.5	+++ (1) ++ (3)	S	56	56 - 0
Mean S.D.	5.25 ± .58			66	65
MORTALITY 60%					
Control Group					
25	5.5	++ (4)	S	62	63 + 1
20	5.0	+++ (3)	D (6)	55	48 - 7
31	5.75	+++ (3)	D (7)	61	55 - 6
33	5.0	++ (2)	S	72	72 - 0
35	5.5	+++ (4)	D (8)	69	56 -13

445	22	+++ (1) ++ (3)	S	61	59 - 2
451	7.5	+++ (4) ++ (3)	D	70	62
455	13	+++ (3)	S	83	78 - 5
461	18	+++ (2)	S	74	70 - 4
464	7	++ (4)	S	94	91 - 3
465	8	++ (3)	S	72	69 - 3
467	8	+++ (3) ++ (2)	S	80	76 - 4
Mean	11.9	+++ (2.1)		76.2	72.1
S.D.	± 5	++ (2.1)			
MORTALITY 14.2%					

The number of +'s marked under the heading of diarrhoea indicates the severity of diarrhoea, the number in brackets immediately after indicates the number of days in which that degree of diarrhoea was observed.
D = Died, S = Survived. Se = Septicaemia.

EXPERIMENT NO. 4.

The Efficacy of the Anticholinergic Pamine in the Treatment of Neonatal Calf Diarrhoea

INTRODUCTION

Little is known regarding the actual state of intestinal motility and tone in the diarrhoeic newborn calf. Mylrea (1968b) using calves of one to three weeks of age, demonstrated that the rate of passage of ingesta through the small intestine, was similar in diarrhoeic and normal non-diarrhoeic calves, but is increased through the large intestine of diarrhoeic calves. The literature concerning different pathological conditions encountered in the human subject characterised by diarrhoea suggest that at least some of such conditions are due to a derangement of intestinal motility (Fordtran, 1967) and increased motility was claimed by Sherbaniuk (1964) as one of the malfunctions of the intestine responsible for diarrhoea. However, in other pathological conditions like sprue, diarrhoea occurs in the presence of an apparently hypomotile intestine (Code, Hightower and Moslock, 1952).

Radostis (1965) was of the opinion that the intestine of the diarrhoeic calf was hypomotile rather than hypermotile and that care should be taken in using anticholinergic drugs with the intention of stopping diarrhoea. However, no experimental evidence was presented supporting this claim.

Pamine in combination with Neomycin under the trademark Neobiotic-P (Upjohn Ltd., Crawley, Sussex, England) has been recommended in the treatment of neonatal calf diarrhoea. The advertising literature states that the decrease in intestinal motility

promotes fluid reabsorption and hence decreases fluid and electrolyte losses. These claims appear to be made as a result of unpublished observations on a very small number of non-diarrhoeic calves given Pamine.

Neomycin has not been demonstrated to be an antibiotic to which *in vitro* sensitivity has been shown in diarrhoeic calves in the Veterinary Hospital; moreover, it has not been effective in treating neonatal diarrhoeic calves in this place.

An experiment was conducted in order to study the effects of Pamine alone in neonatal calf diarrhoea, since there was no reason to expect any benefit from Neomycin.

Materials and Methods

The methods followed for the selection of the experimental animals and clinical examination and performance of the calves were those mentioned in the section of General Materials and Methods. Fourteen calves with similar serum immune globulin concentrations were divided into two groups of seven. One group was allocated at random to serve as controls and the other as treated. The calves in the treated group received orally 50 mg. (2 tablets of Pamine) daily after the onset of +++3 diarrhoea; the treatment was continued until the animal recovered or died.

Application of Treatment

The tablets of Pamine (25 mg.) were placed by hand far back in the mouth of the calves. Once the animal had swallowed the tablets, it was offered its daily ration of milk. The same procedure was adopted in the afternoon.

Results

Table XVII illustrates the mean serum immune globulin of the calves used in this experiment, the severity of diarrhoea, the fate of the calves and the changes in bodyweight observed during the experimental period.

The mean serum immune globulin concentrations is not significantly different between the groups - 11.07 ± being the mean for the treated group and 11.9 ± for the control group. The severity of the diarrhoea, as judged by the number of days during which calves from both groups showed two and three plus stools, does not appear to be different. However, the mortality rate in the treated group was significantly higher than in the control group. A mortality of 57% was seen in the treated group as compared with a mortality of 14.2% in the control group. One of the survivors, Calf No. 448 in the treated group, was the only calf that did not suffer from diarrhoea. This was also the only calf that did not lose any weight.

Discussion

It appears from the results obtained in this experiment that the use of an anticholinergic drug alone is of no value in preventing death from or reducing the incidence of neonatal calf diarrhoea. It appears that this substance has, in fact, a deleterious effect on neonatal calf diarrhoea.

An explanation for the negative results could be that impairment of the intestinal motility is not primarily affected in neonatal

calf diarrhoea and that other functions, such as absorption and secretion, may be more actively involved.

Although no detailed studies were made of the direct effect that the drug was having on the motility of the gut, it was apparent from other clinical signs observed in some of the calves treated, such as mild tympany and dryness of the muzzle and mouth, that the dosage applied was sufficient to bring about a parasympatholitic effect. On post mortem two of the treated animals that died, Calves No. 443 and 452, showed very distended abomasum and a very fluid filled intestinal tract.

The higher mortality observed in the treated group as compared with the control group might indicate that the anticholinergic drug used actually aggravated the condition. Although apparently the severity of diarrhoea was similar in both groups, it has been stressed before that such assessment is only partially reliable. The fact that the treated animals lost on average a considerably greater amount of bodyweight (6.5 lbs.) as compared with a mean loss of 4.1 lbs. in the control group, would suggest a more severe loss of body water through the faeces.

TABLE XVII

The efficacy of the anticholinergic Pamine (Methscopolamine) in the treatment of neonatal calf diarrhoea

PAMINE EXPERIMENT

Calf No.	Mean serum Immune Globulin level (Z.S.T. Units)	Diarrhoea	Fate	Body Weight at the beginning of experiment	Body Weight at the end of experiment
Treated Group					
443	8.5	++ (2) +++ (5)	D	76	62 - 14
448	18	-	S	81	82 + 1
452	10	++ (2) +++ (3)	D	72	56 - 16
453	6	++ (2) +++ (3)	D	76	68 - 8
454	16	++ (3)	S	62	60 - 2
457	9	+++ (2) ++ (2)	D	48	42 - 6
462	10	+++ (2) ++ (2)	S	82	79 - 3
Mean S.D.	11.07 ±4.5	+++ (2.5) ++ (2.1)		71	64
MORTALITY 57%					
Control Group					

Mean S.D.	5.35 ± .33			63.8	58.8
MORTALITY 60%					
Control Group - with higher immune globulin concentrations					
22	25.25	++ (2)	S	65	69 + 4
39	17.0	+++ (1) ++ (2)	S	70	68 - 2
38	16.0	+++ (2) ++ (2)	S	78	75 - 3
36	12.25	+++ (3) ++ (1)	S	68	64 - 4
28	14.0	++ (2)	S	77	77 - 0
26	13.5	+++ (1)	S	68	69 + 1
Mean S.D.	16.33 ± 4.69			71	70
MORTALITY 0%					

The number of +'s marked under the heading of diarrhoea indicates the severity of diarrhoea, the number in brackets immediately after indicates the number of days in which that degree of diarrhoea was observed. D = Died. S = Survived.

The effects of fluid and electrolyte therapy on the outcome of neonatal diarrhoea in calves of known low serum immune globulin concentrations

Introduction.

The reports of McSherry and Grinyer (1954), Blaxter and Wood (1953), Roy et al (1959), Dalton et al (1965), Fisher (1965), Watt (1965), Fisher et al (1967), Fayet (1968), clearly indicate that the water and electrolyte balance is grossly affected as a result of neonatal calf diarrhoea, a situation which is also the outstanding feature in infantile diarrhoea, and other diarrhoeic maladies found in human beings (Darrow, Pratt, Flett, Gamble and Wiese (1949), Elkinton and Donowski (1956), Brusilov and Cook (1959), Fienberg, Cheung, Fleishman (1960), Phillips (1964), Kooh and Metcoff (1963), Torres Pinedo, Lavastida, Rivera, Rodrigues and Ortiz (1966). In the field of human medicine, the correction of the water and electrolyte deficit by an adequate fluid therapy has been of great value in reducing mortality in infants suffering from diarrhoea, (Welt, 1959, Darrow and Welsh, 1960, Reardon, 1959). Perhaps the most noteable example of the effects of fluid replacement is found in the treatment of human cholera. (Phillips, 1966, Gordon, Feeley, Greenough, Sprinz, Oseasohn, 1966). These findings have not been ignored in the veterinary field.

A number of reports are found in the literature concerning the use of different water and electrolyte solutions in the treatment of neonatal calf diarrhoea (McSherry and Grinyer (1954), Radostis (1965), Watt (1965), Carter (1969), Dickson (1969). Such treatments, however, because of the dearth of detailed information concerning the total

losses of water and electrolytes occurring during neonatal calf diarrhoea, have been empirical or based on results obtained in the human subject. When used, the electrolyte solutions have usually been applied in conjunction with chemotherapeutics or plasma, thus confusing the true effect of the electrolyte therapy per se. The reports available have ignored the influence of passive immunity on the outcome of the condition, and one report has included calves suffering from E.coli septicaemia (Watt 1965). Previous experiments reported in this thesis have indicated that by selecting calves on the basis of their serum immune globulin concentrations, E.coli septicaemia can be avoided.

If the beneficial effects of electrolyte therapy are to be ascertained it is imperative that no animals potentially susceptible to E.coli septicaemia be included in such investigation, for little benefif will be derived from the application of electrolytes in a condition where the death of the calves is due to a bacterial invasion and water and electrolyte derangements are minimal (Fisher 1965).

It should be at least theoretically possible, to provide sufficient water and electrolytes to calves suffering from neonatal diarrhoea, so that the fatal effects of the condition may be overcome.

The experiments reported below were designed with the intention of testing such a hypothesis.

Materials and Methods

The procedures of selection, clinical examination, feeding, weighing and other assessments of the calves used during this experiment, were the same as those reported in the section of general materials and methods.

Two groups of nine calves with similar serum immune globulin concentrations were formed. Once the calves had been allocated to the respective groups, one of the groups was selected at random to serve as control, and the other as treated.

Treatment of Experimental Calves

The calves to be treated, received Darrow's * Solution intravenously. The volume given was varied according to the clinical appearance of the animals and to the changes observed in the blood and plasma parameters before and after treatment of the calves investigated. The electrolyte therapy was commenced after the calves had passed a +++ diarrhoea.

Injection of the Darrow's Solution

All the animals treated were fitted with a sterile cannula (Brannula cannula, Armour Pharmaceutical Company Ltd., Eastbourne, England), into one jugular vein.

The necks of the calves were cleaned and clipped, and the skin thoroughly disinfected with Cetavlon (I.C.I.) With a sterile scalpel, a small incision was made through the skin along the jugular groove in order to facilitate the insertion of the cannula into the jugular

* (Allen & Hanburys Ltd., London, England)

vein. Once in the vein the cannula was sutured to the skin by two or three silk stitches. The stoppers provided with the cannula in order to prevent the outflow of blood, when not in use, were adhered to the bodies of the cannula with plastic water-proof adhesive to prevent any accidental leakage of blood. The patency of the cannula was checked twice a day when not being used. The electrolyte solution was warmed to 37°C and injected using sterile disposable recipient sets (Capon, Heaton & Co.Ltd., Birmingham, England).

Sampling Experimental Animals

Blood samples were taken from the jugular vein in heparinised tubes, on alternate days. When the animals were being treated, however, the collection of blood was perfoemed before and after treatment in order to record changes if any, in the plasma electrolyte concentrations and other blood parameters analysed.

Packed Cell Volume

The estimation of the Packed Cell Volume was performed by the microhaematocrit technique as described by Fisher (1962).

Sodium and Potassium

The plasma, sodium and potassium concentrations were estimated on an E.E.L. (Evans Electroselenium Ltd., Halstead, Essex) photometer using the technique described by Varley (1962).

Chloride

The plasma chloride concentration was estimated using the E.E.L. Chloride meter.

Blood Urea

This was determined by the Urease Nesslerization method described by Varley (1962).

Results

Table No. XVIII illustrates the serum immune globulin concentrations of the calves studied, the severity and duration of diarrhoea, fate, weight of the calves at the beginning and at the end of the experiment. It also shows the total amount of fluid injected into the animals belonging to the treatment group, the period in days over which the amount indicated was given, and the maximum quantity administered at any one time.

It may be seen that the mean serum immune globulin concentrations are not significantly different between the two groups. 9.9 ± 5.6 (Z.S.T. units) being the mean for the control group and 9.6 ± 4.2 (Z.S.T. units) for the treated group. The mortality in both groups was 77%, two calves surviving in each group. When investigating the mean days of survival from the onset of severe diarrhoea for the dying calves, those animals belonging to the treated group showed a mean of 4.1 ± 1.9 three days while the mean for the untreated group was 3 ± 2 days. There is no significant difference between these times.

Of the 18 animals in this experiment only two calves, number 72 and 81, did not lose weight. Calf No. 72 in the control group had gained 1 lb. at the end of the experiment and calf number il in the treated group showed no overall change in bodyweight by the end of

TABLE XVIII

The efficacy of the intravenous administration of fluid and electrolytes in diarrhoeic newborn calves of known serum immune globulin concentration

ELECTROLYTE EXPERIMENT
Darrow's Solution

Calf No.	Serum I.G. Concentration (Z.S.T. Units)	Diarrhoea	Fate	Treatment Total Amount Injected (litres)	Maximum Quantity given in any one day (litres)	Period of time over which treatment was given (days)	Weight Before	Weight After
Control Group								
73	6.5	+++ (3) ++ (1)	D	-	-	-	59	56
80	7.5	+++ (4)	D	-	-	-	61	56
72	21.0	+++ (3)	S	-	-	-	79	80 + 1
71	11.5	+++ (3)	D	-	-	-	64	60
70	6.5	+++ (1)	D	-	-	-	61	58
47	17.5	+++ (3) ++ (2)	S	-	-	-	70	67 - 3
46	5.5	+++ (2)	D	-	-	-	74	70
29	7.5	+++ (2)	D	-	-	-	63	58
44	6.0	+++ (5)	D	-	-	-	85	80
Mean S.D.	9.9 5.6	+++ (3) ++ (2)					68.9	65
MORTALITY 77%								
Treated Group								

67	10.0	+++ (2)	D	3	1.5	2	73	68
83	12.0	+++ (2) ++ (1)	D	7	2.5	4	74	70
79	20.0	+++ (5) ++ (1)	S	9.5	3	6	70	67 - 3
74	7.5	+++ (2) ++ (5)	D	7	2.5	5	65	60
81	7.0	++ (1)	S	8	2.5	6	72	72 - 0
20	7.5	+++ (3) ++ (1)	D	10	4	5	59	54
17	9.0	+++ (2) ++ (2)	D	7	3	3	64	59
24	8.0	+++ (4) ++ (2)	D	14	4	6	71	67
21	6.0	+++ (3)	D	9	4	4	72	68
Mean S.D.	9.6 ± 4.2	+++ (2.5) ++ (1.4)					68.4	65
MORTALITY 77%								

The number of +'s marked under the heading of diarrhoea indicates the severity of diarrhoea, the number in brackets immediately after indicates the number of days in which that degree of diarrhoea was observed. D = Died, S = Survived.

of the experimental period.

There was no significant difference in body weight, between the survivors belonging to the control group and those belonging to the treated group. A total loss of 2 lbs. was recorded in the survivors of the control group and a total loss of 3 lbs. in the survivors of the treated group.

As judged by the death rate recorded in the control and treated groups, the electrolyte therapy applied under the conditions of this experiment did not appear to have any beneficial effects. The changes occurring in the plasma electrolyte concentrations of the animals treated were inconsistent and there did not appear to be a correlation between the total volume of fluid given and the changes recorded in the plasma and blood parameters analysed. The detailed data for this experiment are reported in the appendix of this thesis. The total volume of fluid given intravenously to the diarrhoeic calves over a period of days and the maximum quantity administered in any one day varied from individual to individual; such variations however did not seem to influence the results. For example, calf number 79 received a total of 9.5 L. of Darrow's solution during the period of treatment, the maximum quantity administered to this calf in any one day was 3 L. This animal survived, having suffered from +++ diarrhoea during five consecutive days. On the other hand calf number 20 received a total of 10 L. of Darrow's solution with a maximum of 4 L. administered in 24 hours. This calf died, in spite of the fact that apparently it only suffered from +++ diarrhoea for three consecutive days.

The significantly higher serum immune globulin level of calf number

79 is to be noted. Once again in this experiment the serum immune globulin concentration of three of the four survivors were the highest values recorded amongst the calves in both groups.

Table XIX summarises the plasma and blood parameters analysed while undertaking this study. (The details of the daily changes recorded are reported in appendix C.) The values illustrated correspond to the samples taken when all the calves were normal (First Sample) and to the sample taken 12 hours or less before death (Terminal Sample).

The changes in the concentration of serum electrolytes, blood urea and P.C.V. that occur in diarrhoea have been reported to vary according to the number of days which the calves are affected with the condition. Roy et al (1959), Dalton et al (1965). Also evidence of significant differences in the concentration of serum potassium, blood urea and blood pH has been given when comparing such values in dying diarrhoeic and surviving diarrhoeic calves, (Fisher, 1965, Fisher et al, 1967) and when comparing calves dying from septicaemia and calves dying from the effects of localised intestinal infection with E.coli (Roy et al (1959)).

In order to make a more accurate assessment of the results obtained of the blood and plasma parameters analysed in the present study, the experimental calves have been grouped according to the number of days during which they suffered from diarrhoea, this is illustrated in Table XIX.

Examination of the results obtained regarding the changes in serum potassium concentrations in the dying diarrhoeic calves in

TABLE XIX

The concentration of Plasma, Sodium, Potassium Chloride, Blood Urea and Packed cell volume in Electrolyte treated and control dying and surviving diarrhoeic calves

		P.C.V. %		Sodium Meq/L.		Potassium Meq/L.		Chloride Meq/L.		Urea Mgm./100 ml	
Calf No.	Z.S.T. Units	First Sample	Terminal Sample	First Sample	Terminal Sample	First Sample	Terminal Sample	First Sample	Terminal Sample	First Sample	Terminal Sample
DYING CALVES SUFFERING FROM DIARRHOEA FOR 1 or 2 DAYS											
Controls											
70	6.5	40	43	139	136	5.0	6.5	104	100	20	50
46	5.5	42	51	142	153	5.6	6.3	108	110	20	63
29	7.5	40	46	151	157	4.2	6.8	110	108	26	35
Treated											
67	10.0	38	42	142	135	5.6	8.8	102	96	20	85
74	7.5	45	52	136	130	5.0	6.8	104	100	24	106
17	9.0	33	33	138	140	4.0	6.6	106	108	40	98
83	12.0	34	36	139	130	5.2	6.2	102	96	20	82
DYING CALVES SUFFERING FROM DIARRHOEA FOR 3 - 4 DAYS											
Controls											
73	6.5	49	55	136	128	4.8	6.4	109	98	27	132
71	11.5	31	39	136	128	4.8	6.2	111	94	11	94
80	7.5	39	56	136	142	5.2	9.4	109	100	19	200
Treated											

20	7.5	44	45	139	128	5.0	6.3	106	100	32	70
21	6.0	36	43	143	132	4.4	6.0	105	100	41	80
24	8.0	33	41	144	124	4.6	6.5	104	104	30	76
DYING CALVES SUFFERING FROM DIARRHOEA FOR 3 - 6 DAYS											
Controls Treatments - None											
44	6.0	28	32	138	130	5.2	7.2	110	98	28	90
SURVIVING CALVES											
Treated											
79	20.0	36	38	136	139	4.4	4.8	108	110	18	22
81	7.0	37	38	142	139	4.4	4.4	110	112	28	22
Controls											
72	21.0	39	39	139	136	4.4	4.8	110	112	8	22
47	17.5	32	30	133	130	4.4	4.6	108	106	22	23

Table XiX (Contd.)

The mean and S.D. values of the plasma parameters analysed in the control and treated calves that died

Calves suffering from diarrhoea for 1 or 2 days	P.C.V.		Sodium		Potassium		Chloride		Urea	
	First Sample	Terminal Sample	First Sample	Terminal Sample	First Sample	Terminal Sample	First Sample	Terminal Sample	First Sample	Terminal Sample
Controls	40.6 ± 1	46.6 ± 4	144 ± 4	148.6 ± 7	4.9 ± 3	6.5 ± 3	107 ± 2	106 ± 2	22 ± 2	49 ± 10
Treated	37.5 ± 3	40.7 ± 7	138.7±3	133.7 ± 6	4.9 ± 4	7.1 ± 1	103 ± 3	100 ± 3	26 ± 8	92 ± 6
Calves suffering from diarrhoea for 3 or 4 days										
Controls	39.6 ± 5	50 ± 6	136 ± 3	132.6 ± 5	4.9 ± 2	7.3 ± 1.5	109 ± 1	97 ± 2	19 ± 5	146 ± 16
Treated	37.6 ± 4	43 ± 3	142 ± 4	128 ± 7	4.6 ± 2	6.3 ± 2	105 ± 1	101 ± 2	34 ± 5	75 ± 4

The mean and S.D. values of the plasma parameters analysed in the control and treated calves that survived

Controls	35.5 ± 4.9	34.5 ± 6.3	136 ± 4.2	133 ± 4.2	4.4 ± 0	4.7 ± .14	109 ± 1.4	109 ± 4.24	15 ± 9.89	22.5 ± .71
Treated	36.5 ± .70	38 ± 0	139 ± 4.2	139 ± 0	4.4 ± 0	4.6 ± .2	109 ± 1.4	111 ± 1.4	23 ± 7.07	22 ± 0

both groups, clearly indicated an overall rise in the serum concentration of this cation. In the control group, the rise appeared to increase as the diarrhoeic period increased. A mean serum potassium concentration of 6.5 meq/L. was obtained in those animals suffering from diarrhoea during one or two days as compared with a mean of 7.3 meq/L. observed in those animals affected for three or four days. Calf number 44 in the control group was the only animal recorded to have had diarrhoea during five consecutive days before dying and its serum potassium concentration was 7.2 meq/L. The animals belonging to the treated group, apart from the overall increase in their serum potassium concentration, did not seem to differ significantly in their potassium values when considering the number of days in which they suffered from diarrhoea. The calves in this group affected with diarrhoea during one or two days, had a serum potassium concentration of 6.6 meq/L. as compared with 6.2 meq/L. obtained in calves affected in three or four consecutive days. The mean serum potassium concentrations observed in dying diarrhoeic calves in both groups was significantly higher ($p = < 0.01$) than the mean serum potassium concentration recorded for the survivors of both groups. The mean overall serum potassium concentration for the calves which survived was 4.6 meq/L., 4.7 meq/L. being the mean for the controls which survived and 4.3 meq/L. for the survivors in the treated group.

The changes observed in the serum sodium concentration were less consistent, however in general both groups showed a decrease in their serum sodium concentration as the period of diarrhoea increased. Three calves, numbers 46, 29 and 80 in the control group

showed an increase in their serum sodium concentration. Calves, numbers 46 and 29 were diarrhoeic for two days and calf number 80 was diarrhoeic for four days. The animals in the treated group all showed a decrease in their serum sodium concentration. When comparing the mean for the serum sodium concentration of the dying diarrhoeic and diarrhoeic surviving calves, no significant difference could be detected, despite the variation in the number of days on which the animals were diarrhoeic, a mean serum sodium concentration of 135 meq/L. was obtained for the diarrhoeic surviving calves and 134 meq/L. for the dying diarrhoeic calves.

An overall increase in the Packed Cell Volume values was recorded in those calves dying from diarrhoea. Although a marked individual variation was observed in such calves the rise in P.C.V. appeared to be greater as the diarrhoeic period increased. Comparing the Packed Cell Volume values of the control calves, that were diarrhoeic for one or two days, with the values of the treated calves suffering from diarrhoea for the same period of time a less marked rise in P.C.V. was observed amongst the treated animals. The same situation prevailed when comparing the P.C.V. values of the treated and control calves, suffering from diarrhoea for three or four consecutive days. The Packed Cell Volume values of the surviving calves showed little change; the two survivors in the control group, calf number 72 showed no change in its P.C.V. by the end of the experiment and calf number 47 showed a decrease in the P.C.V. value despite the fact that both calves suffered from diarrhoea for three and four consecutive days respectively.

There was a marked increase in the blood urea concentration in the dying calves of both groups. The mean values obtained for the dying calves within 12 hours of death were significantly higher than the values considered as normal for animals of similar age. Fisher (1965), Dalton (1965), de la Fuente, unpublished data.

Although the increase in blood urea concentration varied from calf to calf, those calves belonging to the control group, showed in general, a progressive rise in their blood urea concentrations as the period of diarrhoea increased, thus the mean values recorded for calves that were diarrhoeic for one or two days was 51 mgm/100 as compared with 144 mgm/100 in those calves suffering from diarrhoea for three or four consecutive days. A value of 90 mgm/100 was obtained for one control calf which suffered from diarrhoea for a period of five days. Although the calves in the treated group also showed a significant increase in their blood urea concentrations, the apparent progressive rise detected in the control group, as the diarrhoeic period increased, was absent. A mean value of 92 mgm/100 was obtained for those calves suffering from diarrhoea for one or two days, while a mean value of 75 mgm/100 was seen in those calves affected for three or four days. In contrast, the surviving calves in both groups showed very little change in their blood urea concentrations and although two of the calves belonging to the treated group were diarrhoeic for five consecutive days, their mean blood urea concentration was significantly lower ($p < 0.001$) than the mean value obtained for the dying diarrhoeic calves. The same applied to the other two survivors in this experiment.

The changes observed in the P.C.V. values of the surviving

calves were not significant.

An overall decrease in the serum chloride concentrations was observed in the dying diarrhoeic calves, however the changes recorded were less consistent than those obtained for the other plasma parameters.

Discussion

The results obtained in this study clearly indicated that there was a progressive decline in the serum sodium concentrations as the diarrhoeic period increased. A concomitant rise in serum potassium blood urea and P.C.V. was also observed. Such findings are in accordance with the results reported by Roy et al (1958), Dalton (1965) and Fisher (1965).

The mean serum potassium concentration obtained 12 hours before death in the dying diarrhoeic calves in the present experiment did not appear to be as high as that reported by Roy et al (1958). The mean values reported by these workers was 9.5 meq/L. as compared with 6.9 meq/L. obtained in the present study, while Fisher (1965) reported a value of 6.1 meq/L. as being the mean serum potassium concentration for a group of 25 dying diarrhoeic calves. The significantly higher concentration of this cation in dying diarrhoeic calves reported by Fisher (1965) was also observed in the present study. Roy et al (1958) reported similar findings when comparing calves dying from septicaemia and calves dying from the localised intestinal infection with E.coli. The significantly higher serum potassium concentration observed by Roy et al (1958) in those calves affected with the localised intestinal infection could be explained by the fact that

in animals suffering from this condition the loss of water and electrolytes was significantly higher than in animals dying from septicaemia. Thus the results obtained in the present experiment regarding the changes in the serum potassium concentration were to be expected since none of the calves that died did so from septicaemia.

The serum potassium concentration of the treated and untreated calves was not significantly different 12 hours before death.

Previous reports by McSherry et al (1954), Roy et al (1958), Dalton et al (1965), Fisher (1965) have not always been in accordance when analysing the changes in the concentrations of serum sodium that occur in the diarrhoeic calf. McSherry et al (1954) observed hypernatraemia and hyponatraemia amongst the diarrhoeic calves they studied, however the calves used in their studies were brought directly from farms, thus the management of such calves varied considerably and many had been diarrhoeic for a number of days. It is possible that the results could have been influenced by any change adopted by the farmers regarding the method of feeding the diarrhoeic calves.

Dalton et al (1965), reported a decrease in the serum sodium concentration of most but not all of the calves suffering from diarrhoea. Similar results were reported by Roy et al (1958) and Fisher (1965). In the present study only two calves were found to be hypernatraemic, the remainder showed a decline in their serum sodium concentration. However it must be borne in mind that as pointed out by Elkinton and Danowski (1965), the values of the serum electrolytes is only a measurement of the relative proportion of water and electrolytes in that body fluid compartment, but it does not necessarily indicate

the overall deficit or excess of water and electrolytes that may prevail in the body. Estimate of this could only be achieved by performing accurate water and electrolyte balance studies.

Fisher in 1965, drew attention to the significantly higher blood urea concentrations found in dying diarrhoeic calves, when comparing them with diarrhoeic surviving calves. Marked uraemia was also reported by Dalton et al (1965). The same situation has been reported to occur in dehydrated human subjects (Elkinton and Danowski, 1956, Bland, 1956). In the study presented herein uraemia was a constant finding amongst diarrhoeic calves. The significantly higher blood urea concentration found in dying diarrhoeic calves as compared with surviving diarrhoeic calves reported by Fisher (1965) was also observed in this study, however it is interesting to note that the treated animals in this experiment did not appear to show the same progressive increase in the blood urea concentration as did the control group. A possible explanation for this could be that the fluid given to the treated calves, contributed to some extent to restore a depleted circulatory volume, thus increasing glomerular filtration and a more efficient excretion of urea.

The changes in the packed cell volume as an indicator of the total amount of fluid that the animal would need in order to return its depleted water compartments to normal, proved to be unreliable. Although on some occasions a marked decline in the packed cell volume followed treatment, this did not seem to be correlated to the actual volumes of fluid given. It must be emphasised that the severity of the diarrhoea in this experiment was only assessed by the consistency of the faeces. In these circumstances it is very difficult to estimate

the true loss of water and electrolytes that is taking place through diarrhoea. Once the faeces become fluid in consistency (+++) the percentage content of water in such stools could vary considerably, similarly the total amount excreted in any given period of time could vary significantly.

It is obvious that the relation of time to total amount of fluid lost is of the utmost importance, since an animal that loses a vast quantity of fluid and electrolytes in a short period of time, demands a quicker and more efficient shift of any reserves available in the different body fluid compartments. If such demands are not met either by the animal's own reserves and balance mechanisms or by the adequate administration of fluids the animal will succumb.

It would appear that the intravenous administration of Darrow's solution in the quantities used in this experiment had little effect in preventing death from diarrhoea in calves of known low immune serum globulin concentrations. Statistically, no significant difference could be found when comparing the mean number of days during which the control calves had diarrhoea before dying, and the mean number of days during which the treated calves had diarrhoea before death. These results, however, do not necessarily indicate that fluid and electrolyte therapy should not be applied as supportive treatment in this condition, for if the main manifestation of diarrhoea is the loss of fluid and electrolytes, it is only logical to believe that their replacement would result in the quicker recovery of the affected animals. It rather suggests that the quantities of body fluids and electrolytes lost through diarrhoea may be of such magnitude, that the administration of the relatively

large quantities of fluid reported herein, was inadequate to overcome such losses. It also suggests that fluid therapy per se is not sufficient to prevent death in hypogammaglobulinaemic calves suffering from severe diarrhoea. The fact that the calves in this experiment which had higher serum immune globulin concentrations survived, would support the se arguments.

These findings would question the beneficial effects attributed to fluid therapy by some workers. Dickson (1968) was of the opinion that the administration of a solution containing sodium chloride and glucose improved considerably the condition of calves suffering from diarrhoea. However in his observations he did not include any controls and some calves were also treated with antibiotics. It is very difficult to visualise any improvement in an animal suffering from severe dehydration by the administration of the fluid volumes and electrolyte quantities that Dickson recommends. In fact taking into consideration the change in the feeding management, i.e. withholding all fluid intake until diarrhoea stops the volumes suggested by the author are grossly inadequate. Dickson suggested 16 ozs. of water (154 ml.), 4 gms. of sodium chloride (70 mq.) and 1 oz. of glucose as the quantities of these substances to be given to diarrhoeic calves every 24 hours. The volume of fluid injected is hardly sufficient to meet the daily necessary losses of water in a normal calf, let alone those deficits brought about by diarrhoea. The amount of sodium chloride administered would appear to be below the quantities given to a normal calf through its milk intake. The apparently beneficial effects reported by Watt (1965) and Radostis (1965), using larger volumes of fluid and balanced

electrolytes (4 to 5 litres) in 24 hours while treating diarrhoeic calves would be more realistic than those used by Dickson (1968).

It is obvious that some of the discrepancies in the results obtained could be due to varying degrees of diarrhoea, and as mentioned before, perhaps to different types of diarrhoea regarding the relative losses of fluid and electrolytes. Since very little work has been done concerning the quantitative losses of fluid and electrolytes in the diarrhoeic calf and their possible correlation with the changes in the serum and blood parameters, the search and discussion of data that would help to clarify this situation is reported in part II of this thesis.

It was apparent during the course of this experiment that the practicality of intravenous supporting therapy with water and electrolytes, would only be justified if a greater rate of recovery were obtained since the procedure required technical skill in implanting cannulae and constant surveillance of the calf while the therapy was being administered.

PART II

GENERAL DISCUSSION

Most of the knowledge regarding the immunological status of newborn calves in Great Britain has been gained through studying bull calves bought through local markets (Gay et al., 1965; Fisher, et al., 1968). Except for 190 calves surveyed on a limited number of farms in England by Smith, H.W., et al. (1967), nothing was known about the serum immune globulin concentration of newborn heifer calves kept on farms. Results obtained in the survey reported in this part concerning these heifer calves clearly indicated that the wide individual variation observed in market calves (Gay, et al., 1965; Fisher, et al., 1968; Smith, H.W., et al., 1967) also existed in these dairy heifer calves. That there was a seasonal variation in the average immune globulin levels was pointed out by Gay, et al. (1965) and confirmed by Fisher, et al. (1968). Although it appeared to be less obvious in England, a seasonal variation was evident in the results of Smith, H.W., et al. (1967). This seasonal variation occurred also in the dairy heifer calves studied.

Factors, such as the concentration of immune globulins in colostrum, the quantity of colostrum offered to the calf, the period of time which elapsed after birth before feeding colostrum, and mothering, have been demonstrated experimentally to influence the serum immune globulin concentration of newborn calves (Kruse, 1968; Selman, 1969). Such factors could vary significantly with different methods of management and thus influence directly or indirectly the eventual passive immunological status of the newborn calf. The

experimental evidence brought forward by Selman (1969), while analysing the effects of varying any one of the factors mentioned above on the serum immune globulin concentration of newborn calves, demonstrated that the individual and, in fact, the seasonal, variation observed in the immune globulin content of newborn calves could be managemental in origin. That this is the case was further supported by the results obtained in the survey reported in this part.

The fact that the seasonal variation disappeared when the newborn calves were encouraged to suck within six hours of birth and were left with their dams for at least twelve hours after birth, as happened in investigation No. 3, strongly supports these views.

The importance of the early feeding of colostrum in order to achieve high immune globulin concentrations has been stressed most recently by Kruse (1968) and Selman (1969). This was confirmed in this survey in that significantly higher serum immune globulin concentrations were found in calves fed within six hours of birth. Although other reports have suggested that in the calf the period of intestinal permeability to immune lactoglobulin remains patent for up to 18 to 36 hours after birth (Smith, V. and Erwin, 1959; Comline, Roberts and Titchen, 1951; Pierce, 1961), the findings of the survey are in accordance with those of Selman (1969), who concluded that the shutdown to colostral lactoglobulins is apparently initiated at birth and on following this, the efficiency of absorption would appear to fall steeply.

Since first pointed out by Smith, T. and Little (1922), the relationship between susceptibility to disease in newborn calves and

colostrum deprivation has been found and reported by other workers (Fey and Margadant, 1961; Smith, H.W. and Halls, 1968; Roberts et al., 1954; Glantz et al., 1966).

The correlation found between low serum immune globulin concentrations and high mortality in the heifer calves studied during this survey further indicates the importance of passive immunity to newborn calves. Since a highly significant positive correlation has been found between the zinc sulphate turbidity units and the concentrations of IgG and IgM in the serum of newborn calves (Penhale, Christie, McEwan, Fisher and Selman, 1969), it would appear that the IgG and IgM immune globulin classes are actively involved in conferring protection to the newborn calf, not only against septicaemia (Michael and Rosen, 1963; Penhale, 1965), but also against diarrhoea.

Analysing the data from the survey it indicated that those calves with the lowest serum immune globulin concentration (9.0 $\pm$ 5.8 Z.S.T. Units) showed the greatest mortality (15%); those with the highest mean serum immune globulin concentration (24.4 $\pm$ 7.9 Z.S.T. Units) showed the lowest mortality (3%); and those with the intermediate mean serum immune globulin concentration (12.0 $\pm$ 7.9 Z.S.T. Units) showed a mortality of 7%. It is relevant to note that the relationship between incidence of mortaltiy and immune globulin concentrations was also correlated to the place of birth, the highest mortality was found in byre-born calves, and the lowest in field-born calves. This would support further the view that the different types of management under which calves are born in the West of Scotland affect significantly the subsequent serum immune globulin levels, and this,

in turn, influences the outcome of E.coli septicaemia and neonatal calf diarrhoea.

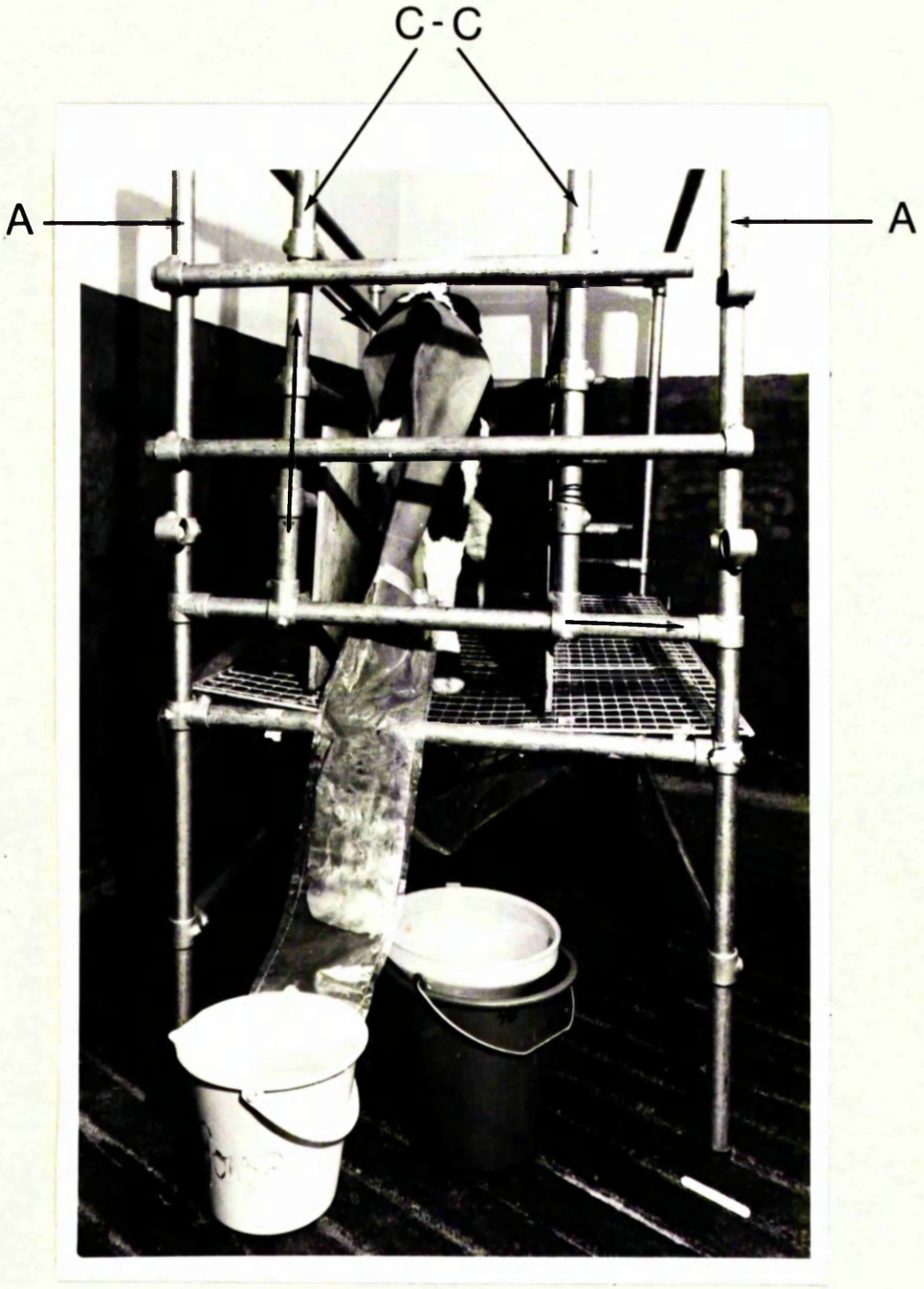
That other factors apart from the serum immune globulin concentrations are involved in the final outcome of E.coli septicaemia and diarrhoea in the newborn calf is demonstrated by the different mortality rates found when analysing the individual farms under different systems of management. However, the influence of managemental, environmental and therapeutic procedures appear to have only limited beneficial effect when calves are frankly hypogammaglobulinaemic. The results reported in Investigation No. 3 could serve as a good example. Despite the good care shown by the stockman, the excellent conditions of hygiene and a variety of therapeutic procedures, the mortality from and the incidence of neonatal E.coli septicaemia and diarrhoea was higher than the mean mortality found for the rest of the farms surveyed. The impressive improvement obtained on this particular farm by changing the methods of management, thus increasing the mean serum immune globulin concentration of calves, is conclusive proof that although other factors, such as build up of bacteria, different serotypes of bacteria, and feeding procedures, may influence the severity of the condition, their role would appear to be secondary to that played by the presence of serum immune globulins.

Further evidence supporting this is provided by the results obtained in Experiment No. 1. In this case, different environmental temperatures had no influence on the outcome of the disease in neonatal calves with similar low serum immune globulin concentrations.

It has been previously stated that apart from insuring that

only E.coli and no other known pathogenic micro-organisms were present in the sick calves studied, no detailed bacteriological serotyping was performed. Although it could be argued that the variations in mortality and the incidence of diarrhoea found on different farms could be attributed to the presence of a more virulent strain on any particular farm, this would not affect the general pattern disclosed by the survey regarding the immune globulin levels and incidence of mortality and diarrhoea. Furthermore, the immediate decline in the incidence of mortality and diarrhoea obtained when increasing the mean serum immune globulin concentrations of the calves reported in Investigation No. 3, all other factors remaining unaltered, would not support this view. It would be unlikely that a virulent strain of E.coli, which has established itself as a resident pathogen in the intestine of its hosts and has been apparently the cause of diarrhoea and death for a number of months on a particular farm, would without any apparent reason cease to be pathogenic. It would be more reasonable to suggest that the high levels of immune globulin then obtained by the calves rendered them resistant to septicaemia, independent of the virulence or serotype of E.coli which may have been present in the environment. Similarly, the high concentration of antibody would appear to have successfully protected them against neonatal diarrhoea.

The septicaemia form of colibacillosis is usually seen in calves with very low serum immune globulin concentrations under a week of age (Glantz, et al., 1959; Penhale, 1965; Fay, 1961; Fisher, et al., 1968; McEwan, 1968). The same situation was apparent in the control calves in the experiments on therapy reported in this part of this



Confinement Cage C-C

Main Frame A-A

Figure 5

Illustration of the metabolic cage used during the present study.

Figure 6

Harness used as support to the faecal collecting system.

thesis. Out of 108 calves studied, only one died from septicaemia. These calves were selected as not being liable to septicaemic death. It would appear that serum immune globulin concentrations equivalent to zinc sulphate readings of over 5 are sufficient to prevent death from septicaemia in newborn calves. Since this relatively small quantity of immune globulin may be obtained by the calf even under suboptimal conditions of management, deaths due to septicaemia should not account for the majority of the losses observed in newborn calves up to one month of age. This, in fact, has been reported to be the case in Denmark (Ottosen, 1959), where of a total of 8715 calves examined on post mortem, 43% were found to have died from scours, while E.coli septicaemia was diagnosed in only 20%. Similarly, Gay, MacKay and Barnum (1964) reported that the colisepticaemic form of colibacillosis was rarely seen in their studies concerning field outbreaks of colibacillosis.

The protective function of the relatively small amounts of immune globulin against septicaemia and the correlation between the syndrome and infectious agent strongly suggests that the function performed by the proteins in this case is an immunological one, although the precise nature of the specific protecting antibody is not yet clear (Gay, 1965; Penhale, 1968). However, the protective role of the immune globulins against neonatal calf diarrhoea is far from clear. McEwan (1968) in an attempt to find benefits other than the immunological function of the proteins, concluded that such immune globulins did not significantly increase the buffering capacity of the protein system present in the body. Thus, a mechanism of increased ability to overcome the metabolic acidosis, which occurs in diarrhoeic calves, could not be attributed

to calves which showed higher serum immune globulin levels. He also failed to show an increase in the expansion of the plasma volume in those calves with high serum immune globulin concentrations as compared with those possessing no immune globulins. Thus, a larger reserve of body fluids could not be given as a reason for the higher rate of survival amongst calves with high serum immune globulins.

The results obtained throughout the investigation discussed in this part, indicated that the status of passive immunity in the newborn calf, has a negative correlation with death from neonatal calf diarrhoea. It would appear that the quantities of immune globulin present in the calves which survived were sufficient to neutralize either the micro-organisms involved, or their products responsible for the continuation of the diarrhoeic syndrome.

The loss of serum proteins via the intestinal tract in the diarrhoeic calf has been demonstrated by Marsh, Mebus and Underdahl (1969). In those diarrhoeic calves fed colostrum and possessing circulating immune globulins, relatively large amounts of these proteins were detected in the intestinal contents and faeces of the calves. Marsh et al (1969) concluded that these losses of immune globulins through the faeces during diarrhoea could seriously reduce the chance of a calf surviving severe diarrhoea or complicating secondary infections. If this were the case, it would seem that calves with high serum immune globulin levels would be better

equipped, at least quantitatively, to cope with such losses, and this might be the reason for their survival. However, it is interesting to speculate upon the possibility of the loss of immune globulins into the intestine serving some useful purpose, such as neutralising in the lumen of the intestine the effects of bacteria or their products responsible for diarrhoea. Here again the recovery of the affected calf could depend on whether or not the animal had sufficient antibody to overcome the bacterial proliferation within the gut.

The results obtained while assessing the efficacy of different therapies, have convincingly shown that the serum immune globulin concentration of the experimental calves must be known in order to prevent the influence of erroneous conclusions from a particular therapeutic trial regarding neonatal calf diarrhoea. The results may be significantly influenced by including calves with a wide variation in their serum immune globulin concentrations. Throughout this work those calves with the highest serum immune globulin concentrations survived, independent of the therapy being assessed or whether the calves belonged to the treated or control groups. The results could also be significantly different if in a particular experiment the efficacy of any therapy is tested using calves born during the summer months as compared with another using calves born in the winter. In retrospect, most of the previous experimental work found in the veterinary literature regarding the evaluation of different therapies in calf diarrhoea, may be criticised because the immunological status of the calves tested was unknown.

The poor results obtained in the experiments 2A, 2B and 3, regarding the efficacy of furazolidone given orally, chloramphenicol given parenterally, or furazolidone given orally as a prophylactic agent in an attempt to stop neonatal calf diarrhoea in hypogammaglobulinaemic calves, might be explained by the fact that individual sensitivity testing is an unsuitable method of determining the efficacy of particular drugs. It is also possible that the recommended dosages used were insufficient to be effective. However, they also emphasise further the importance of the immune globulins. Additional evidence supporting this situation was produced in Experiment No. 4. In this case, the two groups of calves with low serum immune globulin concentrations (5.25 $\pm$ 5.8 and 5.35 $\pm$ .33 Z.S.T. Units), one of them being given Furazolidone prophylactically showed no difference in their mortality or incidence of diarrhoea. However, when compared with a third group composed of calves with significantly higher serum immune globulin concentrations (16.33 $\pm$ 4.6), included in this experiment, there was a highly significant difference in the incidence of mortality. None of the calves in the group with high serum immune globulin concentrations died.

Comparing the overall mortality found in the survey reported in this part and the mortality reported by other workers in previous surveys (Withers, 1952-53; Leech, et al., 1968; Sellars, Smith, G.F. and Wood, 1968), with the overall mortality observed in the calves kept under the managemental conditions prevailing while undertaking the experimental work regarding the different therapies, a significantly higher mortality is to be found amongst these calves. The existence for such marked difference could be explained by the

fact that the previous surveys including the one reported herein, have considered mainly home-bred calves and a very small number of bought-in calves. Thus, the diversity of E.coli strains to which such calves may be exposed would be considerably less than the challenge to which the calves bought through a market and used in these studies are usually exposed. The experiments previously reported were intentionally performed during the winter, and it is well established that it is at this time of the year when the mortality is at its peak and a greater variety of E.coli serotypes can be isolated from the faeces and the intestinal content of newborn calves (Rees, 1958). Yet another factor contributing to the higher mortality could be the constant build-up of bacteria and passage of virulent strains through susceptible hypogammaglobulinaemic calves which certainly prevailed in the present study.

In contrast with the reports of McSherry et al (1954), Watt (1965), Dickson (1968), no beneficial effects as judged by the incidence of mortality were obtained when newborn diarrhoeic calves were treated intravenously with different volumes of Darrow's solution. This could be a repercussion of different levels of serum immune globulins present in the calves at the time of treatment.

Although some changes in the different plasma parameters analysed were recorded immediately after treatment, apart from the blood urea values there were no significant differences in the rest of the plasma parameters analysed of dying diarrhoeic treated calves and control diarrhoeic dying calves.

The lack of correlation found between the volumes of fluid and

electrolytes administered intravenously, and the subsequent changes detected in the plasma parameters, could suggest that volumes of fluid and electrolytes lost through diarrhoea during a given period of time might vary considerably from calf to calf. Such inconsistency could also be due to individual variations in the capacity of the individual calf to regulate its water and electrolyte metabolism. Little is known concerning the volumes of water and quantities of electrolytes a newborn calf can afford to lose before reaching a fatal stage. Yet another possibility which cannot be disregarded is the chemical composition and ionic strength of the electrolyte solution used to correct the deficits. Answers to some of these questions could only be obtained by performing accurate balance studies, and at the same time recording and correlating the results of such balance studies with the changes occurring in the different blood and plasma parameters. Since very little work was found in the veterinary literature, regarding this aspect of the water and electrolyte balance in the newborn calf, it was decided to undertake the study which is reported in the final part of this thesis.

PART 3

STUDIES ON THE FAECAL WATER AND ELECTROLYTE LOSSES IN NORMAL, DIARRHOEIC SURVIVING AND DIARRHOEIC DYING NEWBORN CALVES OF KNOWN SERUM IMMUNE GLOBULIN CONCENTRATION, THEIR CORRELATION TO CHANGES IN THE PLASMA ELECTROLYTES, OSMOLARITY, BLOOD pH, UREA AND PACKED CELL VOLUME

INTRODUCTION

Losses of water and electrolytes from the body normally take place through three channels.

Water is continuously being lost through the skin and lungs as a result of the energy metabolism. This insensible loss which is essential for the regulation of the body temperature, is dependent on metabolic rate and on the environmental temperature. Secondly, a significantly smaller amount of water and electrolytes is lost through the faeces and thirdly water and electrolytes are excreted by the kidney in order to establish and maintain the dynamic osmotic equilibrium prevailing between the different fluid compartments of the body i.e. the intracellular and the extracellular space. The regulation of the reaction of the body fluids, and the excretion of metabolites, is also dependent on such excretion. It is obvious that the daily requirements of water and electrolytes will depend on the demands of each one of the channels of excretion, and on the amount of such substances that need to be retained in the body in order to preserve its physiological integrity.

In the adult animal, these demands are met by the ingestion of water as such, by the water and electrolytes present in the daily food intake and by the water eventually released by oxidative processes within the body. For the newborn calf, however, the only external source of such substances is its daily intake of milk.

The daily requirements of water and electrolytes by the human infant and adult, have been studied by Forbes (1951), Bergstrom (1959)

Darrow (1959). However little is known about such requirements in the newborn calf. The fact that the newborn calf depends entirely on its daily milk intake, not only for the acquisition of nutrients, but also as its only source of water, renders it particularly susceptible to the effects of dehydration. Any situation, pathological or otherwise interfering either with the ingestion of milk, or with the process of digestion and absorption of such substance, will result in dehydration.

Such is the case occurring in diarrhoea. In this condition not only is the excretion of water and electrolytes apparently grossly augmented (Blaxter and Wood, 1953, Fayet, 1968) but the milk intake is in many cases reduced.

The quantitative estimation of such losses has not been properly ascertained, and except for the data reported by Blaxter and Wood (1953) and Fayet (1968), no data can be found regarding the water and electrolyte losses in calves suffering different degrees of diarrhoea, and their correlation to the changes observed in the different plasma parameters.

The object of the studies reported herein, was to investigate the daily loss of water, sodium and potassium through urine and faeces, in normal newborn calves, and in calves suffering from different degrees of diarrhoea fed a constant milk diet according to their bodyweight. The changes that occurred in the plasma, sodium, potassium chloride and osmolality, blood pH, bicarbonate, urea and packed cell volume, were also recorded, and an attempt was made to correlate such

changes to the losses of water and electrolytes observed. Particular attention was paid to the losses of sodium and potassium, since the plasma concentration of these electrolytes appears to be the most severely affected during dehydration due to diarrhoea. Roy et al (1959), McSherry and Grinyer (1954), Dalton, Fisher and McIntyre (1965), Fisher (1965), Fisher and McEwan (1967).

Materials and Methods

Twenty eight Ayrshire and Ayrshire cross-bred bull calves were used in these experiments studying normal and diarrhoeic animals. All were under one week of age at the beginning of the experimental period. The calves were obtained through a dealer as mentioned in the 'Materials and Methods', part II, section III of this thesis.

Clinical examination of the experimental animals

On arrival at the Veterinary Hospital a detailed clinical examination of the calves was conducted in order to ensure that they were clinically healthy. Thereafter, the rectal temperature, pulse rate and quality, respiratory rate and demeanour were checked daily. Also particular attention was paid to the presence or absence of enophtalmus, and changes in the texture and appearance of the coat.

Sampling of experimental animals

A blood sample was taken from the jugular vein and emptied into two containers, one a heparinised 10 ml. plastic tube and the other a clean universal bottle. The sample contained in the heparinised tube was gently shaken and the Packed Cell Volume was immediately estimated. The sample was then centrifuged at room temperature for

20 minutes at 2,000 r.p.m. in an M.S.E. Centrifuge (Measuring Scientific Equipment, London, England). The plasma was then transferred with a clean acid washed pipette into clean 5 ml. bottles, and urea, sodium, potassium chloride and osmolality estimated. The blood sample contained in the universal bottle was allowed to clot at room temperature, and centrifuged. The serum was then extracted and its immune globulin concentration estimated, as described in the 'Materials and Methods' of part II. A second blood sample used for the estimation of venous pH was collected anaerobically from the jugular vein into a 2 ml. heparinised syringe. Air bubbles if present were immediately expelled, and the tip of the needle sealed. The pH estimations were all performed within one half hour of collection.

Following the initial sampling, a daily blood specimen was obtained from the jugular vein of the experimental calves and the parameters mentioned above analysed. The duration of the experimental period, for the diarrhoeic calves, varied according to the severity of the condition, and covered a maximum of 8 days when studying normal calves.

Accommodation of Experimental Animals

The experimental calves were kept in metabolic cages. A maximum of three calves were kept under experimentation at any one time. The cages were placed in the same room, thermostatically maintained at $65^{\circ} \pm 4^{\circ}F$. The room environmental temperature was continuously monitored by a bi-metallic thermograph (supplied by Baird and Tatlock Ltd.)

The calves were placed in the metabolic cages either two or three hours after arrival at the Veterinary Hospital, as was the case with the group of normal calves described in section I, or they were placed in individual pens until they became diarrhoeic and then were transferred into the metabolic cages (section II).

Collection of Excreta from Newborn Calves

One of the reasons for the dearth of information regarding the quantitative losses of water and electrolytes through the faeces in calf diarrhoea would appear to be the technical difficulties involved in collecting the excreta.

The methods of collection described below were the results of many attempts to overcome these technical difficulties and they enabled accurate quantitative studies to be made.

Description of Metabolic Cage

The cage used was adapted from a cage designed for faecal collections in parasitised sheep, and eventually it had the following essential features that made it practical for the purpose for which it was utilised.

(a) It was adaptable in length, width and height to fit individual calves

(b) It was made of a durable material, easy to clean and disinfect

(c) It rendered the calf in an accessible position for treatment, sampling and clinical examination.

The cage is illustrated in figure 5.

The overall size was 1.60 metres long, 1.55 metres high, and 84 centimetres wide. It was assembled from separate sections of 2.5 cm. diameter steel tubing; joined together by Key* couplings. The floor was made from steel mesh, each rectangle of the mesh measuring 5 cm. long by 2 cm. wide. The bars which crossed the mesh floor were raised slightly to give the calf a better grip when trying to stand and when standing. Assembling the metabolic cage was quite simple. The main frame was first joined together (the main frame is marked A in the photograph, Fig. 5). The mesh floor was then fitted in the supports provided by the tube segments that formed the middle part of the main frame, at a height of 60 cm. from the ground. Further segments were then fitted to provide the confinement cage within the main frame. The arrows in the photograph show the limits of adjustments possible for the confinement cage.

Description and fitting of faecal bags

A modified dog harness made from leather was used as a means of front support to the faecal bag. The harness, although made of a standard size, could be easily adapted to different sizes of calves by adjusting a ventral strap. The straps were 1.5 centimetres wide. This harness is illustrated in Fig. 6.

Faecal Bags

The shoulder length gloves designed for rectal examination of cattle proved, after different rubber and waterproof bags had been tried, to be the most suitable items for the purpose of forming the initial part of the collecting system. The strength and texture of the rubber from which the gloves were made, proved to be both strong

* Gascoines (Kee Klamps) Ltd., East Kilbride.

and sufficiently elastic to permit the calf free movement as well as providing a well-sealed tube. The shoulder of the glove fitted closely to the coccygeal and perineal regions of the calves. The rubber shoulder strap, which is welded onto the sides of the glove, served as the lateral points of anchor.

The following simple procedure was used to convert the gloves into part of the faecal collecting system. The shoulder strap was cut in its midline leaving two even lateral straps; a hole through which the tail was inserted was cut in the middle dorsal part of the sleeve of the glove - equidistant from the strap attachments, about 3.5 cms. from its anterior border. The hole was then reinforced with elastic tape to prevent tearing at this point. A further elastic strap was fitted to the ventral part of the glove at about 5 cm. from the border. In this way, the bag had three main points of anchorage, two lateral (the straps) and one ventral. These straps were tied onto the harness fastened around the thorax of the animal behind its shoulders. In some cases it was necessary to attach a further elastic strap to the dorsal part of the bag in order to prevent it from sliding down the tail head. This was particularly necessary in small, thin calves that had a marked declination of the sacro-coccygeal region. The actual glove was cut off from the sleeve, thus leaving a reasonably long piece of 'rubber chute'. This chute was then inserted into wider disposable polythene bags which were attached to the rubber by plastic waterproof tape. The polythene bags used were 20 cm. in diameter, and varied in length. The faecal collecting apparatus was then fitted to the calf and it is illustrated in Fig. 7.

Figure 7

Calf with faecal bag in situ.

Collection of Faeces

When collecting the faeces from normal calves the 'rubber chute' alone sealed at the distal end, was sufficient to retain the stools passed during several days.

In calves suffering from diarrhoea the collecting of stools was relatively easy. The actual 'rubber chute' was seldom removed since fluid faeces were not caught in this part. The polythene bag was unfastened from the glove and immediately replaced by a new one. Once removed the bag was weighed, emptied into a container, and if any material was adhered to the walls it was removed with a spatula.

The faeces were collected every morning at the same time, and the total amount excreted was weighed to the nearest miligram. The excreta was then homogenised, and a representative sample taken for analysis.

Analysis of Faeces

Sodium and Potassium; A sample of the supernatant fluid obtained by centrifuging a homogeneous volume of faeces was used directly for sodium and potassium determination. When due to the consistency of the faeces this procedure was impossible, the method described by King and Wooton (1956) was adopted. No significant difference was found when analysing the same sample by the two methods. This is reported in appendix No.

Water Content

This was estimated by drying to a constant weight in an oven at 90°C. A homogeneous sample of fresh faeces previously weighed to the nearest milligram. An oven dried dish was weighed to the nearest

milligram, the faecal sample was then added to the dish and both weighed, they were then placed in the oven and allowed to dry. The amount of water was then estimated by a simple substraction, and expressed as percentage of the total amount of faeces excreted.

The collection of urine

A polythene sheet was placed underneath the mesh floor, securely sealed to the cage on both sides and front. The middle line of the sheet dropped 30 cm. from the mesh floor. From this lowest point urine was drained into a filtering funnel and collected in a bucket or other suitable container lying in the back of the metabolic cage.

Care had to be taken that the collecting sheet collected only urine and not milk being fed to the calf. This was achieved by limiting the sheet anteriorly at the farthermost point that the animal was likely to urinate. Since the movements of the calf were restricted and could be controlled at will by increasing or reducing the length of the confinement cage, urination could be restricted to a defined area. The front of the cage from where the animal was fed was left without sheeting.

The total volume of urine excreted was collected every morning at the same time and measured in a glass cylinder to the nearest millilitre. A representative sample was then obtained in a clean universal bottle for analysis.

Analysis of Urine

Sodium and Potassium; these were estimated directly from the sample, after making the appropriate dilutions, as described by Varley (1962).

Osmolarity; this was performed following the same procedure as described later for plasma.

Weighing of the Experimental Calves

On arrival at the hospital and every three days thereafter, the calves were weighed on 'Avery' cattle scales, which were accurate to the nearest half-pound.

Feeding of the Experimental Calves

All the calves in these experiments were fed bulked cow's milk by bucket. In order to keep the diet of the calves under these experiments as constant as possible, sufficient milk was obtained to last for the whole of the experimental period always from the same herd. The milk containers were kept in the refrigerator, and the milk was warmed at approximately 36°C before feeding it to the calves. The milk was analysed for its concentration of sodium potassium and water every two days so that if any change appeared it could immediately be recorded. The calves were fed at a rate of 10 per cent of their total bodyweight. Great care was taken to measure this amount carefully and to record any amount left by the calves.

Estimation of the Packed Cell Volume

This was performed by the microhaematocrit technique described by Fisher, 1962.

Blood pH. and p.CO_2

These were estimated by using the Astrup micro equipment (type AMEL.C., Copenhagen, Denmark). The blood bicarbonate was calculated from these values using the Siggaard Anderson curve nomogram.

Sodium and Potassium

The sodium and potassium concentrations in plasma, urine, faeces and milk were estimated using the E.E.L. Photometer as described by Varley, 1962.

Blood Urea

This was determined by the urease Nesslerisation method.

Osmolarity

The plasma and urine osmolarities were determined within 1 hour of collection, using a Knaur semi-micro osmometer (Shandon Scientific Products Ltd, London).

RESULTS - Balance Studies in normal calves

Table XX illustrates the main daily intake of water, sodium and potassium of seven healthy newborn calves over a period of seven days. The mean daily amount of faecal material excreted, its dry matter content and the total loss of water, sodium and potassium in such faeces is also illustrated. The same table illustrates the mean daily output of urine and the excretion of sodium and potassium via this channel. Also recorded in this table is the mean daily gain in bodyweight.

The individual variations observed in the intake of water, sodium and potassium, are proportionate to the variation in bodyweight and are due also to a slight variation in the sodium and potassium concentrations of the milk fed.

The mean daily excretion of faeces was 95.82 g. $\pm$ 73.70 with a mean dry matter content of 29.50% $\pm$ 7.73%.

TABLE

The Mean Daily Intake and Output of 7 Normal

Calf No.	Mean Intake in 24 hours				Mean Output in Faeces - 24 hours			
	Z.S.T. Units	Sodium M.eq.	Potassium M.eq.	Water Mls.	Mean Total Faecal Output gms.	Dry Matter %	Sodium M.eq.	Potassium M.eq.
A	25	81.21 ±	91.29 ±	2766.0 ±	49.97 ±	41.89 ±	1.98 ±	1.22 ±
S.D.		1.61	7.42	225.03	22.2	5.2	6.8	.47
C	21	99.21 ±	117.0 ±	3247.7 ±	116 ±	27.6 ±	2.65 ±	1.10 ±
S.D.		11.41	13.49	205.4	60.2	6.3	.6	.40
D	20	80.54 ±	94.93 ±	2876.8 ±	77.3 ±	38.5 ±	2.00 ±	1.08 ±
S.D.		4.81	5.67	171.87	41.2	7.9	.17	.26
538	23	79.18 ±	104.8 ±	2826.4 ±	76.5 ±	33.1 ±	2.26 ±	1.62 ±
S.D.		3.15	4.14	112.78	70	3.6	.53	.47
733	21	64.71 ±	82.32 ±	2204.1 ±	56.5 ±	31.9 ±	2.69 ±	1.60 ±
S.D.		4.34	9.35	155.34	32.2	2.7	.51	.61
741	3.5	97.17 ±	96.12 ±	3037.9 ±	87.57 ±	20.1 ±	2.16 ±	1.71 ±
S.D.		3.58	9.61	112.2	33.2	2.7	.54	1.37
27	9.5	92.73 ±	109.29 ±	2947.0 ±	211.0 ±	17.30 ±	6.73 ±	3.00 ±
S.D.		0	0	0	92.9	3.7	3.23	1.35
Overall Mean	17.60	90.0 ±	99.38 ±	2843.8 ±	95.82 ±	29.50 ±	3.55 ±	1.64 ±
S.D.	7.95	7.0	11	110.0	73.70	7.73	2.58	1.02
N =		48	48	48	48	44	44	44

Water, Sodium and Potassium in Calves

Mean Output in Urine 24 hours				Mean gain in bodyweight 24 hours grammes	Bodyweight at beginning of Experiment Kg.	Bodyweight at end of Experiment
Water Mls.	Sodium M.eq.	Potassium M.eq.	Water Mls.			
29.88 ± 17.38	34.02 ± 6.36	36.47 ± 15.89	1764.7 ± 292.9	628	28.4	32.8
83.19 ± 46.52	48.57 ± 22.01	93.64 ± 17.23	2848.5 ± 870	428	34.2	37
45.83 ± 24.95	40.15 ± 14.6	67.23 ± 9.80	2448.3 ± 540.7	428	31	34
53.72 ± 48.28	33.7 ± 9.8	56.67 ± 6.12	2067.1 ± 635.7	285	31.3	34
38.51 ± 22.36	32.22 ± 13.22	57.51 ± 12.07	1830.0 ± 255.6	428	21	23
65.94 ± 26.65	60.38 ± 18.56	90.32 ± 19.81	2406.4 ± 637.22	285	33.7	35
176.87 ± 82.33	14.15 ± 5.34	43.45 ± 5.66	2051 ± 536.4	285	34	36
77.3 ± 61.6	36.94 ± 22.90	72.32 ± 22.17	2199.33 ± 639.32	395 ± 122	30.51 ± 4.68	32.96 ± 5
48	48	48	48			

The loss of sodium and potassium in the faeces was fairly constant, with only one calf, Calf No. 27, showing a greater loss of these ions. The amount of sodium lost through the faeces consistently exceeded that of potassium. The mean loss of sodium was 3.55 m.Eq. ± 2.58 m.Eq. per day and that of potassium 1.64 m.Eq. ± 1.02 m.Eq. per day. The mean loss of water was 77.3 ml ± 61.6 ml. Again, Calf No. 27 showed a significantly higher loss. A significant positive correlation ($p < 0.001$) was found between the mean volume of water excreted and the sum of sodium and potassium excreted in the faeces; this is illustrated in Fig. 8. Fig. 8 illustrates the positive correlation found between faecal sodium and potassium.

The excretion of water, sodium and potassium through the urine was considerably greater. In this case the excretion of potassium consistently exceeded that of sodium. The mean excretion of urine was 2199.33 ml ± 639.32 ml., with a mean osmolarity of 274.3 ± 102.6 milli Osmoles/L., the mean excretion of sodium was 36.94 m.Eq. ± 22.90 m.Eq., and that of potassium, 72.32 ± 22.17 m.Eq. A significant positive correlation was found between the mean volume of water ingested and the mean amount excreted in the urine (Fig. 9).

Table XXI illustrates the mean total output of water, sodium and potassium. It also illustrates the percentage of these substances lost through urine and faeces and thepercentage retained by the different calves.

It can be observed that 45.63% of the sodium ingested was excreted. Of this amount, only 2.46% was lost through the faeces and 43.89% was excreted through the kidneys. This would represent a mean retention of 44.4% of the sodium ingested. There was, however, a marked individual

Fig. 8.

Correlation of Sodium plus Potassium to Water in the Faeces of Normal Calves

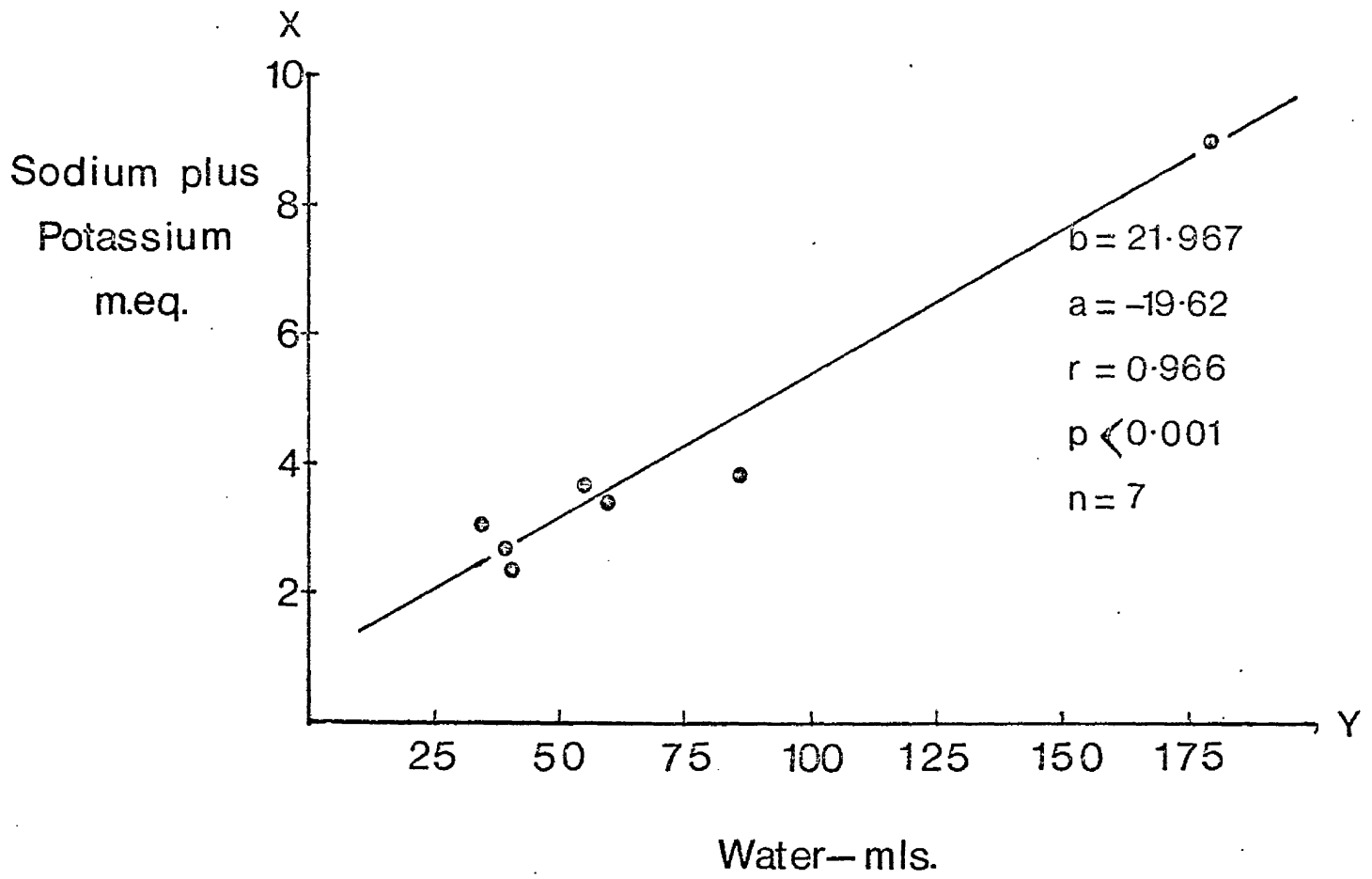


Fig. 8(b)

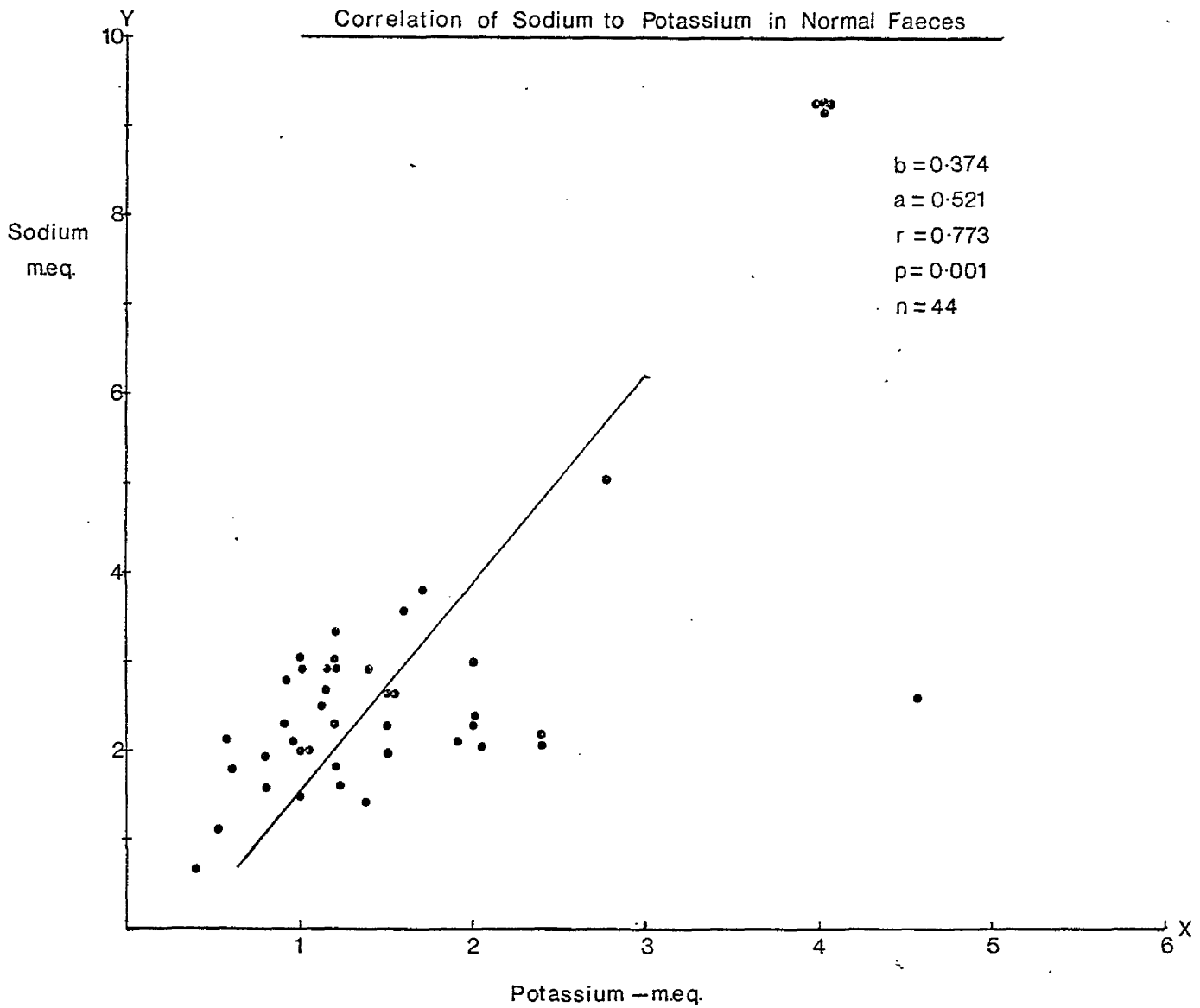

Correlation of Sodium to Potassium in Normal Faeces
Y
10
8
6
4
2
Sodium
m.eq.
b = 0·374
a = 0·521
r = 0·773
p = 0·001
n = 44
1
2
3
4
5
6
X
Potassium — m.eq.

Fig. 9.

Correlation of Water Intake to Urine Output in Normal Calves

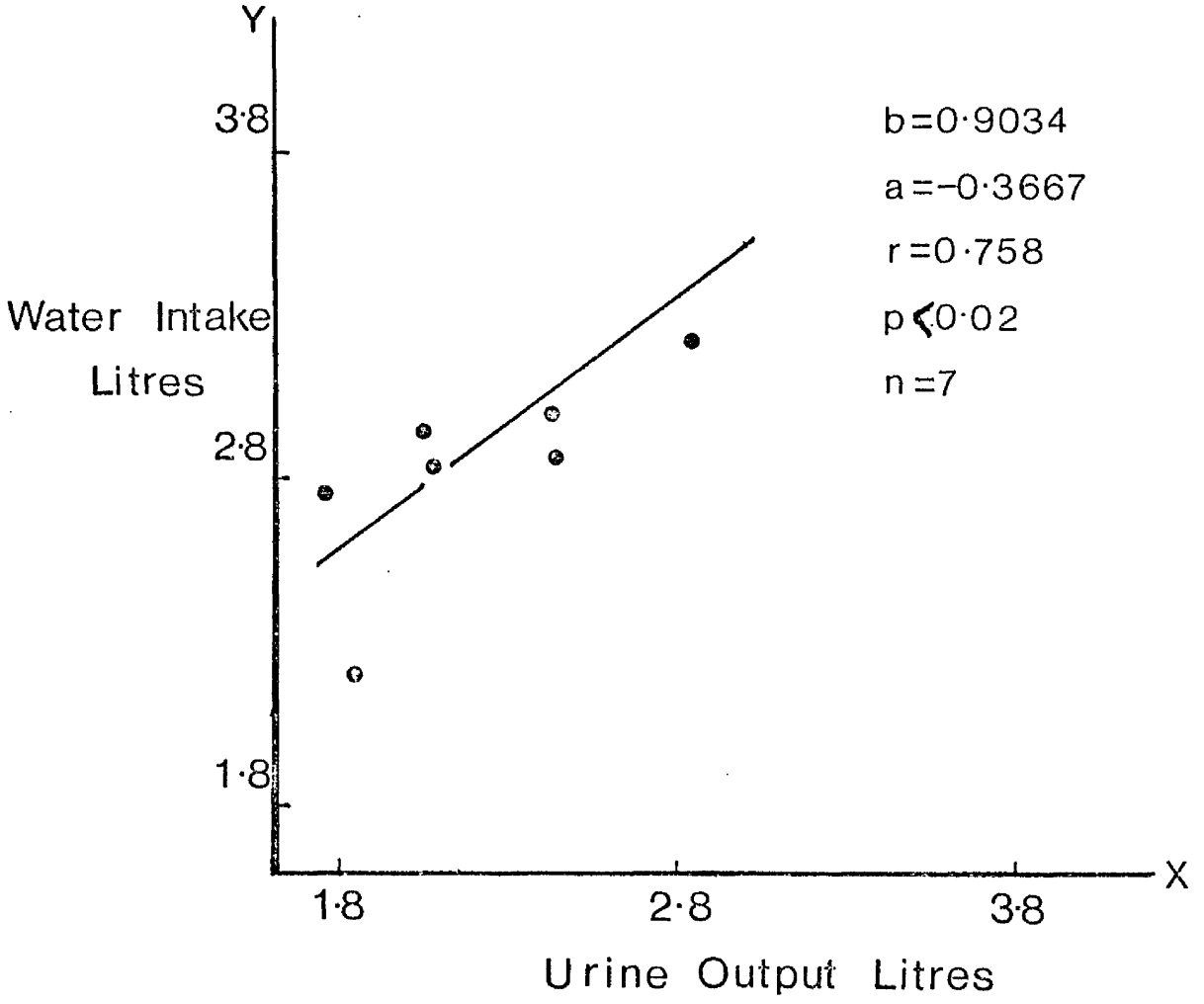


TABLE XXI

Percentages of water, sodium and potassium intakes excreted in urine and faeces

alf No.	Mean Total Output m.Eq. - day			Percentage of Sodium Excreted			Percentage of Potassium Excreted			Percentage of Water Excreted		
	Sodium	Potassium	Water	Faeces	Urine	Total	Faeces	Urine	Total	Faeces	Urine	Total
	36.02	41.38	1793.58	2.45	41.89	44.35	1.33	44.01	45.34	1.04	63.77	64.81
	51.21	94.74	2931.69	1.1	48.99	50.09	.91	80.03	80.93	2.56	87.7	90.26
	41.81	68.13	2137.78	1.1	49.85	50.90	.94	70.83	71.76	1.36	72.94	74.30
38	62.46	92.01	1837.72	2.1	75.85	77.95	1.82	96.39	98.21	2.10	69.82	71.92
33	35.3	57.7	1868.50	1.3	42.58	43.88	1.04	53.99	55.03	1.36	64.74	66.10
41	34.5	58.8	2471.94	2.0	33.13	35.13	1.35	59.82	61.17	2.17	79.22	81.39
17	20.0	47.0	2227.89	7.2	15.00	22.2	2.72	40.25	42.97	6.00	69.59	75.59
	40.18	65.68	2181.30	2.46%	43.89%	45.63%	1.44%	63.61%	65.05%	2.37%	72.54%	74.91%

variation in the percentage of sodium retained, the maximum being 72.8% and the minimum, 23%. That the amount of sodium lost through the faeces was consistently small was again illustrated by the small variation seen in the percentage of sodium lost through this channel. Except for calf 27 the loss of sodium through the faeces never exceeded 3%. The percentage of potassium retained was smaller than that of sodium; only 35% of the amount ingested was retained. 1.44% was lost through the faeces and 72.54% was excreted through the urine.

75% of the water ingested was lost; 2.337% was lost through the faeces and 72.54% was excreted by the kidney. It would appear that the retention of water in the normal calf takes place to a lesser degree than that of sodium and or potassium. Only 25% is retained after faecal and urine excretion, and from this amount, the water lost through the lungs and skin must be deducted.

The ratio of sodium and potassium to water in the milk ingested, their ratio in the faeces and the ratio of the total excretion of sodium and potassium to water are illustrated in Tables XXII and XXIII. It can be seen that a mean ratio of .06 was found for the milk ingested. No significant individual variation was found in this ratio. The ratio for these substances in the faeces was also .06; however, some variation did occur in this case. When considering the ratio of the total quantities of sodium and potassium to the total water excreted, a smaller ratio of .04 was obtained.

Table XXIV illustrates the mean values of plasma sodium, potassium, bicarbonate, urea, osmolarity, blood pH, packed cell volume and urine osmolarity observed in these calves over the period

TABLE XXII

Ratio of the mean daily intake of sodium and potassium, to water in normal calves

Calf No.	Sodium + Potassium M.eq.	Water Mls.	Ratio
A	172.42	2766.6	.06
C	216.21	3247.7	.06
D	175.47	2876.8	.06
538	173.17	2555.0	.06
733	183.95	2826.5	.06
741	193.29	3037.0	.06
27	202.02	2947.0	.06
Mean	190.90	2893.0	.06

TABLE XXIII

Ratio of the mean daily excretion of sodium plus potassium to water in the faeces of normal calves

Calf No.	Sodium + Potassium M.eq.	Water Mls.	Ratio
A.	3.21	28.88	.11
C.	3.75	83.19	.04
D.	2.56	39.25	.06
538	3.87	53.72	.07
733	2.70	38.50	.07
741	3.60	65.94	.05
27	9.70	176.89	.05
Mean	4.18	69.48	.06

Ratio of the mean total daily excretion of sodium plus potassium, to water in normal calves

A.	77.40	1793.58	.04
C.	145.95	2931.69	.04
D.	109.94	2137.78	.05
538	154.47	1837.72	.08
733	93.0	1868.50	.04
741	93.3	2471.94	.03
27	67.0	2227.89	.03
Mean	105.8	2181.30	.04

of study. Although the mean of the different parameters analysed would appear to vary from calf to calf, the variation of such parameters from day to day in the individual calves was less apparent. This is illustrated in Table XXIV.

In this study the mean plasma sodium concentration found was 142.5 $\pm$ 6.5 m.eq. per litre. That of potassium was 4.70 $\pm$ .7 m.eq. per litre; the plasma urea concentration was 25.3 $\pm$ 6.8 mg per 100 ml.; the packed cell volume was 36.9 $\pm$ 3.41 and the plasma osmolarity was 290.6 $\pm$ 11.49. The blood pH was 7.38 $\pm$ .02 and the bicarbonate concentration 26.6 $\pm$ meq/l.

Table XXV illustrates the clinical findings observed in these animals. The mean temperature recorded for these calves was 102.4^{o}F; the mean respiratory rate was 20.38 respirations per minute; the mean pulse rate was 99.06 per minute. Only one calf, Calf No. 741 showed a temperature above 103^{o}F.

The demeanour of the animals showed very little change from day to day. All of the calves appeared to be bright, playful and eager to drink their milk when it was offered to them. Although most of these calves during the first day showed some distress by being confined in the metabolic cages and made several attempts to turn within the cage or to jump through the bars, by the second day, they were accustomed to it and stood and lay down at will within the cage. As shown in Table XX, the amount of faeces excreted varied from day to day, as did the consistency and colour of the faeces. The colour varied from a dark brown to a very light creamy yellow. However, the darker the faeces, the more consistent and well formed they appeared to be. All the

TABLE XXIV

The Mean Plasma, Sodium, Potassium, Osmolality, Urea, Blood pH and Bicarbonate Packed Cell Volume and Urine Osmolality of Normal Newborn Calves

Calf No.	Sodium m.Eq./L.	Potassium m.Eq./L.	mM./L.	Packed Cell Volume %	Urea mg/100	pH	Bicarbonate m.Eq./L.	Urine Osmolality mm/L.
A	143.5 ± 2.37	4.80 ± .50	296.7 ± 6.9	38.25 ± 1.5	20.75 ± 2.91	7.38 ± .02	26.62 ± 4.786	260.0 ± 34.95
C	144.0 ± 5.0	4.90 ± .11	294.0 ± 16.37	39.16 ± 1.1	24.66 ± 6.10	7.34 ± .01	24.66 ± 2.30	165.0 ± 12.80
D	148.6 ± 12.0	5.40 ± .20	290.0 ± 10.0	36.33 ± 1.1	32.00 ± 2.00	7.38 ± .02	27.00 ± 4.58	275.0 ± 23.8
538	139.0 ± 10.81	4.06 ± .40	305.0 ± 5.0	42.50 ± 1.7	16.30 ± 4.04	7.39 ± .03	26.83 ± 1.54	400.0 ± 165.7
733	144.3 ± 6.02	4.93 ± .11	285.0 ± 5.0	35.50 ± 3.5	22.00 ± 2.00	7.39 ± .02	27.66 ± 1.52	220.0 ± 60.0
741	146.6 ± 4.6	5.66 ± .23	280.0 ± 0	39.83 ± 1.1	30.00 ± 2.00	7.40 ± .03	27.33 ± .577	288.0 ± 5.9
27	137.8 ± 2.8	3.88 ± .80	283.0 ± 11.48	34.28 ± 1.7	29.00 ± 3.2	7.37 ± .01	25.78 ± 2.65	257.0 ± 33.1
Mean	142.5.	4.78	290.16	36.9	25.30	7.38	26.44	274.3
S.D.	± 6.5	± .7	± 11.49	± 3.4	± 6.82	± .028	± 2.233	± 102.6
N.	25	25	24	26	23	26	26	26

TABLE XXV

The mean daily temperature, pulse rate and respiratory rate of 7 newborn healthy calves

Calf No.	Mean Daily Temperature	Mean Daily Pulse Rate/Min.	Mean Daily Respiratory Rate/Min.
A	101.07	90	23.4
C	102.40	82.5	19.7
D	102.10	112.0	19.8
538	101.8	102.8	20.5
733	102.4	105.7	22.8
741	103.0	112.0	19.8
27	102.1	102.0	17.0
Mean	102.12	101.0	20.42
S.D.	± 0.5	11	2.14

animals appeared to defaecate with ease, and neither the harness or the presence of thefaecal bag appeared to bother them when doing so. Some of the faeces were stained with blood and the presence of mucus was also observed. This did not seem to accompany any change in the demeanour or clinical condition of the calves. The calves appeared to defaecate at a more or less fixed time during the day. This usually happened after feeding time. Only occasionally were there two or more productive bowel movements during the day. Three of the calves, Calf No. 538, Calf 733, and Calf D did not show a passage of faeces for a period of 48 hours. This is in contrast with the reports of Blaxter and Wood (1953), and Smith, R.H. (1962) who found that some calves did not pass any faeces for periods as long as five and seven days respectively.

All the calves in the present study gained weight, the mean daily gain being 395 grammes.

Diagrams illustrating the daily balance of water, sodium and potassium of the individual calves are given in the appendix.

DISCUSSION

The results obtained in this study, have shown that the daily excretion of faeces in the normal, newborn calf, fed a constant diet of milk, varies from day to day and from calf to calf.

The mean daily faecal excretion found in the present study was 95.82 g. $\pm$ 73.70 g. This is in accordance with the findings of Blaxter and Wood (1953) who reported the daily weight of fresh faeces from one healthy calf given whole milk, as being: 308, nil, 35, nil, nil, nil, nil, 141 and 60 g., and with those of Fayet, who reported in his studies that the daily faecal excretion in two normal calves was always below 500 g. Although this amount is higher than the one obtained in the present study, it must be pointed out that his observations included two calves kept over a longer period of time.

The dry matter content of the faeces remained fairly constant, a mean of 29.50% $\pm$ 7.73% dry matter, was recorded; this value agrees with the findings of Fayet (1968), but it is higher than the value of 12% regarded by Blaxter and Wood (1953) as the dry matter content of normal faeces.

Studies concerning the flow of contents through the intestine, have shown, that the amount of fluid reaching the large intestine in milk fed calves is approximately 300 ml. every 12 hours. Mylrea (1966 b.) Taking this finding into consideration, it follows that of this volume presented to the colon only a small fraction is lost through the faeces as indicated by the content of water found in the faeces during the present study. 77.3 $\pm$ 61.6 ml/24 hours. It would appear that a considerable amount of water is absorbed by the colon

of the young calf. Such absorption has been well recognised in human subjects. Levitan, Fordtran, Burrows, and Engelfinger (1962) reported that approximately 600 ml. water reached the large intestine daily; of these 500 ml. was absorbed by the colon, and only 100 ml. excreted in the faeces. Curran and Schwartz (1960) found that water was also passively absorbed by the Rat colon.

The small amount of sodium present in the faeces, is indicative of the efficiency with which the intestinal epithelium can absorb this ion. Only 3.55 $\pm$ 2.50 m.eq/L. per 24 hours were lost, this represents 2.46% of the total amount ingested. Mylrea (1966 b) found that in the calf a substantial amount of sodium was added to the chyme in the upper half of the small intestine, thereafter a net absorption took place, but approximately 42% of the sodium ingested reached the large intestine. Here again, when comparing such a value with the percentage of ingested sodium recovered in the faeces during the present study, it would appear that approximately 43% of the sodium ingested is absorbed by the colon. This is in agreement with the results reported by Fordtran (1967), Kramer (1966), Curran and Schwartz (1960), Smith, RN. (1962) and Levitan et al. (1962).

Only 1.44% of the potassium ingested was lost through the faeces, since Mylrea (1966 b) found that approximately 3% only of the potassium ingested reached this organ, this would indicate that potassium absorption does not take place to a great extent through the colon of the newborn calf.

In the human subject it has been repeatedly reported that the concentration of potassium in the stools exceeds that of sodium

(Wrong, Gibson, Morrison, N.E., and Howard, 1965, Fordtran, 1967, Visscher, 1957, Levitan et al (1962). This greater loss of potassium is apparently due to a passive diffusion of potassium into the lumen of the colon in response to the active transport of sodium by this organ (Fordtran, 1966). However such a ratio of sodium to potassium was not found in this study, in fact the reverse occurred (as shown in fig. 8b) in that consistently the amount of sodium exceeded that ot potassium. Blaxter and Wood (1953) and Fayet (1968) also reported the loss of sodium through the stools in calves as being greater than that of potassium.

The work of Curran and Schwartz (1960) and Fordtran (1966) suggested that the flux of water through the intestinal epithelium was strongly correlated to the net solute flux, and that in the colon, water transport is an entirely passive process, dependent on such a flux. The findings reported here would agree with such an observation, inasmuch as a positive correlation was found to exist between the volumes of water and the sum of sodium and potassium excreted in the faeces of the experimental animals.

In contrast to the intestinal tract, lungs and skin, the normal mature kidney has the ability to absorb and excrete fluid and electrolytes according to the needs of the organism. Dalton (1968) produced evidence indicating that unlike the kidney of the newborn of other animal species, the calf's kidney is capable of performing such functions as efficiently as the adult bovine. In his studies, Dalton found that newborn calves showed a marked diuretic response when fed, large volumes of milk, water and hypotonic electrolyte solutions, rapidly excreting excess fluid. Dalton (1968b) also

also found that newborn calves, when starved, were able to concentrate their urine at least to the same extent as adult cattle.

It would appear in view of the above mentioned findings, that the calves kept under the conditions of the present study, were constantly defending against an excessive load of water, as judged by the mean volume or urine being produced daily, 2199.33 $\pm$ 639.32 mls. that is 75% of the water ingested. Fayet (1968) found that under his conditions the daily output of urine in two normal calves was 3.5l., however this higher production of urine is no doubt due to effect of feeding, since in his experiment the animals were fed ad libatum. That the volume of urine is influenced by the volume of water ingested is indicated by the positive correlation found in this study between the volume of milk ingested, and urine production.

In contrast to the loss of sodium and potassium through the faeces, a greater amount of potassium was consistently excreted by the kidneys. The overall retention of sodium being significantly higher than that of potassium, 44.4% and 35% respectively. This would indicate a greater need of sodium than potassium at this early age. An explanation for this apparent greater retention of sodium could be that during the process of bone calcification more sodium is taken up than potassium.

The calves under the conditions of the experiment, consistently lost more water than sodium and potassium in order to preserve their constant water and electrolyte equilibrium. This is illustrated by the smaller ratio of water to sodium and potassium (.04) found in the total amount of these substances excreted, as compared with the

ratio of .06 for such substances ingested. The mean daily gain in bodyweight recorded, was higher than the mean daily gains for Ayrshire calves, as judged by the data compiled by Brody (1945). In the first month after birth, Ayrshire calves grow at a rate of about 257 g. per day. In the present study, the mean daily gain in bodyweight was 395 g. This value is also higher than that recorded by Blaxter and Wood (1951) for Ayrshire calves fed at the same rate (10% bodyweight). They reported the mean gain in bodyweight for three calves as being 228 g./day. In their study, however, the calves were fed synthetic milk.

The plasma parameters analysed showed little change from day to day in the individual calves. The mean obtained for such parameters is in accordance with the findings of MacSherry and Grinyer (1954a), Fisher (1965), Dalton et al (1965) and Fayet (1968).

Balance Studies on Dying Diarrhoeic and Surviving Diarrhoeic New-born Calves

The following observations were performed in order to ascertain the daily losses of water, sodium and potassium in new-born calves suffering from diarrhoea. The effect that such losses may have on the physiological integrity of the calves will depend on how extensive they are, and on the efficiency with which the new-born calf can modify the excretion of such substances in order to regulate its water and electrolyte balance. Because such regulation takes place mainly through the kidney, analyses of the urine were also undertaken in order to assess such changes. Concomitant with the assessment of the loss of water and electrolytes through the faeces and their possible regulation through the kidneys, changes in the concentration of these electrolytes in the plasma were also recorded, and probable correlations between the loss of these electrolytes, and changes in their plasma concentrations were estimated.

The diarrhoeic calves have been divided into two groups, those which died and those which survived. A comparison is made of the losses and changes recorded in the diarrhoeic calves with the losses obtained for normal calves previously reported.

Materials and Methods

The general materials and methods followed during this experiment were the same as those mentioned in the previous study. In this case, however, the calves were not fed a constant diet. They were offered a quantity of cows' milk equivalent to 10 per cent of their bodyweight, but they were not forced to drink the total amount, therefore precise measurements of the milk volumes left by the calves were recorded

in order to perform the appropriate balance studies. The details of the daily values recorded and the graphs illustrating the balance of the individual calves are reported in the appendix. Only calves that had diarrhoea or died from diarrhoea were included in these experiments.

The Zinc Sulphate Turbidity test as reported in part II of this thesis was used in order to avoid including the calves which may have been liable to death from septicaemia. Thus only calves with values of 5 Z.S.T. units or over were used. A necropsy was performed of all the calves that died in order to rule out the possibility of any other pathological condition being present in the dead animals. At the same time samples from the spleen and the kidney of the dead calves were cultured in blood agar and McConkey agar in order to confirm the absence of septicaemia at the time of death.

Results

Table XXVI illustrates the mean daily intake and output of water, sodium and potassium in 13 newborn calves which died from diarrhoea. It also illustrates the mean daily excretion of faeces and their dry matter content, the mean daily excretion of urine and the changes in bodyweight recorded.

As indicated by the mean and standard deviations for the daily intake of water and electrolytes in the individual calves, a marked variation existed. These large variations are due to the fact that the intake of milk was restricted and conditioned by the state of health of the calves.

		Mean Intake in 24 hours			Mean Output in Faeces in 24 hours			
Calf No.	Z.S.T. Units	Sodium M.eq.	Potassium M.eq.	Water Mls.	Total Faecal Output g.	Dry Matter %	Sodium M.eq.	Potassium M.eq.
35	4	39.74 ± 56.20	46.87 ± 66.28	1263 ± 1786	2361 ±	8.2 ± 4.7	97.36 ± 83.3	36.0 ± 5.65
26	8.75	61.82 ± 47.88	72.86 ± 56.44	1964 ± 1521.8	1425 ± 82	6.3 ± 2.4	73.3 ± 44.9	30.2 ± 18.43
019	6	12.88 ± 0	15.18 ± 0	409 ± 0	2001.5 ± 1136.1	3.3 ± .5	50.2 ± 1.4	20.3 ± .98
207	7	70.65 ± 61.18	83.32 ± 72.15	2245 ± 1944.5	4113.6 ± 487	4.8 ± 1.1	137.6 ± 23.9	50.2 ± 9.4
21	7	62.45 ± 31.27	73.65 ± 36.87	1978 ± 999.55	1869.2 ± 1273	10.3 ± 5.5	64.2 ± 51.4	24.07 ± 12.57
214	8	105.98 ± 0	124.94 ± 0	3368 ± 0	2781.7 ± 1051	3.6 ± 1.0	120 ± 40.3	31.70 ± 9.54
A1	6	50.77 ± 32.67	59.86 ± 38.52	1613 ± 1038	3297.6 ± 2051	5.4 ± .9	148.4 ± 94	37.01 ± 22.4
061	7	33.10 ± 9.36	39.04 ± 11.3	1052.6 ± 297.55	1822.5 ± 392.4	4.3 ± 1.6	93.8 ± 27.7	24.4 ± 9.26
022	8.25	4.20 ± 5.93	4.95 ± 7.00	133.50 ± 188.79	1589 ± 801.8	8.2 ± 1.1	40.8 ± 6.3	12.75 ± 1.20
4	6	43.04 ± 4.68	50.76 ± 5.53	1367.90 ± 149.76	2578.5 ± 2237	6.1 ± 3.5	112.4 ± 99.6	21.3 ± 20.7
64	3	41.54 ± 16.15	48.99 ± 19.05	1320 ± 512.93	2351 ± 1557	4.3 ± .8	100.7 ± 64.6	22.6 ± 12.9
22	9	68.44 ± 59.36	80.68 ± 69.98	2175 ± 1886.73	3888 ± 2723	5.4 ± .4	161.6 ± 115.5	42.12 ± 30.08
63	5.5	35.32 ± 40.47	41.65 ± 47.73	1222.73 ± 1286.15	1764 ± 388.1	4.3 ± .8	84.1 ± 34.4	19.53 ± 3.23
Overall Mean	6.57	56.65 ±	64.89 ±	1801.6 ±	2430.8 ±	6.22 ±	96.5 ±	29.2 ±
S.D.	1.76	39.42		1283.9	1431	3.27	56.0	16.0
N		41	41	41	41	41	41	41
Coeff. of Variation		69.5%	60.1%	71.2%	58%	52%	58.0%	54.79%

dium and Potassium in Thirteen Dying Diarrhoeic Calves

Mean Output in Urine in 24 hours						
Water Mls.	Sodium M.eq.	Potassium M.eq.	Water Mls.	Mean loss in Bodyweight 24 hours Kg.	Bodyweight at beginning of Experiment Kg.	Bodyweight at end of Experiment Kg.
2162.5 ± 572.21	10.65 ± 6.5	77.30 ± 81.0	890 ± 29.83	- 1.5	26	23
1875 ± 1065.3	7.23 ± 2.7	44.20 ± 21.30	818 ± 597.07	- 1.2	33	27
1377.1 ± 737	1.9 ± 0	9.12 ± 0	190 ± 268.70	- 1.4	28	25
3911 ± 434.9	1.29 ± 0	9.45 ± 0	58.33 ± 101.03	- 1.60	34	29
1717 ± 1235.2	6.55 ± 7.08	41.08 ± 34.12	797.111 ± 672.7	- .760	31.2	26.6
2676.5 ± 1006.9	9.70 ± 8.19	64.43 ± 36.48	1315 ± 970	- .770	38.1	35
3116.6 ± 1942.3	2.98 ± 1.95	17.69 ± 6.9	1612 ± 860.0	- 2.50	35	27.3
1745 ± 391.73	1.89 ± 0	28.9 ± 0	175 ± 247.4	- 1.0	33	31
1459 ± 741	0.48 ± 0	8.4 ± 0	50 ± 70.71	- 1.300	33.6	31
2457.7 ± 690.16	3.6 ± 0	36 ± 0	150 ± 212.13	- 1.45	27	24.1
2252.50 ± 1502.6	2.88 ± 3.16	9.15 ± 9.68	370 ± 381.83	- 1.45	36.7	33.1
3687.00 ± 2600.4	1.96 ± .26	42.9 ± 5.5	373 ± 325	- 2.3	37	30
1686.86 ± 375.30	2.3 ± 0	20.3 ± 14	153.3 ± 215	- 1.0	31	28
2294 ± 1370	5.2 ± 5.4	36.1 ± 33.0	650 ± 697	- 1.406 ± 0.436	32.63 ± 3.9	28.46 ± 3.5
41	41	41	41			
59%	103%	95%	107%			

Because of the wide variations found in the intake and output of the different parameters analysed, not only from calf to calf, but from day to day within each calf, the overall means and standard deviations obtained while performing these experiments, may not be a valid representation of the severity of the imbalances occurring in the individual calf, nor is it possible to assess from these values the amounts of water and electrolytes which a calf can afford to lose without endangering its vital functions. It would also be very difficult to correlate mean overall losses with the mean changes in the plasma electrolyte concentrations. In order to obtain the information previously mentioned it is necessary to analyse the changes occurring in the individual calves. This has been done, and it is reported herein. However, the overall means and standard deviations, must be considered in order to attempt a comparison of the intake and the losses of water, sodium, and potassium in normal dying diarrhoeic, and surviving diarrhoeic calves. The overall changes observed in the dying diarrhoeic calves and in the surviving calves are sufficiently consistent so that a valid comparison can be made between these animals and the normal calves.

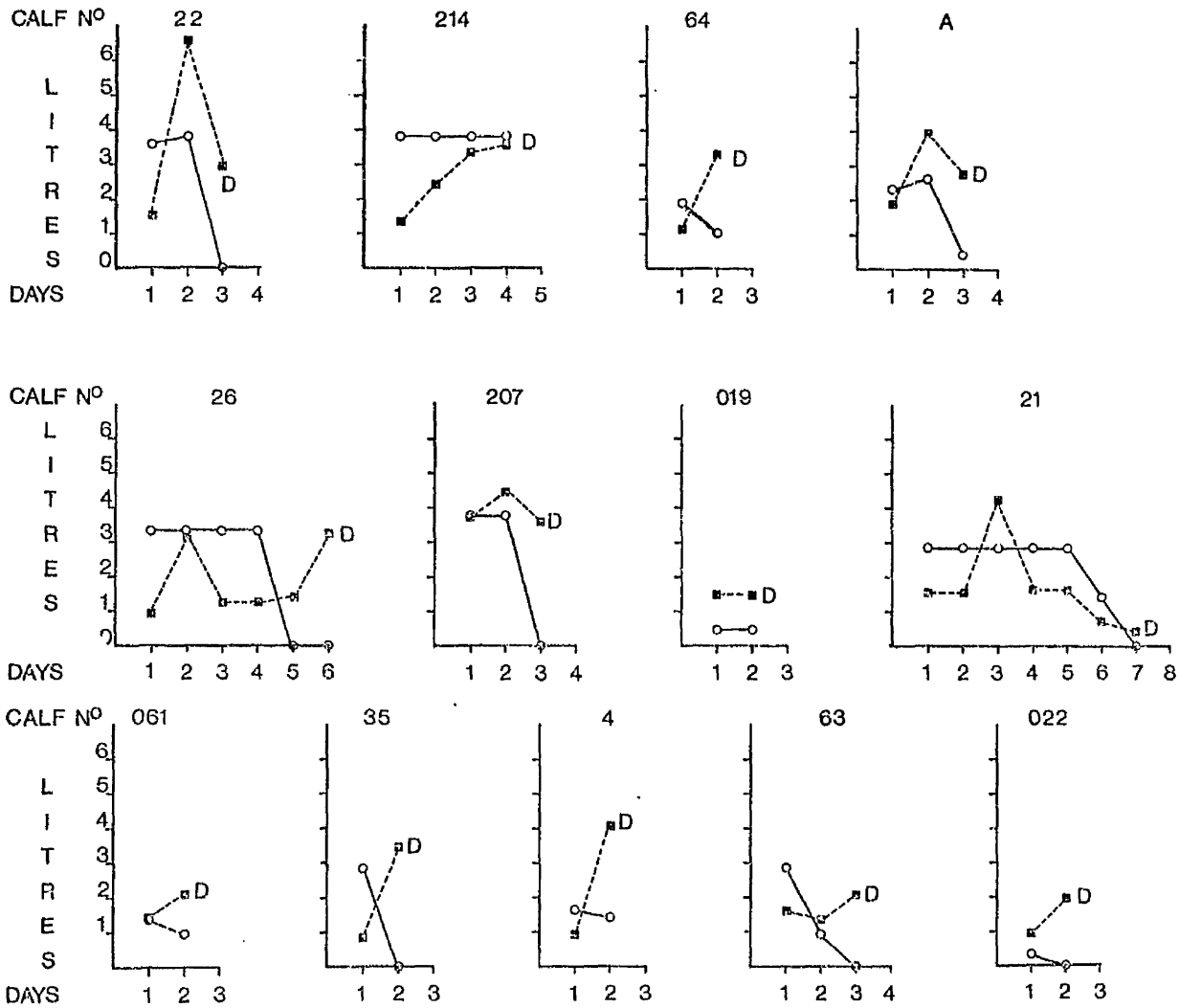
As illustrated by the balance studies, most calves refused to drink their milk at least on one occasion. Thus the mean overall intake of water, sodium and potassium was considerably less than that expected for healthy calves of similar weights. The mean overall intake of water was 1801.6 $\pm$ 1283.9 ml. That of sodium was 56.65 $\pm$ 39.42 m.Eq., and that of potassium 64.89 $\pm$ 33.08 m.Eq.

In an attempt to ascertain if the decreased milk intake had

any influence on the quantity of faeces excreted, the values for intake of milk, and faecal production, were plotted against each other. This is illustrated in figure 10. No evidence of correlation between milk intake and faecal production could be obtained from these figures. However it must be pointed out that the milk intake was completely stopped only when the calves showed no desire to drink.

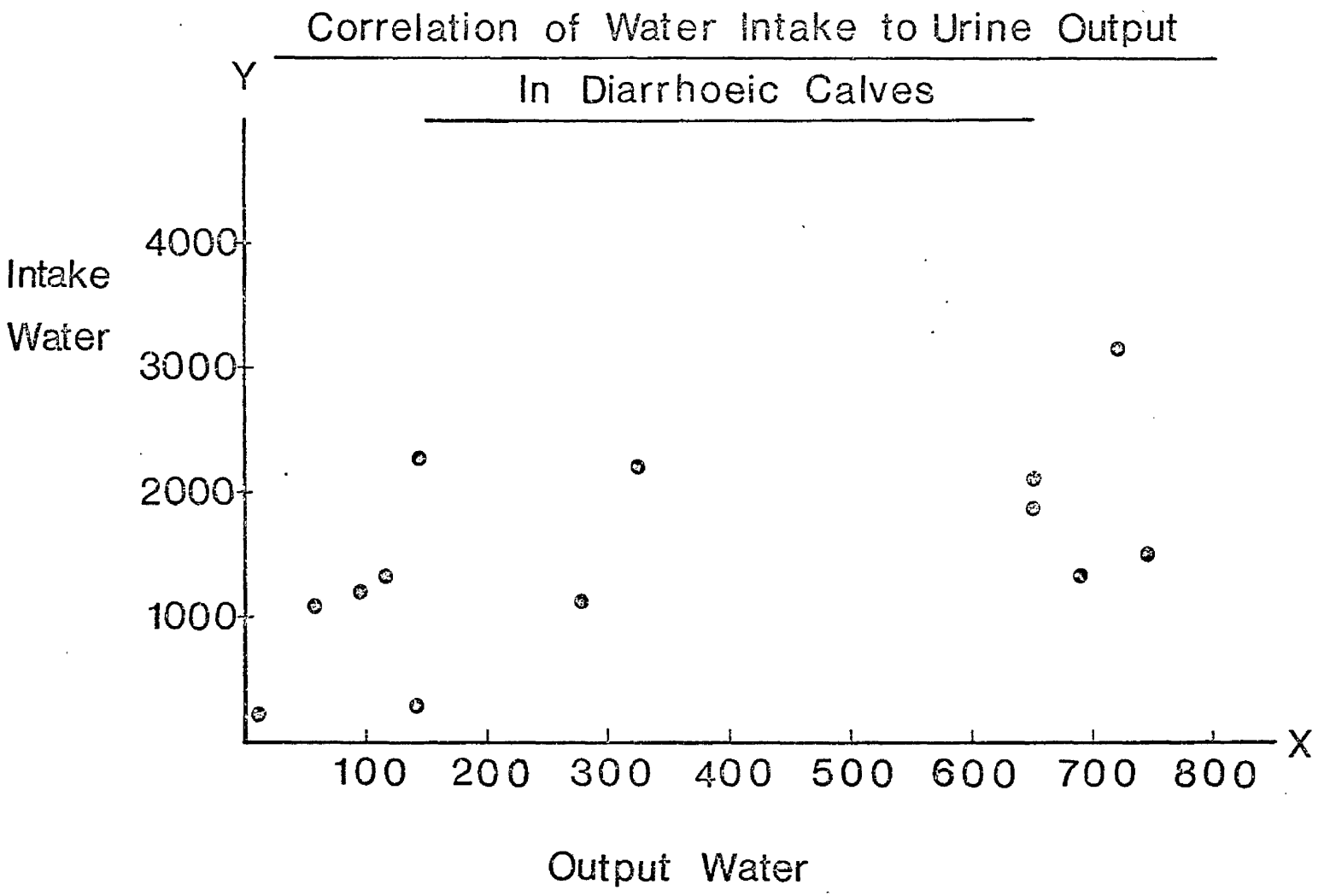
The mean daily excretion of faeces in dying diarrhoeic calves was 2,430.8 ± 1,431 grams, with a dry matter content of 6.22 ± 3.27 per cent. Thus 2,294 ± 1,371 mls. (range 883 to 6567 mls.) of water were lost daily through the faeces. The loss of sodium was 96.5 ± 56 m.Eq. (range 38.4 - 290.0 m.Eq.) and that of potassium 29.2 ± 16 m.Eq. (range 11.2 to 75.9). The urine excretion was considerably decreased, as shown in Table XXVI, and no correlation was found between milk intake and the volume of urine excreted. This is illustrated in fig. 11. Also a considerable decline was found in the excretion of sodium and potassium through this channel. Potassium was consistently excreted in a greater quantity than sodium. The mean amount of urine produced daily was 650 ± 697 ml. with a daily sodium excretion of 5.2 ± 5.4 m.Eq. and 36.1 ± 33 m.Eq. of potassium. Judging by the means corresponding to the intake and output of the parameters analysed (Table XXVI) it is clear that a negative balance of water and sodium prevailed in these dying diarrhoeic calves. As seen from the values illustrated in table XXVI all the calves in these experiments lost weight; the mean daily loss found was 1.42 kg. per day, and a highly significant positive correlation was found between the total water deficits and the overall loss of bodyweight.

Fig. 10.



The Relationship Between the Milk Intake and the Faecal Output in 13 Dying Diarrhoeic Calves

Fig. 11.


Correlation of Water Intake to Urine Output
In Diarrhoeic Calves
Y
Intake Water
4000
3000
2000
1000
X
100
200
300
400
500
600
700
800
Output Water

This is illustrated in fig. 12.

The negative balances are again stressed in Table XXVII. The mean output of sodium, potassium and water is illustrated and the percentage of sodium, potassium and water excreted through the faeces and through the urine is also illustrated. As previously mentioned the total deficit of water and electrolytes varied considerably from calf to calf. However this cumulative deficit apparent in every animal for both sodium and water did not seem to apply to potassium, although all of the calves showed a negative balance on the last day of the experiment.

The ratio, sodium plus potassium to water ingested was .06. The ratio for this substance in the faeces was .05, and the ratio for the overall loss of sodium plus potassium to water was .05. The last two ratios in particular, differ from the ratios found in normal calves previously reported, .06 and .04 respectively, in that a higher dilution of sodium plus potassium was found in the diarrhoeic faeces, and a higher concentration of these substances in the urine of the diarrhoeic calves. This is illustrated in Tables XXVIII, XXIX and XXX.

As judged by the ratios of the intake and total output of sodium plus potassium to water, it appears that relatively more water than the sum of these electrolytes is lost by the dying diarrhoeic calves.

A highly significant ($P = <0.001$) positive correlation was found between water and sodium plus potassium excreted in the

Fig. 12.

Correlation of Water Deficit to Total Loss in Body Weight

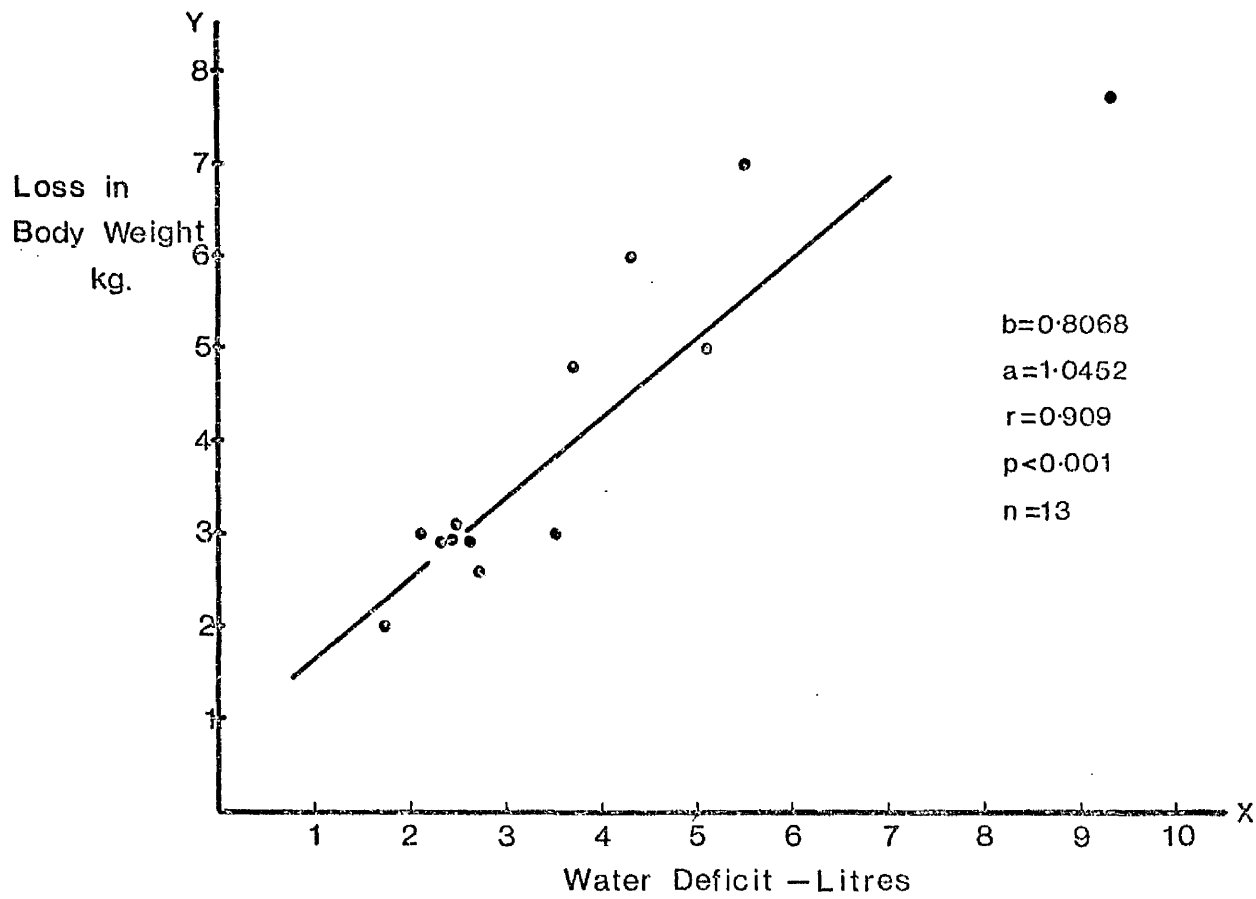


TABLE XXVII

Percentage of the Mean Intake of Water, Sodium and Potassium excreted by Dying Diarrhoeic Calves

Calf No.	Mean Total Output (m.Eq.)			% Na Excreted			% K Excreted			% H_2O Excreted		
	Na	K	Water	Faeces	Urine	Total	Faeces	Urine	Total	Faeces	Urine	Total
35	108.01	113.30	3052.5	244.9	26.79	271.69	76.00	164.9	240.9	171.21	70.40	241.64
26	80.50	74.40	2693.0	118.5	11.69	130.19	41.00	60.6	101.6	95.64	41.64	137.11
019	52.10	29.42	1567.0	389.7	14.75	404.45	133.00	60.0	193.0	336.67	46.45	383.12
207	138.29	59.65	3967.3	194.9	1.82	196.72	60.20	11.34	71.54	174.2	2.5	176.70
21	70.81	65.15	2514.1	102.8	10.48	113.28	32.68	55.75	88.43	86.8	40.29	127.10
214	129.70	96.43	3991.5	113.2	9.15	122.35	25.37	51.80	77.17	79.4	39.04	118.5
A1	151.38	54.70	4728.6	292.2	5.86	298.06	61.87	29.55	91.42	193.2	99.93	293.15
061	95.69	52.30	1920.0	283.3	5.70	289.00	62.5	74.02	136.50	165.87	16.63	182.50
022	41.28	21.15	1509.0	971.4	11.40	982.8	257.5	169.69	427.19	1092.88	37.45	1130.33
4	116.00	57.30	2607.0	261.1	8.32	269.3	41.96	70.92	112.80	179.73	10.92	190.70
64	103.58	31.75	2622.5	242.4	6.93	249.3	46.13	18.67	64.80	170.64	28.03	198.67
22	163.57	85.02	4060.0	236.1	2.86	238.9	52.2	53.17	105.37	169.51	17.14	186.66
63	86.40	39.83	1840.1	238.1	6.51	244.6	46.89	48.09	94.98	137.95	12.53	150.49
lean	102.87	58.70	2851.7	283.7%	9.40%	293.12%	72.10%	66.80%	138.90%	234.90%	35.60%	270.50%

TABLE XXVIII

Ratio of the mean daily intake of sodium and potassium to water in dying diarrhoeic calves

Calf No.	Sodium + Potassium M.eq.	Water (mls)	Ratio
35	86.61	1263.0	.06
26	134.68	1964.6	.06
019	28.06	409.0	.06
207	153.97	2245.3	.06
21	136.10	1978.4	.06
214	230.88	3368.0	.06
A1	110.63	1613.6	.06
016	72.14	1052.6	.06
022	9.15	133.5	.06
4	93.80	1367.9	.06
64	90.53	1320.3	.06
22	149.12	2175.2	.06
63	76.97	1122.7	.06
	Mean 105.58 m.eq.	1539.3 mls.	.06
Normal Calves	Mean 190.90 m.eq.	2893.0 mls.	.06

TABLE XXIX

Ratio of the mean daily excretion of sodium plus potassium, to water, in faeces of dying diarrhoeic calves

Calf No.	Sodium + Potassium m.eq.	Water Mls.	Ratio
35	133.36	2162.5	.06
26	103.50	1875.0	.05
019	70.35	1377.15	.05
207	187.94	3911.3	.04
21	88.33	1717.25	.05
214	157.17	2676.5	.05
A1	185.42	3116.6	.05
061	118.25	1745	.06
022	53.60	1459	.03
4	133.75	2457.75	.05
64	123.35	2252.5	.05
22	203.73	3687.0	.05
63	103.63	1686.86	.06
	Mean 127.89	2318.0 mls.	.05
Normal Calves	Mean 4.18 m.eq.	69.48 mls.	.06

TABLE XXX

Ratio of the mean total daily excretion of sodium plus potassium to water, in dying diarrhoeic calves

Calf No.	Sodium + Potassium m.eq.	Water Mls.	Ratio
35	221.31	3052.5	.07
27	146.35	2693.0	.05
019	81.52	1567.1	.05
207	197.94	3969.3	.04
21	135.96	2514.2	.05
214	225.83	3991.5	.05
A1	206.09	4728.2	.04
061	147.99	1920.0	.07
022	62.43	1509.0	.04
4	173.33	2607.7	.06
64	135.47	2622.5	.05
22	248.59	4060.3	.06
63	109.16	1840.8	.06
	Mean 160.92	2852.0 mls.	.05
Normal Calves	Mean 105.8 m.eq.	2181.3 mls.	.04

diarrhoeic faeces. This is illustrated in fig. 13. It is interesting to note that the positive correlation between the excretion of sodium and potassium in faeces found in normal calves, prevailed in the dying diarrhoeic calves. When these values were plotted against the volumes of water excreted, a considerably higher loss of sodium, than potassium per volume of water became apparent; this is seen in fig. 14. Fig. 15 illustrates the relative losses of sodium and potassium per volume of water in some of the diarrhoeic conditions encountered in the human subject. When comparing these values with those obtained in the present study, it was found that the losses occurring in neonatal calf diarrhoea were very similar to those seen in osmotic diarrhoea.

No correlation was found between the plasma levels of sodium and the amount of sodium excreted in the faeces. This is illustrated in fig. 16.

Table XXXI shows the cumulative balances of water, sodium and potassium. It also illustrates the initial bodyweight, and the total loss of bodyweight.

The total body water of the young calf has been estimated by several workers, and although the methodology while undertaking such estimations was different, they all arrived at similar conclusions; Haigh, Moulton, and Trowbridge (1920), using the dessication technique, found that the water content of newborn

Fig. 13.

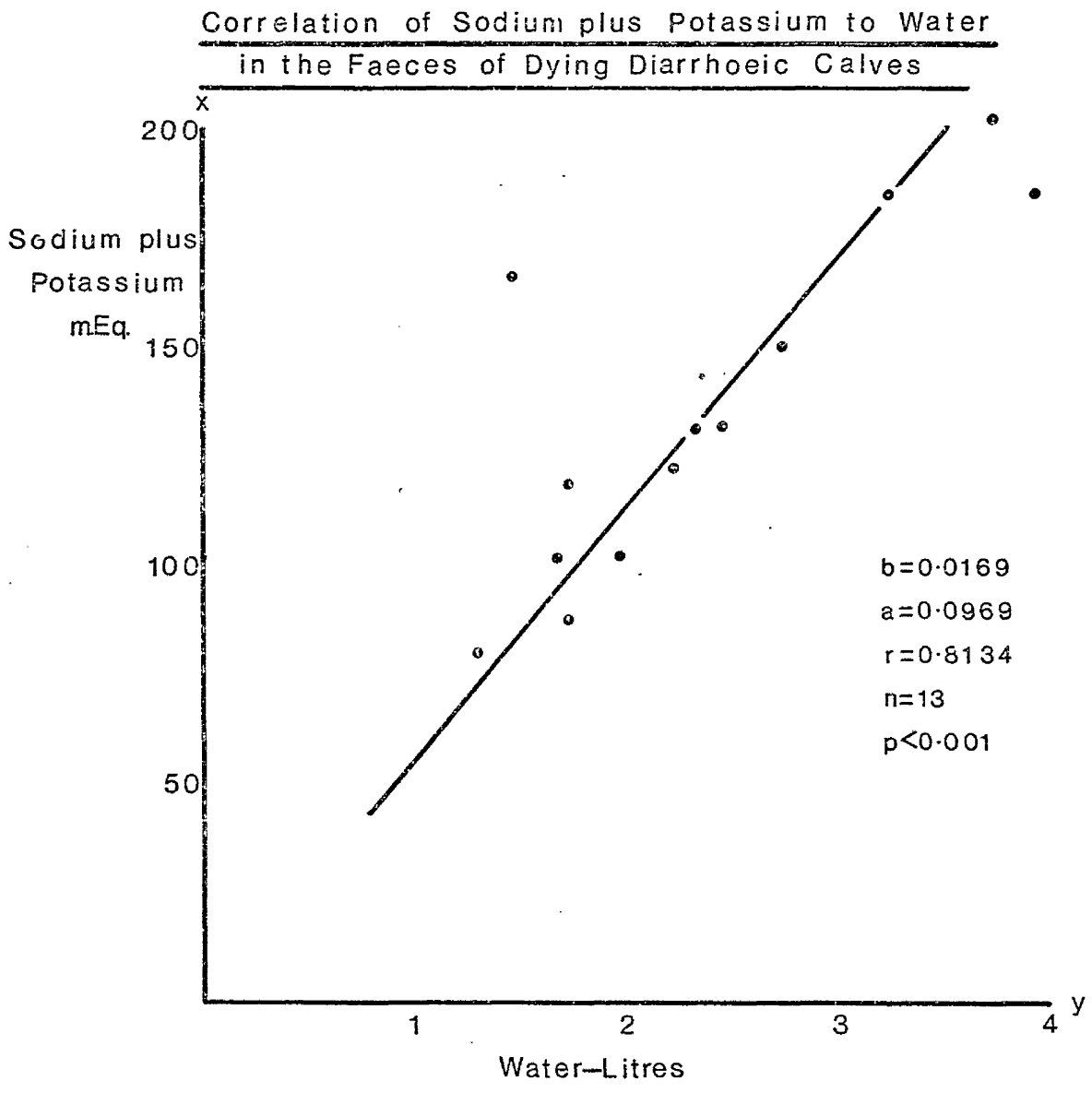

Correlation of Sodium plus Potassium to Water
in the Faeces of Dying Diarrhoeic Calves
x
200
150
100
50
Sodium plus
Potassium
mEq.
b=0·0169
a=0·0969
r=0·8134
n=13
p<0·001
1
2
3
4
y
Water–Litres

Fig. 14.

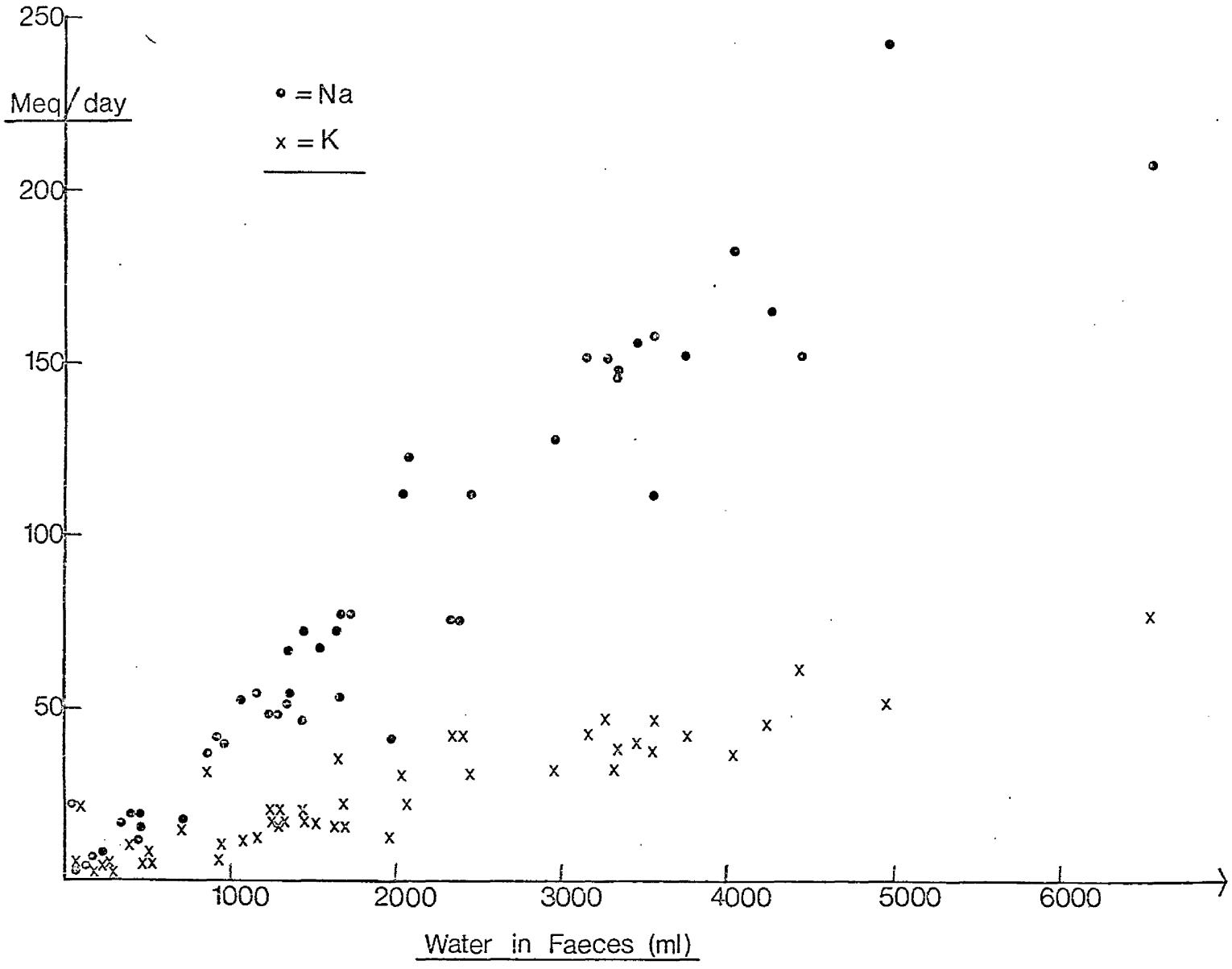

250
200
150
100
50
Meq / day
o = Na
x = K
1000
2000
3000
4000
5000
6000
Water in Faeces (ml)

Fig. 16

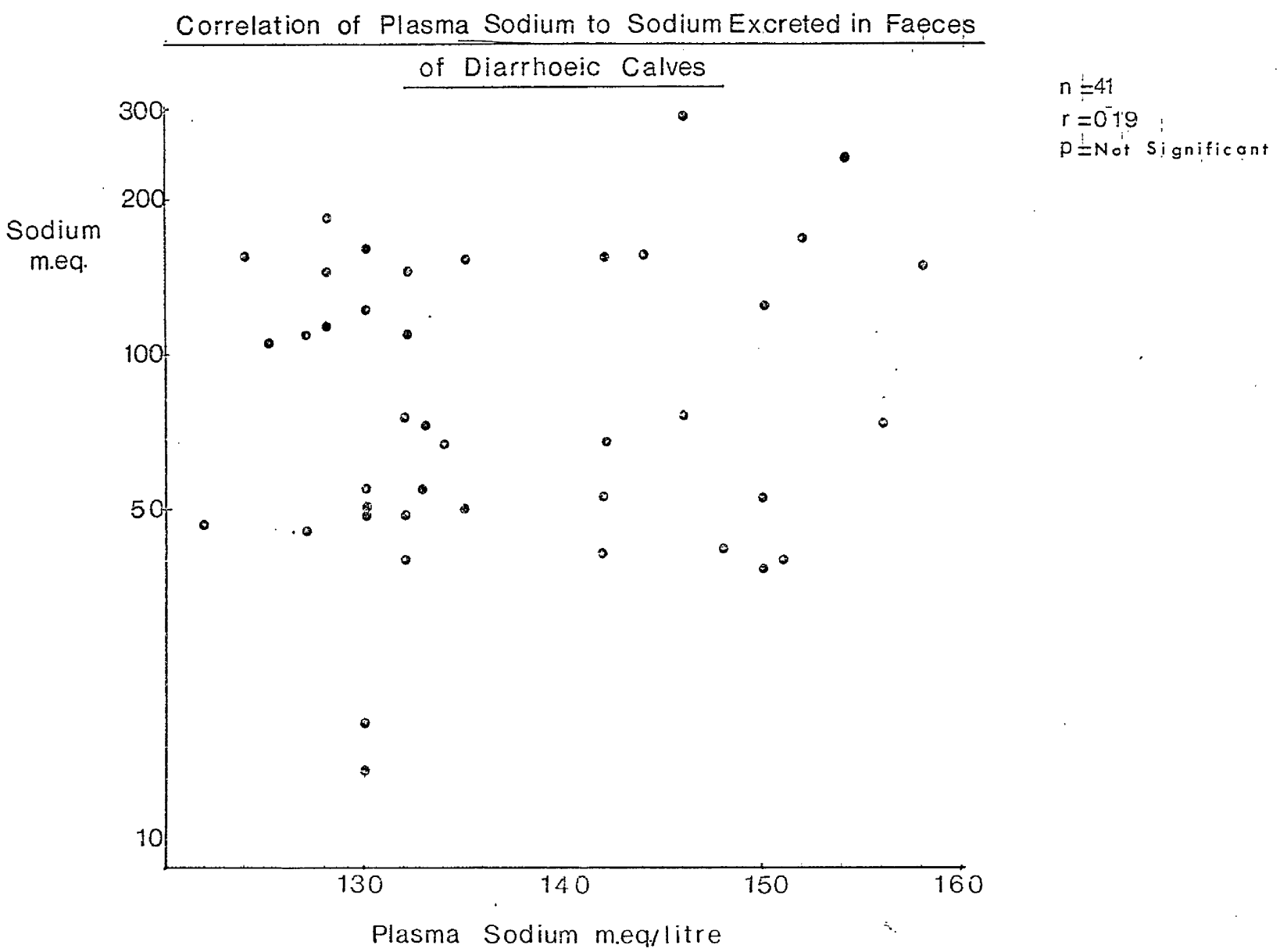

Correlation of Plasma Sodium to Sodium Excreted in Faeces
of Diarrhoeic Calves
n =41
r =0·19
p =Not Significant
Sodium
m.eq.
300
200
100
50
10
130
140
150
160
Plasma Sodium m.eq/litre

TABLE XXXI

Cumulative Balances of Water, Sodium and Potassium and the total loss of Bodyweight of 13 Dying Diarrhoeic Calves

Calf No.	Bodyweight Kg.	Cumulative Water Balance	Cumulative Sodium Balance	Cumulative Potassium Balance	Total loss of Bodyweight Kg.	Period of Study days
35	26	- 3579	- 136.6	- 132.86	3.0	2
26	33	- 4373	- 99.67	+ 33.98	6.0	5
019	28	- 2316	- 76.22	- 19.36	2.8	2
207	34	- 5181	- 202.55	+ 89.55	5.0	3
21	31.25	- 3706	- 51.92	+ 100.57	4.6	6
214	38.10	- 2539	- 97.05	+ 115.08	3.1	4
A1	35	- 9390	- 301.87	+ 18.80	7.7	3
061	33	- 1734	- 123.31	000	2.0	2
022	33.6	- 2751	- 73.78	- 24.00	2.6	2
4	27	- 2480	- 142.41	+ 22.93	2.9	2
64	36	- 2605	- 124.07	+ 34.32	2.9	2
22	37	- 5566	- 202.54	+ 30.18	7.0	3
63	31	- 2144	- 150.93	+ 25.77	3.0	3
Mean	32.534	- 3719	- 137.183	+ 22.61	4.046	
S.D.	± 3.770	± 2074	± 11.712		± 1.840	

calves ranged from 72.4 to 73.5 per cent of their bodyweight. Ellenberger, Newlander and Jones (1950) found the total body water in newborn calves to be 74.2 per cent of their bodyweight, and McFadden and Richards (1956) reported a value of 72 - 74 per cent of the calves' bodyweight as being the value for the antipyrine space. More recently Dalton (1965) using calves, which in age, and conditions of management prior to arrival at the Veterinary Hospital, resembled those of the present study, found that their total body water was equal to 73.6 per cent $\pm$ 6.4 per cent of their bodyweight. The same author measuring the extra cellular fluid volume (thiosulphate space) found it to be equivalent to 24.2 $\pm$ 2.6 per cent of the total bodyweight of the calves. Applying his findings to calculate the total body water and extra cellular fluid of the calves studied, the values illustrated in Table XXXII were obtained. The values were derived from the initial bodyweights recorded, that is when all the calves were normal. The cumulative losses of water for the individual calves are also illustrated in this table, so are the losses of water expressed as per cent of the total body water and as per cent of the total bodyweight. Finally the amount in millilitres per kilogram, which the different calves studied lost before dying, is also given.

As illustrated in Table XXXII the initial bodyweights of the calves was fairly uniform, the mean being 32.53 $\pm$ 3.77 kgrams. with a variation coefficient of 11.58 per cent. Consequently the same coefficient of variation may be applied to the values for total body water and extra cellular water. The values obtained for

TABLE XXXII

The Cumulative Water Deficit of 13 Dying Diarrhoeic Calves

Calf No.	Body weight	Total Body Water L. Estimated as 73.6% Bodyweight (Dalton, 1965)	Extracellular Water L. Estimated as 24.2% Bodyweight (Dalton, 1965)	Cumulative Water Deficit	Water Loss % of Total Body Water	Water Loss % per kg. Bodyweight	Water Loss ml/kg. Bodyweight
35	26.00	19.13	6.29	3579	18.70	13.76	137.6 ml.
26	33.00	24.28	7.98	4373	18.01	13.25	132.5 ml.
019	28.00	20.60	6.77	2316	11.24	8.27	8.20 ml.
207	34.00	25.02	8.22	5171	20.66	15.20	152.0 ml.
21	31.250	23.00	7.56	3706	16.11	11.85	118.5 ml.
214	38.700	28.00	9.23	2539	9.06	6.60	66.5 ml.
A1	35.00	25.00	8.47	9390	37.5	26.62	266.2 ml.
061	33.00	24.28	7.98	1734	7.14	5.25	52.5 ml.
022	33.60	24.72	8.13	2751	11.12	8.18	81.8 ml.
4	27.00	19.80	6.53	2480	12.50	9.18	91.8 ml.
64	36.00	26.49	8.71	2605	9.66	7.23	72.36 ml.
22	37.00	27.23	8.95	5566	20.41	15.0	150.43 ml.
63	31.00	22.80	7.50	2144	9.40	6.91	69.16 ml.
Mean	32.534	23.873	7.870	3719	15.500%	11.33%	113.33 ml.
S.D.	± 3.770	± 2.746	± .913	± 2074	± 8.065	± 5.71	± 57.14
Co-efficient of Variation	11.58%	11.50%	11.50%	55.76%	52.03%	50.50%	50.41%

total body water and extra cellular water were 23.873 ± 2.74 litres and 7.870 ± .913 litres respectively. A significantly higher coefficient of variation was found for the mean water deficits and mean water loss expressed as per cent of total body water, and bodyweight. Similarly a higher coefficient of variation was obtained for the amount of water lost expressed in millilitres per kilogram of bodyweight. The mean deficit of water recorded in these dying diarrhoeic calves was 3.719 litres ± 2.074 litres (coefficient of variation 52.03), and 11.33 per cent ± 5.71 per cent (coefficient of variation 50.50 per cent) were recorded as the water loss per cent of bodyweight. The mean loss of water expressed as millilitres per kilogram of bodyweight was found to be 113.33 ml. ± 57.44 ml. with a variation of coefficient of 50.41 per cent.

Table XXXIII illustrates the accumulative sodium deficit. The theoretical extra cellular amount of sodium has been calculated taking into consideration the plasma sodium concentration obtained from the first blood sample taken when all the calves were healthy. As for water, a variation was also found in the mean deficit of sodium, the mean value being 137.14 ± 67.25 m.Eq. per litre with a coefficient of variation of 43 per cent. This value corresponds to a loss of 12.35 ± 5.47 per cent of the total extra cellular sodium; expressed as m.Eq. per kilogram of bodyweight the value obtained was 4.20 ± 1.95 m.Eq.

The results of the plasma parameters analysed are illustrated in Table XXXIV. The values shown correspond to the means of the samples taken on the first day of the experiment (First Sample) when

TABLE XXXIII

The Cumulative Sodium Deficit of 13 Dying Diarrhoeic Calves

Calf No.	Bodyweight Kg.	Extra Cellular Water	Plasma Na m.Eq. L. First Sample	Extra Cellular Sodium m.Eq.	Sodium Deficit m.Eq.	Sodium lost m.Eq./Kg.	% of E.C. Sodium lost
35	26	6.29	150	943.50	136.6	5.25	14.47
26	33	7.98	132	1053.36	99.67	3.02	9.46
019	28	6.77	130	880.10	76.22	2.72	8.66
207	34	8.22	138	1134.36	202.55	5.95	17.85
21	31.25	7.56	146	1103.76	51.92	1.66	4.70
214	38.10	9.23	134	1236.82	97.05	2.54	7.84
A1	35.00	8.47	150	1270.50	301.87	8.62	23.75
061	33.00	7.98	136	1085.28	123.31	3.73	11.36
022	33.60	8.13	151	1227.63	73.78	2.19	6.00
4	27.00	6.53	148	966.44	142.41	5.27	14.73
64	36.00	8.71	133	1158.43	124.07	3.44	10.71
22	37.00	8.95	142	1270.90	202.54	5.47	15.93
63	31.00	7.50	133	997.50	150.93	4.86	15.13
Mean	32.534	7.87	140.23	1102.128	137.14	4.20	12.35%
S.D.	± 3.770	± .93	± 7.86	± 129.55	± 67.25	± 1.95	± 5.475

TABLE XXXIV

The Mean Values of Plasma, Sodium, Potassium, Urea, Osmolality, Blood pH, and Packed Cell Volume of the First and Terminal Samples of 13 Dying Diarrhoeic Newborn Calves

	First Sample	Terminal Sample	Significance
Sodium m.Eq./L. S.D.	140.23 ± 7.86	134.5 ± 10.2	N.S.
Potassium m.Eq./L. S.D.	5.12 ± .84	7.10 ± 1.57	P = 0.001
Osmolality M.O.M./L. S.D.	298.16 ± 23.45	291.8 ± 18.91	N.S.
Packed Cell Volume % S.D.	42.7 ± 8.3	51.7 ± 9.8	P = 0.02
Urea mg/100 S.D.	39.84 ± 13.9	151.53 ± 67.09	P = 0.001
pH S.D.	7.360 ± .040	6.991 ± 0.15	P = 0.001
Bicarbonate m.Eq./L S.D.	27.041 ± 3.726	10.08 ± 2.86	P = 0.001
Urine Osmolality m.Eq./L. S.D.	335.87 ± 122.38	693.3 ± 181.81	P = 0.001

when none of the calves were suffering from diarrhoea, and to the samples taken 12 hours or less before death, with the exception of the values obtained for sodium and plasma osmolarity. There was a significant difference between the values obtained for the first and terminal samples of all the other parameters analysed. However an overall decline was observed in the plasma sodium concentration, the mean for the first sample being 140.2 $\pm$ 7.86 and that for the terminal sample 134.5 $\pm$ 10.2; only three of the calves showed a higher serum sodium concentration at the time of death than that recorded at the beginning of the experiment. See appendix.

The decline in the serum sodium concentration varied from calf to calf, the range being 2.25 per cent to 13.51 per cent of the original value.

The mean serum potassium concentration for the terminal sample was 7.10 $\pm$ 1.57 m.Eq. The mean terminal P.C.V. and blood urea were 51.7 $\pm$ 9.8 per cent and 151.33 $\pm$ 67.02 mg/100 respectively. The values for blood pH and bicarbonate fell steeply. The terminal value for pH was 6.991 and that for bicarbonate 10.08 $\pm$ 2.86. The urine osmolarity rose to 693.3 $\pm$ 181.8 mm/L.

The appearance of the stools varied considerably from calf to calf and from day to day in each calf. No particular relationship could be found between the colour and the homogenicity of the faeces withthe quantities excreted or with the clinical status of the calf.

The colour of the stools varied from a creamy white to a dark green. Although accurate measurements of the number of occasions on

which the diarrhoeic calves defaecated were impossible, it became obvious during routine sampling and clinical examination that the diarrhoeic calves defaecated more frequently than normal calves. Up to four productive bowel movements in an hour were observed in calf 22. On occasion the defaecation was accompanied by grunting followed by shivering and attempts to kick the under abdomen.

The demeanour of the calves studied varied from calf to calf, particularly at the onset of diarrhoea. In some animals the diarrhoea did not seem to affect them in any way. They were initially eager to drink and able to stand and move within the metabolic cage. The calves, however, became lethargic and were not interested in their surroundings as the number of days on which they had diarrhoea increased. However, all the calves died within seven days of the appearance of diarrhoea. The mean number of days during which the animals suffering from diarrhoea survived was three. The clinical signs related to dehydration such as enophthalmos and changes in the texture of the skin, dryness of the muzzle and change in voice were not consistently seen in all of these dying diarrhoeic calves. However when they appeared they did so usually 24 or 48 hours before the death of the animals. Abnormally high temperatures were only seen in two calves. A clinical finding, which did appear quite consistently, in most of the calves affected with severe diarrhoea was a rapid and weak pulse. This usually appeared 24 hours after the onset of diarrhoea. Cardiac arrhythmias were detected in three of the animals studied.

Studies on Surviving Diarrhoeic Newborn Calves

Results

Table XXXV illustrates the mean daily intake and output of water, sodium and potassium of eight diarrhoeic calves which recovered. Also illustrated are the mean daily changes in bodyweight and the mean daily faecal excretion.

The wide standard deviation found in the mean daily faecal excretion is understandable, and it is the result of having taken into consideration the amount of faeces passed by these calves while being healthy and while being diarrhoeic. The same would apply to the rest of the faecal components.

The mean daily excretion of faeces found in these calves was 637.79 $\pm$ 674.95 grams with a dry matter concentration of 13.51 per cent $\pm$ 7.17 per cent. The sodium lost through the faeces was 21.2 $\pm$ 27.49 m.Eq. and 9.49 $\pm$ 9.60 m.Eq. was the mean daily excretion of potassium. Once again the excretion of sodium exceeded that of potassium. This was a consistent finding which occurred during the diarrhoeic period and during normality. The mean daily volume of urine produced by these calves was 1,348.40 $\pm$ 605.16 millilitres, the mean excretion of sodium through this channel being 13.67 $\pm$ 10.32 m.Eq. per day and that of potassium 41.38 $\pm$ 32.84 m.Eq. The daily intake of milk was not significantly different from that recorded for normal calves, however it was significantly higher than the values obtained for diarrhoeic dying calves. Six of the eight calves gained bodyweight, only one calf lost weight and

TABLE

The Mean Daily Intake and Outpu
Eight Diarrhoeic

Calf No.	Mean Intake - 24 hrs.				Mean Output in Faeces in 24			
	Z.S.T. Units	Sodium m.Eq.	Potassium m.Eq.	Water mls.	Total Faecal Output g.	Dry Matter %	Sodium m.Eq.	Pota m.
40	7.5	65.67 ± 2.45	84.85 ± 3.12	2525.90 ± 94.13	727.45 ± 1022.05	14.31 ± 8.95	26.72 ± 43.2979	7. ± 8.
944	7.0	65.67 ± 0	84.87 ± 0	2526 ± 0	607.600 ± 771.13	12.60 ± 6.12	20.25 ± 31.35	9. ± 10.
619	13.5	56.76 ± 3.07	73.35 ± 3.97	2170.75 ± 118.32	572.500 ± 496.18	12.07 ± 3.37	28.200 ± 36.01	10. ± 10.
101	8	76.28 ± 7.251	96.26 ± 5.32	2468.45 ± 136.44	882.27 ± 562.75	8.17 ± 2.99	17.8245 ± 11.20	14. ± 12.
018	9	70.72 ± 0	98.51 ± 0	2526 ± 0	399.37 ± 151.25	16.61 ± 10.57	10.52 ± 5.315	5. ± 2.
470	10	63.83 ± 24.29	88.92 ± 33.84	2280.15 ± 867.22	1030.00 ± 813.12	11.700 ± 2.2058	32.43 ± 30.74	12. ± 11.
4	12	65.67 ± 0	85.88 ± 0	2526 ± 0	424.16 ± 358	18.24 ± 8.77	16.73 ± 20.87	4. ± 5.
686	15.25	88.71 ± 12.15	100.54 ± 10.72	2631.12 ± 318.29	371.0 ± 489.0	17.12 ± 5.74	19.82 ± 22.13	10. ± 9.
Mean ± S.D.	10.28 ± 3	70.88 ± 14.78	87.83 ± 12.49	2465.54 ± 301.5	637.79 ± 674.952	13.51 ± 7.17	21.26 ± 27.49	9. ± 9.
N.		67	67	67	67	67	67	67
Coeff. of Var.		16.2%	14.2%	12.22%	105.82%	53.07%	129.3%	101.

t of Water, Sodium and Potassium in
Surviving Calves

hours		Mean Output in Urine			Bodyweight at the beginning of Experiment Kg.	Bodyweight at the end of Experiment Kg.
ssium Eq.	Water mls.	Sodium m.Eq.	Potassium m.Eq.	Water mls.		
64	663.36 ±	21.10 ±	70.94 ±	1276.36 ±		
81	958.70	16.05	35.38	580.34	28.6	29.7
314	555 ±	14.31 ±	58.81 ±	1555.00 ±		
21	719	10.32	33.66	732.91	31.13	31.8
264	589.5 ±	12.68 ±	56.65 ±	1618.57 ±		
25	673.5	4.48	26.86	352.77	36.36	39
73	681.0 ±	9.68 ±	46.66 ±	1343.00 ±		
28	488.36	6.73	29.99	577.92	32.2	34.5
932	333.5 ±	16.59 ±	25.82 ±	1893.75 ±		
449	137.9	8.81	24.57	427.98	32.2	32.2
1933	916.33 ±	6.70 ±	20.00 ±	1086.60 ±		
89	747	5.82	4.54	348.538	35.4	33.7
44 50	365.66 ±	12.64 ±	22.17 ±	1137.50 ±		
4 2	410.32	7.60	11.63	521.45	31.4	31.9
4 6	342.12 ±	12.71 ±	40.814 ±	768.75 ±		
2 8	310.15	12.16	13.89	515.43	38.90	40.8
49	560.68 ±	13.67 ±	41.88 ±	1348.40 ±	33.27 ±	34.20 ±
60	621.15	10.82	32.84	605.16	3.3	3.8
	67	61	61	N = 67		
1 5%	110.7%	79.1%	78.41%	44.87%		

one showed no change.

The number of days during which the animals suffered from diarrhoea varied. However they were never diarrhoeic for more than three consecutive days. At the same time only one calf, calf number 40, passed a volume of faeces which was similar to the mean faecal output of the dying diarrhoeic calves. In only calf number 101 did diarrhoea recur once it had stopped for two days or more. It was apparent that although these calves became affected with diarrhoea, the overall balance of water, sodium and potassium, because of the considerably smaller excretion of faeces than that shown by the dying diarrhoeic calves, the short duration of the condition, and the continuous milk intake, did not fall into a negative value at any time. The individual values are reported in the Appendix. However the same inference may be drawn from the mean values illustrated in Table XXXV for the individual calves.

Table XXXVI illustrates and compares the values for the faecal and urine outputs for water, sodium and potassium recorded from normal, diarrhoeic surviving and diarrhoeic dying calves. It is interesting to note that as the amount of faeces excreted rises the dry matter concentration drops. In this respect, a highly significant negative correlation was found between the dry matter per cent and the amount of faeces excreted - this is illustrated in fig. 17.

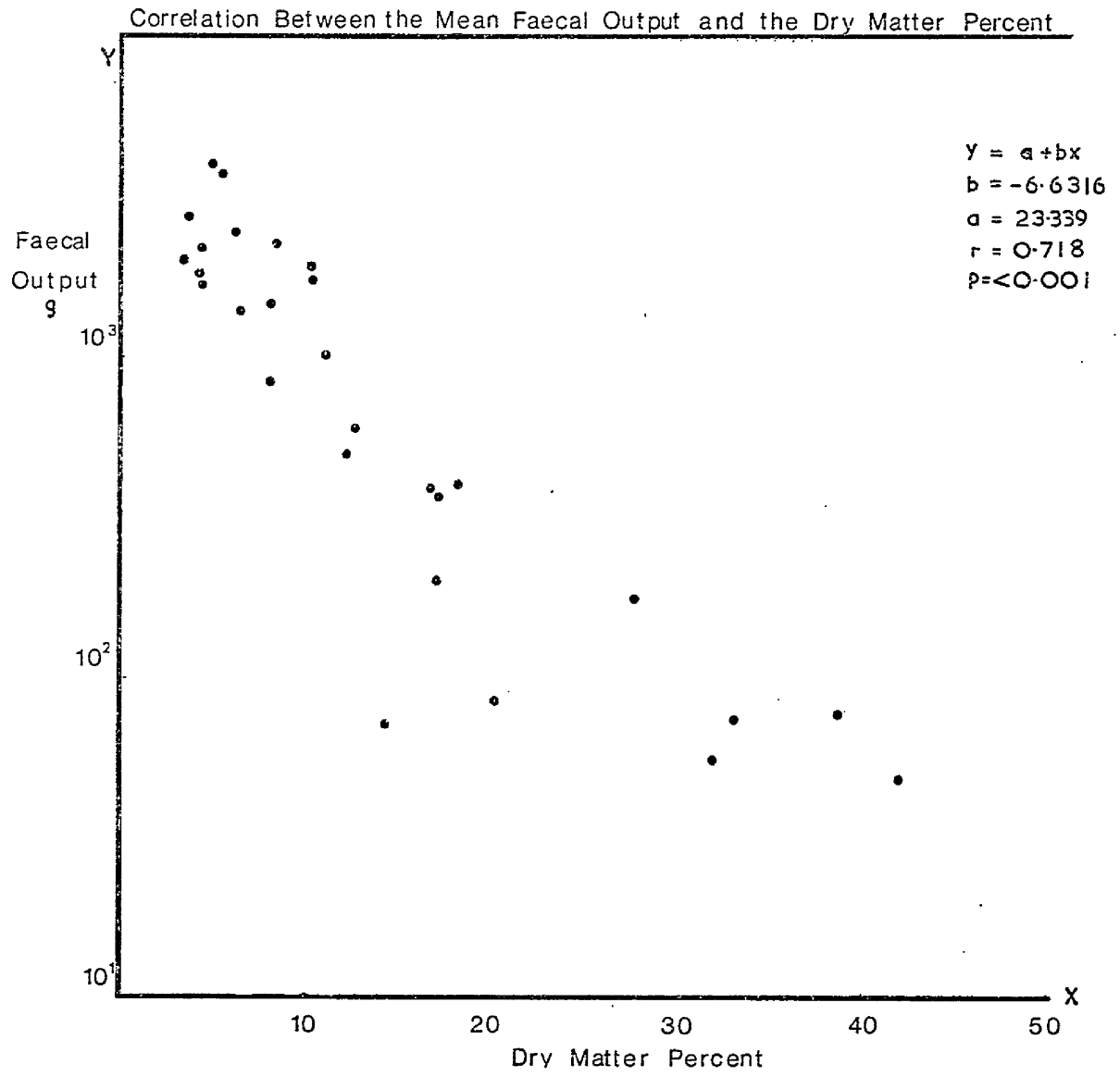
When analysing the changes that occurred in the plasma parameters of these calves, no significant differences could be found amongst the values recorded at the beginning of the experiment at the time of

TABLE XXXVI

The mean daily output of faeces and urine, and the mean daily water, sodium and potassium excretion, in normal, dying diarrhoeic and surviving diarrhoeic newborn calves

Condition of Calves	Total faecal Output gr./day	Total water excreted in faeces ml./day	Percentage of dry matter in faeces	Sodium excreted in faeces m.Eq/day.	Potassium excreted in faeces m.Eq./day	Urine Output	Sodium Excreted in urine	Potassium excreted in urine
Normal (7 calves)	95.82 ± 73.70 N = 48	77.3 ± 61.6	29.50 ± 7.33 N = 44	3.55 ± 2.58 N = 44	1.64 ± 1.02 N = 44	2199.33 ± 639.32 N = 48	36.94 ± 22.90 N = 48	72.32 ± 22.17 N = 48
Diarrhoeic Dying (13 calves)	2430.8 ± 1431.3 N = 41	2294 ± 1370 N = 41	6.22 ± 3.27 N = 41	96.5 ± 56.0 N = 41	29.2 ± 16.0 N = 41	650 ± 697 N = 40	5.2 ± 5.4 N = 40	36.1 ± 33.0 N = 40
Diarrhoeic Recovered (8 calves)	637.79 ± 674.95 N = 67	560.68 ± 621 N = 67	13.51 ± 7.17 N = 67	21.26 ± 27.49 N = 67	9.49 ± 9.60 N = 67	1348.40 ± 605.16 N = 67	13.67 ± 10.82 N = 61	41.88 ± 32.84 N = 61

Fig. 17


Correlation Between the Mean Faecal Output and the Dry Matter Percent
Y
Faecal
Output
g
10^3
10^2
10^1
y = a+bx
b = -6·6316
a = 23·339
r = 0·718
p=<0·001
X
10
20
30
40
50
Dry Matter Percent

diarrhoea or at the end of the experiment. These values are illustrated in Table XXXVII. Again when compared with the values recorded in the other groups of calves significant differences in most of the parameters analysed were found between the terminal samples of the dying diarrhoeic calves and the samples taken at any one time from the diarrhoeic surviving calves. No significant difference could be encountered for any of the values recorded between the normal calves and diarrhoeic recovered calves. It was previously pointed out that no apparent relationship could be found between the severity of the diarrhoea and the ingestion of milk amongst the dying diarrhoeic calves. Further support for this finding may be encountered by the fact that the calves in the present experiment which recovered from diarrhoea did so spontaneously in spite of the fact that the milk intake was unaltered.

The very interesting and significant incidental finding which arose from this study was the strong negative correlation found between the serum immune globulin concentration and the amount of faeces excreted. This is illustrated in fig. 18.

As mentioned in the 'Material and Methods' corresponding to this part only calves with serum immune globulin concentrations of 5 (Z.S.T. units) or over were included in this study. However no particular attention was made to acquiring calves with very similar values. Because eventually there was a variation in the values obtained for the serum immune globulin concentrations of these calves, such variation appeared to be closely related to the severity of diarrhoea. Table XXXVIII illustrates the serum immune globulin

TABLE

The plasma sodium, potassium, osmolar and bicarbonate of eight dia

Calf No.	Osmolarity mom./L.			Blood P.H.			Bicarbonate m.Eq./L			
	F.	M.D.	T.	F.	M.D.	T.	F.	M.D.	T.	
40	280	296	280	7.34	7.28	7.36	30	22	26.3	
944	280	298	280	7.37	7.25	7.56	26	17.1	39.0	
619	280	295	280	7.39	7.35	7.36	30	24	26.5	
101	290	263	290	7.33	7.33	7.42	23	29.9	31.0	
018	270	295	270	7.39	7.39	7.39	29	28.1	28.5	
470	280	275	290	7.37	7.29	7.34	29.5	23.7	25.0	
4	280	270	290	7.37	7.37	7.39	30.0	26	31.0	
686	300	298	280	7.41	7.30	7.34	28	26.6	26.0	
Mean	282.5	286.25	282.5	7.37	7.32	7.39	28.18	24.66	29.16	
S.D.	± 8.86	± 14.41	± 7.07	± 0.024	± 0.047	± 0.072	± 2.5	± 3.95	± 4.57	

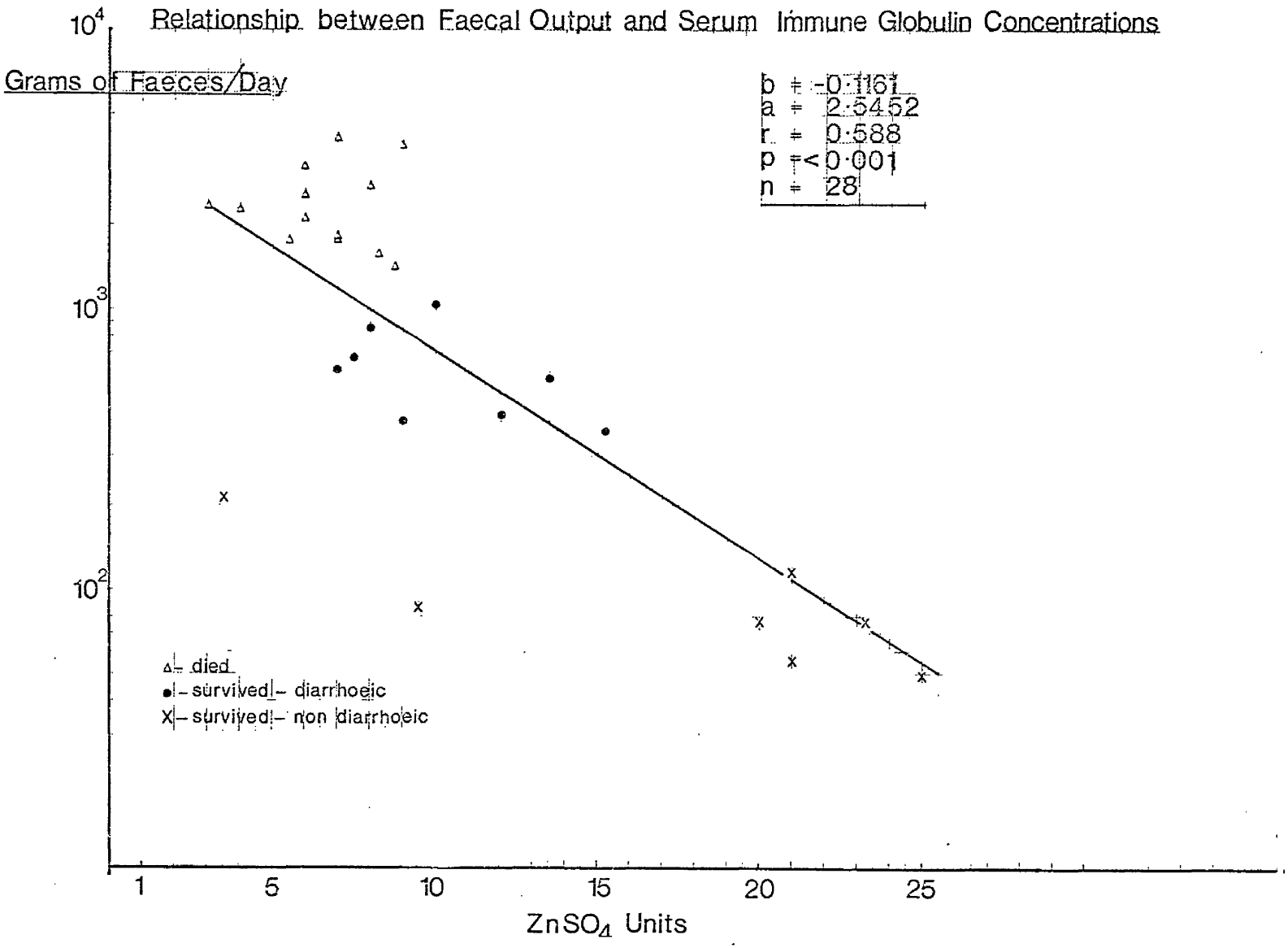
The values illustrated correspond to
of the experiment, that is when all
mean of the values obtained during
the values obtained at least two days

ity urea, packed cell volume, blood pH
rrhoeic recovered calves

Packed Cell Volume %			Sodium m.Eq/L.			Potassium m.Eq/L.			Urea mg/100		
F	M.D.	T.	F.	M.D.	T.	F.	M.D.	T.	F.	M.D.	T.
35	31	33	138	150	148	4.4	5.1	5.0	24	26	25
42	49	46	140	146	138	4.4	5.4	5.2	26	34	14
39	36	28	144	131	140	4.9	4.2	4.8	24	24	28
45	37	37	138	133	132	4.8	4.6	4.4	36	26	26
43	46	43	130	136	135	4.6	5.4	4.5	21	20	20
45	45	43	145	133	127	5.0	5.4	5.0	14	34.5	57
42	41	40	142	128	140	4.5	4.8	4.4	19	26	43
29.5	29	30	130	140	144	5.5	5.0	5.0	25	25	25
40.62 ± 5.38	39.25 ± 7.22	37.5 ± 6.61	138.37 ± 5.75	137.12 ± 7.64	138 ± 6.5	4.76 ± 0.37	5.033 ± 0.43	4.78 ± 0.99	24.87 ± 6.72	26.93 ± 4.93	29.75 ± 13.75

the samples taken during the first day
the calves were healthy (F), to the
the period of diarrhoea (M.D.) and to
after diarrhoea had stopped (T)

Fig. 18.


Relationship between Faecal Output and Serum Immune Globulin Concentrations
Grams of Faeces/Day
10^4
10^3
10^2
b = -0·1161
a = 2·5452
r = 0·588
p =< 0·001
n = 28
Δ – died
● – survived – diarrhoeic
X – survived – non diarrhoeic
1
5
10
15
20
25
$ZnSO_4$ Units

concentrations of the calves studied, the mean daily amount of faeces passed, and the fate of the calves. The mean serum immune globulin concentration recorded for the dying diarrhoeic calves was 6.57 ± 1.76 (Z.S.T. units) and for the diarrhoeic recovered calves 10.28 ± 30 (Z.S.T. units). A significant difference ($P > 0.01$) was found between these values. In order to compare the Z.S.T. values of the dying diarrhoeic and recovered diarrhoeic calves with those of the normal calves these are also included in the table. Here again a significant difference was found between the values of the normal calves (17.60 ± 7.95) and those of the diarrhoeic calves ($P > 0.001$).

It must be emphasised that the Z.S.T. values recorded for the diarrhoeic calves were not specifically selected as was the case for most of the normal calves and as was the case in previous experiments reported in this thesis.

Correlation between the serum immune globulin concentration and the faecal excretion in newborn calves

Calf No.	Serum immune globulin Z.S.T. Units	Mean daily faecal output g.	Fate of Calf
A	25	49.9	L
C	21	116	L
D	20	77	L
538	23.25	76	L
733	21	56	L
741	9.5	87	L
27	3.5	211	L
Mean	17.60		
S.D.	± 7.95		
35	4	2361	D
26	8.75	1425	D
019	6	2001.5	D
207	7	4113.3	D
21	7	1869.2	D
214	8	2781.7	D
A1	6	3297.6	D
061	7	1822.5	D
022	8.25	1589.0	D
4	6	2578.0	D
64	3	2351.0	D
22	9	3888.0	D
63	5.5	1764.0	D
Mean	6.57		
S.D.	± 1.76		
40	7.5	686.75	L
944	7.0	607.6	L
619	13.5	577.55	L
101	8.0	882.27	L
018	9.0	399.37	L
470	10.0	1030.00	L
4	12.0	424.16	L
686	15.25	371.0	L
Mean	10.28		L = Lived
S.D.	± 3.0		D = Died

DISCUSSION

The results have clearly indicated that fluid losses in the faeces resulted in a loss of body water. However the elimination of a very considerable amount of water through the faeces, was always accompanied by an important reduction in the amount of water lost through urine. This situation is stressed by the fact, that although the water lost through the faeces in dying diarrhoeic calves was increased by a factor of 29.61, the total amount of water excreted was only increased by a factor of 1.29.

The positive correlation found in the normal calves, between water ingested and urine production, disappeared in the diarrhoeic calves. Thiw was to be expected since, because of the vast losses of fluid taking place through the intestine, the kidneys would dispose of the daily metabolites in a highly concentrated urine. Such correlation then will no longer depend on the intake, but on the severity of the faecal losses.

The decreased output of urine was parallel to an increased urine osmolarity, which rendered the urine no longer isotonic or hypotonic as was the case with the urine of normal calves. The mean urine output measured (650 $\pm$ 699 ml.) was significantly smaller than that reported by Fayet (1968). It was apparent, however, that the newborn calf was capable of concentrating its urine, the mean 693.3 milliosmols per litre (range - 1000 to 418 m.osm/L) being in agreement with the findings of Dalton (1967). The amount of sodium excreted through the urine was significantly lower than that found in the normal calves,

so was the excretion of potassium; however, the decrease in the excretion of sodium was substantially higher than that of potassum; sodium excretion through urine decreased by a factor of 7.1 while potassium only showed a 2.1 decrease.

Although it seems logical to think that because of this less efficient renal conservation of potassium the overall deficit of this ion would be greater than sodium, this was not so since the excretion of sodium through the faeces exceeded that of potassium to a greater extent than potassium exceeded sodium in urine. In spite of the increased retention of these ions by the kidney, the calves fell promptly into a negative balance of sodium and water. However, the capacity of the kidney to ameliorate the loss became evident as indicated by the fact that the mean sum of sodium and potassium excreted in the faeces of diarrhoeic calves, was increased by a factor of 24.1 while the total loss of these substances was only 1.45 times the normal losses.

This marked increase in the amount of sodium and potassium excreted through the faeces by the diarrhoeic calves in the present study, is approximately double the amount reported by Blaxter and Wood, 1953. The loss of water and electrolytes becomes even more impressive when taking into account the marked decline in the mean intake of these substances, in fact the diarrhoeic calves only ingested 63% of the sodium, potassium and water ingested by the normal calves. The decreased appetite seen in these diarrhoeic calves has also been reported by Fayet (1968).

The mean daily loss of bodyweight found in this study (1.4218) was higher than that reported by Fayet, 1968, Dalton, Fisher, McIntyre, 1965, Blaxter and Wood, 1951. However a highly significant positive correlation was found between the balance of water and the bodyweight loss. The smaller loss in bodyweight reported by the previous mentioned authors could have been due to the fact that the calves in their studies did not always die and presumably the condition was less severe.

Although all the calves showed abnormally high output of water and electrolytes as soon as diarrhoea became evident, most of them did not fall into a negative balance until their milk intake had either decreased considerably or voluntarily stopped. The balance diagrams illustrating these findings are given in the Appendix. Withdrawal of the milk intake in diarrhoeic calves has been suggested as a measure that needs to be taken in order to stop the diarrhoea, Watt, 1965, Radostis, 1965, Blaxter and Wood, 1953. Similar advice is also found in the human literature regarding infantile diarrhoea (Darrow, Pratt, Flett, Gamble, and Wiese, 1949 and Brusilow and Cooke, 1959). However it is apparent from the results obtained in the present balance studies, that if milk intake is to be withdrawn a volume of fluid and electrolytes equivalent to the volume of milk intake, plus, the necessary volume to meet the abnormal loss of water and electrolytes must be made available to the calf immediately, if a fatal negative balance of water and electrolyte is to be prevented. So far the possible beneficial effects of withholding the milk intake during diarrhoea in the newborn calf have not been substantiated. In the present study although the calves were

not starved, the continuation or severity of diarrhoea could not be related to the amount of milk ingested; as illustrated in fig. 10 seven calves showed an increase in faecal output, as the quantity of milk ingested decreased. In four of the animals studied the decrease in intake corresponded with a decrease in faecal excretion and in two calves no relationship seemed to exist.

The consistently more severe negative balance of sodium found in these calves, compared with the balance of potassium would appear to be the result of the more dramatic loss of sodium through the diarrhoeic stools, which was clearly illustrated by the values plotted in fig. 14. It is interesting to note that in a number of diarrhoeic conditions encountered in the human subject, there is a progressive rise in sodium and a decrease in potassium concentrations in stool water as the severity of diarrhoea increases. Watten, Morgan, Songkhla, Vanikati and Phillips (1959) found this to be the case in cholera stools; Shnitka, Friedman, Kidd and McKenzie (1961) reported similar findings in Villous adenoma and Lubran and MacAllen (1951) in ulcerative colitis.

Fig. 15 illustrated that this situation also occurs in neonatal calf diarrhoea. In this respect it is also interesting to note that in the previously mentioned diarrhoeic conditions the amount of sodium lost per volume of water is variable and can reach proportions close to the concentrations of plasma, as is the case in cholera (Watten et al, 1959), or may be considerably less as is the case in osmotic diarrhoea, Fordtran, (1967.) However the loss of potassium to volume of water, is practically the same for most of the conditions

mentioned previously. The results obtained for the loss of sodium and potassium per volume of water in the present study closely resembled the losses obtained in osmotic diarrhoea in the human subject.

Osmotic diarrhoea in the human may be explained by the retardation of water and electrolyte absorption due to the presence of non-absorbable solutes in the lumen of the intestine causing a net water flux from the circulation into the lumen. In this case since the ileum and colon can absorb sodium against large concentration gradients, Curran et al, 1960, Fordtran, 1966, Levitan et al, 1962, the movement of water would be retarded by the non-absorbable solutes and the concentration of sodium in the stool water would fall. Whether this situation occurs in neonatal calf diarrhoea is difficult to say. However Blaxter and Wood in 1953 in fact suggested that diarrhoea was the consequence of a disfunction of the small intestine leading to undigested feed residues reaching the lower part of the intestinal tract. Here a massive proliferation of bacteria spreading to higher parts of the gut would result in the production of osmotically active substances, thereby increasing the osmotic activity in the lumen of the gut. Another form of osmotic diarrhoea in humans is found in the malabsorption syndrome due to disaccharidase deficiency, and glucose galactose malabsorption. In such cases due to the malabsorption of glucose, the major driving force for sodium and water absorption is grossly impaired. Thus the accumulation of these substances occurs in the lumen of the gut with the respective increase in osmotic attraction. The report of Bywater and Penhale (1969) would be relevant to this discussion in that they found that the lactase activity of diarrhoeic calves was

significantly reduced. Thus if the lactase in the gut is inadequate to cope with the lactase in the diet, not only would this provide a source of increased osmotic activity within the lumen of the gut, but would also, if the mechanisms of water and sodium transport in the small intestine of the calves are similar to those found in the other animals species, inhibit the transport of these substances into the circulation. Unfortunately it is not possible to ascertain if the lactase deficiency found by Bywater (1969) is a primary abnormality in calf diarrhoea, or whether it results from the effects of diarrhoea.

Another interesting point which may be of some relevance to the present findings, is that brought forward by Smith, H.W. and Halls (1967a) (1967b). These authors concluded that certain E.coli serotypes were capable of producing severe diarrhoea in newborn calves, however, for this to take place, it was necessary that the E.coli implanted themselves in the small intestine, proliferated actively, and produced their toxim. It was also reported by Smith, H.W. and Halls (1967a) that the pathological effects of E.coli enterotoxin were more severe in the small intestine, in fact the colon appeared little affected by the enterotoxin. It would be interesting to speculate on whether such was the case in the present study. If so, this could explain the type of diarrhoea seen under this condition, in that it would appear that absorption of electrolytes was taking place through the colon, as indicated by the ratio of water to electrolytes excreted in the diarrhoeic faeces. However this can only be hypothesised since the composition of the stools of the diarrhoeic calves reported by Smith, H.W. and Halls (1967a) (1967b) was not looked into.

Interpreting the systemic effects of the diarrhoea observed in the present study, it would appear that the greater loss of water than electrolytes through the faeces in these calves would consequently increase the effective osmotic pressure of the extracellular space. This, in turn, would cause a shift of fluid from the intracellular space in an attempt to maintain osmotic equilibrium and an efficient plasma volume. In this process, potassium is transferred to the extracellular fluid and excreted in the urine. At the same time the kidney would, under the influence of the antidiuretic hormone, retain water by producing a more concentrated urine. Because of this attempt of the organism to prolong the survival time in dehydration, an apparently normal osmolarity and serum sodium concentration may be found under the circumstances, even though a severe water and sodium depletion exists. That the serum sodium concentration does not directly reflect the loss of sodium from the extracellular water is supported by the lack of correlation found between the concentration of sodium in plasma and the quantities of sodium excreted reported previously in the results. The same proportional loss of sodium to water has been reported in infants (Weil and Wallace, 1956). However, in such cases hypernatraemia, and increased plasma osmolarity were invariably found. An explanation for the discrepancy between their findings and those reported in the present study for the newborn calf could be due to the fact that the newborn infant is not capable of concentrating its urine to the same extent as the newborn calf.

Although no measurements of bicarbonate were made in the faeces of the diarrhoeic calves, the impressive decline observed in the plasma

bicarbonate concentration is indicative that large amounts of such ion were lost in the faeces. This was presumably along with sodium. The positive correlation found between the overall deficit of sodium and the decline in the bicarbonate concentration would support this view. As a result of this loss of base, a fall in the blood pH occurred, and the values of the terminal samples were always significantly lower than the first sample. The value obtained for the last sample (6.991 $\pm$ .15) is similar to that reported by Fisher (1965) and Fayet (1968). The abnormally high potassium plasma concentration found in these calves has been previously reported by several workers (Roy et al, 1959; Fisher, 1965; Fayet, 1968). At the same time a decline in the cell potassium concentration has been observed, and this decline, which also occurs in the myocardium, has been suggested by Fisher and McEwan (1967) as the cause of the arrhythmias and probably heart failure associated with calf diarrhoea.

No doubt, the high serum potassium values obtained in this study resulted mainly from the release of cellular potassium and possibly some from the catabolism of cells in the diarrhoeic calves. The observations of Holliday and Egan (1959), Darrow et al, 1949, and Hoffman (1958), suggesting that during diarrhoea although the serum potassium concentrations may be higher than normal, there exists an overall potassium deficiency, could also be applicable to the present study. Although a negative balance of potassium was not present in all the calves studied, it is obvious, as judged from the results obtained in the normal calves regarding the mean amounts of potassium retained, that a deficit of such ion prevailed.

Uraemia was a consistent finding in the dying diarrhoeic calves, this presumably due to the fact that although the diarrhoeic calves managed to concentrate their urine, the total amount of solutes available for excretion was higher than the amount the kidney could cope with.

The packed cell volume also showed a marked increase indicating a haemoconcentration. The lack of correlation found between the total increase in the packed cell volume percent, and the deficit of water, would again be indicative of a transfer of water from the cells into the extracellular compartment.

Another important fact is also stressed by these findings; that is, that an isolated estimation of the packed cell volume in the diarrhoeic calf will be of no aid in assessing the severity of the condition. As seen by the figures reported in the Appendix, some of the values recorded at the terminal sample for some calves are similar and, on occasion, lower than the first sample recorded for other calves.

Death will occur in primary dehydration, that is when the loss is mainly confined to water, after a loss of 15% of the bodyweight; that is, about 22% of the total body water. In such cases, there is mainly a cellular dehydration (Bland, 1963).

Yannet and Darrow (1954) reported that in dogs, losses of 80 ml. of water per kg. bodyweight resulted in severe symptoms of dehydration. In infantile diarrhoea, they found that the symptoms of severe dehydration were observed when the infants lost 125 ml. of water and 9 m.Eq. sodium per kg. bodyweight. Brusilow and Cooke (1959) regarded

a loss of 160 ml. per kg. bodyweight as being present in severe dehydration, and any loss in excess of this, if acute, would lead into circulatory collapse and death. They were also of the opinion that clinical signs of dehydration were not present when losses were in the region of less than 60 ml. per kg. Wallace (1958) reported that infants could lose 5% of their bodyweight as water with little evidence of functional impairment. However, losses of 10% would result in signs of dehydration, and 15% of their bodyweight lost as water would certainly result in shock. They recognised the losses of water in severe diarrhoea as being 70 ml. per kg. per day. In the present study it became apparent that the amount of water and sodium lost by these calves varied from individual to individual. However, all the animals showed a value of over 5% loss in bodyweight as water, with a mean of 11.33%. This is equivalent to about 113.33 ml. per kg. bodyweight. Thus, this figure is within those values quoted by workers in the human field. The losses of sodium, however, were not as large and a mean value of 4.20 m.Eq. per kg. was recorded in these dying diarrhoeic calves.

GENERAL SUMMARY AND CONCLUSION

The immunological status of newborn heifer calves kept on farms in the West of Scotland proved to be similar to that found in newborn bull calves bought from markets by Gay et al (1965) and Fisher et al (1968), in that a marked seasonal variation in the serum immune globulin concentrations existed, with low average values being obtained during the winter months and high average values in the summer. Such colostrum derived passive immunity influenced the fate of the newborn calves up to one month of age. Mortality from septicaemia and diarrhoea in these newborn calves was inversely related to their serum immune globulin concentrations, and such concentrations appeared to be directly influenced by different methods of management.

Regarding the factors which may influence the serum immune globulin concentrations of newborn calves, such as time of first feeding colostrum, and leaving the calf with its dam for at least 12 hours, the results obtained under experimental conditions by Selman (1969) were confirmed in the field survey reported in this thesis. It was demonstrated also that the incidence of death from neonatal septicaemia and diarrhoea could effectively be reduced by adopting a method of management whereby the newborn calf had the best possible chance of obtaining colostrum as soon as possible after birth, and certainly within six hours of birth while remaining with its dam.

The use of antibiotics has been widely advised for the treatment of neonatal calf diarrhoea, mostly on the basis of experimental work which has not considered the passive immunological status of the newborn calf or discriminated between the septicaemic form of colibacillosis and the enteric form of colibacillosis. Zinc sulphate turbidity tests to ascertain the serum immune globulin concentration of the newborn calves were used throughout this work to exclude successfully those calves liable to die from septicaemia. Thus only calves which were liable to suffer from diarrhoea were included in these studies, and at the same time it provided groups of calves of similar serum immune globulin concentrations, thereby minimising the influence of this variable. Under these circumstances it became apparent that the serum immune globulin concentrations of the groups of calves could strongly influence the results of experiments designed to test the efficacy of a given therapy. The poor results of therapy comprising furazolidone and chloramphenicol against neonatal calf diarrhoea in hypogammaglobulinaemic calves known to have been sensitive in vitro to such drugs, challenges the rationale for their use under such circumstances. Furthermore that a higher serum immune globulin concentration is more valuable in preventing mortality from diarrhoea than either of the drugs mentioned above was clearly indicated in experiment number 3 in part 2 of this thesis. In this case no difference in mortality could be found between the treated groups with similar low serum

immune globulin concentrations (60%). However, the third group included in the experiment with a significantly higher serum immune globulin concentration showed no mortality.

Throughout the experimental work reported in part 2 of this thesis those calves which survived were repeatedly shown to be the ones with the highest serum immune globulin concentrations. That the degree of passive immunity in the newborn calf bears a strong negative correlation with the severity of the diarrhoea was undoubtedly demonstrated in part 3 of this thesis. Since no further function apart from the immunological one can be attributed to the immune globulins, such correlation would suggest that in the diarrhoeic syndrome observed throughout this work bacteria or other biological micro-organisms were implicated, and that in some way the quantities of immune globulins, as estimated by the zinc sulphate turbidity test, present in the calves which survived, were sufficient to neutralise either the micro-organisms involved or their products responsible for the continuation of the diarrhoeic syndrome. The main systemic effects of the diarrhoeic syndrome were, on the evidence of the measured losses, those of a severe apparently hypertonic dehydration. However the severity of the diarrhoea varied from calf to calf, and so did the total deficits of water and sodium recorded in these calves, and although a marked retention of

sodium and water was achieved by the kidneys of these calves a negative balance of such substances prevailed amongst all the animals at the time of death. A mean loss of 113 ml. of water per kilogram per day and 4.2 m.Eq. of sodium per kilogram per day was seen in these calves. Nevertheless it must be emphasised that such values are to be taken only as a rough estimate of the loss that the diarrhoeic calf may suffer, since such a wide variation was found. Such variation in the loss of these substances could explain in part the poor results obtained during the electrolyte therapy performed and reported in the experiment no. 5 in part 2 of this thesis.

Although valuable information may be obtained from the biochemical analysis of the blood of diarrhoeic calves, an isolated sample is of no aid in the assessment of the severity of the condition. Nonetheless the blood pH and bicarbonate concentration appeared to be the most reliable parameters in determining the severity of the condition. In normal calves little day to day variation was found in these parameters and a change towards acidity was always observed when diarrhoea was present.

The findings reported in this thesis indicate that if a lower mortality rate from E.coli septicaemia and diarrhoea in the neonatal calf is to be expected, efforts should be made to

bring about an increase in the serum immune globulin concentrations of the newborn calf, and that although other factors, such as prevention of build-up of infection, hygiene, and individual pens, may play a part in the outcome of the condition, their role is only secondary to the efficient acquisition of passive immunity.

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APPENDIX 1

THE MONTHLY SERUM IMMUNE GLOBULIN CONCENTRATIONS OF THE HEIFER CALVES SAMPLED DURING THE SURVEY.

THE SERUM IMMUNE GLOBULIN CONCENTRATIONS OF NEONATAL HEIFER CALVES - FARM SURVEY

February, 1968

Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)
1	18	12	10
2	1	13	5
3	3	14	10
4	2	15	5
5	7	16	19
6	10	17	11
7	5	18	7
8	8	19	12
9	13	20	19
10	5	21	3
11	10	22	28
		23	14

Mean = 9.8

S.D. = ±6.41

THE SERUM IMMUNE GLOBULIN CONCENTRATIONS OF NEONATAL HEIFER CALVES - FARM SURVEY

March, 1968

Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)
1	6	26	23	51	2
2	4	27	19	52	13
3	9	28	9	53	9
4	4	29	3	54	15
5	7	30	15	55	15
6	3	31	10	56	6
7	11	32	4	57	2
8	16	33	2	58	9
9	28	34	2	59	17
10	6	35	21	60	10
11	9	36	7	61	8
12	19	37	2	62	3
13	10	38	2	63	7
14	3	39	0	64	13
15	6	40	2	65	10
16	24	41	13	66	11
17	14	42	5	67	0
18	18	43	6	68	6
19	4	44	14	69	14
20	4	45	14	70	5
21	6	46	9	71	10
22	14	47	10	72	2
23	14	48	26	73	3
24	16	49	5	74	12
25	1	50	1	75	20

THE SERUM IMMUNE GLOBULIN CONCENTRATIONS OF NEONATAL HEIFER CALVES - FARM SURVEY

March, 1968 (cont.)

Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)
76	12	89	0	102	7
77	6	90	11	103	11
78	2	91	6	104	4
79	22	92	2	105	5
80	3	93	11	106	2
81	7	94	13	107	14
82	22	95	2	108	4
83	5	96	7	109	5
84	23	97	13	110	9
85	4	98	15	111	14
86	6	99	14	112	9
87	4	100	3	113	8
88	5	101	6	114	23

Mean = 9.1

S.D. = ±6.4

THE SERUM IMMUNE GLOBULIN CONCENTRATIONS OF NEONATAL HEIFER CALVES - FARM SURVEY

April, 1968

Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)
1	1	28	10	55	14
2	5	29	3	56	17
3	28	30	16	57	14
4	18	31	10	58	12
5	6	32	19	59	13
6	4	33	2	60	10
7	9	34	4	61	14
8	6	35	5	62	12
9	9	36	5	63	3
10	6	37	9	64	14
11	6	38	9	65	26
12	9	39	10	66	4
13	3	40	4	67	3
14	16	41	22	68	3
15	4	42	6	69	13
16	3	43	6	70	8
17	5	44	20	71	5
18	6	45	19	72	11
19	7	46	12	73	21
20	4	47	31	74	3
21	16	48	30	75	17
22	10	49	20	76	5
23	5	50	30	77	8
24	9	51	12	78	5
25	5	52	7	79	13
26	20	53	5	80	8
27	8	54	17	81	16
				82	5

Mean = 10.60

S.D. = ±7.06

THE SERUM IMMUNE GLOBULIN CONCENTRATIONS OF NEONATAL HEIFER CALVES - FARM SURVEY

May, 1968

Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)
1	31	30	20	59	10
2	10	31	13	60	10
3	6	32	13	61	23
4	36	33	37	62	14
5	24	34	3	63	29
6	27	35	41	64	21
7	18	36	6	65	8
8	20	37	26	66	12
9	2	38	19	67	29
10	30	39	12	68	5
11	35	40	14	69	40
12	21	41	0	70	26
13	4	42	21	71	7
14	10	43	2	72	30
15	36	44	8	73	6
16	26	45	2	74	3
17	3	46	9	75	13
18	18	47	20	76	7
19	20	48	37	77	28
20	37	49	11	78	40
21	1	50	8	79	21
22	3	51	7	80	20
23	37	52	15	81	26
24	1	53	11	82	1
25	6	54	15	83	32
26	3	55	37	84	39
27	10	56	0	85	22
28	29	57	18	86	3
29	18	58	36	87	6

Mean = 17.40

S.D. = ±11.94

THE SERUM IMMUNE GLOBULIN CONCENTRATIONS OF NEONATAL HEIFER CALVES - FARM SURVEY

Jun June, 1968

Calf No.	Serum Immune Globulin (Z.S.T. Units)	Calf No.	Serum Immune Globulin (Z.S.T. Units)
1	11	12	28
2	23	13	42
3	26	14	32
4	13	15	34
5	7	16	36
6	7	17	23
7	2	18	23
8	14	19	38
9	32	20	24
10	30	21	20
11	27		

Mean = 23.40

S.D. = ±10.78

APPENDIX NO. 2

DAILY CLINICAL AND BIOCHEMICAL DATA REGARDING THE CALVES USED IN THE FLUID AND ELECTROLYTE TREATMENT EXPERIMENT - PART II, SECTION II, EXPERIMENT No. 5.

Calf No. 71 Z.S.T. Units 11.5

Day	1	2	3	4	5	6	7
Packed Cell Volume (%)	31	32	32	30	32	32	39
Plasma Sodium m.Eq/L	136	144	150	142	130	112	128
Plasma Potassium m.Eq/L	4.8	5.6	5.4	5.2	4.4	5.4	6.2
Plasma Chloride m.Eq/L	111	110	98	96	115	100	94
Urea mg/100	11	14	16	24	12	40	94
Temperature F^{O}	102.5	101.8	102.7	102.1	103.1	101.7	100.5
Pulse Rate /min.	100	100	100	100	100	116	110
Respiratory Rate/ min.	20	20	24	24	20	30	30
Demeanour	B	B	B	B⁻	B⁻	B⁻	D
Faeces	-	-	-	-	+++	+++	+++
Treatment							
Bodyweight lbs.	64						60

CONTROL DIED

Calf No. 73 Z.S.T. Units 6.5

Day	1	2	3	4	5	6	7	8
Packed Cell Volume %	49	45	47	41	49	49	53	55
Plasma Sodium m.Eq/L	136	154	143	145	142	130	136	128
Plasma Potassium m.Eq/L	4.8	5.4	6.4	6.0	5.6	5.8	6.0	6.4
Plasma Chloride m.Eq/L	109	106	110	120	120	109	110	98
Urea mg/100	27	30	30	32	38	57	72	132
Temperature F^{O}	102.5	102	102	101.5	102.7	103.5	102	100
Pulse Rate/min.	112	120	112	120	120	112	120	110
Respiratory Rate/ min.	20	24	24	30	20	16	16	16
Demeanour	B	B	B-	B	B-	B-	D	R
Faeces					++	+++	+++	+++
Treatment								
Bodyweight lbs.	59							56

CONTROL DIED

Calf No. 44 Z.S.T. Units 6

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	28								32
Plasma Sodium m.Eq/L	138	144	148	138	138	136	136	138	130
Plasma Potassium m.Eq/L	5.2	5.6	5.2	5.0	5.2	5.4	6.2	6.8	7.2
Plasma Chloride m.Eq/L	110	110	106	112	110	120	116	108	98
Urea mg/100	28	30	26	28	36	50	55	70	90
Temperature F°	102.5	104	103	102.5	102.5	102.3	102	101.5	100.7
Pulse Rate/min.	110	110	110	110	112	110	112	112	110
Respiratory Rate/ min.	16	20	20	26	20	18	20	28	30
Demeanour	B	B	B	B-	B-	B-	B-	B-	R
Faeces	-	-	-	+	+++	+++	+++	+++	+++
Treatment									
Bodyweight lbs.	85			86			83		80

CONTROL DIED

Calf No. 46 Z.S.T. Units 5.5

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	42	45	51						
Plasma Sodium m.Eq/L	142	140	153						
Plasma Potassium m.Eq/L	5.6	6.0	6.3						
Plasma Chloride m.Eq/L	108	109	110						
Urea mg/100	20	40	63						
Temperature F°	102.5	102.5	100						
Pulse Rate/min.									
Respiratory Rate/ min.									
Demeanour	B	D+	R						
Faeces	-	+++	++						
Treatment									
Bodyweight lbs	74		70						

CONTROL DIED

Calf No. 70 Z.S.T. Units 6.5

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	40	42	43						
Plasma Sodium m.Eq/L	139	142	136						
Plasma Potassium m.Eq/L	5.0	5.2	6.5						
Plasma Chloride m.Eq/L	104	109	100						
Urea mg/100	20	30	50						
Temperature F^{o}	101.5	100	98.5						
Pulse Rate/min.	100	110	90						
Respiratory Rate/ min.	16	20	30						
Demeanour	B	D	R						
Faeces	-	+++	+++						
Treatment									
Bodyweight lbs.	61		58						

CONTROL DIED

Calf No. 80 Z.S.T. Units 7.5

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	39	37	39	37	41	41	45	45	
Plasma Sodium m.Eq/L	136	142	147	136	130	127	133	142	
Plasma Potassium m.Eq/L	5.2	5.0	5.2	4.8	4.2	5.2	6.0	9.4	
Plasma Chloride m.Eq/L	109	110	114	106	103	106	109	100	
Urea mg/100	19	14	22	20	32	50	200	200	
Temperature F^{o}	102.5	102.1	101.5	103.2	105.1	102.2	103	95	
Pulse Rate /min.									
Respiratory Rate/ min.	24	24	26	24	20	30	24	30	
Demeanour	B	B	B	B	B-	D	D+	R	
Faeces	-	-	-	-	+++	+++	+++	+++	
Treatment									
Bodyweight lbs.	61							56	

CONTROL DIED

Calf No. 29 Z.S.T. Units 7.5

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	40	41	46						
Plasma Sodium m.Eq/L	151	150	157						
Plasma Potassium m.Eq/L	4.2	5.0	6.8						
Plasma Chloride m.Eq/L	110	112	108						
Urea mg/100	26	30	35						
Temperature F^{O}	103	102.1	100						
Pulse Rate /min.	120	110	110						
Respiratory Rate/ min.	20	12	16						
Demeanour	B	D	R						
Faeces	+	+++	+++						
Treatment									
Bodyweight lbs.	63		58						

CONTROL SURVIVED

Calf No. 72 Z.S.T. Units 21

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	39	42	41	40	43	41	42	42	39
Plasma Sodium m.Eq/L	139	151	167	133	130	128	130	139	136
Plasma Potassium m.Eq/L	4.4	5.4	5.8	5.2	4.4	4.8	4.6	4.2	4.8
Plasma Chloride m.Eq/L	110	108	112	110	109	116	114	113	112
Urea mg/100	8	22	36	46	38	28	30	34	22
Temperature F^{O}	103	103	103	102	102	102	102	102	101.5
Pulse Rate/min.	100	100	100	100	110	110	110	110	100
Respiratory Rate/ min.	16	16	16	20	20	16	24	16	20
Demeanour	B	B	B	B-	B-	B-	B-	B-	B-
Faeces	-	-	-	+++	+	+++	+++	+	-
Treatment									
Bodyweight lbs.	79								80

CONTROL SURVIVED

Calf No. 47 Z.S.T. Units 17.5

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	32	33	30	34	32	33	34	30	30
Plasma Sodium m.Eq/L	133	140	154	139	130	128	128	130	130
Plasma Potassium m.Eq/L	4.4	5.4	5.2	4.8	5.0	5.0	5.2	4.8	4.
Plasma Chloride m.Eq/L	108	106	109	110	109	112	108	108	106
Urea mg/100	22	25	29	30	37	28	26	27	23
Temperature F^{O}	102	102	102.5	102.2	102.5	103	102	102.1	102
Pulse Rate/min.	100	110	112	110	110	112	110	112	110
Respiratory Rate/ min.	20	20	16	16	20	22	20	20	16
Demeanour	B	B	B	B-	B-	B-	B	B	B
Faeces	-	-	+++	+++	+++	++	++	-	+
Treatment									
Bodyweight lbs.	70		73		70				67

TREATED DIED

Calf No. 83 Z.S.T. Units 12

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	34	34	34	35	36	37	31	33	36
Plasma Sodium m.Eq/L	139	144	143	133	136	134	133	142	130
Plasma Potassium m.Eq/L	5.2	5.6	5.4	5.2	5.0	5.4	4.2	5.6	6.
Plasma Chloride m.Eq/L	106	108	110	112	110	109	109	112	108
Urea mg/100	20	16	28	34	36	32	40	56	82
Temperature F^{O}	102	102	102.1	102	102.2	102	102	102	96.
Pulse Rate/min.	90	100	90	100	100	100	100	110	90
Respiratory Rate/ min.	20	24	24	26	26	20	28	30	34
Demeanour	B	B	B-	B	B	B	B-	D	R
Faeces		-	+	-	-	++	+++	+++	++
Treatment						1	2.5	2.5	1
Bodyweight lbs	74								70

TREATED DIED

Calf No. 67 Z.S.T. Units 10

Day	1	2	3	4	5	6	7
Packed Cell Volume %	38	36	35	40	43	42	
Plasma Sodium m.Eq/L	142	144	143	140	136	138	
Plasma Potassium m.Eq/L	5.6	5.0	5.3	5.4	6.0	8.8	
Plasma Chloride m.Eq/L	102	104	110	110	106	96	
Urea mg/100	20	26	28	25	60	85	
Temperature F^{O}	102	101.7	102.1	103.2	102.2	96	
Pulse Rate/min.	100	100	90	100	120	60	
Respiratory Rate/ min.	20	20	24	24	20	40	
Demeanour	B	B	B	D	R	R	
Faeces	-	-	-	+	+++	+++	
Treatment Darrow's Solution					1.5	1.5	
Bodyweight lbs.	73		75		74		68

TREATED DIED

Calf No. 74 Z.S.T. Units 7.5

Day	1	2	3	4	5	6	7	8
Packed Cell Volume %	45	45	47	46	49	50	53	52
Plasma Sodium m.Eq/L	136	137	138	140	142	146	136	130
Plasma Potassium m.Eq/L	5.0	5.1	4.8	4.6	5.1	5.6	5.4	6.5
Plasma Chloride m.Eq/L	104	103	107	110	108	101	105	100
Urea mg/100	24	20	30	30	45	78	95	106
Temperature F^{O}	102	102	103	103	104.2	104	103.1	97
Pulse Rate/min.	116	96	88	100	120	112	100	100
Respiratory Rate/ min.	20	16	16	20	20	24	20	28
Demeanour	B	B	B	B-	D	B-	B	R
Faeces	-	++	++	++	+++	+++	++	++
Treatment Darrow's solution				.500 l.	2 l.	2.5 l.	2 l.	
Bodyweight lbs								

TREATED DIED

Calf No. 20 Z.S.T. Units 6.0

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	36		36.5		36.5	38		47.5	43
Plasma Sodium m.Eq/L	143		145		143	140		132	132
Plasma Potassium m.Eq/L	4.4		4.6		4.4	4.8		5.8	6.0
Plasma Chloride m.Eq/L	105		106		100	99		103	100
Urea mg/100	41		38		47	46		112	80
Temperature F°	103	102	102.5	102.4	102.4	102.4	102.2	101.1	101.5
Pulse Rate/min.	100	96	90	100	120	132	126	110	110
Respiratory Rate/ min.	20	20	24	24	26	28	30	36	38
Demeanour	B	B	B	B-	B-	D-	R	R	R
Faeces	-	-	-	+	+++	+	+	+++	+++
Treatment Darrow's solution					2 l.	2 l.	1 l.	4 l.	
Bodyweight lbs		72½			70		68		68

TREATED DIED

Calf No. 17 Z.S.T. Units 9.0

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %			33		34.5			32.5	33
Plasma Sodium m.Eq/L			138		132			136	140
Plasma Potassium m.Eq/L			4.0		3.6			4.4	5.6
Plasma Chloride m.Eq/L			106		95			101	108
Urea mg/100			40		42			84	98
Temperature F°			101.8	104	103.5	101.4	102.2	98	98
Pulse Rate/min.			100	100	96	96	100	102	100
Respiratory Rate/ min.			24	24	26	26	34	24	26
Demeanour			B	B-	B-	D	D	R	R
Faeces			-	-	+++	++	+	-	+++
Treatment Darrow's solution					2 l.	2 l.	3 l.		
Bodyweight lbs.			64		62			59	

TREATED DIED

Calf No. 24 Z.S.T. Units 8.0

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %		33	33.5	39	38.5			35.5	41
Plasma Sodium m.Eq/L		144		144	146			24	
Plasma Potassium m.Eq/L		4.6	4.6	4.8	5.1			6.5	
Plasma Chloride m.Eq/L		104	102	102	101			104	
Urea mg/100		30			40			76	
Temperature F°		102	103	103	102.5	102.4	102.2	102.2	102.5
Pulse Rate/min.		96	100	100	110	110	108	100	100
Respiratory Rate/ min.		26	26	26	28	24	24	28	34
Demeanour		B	B	B	B	B-	B-	D	Weak
Faeces		-	++	+++	+++	++	+++	+	+++
Treatment Darrow's solution				4 l.	2 l.	2 l.	2 l.		3½ l.
Bodyweight lbs.		71			69				67

TREATED DIED

Calf No. 20 Z.S.T. Units 7.5

Day	1	2	3	4	5	6	7
Packed Cell Volume %		44	48.5	42	48	45	
Plasma Sodium m.Eq/L		139	142	138	136	128	
Plasma Potassium m.Eq/L		5.0	5.0	4.8	5.1	6.3	
Plasma Chloride m.Eq/L		106	105		106	100	
Urea mg/100		32	42	41	67	70	
Temperature F°	102.4	102.6	102.5	101.5	101.2	98.0	
Pulse Rate/min.	100	110	110	100	120	108	
Respiratory Rate/ min.	24	24	30	42	30	40	
Demeanour	B	B	B-	B-	D	D	
Faeces	-	+	+++	++	+++	+++	
Treatment Darrow's solution			5 l.	2 l.	2 l.	1 l.	
Bodyweight lbs.		59			56	54	

TREATED SURVIVED

Calf No. 81 Z.S.T. Units 7.0

Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	37	38	39	36	38	37	31	32	38
Plasma Sodium m.Eq/L	142	148	147	133	127	127	136	142	139
Plasma Potassium m.Eq/L	4.4	5.4	5.0	4.4	3.8	5.4	4.8	4.0	4.6
Plasma Chloride m.Eq/L	109	114	116	107	106	107	116	121	111
Urea mg/100	23	28	34	44	40	36	48	30	22
Temperature F^{O}	103	102.1	104.2	105	103	102.8	102	102	103
Pulse Rate/mins.	86	86	90	100	100	110	110	110	100
Respiratory Rate/ mins.	28	28	20	20	16	20	20	16	20
Demeanour	B	B	B-	D	D	B	B	B	B
Faeces	-	-	+++	+++	+++	+++	+++	++	-
Treatment Darrow's solution			.500	1.000	2.0	2.5	2.0		
Bodyweight lbs	72		72						72

TREATED SURVIVED

Calf No. 79 Z.S.T. Units 20

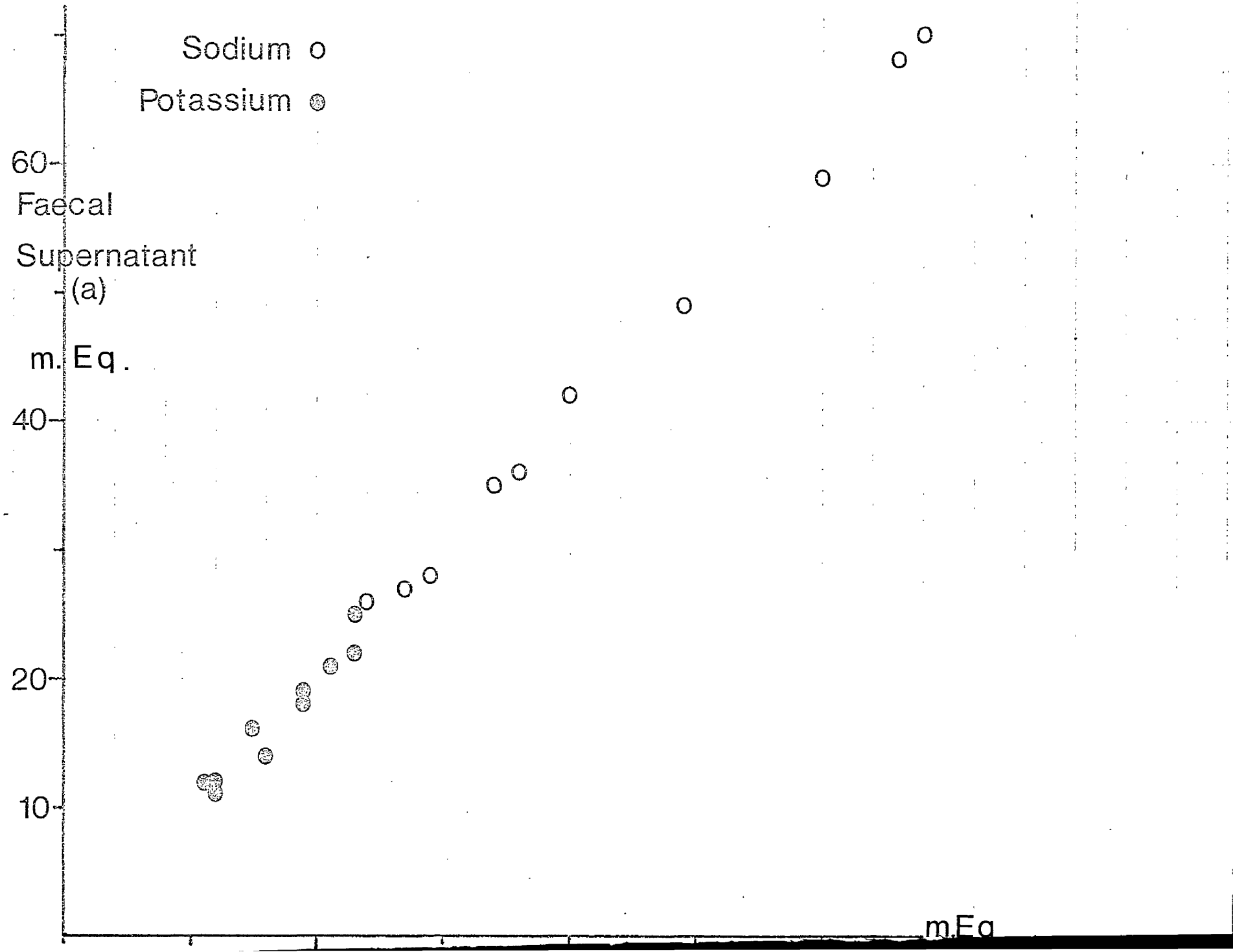
Day	1	2	3	4	5	6	7	8	9
Packed Cell Volume %	36	36	35	40	42	40	39	38	38
Plasma Sodium m.Eq/L	136	148	151	142	136	133	136	137	139
Plasma Potassium m.Eq/L	4.4	5.4	5.2	5.2	4.0	5.6	4.6	4.2	4.8
Plasma Chloride m.Eq/L	108	106	115	110	110	105	110	108	110
Urea mg/100	18	20	26	18	22	22	28	30	22
Temperature F^{O}	103	102	102.5	102.5	102	102	102	102	101.5
Pulse Rate/min.	96	100	92	100	120	110	110	110	100
Respiratory Rate/ min.	20	20	20	24	24	18	20	18	20
Demeanour	B	B	B	D	B-	B	B	B	B
Faeces		++	+++	+++	+++	+++	+++	+	-
Treatment			1.500	2.000	3	1.500	1.500		
Bodyweight lbs.	70								67

APPENDIX 3

The correlation of the faecal sodium and potassium concentration obtained by two different methods - (a) direct estimation of faecal supernatant fluid, (b) using the methods described by King and Woolton (1956).

Sample	Method (a)		Method (b)	
	Sodium m.Eq/L.	Potassium m.Eq/L.	Sodium m.Eq/L.	Potassium m.Eq/L.
1 - a	26	12	24	11
1 - b	27	11	27	12
2 - a	68	22	66	23
2 - b	70	21	68	21
3 - a	42	18	40	19
3 - b	60	19	59	19
3 - c	49	25	49	23
4 - a	35	14	34	16
4 - b	36	16	36	15
5 - a	28	12	29	12

The Correlation of Faecal Sodium and Potassium Obtained by Two Diffent Methods



APPENDIX NO. 4

THE DAILY VALUES RECORDED FOR THE PARAMETERS ANALYSED DURING THE BALANCE STUDIES PERFORMED ON, NORMAL, DYING DIARRHOEIC AND SURVIVING DIARRHOEIC NEWBORN CALVES.

NORMAL CALVES

CALF NO. A	Serum Immune Globulin 25 expressed as $ZnSO_4$ Units						
	DAY OF EXPERIMENT						
	1	2	3	4	5	6	7
Body Weight in Kilograms	28.4			30			32.8
INTAKE							
Milk Millitres per day	2839	2839	2839	3312	3312	3312	3312
Total amount of water ingested mls/day	2526	2526	2526	2947	2947	2947	2947
Sodium mEq/day	79.49	79.49	79.49	82.51	82.51	82.51	82.51
Potassium mEq/day	83.35	83.35	83.35	97.25	97.25	97.25	97.25
OUTPUT							
FAECES							
Total output gms/day	13	34.67	34.91	59.5	79.5	64.25	50
Percentage dry matter	34.49	57.4	58.33	27.34	30.53	40.2	45
Percentage water	65.51	42.6	41.67	72.66	69.47	59.8	55
Total amount of water excreted mls/day	8.51	14.76	14.54	43.23	55.22	38.42	27.5
Sodium mEq/day	1.14	2.84	2.14	2.82	2.03	1.61	1.41
Potassium mEq/day	.55	.92	.96	1.45	2.07	1.26	1.38
URINE							
Total output mls/day	1553	1270	1680	2050	2000	1750	2050
Sodium mEq/day	36.1	38.1	38.5	30.5	38	36	21
Potassium mEq/day	28.1	24.6	32.9	61.5	44	50	40
Osmolarity mOsm./l	240	238	230	-	312	280	-
PLASMA AND BLOOD PARAMETERS							
Sodium mEq/l	144	-	140	-	145	-	145
Potassium mEq/l	4	-	5	-	5	-	5.2
Osmolarity mOsm./l	292	-	290	-	305	-	300
Urea mg/100 ml.	24	-	17	-	20	-	22
Packed Cell Volume	40	-	37	-	39	-	37
Blood pH.	7.39	-	7.40	-	7.40	-	7.36
Bicarbonate mEq/l	26.5	-	27.0	-	27.0	-	26.0

CALF NO. C

Serum Immune Globulin 21 expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT						
	1	2	3	4	5	6	7
Body Weight in Kilograms	34.2	-	-	-	35	-	37
INTAKE							
Milk millitres per day	3312	3312	3785	3785	3785	3785	3785
Total amount of water ingested mls/day	2947	2947	3368	3368	3368	3368	3368
Sodium mEq/day	82.51	82.51	105.9	105.9	105.9	105.9	105.9
Potassium mEq/day	97.25	97.25	124.9	124.9	124.9	124.9	124.9
OUTPUT							
FAECES							
Total output gms/day	63	107	69	78	98	223	175
Percentage dry matter	37.16	35.52	23.45	22.51	22.93	24.51	27.57
Percentage water	62.84	64.48	76.55	77.49	77.47	75.45	72.43
Total amount of water excreted mls/day	39.58	68.99	52.81	60.44	65.52	168.25	126.75
Sodium mEq/day	3.	3.5	1.8	2.	1.6	3.8	2.9
Potassium mEq/day	1.	1.6	.6	1.	.8	1.7	1.
URINE							
Total output mls/day	1500	2450	2700	3050	2400	3970	3870
Sodium mEq/day	12	39.4	39.7	49.4	50.2	69.9	79.4
Potassium mEq/day	64.5	93.1	91.8	97.6	91.8	123.8	92.9
Osmolarity mOsm./l	200	-	-	160	-	150	150
PLASMA AND BLOOD PARAMETERS							
Sodium mEq/l	139	-	-	149	-	-	144
Potassium mEq/l	5.	-	-	4.8	-	-	5.
Osmolarity mOsm./l	280	-	-	312	-	-	290
Urea mg/100 ml.	18	-	-	30	-	-	26
Packed Cell Volume	38.5	-	-	40.5	-	-	38.5
Blood pH.	7.33	-	-	7.34	-	-	7.36
Bicarbonate mEq/l	22.0	-	-	26.0	-	-	26.0

CALF NO. D	Serum Immune Globulin 20 expressed as $ZnSO_4$ Units					
	DAY OF EXPERIMENT					
	1	2	3	4	5	6
Body Weight in Kilograms	31	-	33	-	34	-
INTAKE						
Milk Millitres per day	2839	3312	3312	3312	3312	3312
Total amount of water ingested mls/day	2526	2947	2947	2947	2947	2947
Sodium mEq/day	70.72	82.51	82.51	82.51	82.51	82.51
Potassium mEq/day	83.35	97.25	97.25	97.25	97.25	97.25
OUTPUT						
FAECES						
Total output gms/day	74	100	120	90	-	80
Percentage dry matter	39.32	47.4	37.4	26.34	-	42.36
Percentage water	60.68	52.6	62.6	73.66	-	57.64
Total amount of water excreted mls/day	44.9	52.6	75.12	56.29	-	46.11
Sodium mEq/day	1.9	2.0	2.3	1.8	-	2.0
Potassium mEq/day	.8	1.0	.9	1.2	-	1.5
URINE						
Total output mls/day	1560	2300	3030	2600	2250	2960
Sodium mEq/day	26.5	25.3	30.2	59.8	50	49.1
Potassium mEq/day	62.4	62.4	84.6	72.8	60.	59.2
Osmolarity mOsm./l	300	-	250	-	290	260
PLASMA AND BLOOD PARAMETERS						
Sodium mEq/l	150	-	-	160	-	136
Potassium mEq/l	5.7	-	-	5.3	-	5.4
Osmolarity mOsm./l	290	-	-	300	-	280
Urea mg/100 ml.	30	-	-	32	-	34
Packed Cell Volume	35	-	-	37	-	37
Blood pH.	7.36	-	-	7.38	-	7.42
Bicarbonate mEq/l	23	-	-	26	-	32

CALF NO. 538 — Serum Immune Globulin 23.25 expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT						
	1	2	3	4	5	6	7
Body Weight in Kilograms	31.3	-	-	-	-	-	34
INTAKE							
Milk Millitres per day	3075	3075	3075	3075	3312	3312	3312
Total amount of water ingested mls/day	2736	2736	2736	2736	2947	2947	2947
Sodium mEq/day	76.60	76.60	76.60	76.60	82.51	82.51	82.51
Potassium mEq/day	101.47	101.47	101.47	101.47	109.29	109.29	109.29
OUTPUT							
FAECES							
Total output gms/day	120	141	53.65	44	-	177	-
Percentage dry matter	30.9	35.06	36.37	34.86	-	28.7	-
Percentage water	69.10	64.94	73.63	65.14	-	71.3	-
Total amount of water excreted mls/day	82.92	91.56	46.71	28.66	-	126.2	-
Sodium mEq/day	2.1	3.0	2.3	2.4	-	1.5	-
Potassium mEq/day	1.9	2.0	1.2	2.0	-	1.0	-
URINE							
Total output mls/day	1800	2000	2870	2600	2300	2000	900
Sodium mEq/day	18	25	28.7	44.2	39.1	40.6	40.3
Potassium mEq/day	61	65	57.4	56.9	46.0	52.2	58.2
Osmolarity mOsm./l	220	230	410	300	540	430	670
PLASMA AND BLOOD PARAMETERS							
Sodium mEq/l	130	-	-	136	-	151	-
Potassium mEq/l	4.4	-	-	3.6	-	4.2	-
Osmolarity mOsm./l	310	-	-	305	-	300	-
Urea mg/100 ml.	12	-	-	20	-	17	-
Packed Cell Volume	43.5	-	-	40.5	-	43.5	-
Blood pH.	7.34	-	-	7.42	-	7.42	-
Bicarbonate mEq/l	25.5	-	-	27.5	-	27.5	-

CALF NO. 733

Serum Immune Globulin 21 expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT						
	1	2	3	4	5	6	7
Body Weight in Kilograms	21	-	-	22	-	-	23
INTAKE							
Milk Millitres per day	2219	2602	2602	2602	2602	2602	2602
Total amount of water ingested mls/day	1852	2263	2263	2263	2263	2263	2263
Sodium mEq/day	51.85	63.36	63.36	63.36	63.36	63.36	63.36
Potassium mEq/day	61.11	85.86	85.86	85.86	85.86	85.86	85.86
OUTPUT							
FAECES							
Total output gms/day	102	-	42	42	70	70	70
Percentage dry matter	29.64	-	31.26	31.26	33.28	33.28	33.28
Percentage water	70.36	-	68.74	68.74	66.72	66.72	66.72
Total amount of water excreted mls/day	71.76	-	28.87	28.87	46.7	46.7	46.7
Sodium mEq/day	3.33	-	2.04	2.04	2.91	2.91	2.91
Potassium mEq/day	1.2	-	2.4	2.4	1.2	1.21	1.2
URINE							
Total output mls/day	1500	2030	2030	1450	2000	2000	1800
Sodium mEq/day	40	49.13	38.57	16.53	19.6	19.6	42.12
Potassium mEq/day	56.5	64.96	36.54	46.4	69	68	61.2
Osmolarity mOsm./l	220	210	250	160	150	220	330
PLASMA AND BLOOD PARAMETERS							
Sodium mEq/l	138	-	-	145	-	-	150
Potassium mEq/l	4.8	-	-	5.0	-	-	5.0
Osmolarity mOsm./l	285	-	-	280	-	-	290
Urea mg/100 ml.	20	-	-	22	-	-	24
Packed Cell Volume	39	-	-	35.5	-	-	32
Blood pH.	7.36	-	-	7.40	-	-	7.41
Bicarbonate mEq/l	26.0	-	-	29	-	-	28

CALF NO. 741

Serum Immune Globulin 9.5 expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT						
	1	2	3	4	5	6	7
Body Weight in Kilograms	33.7	-	-	34.5	-	-	35
INTAKE							
Milk Millitres per day	3312	3312	3312	3312	3548	3548	3548
Total amount of water ingested mls/day	2947	2947	2947	2947	3157	3157	3157
Sodium mEq/day	94.30	94.30	94.30	94.30	101.0	101.0	101.0
Potassium mEq/day	88.71	88.41	88.41	88.41	106.4	106.4	106.4
OUTPUT							
FAECES							
Total output gms/day	102	102	102	30	102	102	38
Percentage dry matter	18.53	18.53	18.53	23.35	22.55	22.55	17.4
Percentage water	.47	31.47	31.47	76.65	77.45	77.45	82.60
Total amount of water excreted mls day	83.09	83.09	83.09	22.99	78.99	78.99	31.38
Sodium mEq/day	2.61	2.61	2.61	.54	2.33	2.33	2.15
Potassium mEq/day	4.56	1.5	1.5	.4	2.	1.5	.56
URINE							
Total output mls/day	2150	2300	2100	3555	1800	2840	2100
Sodium mEq/day	45.6	54.3	52.5	88.9	45.	85.2	51.2
Potassium mEq/day	70	69	94.5	125	79.2	102.2	92.4
Osmolarity mOsm./l	400	-	230	250	285	275	290
PLASMA AND BLOOD PARAMETERS							
Sodium mEq/l	142	-	-	150	-	-	142
Potassium mEq/l	5.8	-	-	5.8	-	-	5.4
Osmolarity mOsm./l	280	-	-	280	-	-	280
Urea mg/100 ml.	30	-	-	28	-	-	32
Packed Cell Volume	41.5	-	-	40	-	-	38
Blood pH.	7.40	-	-	7.39	-	-	7.41
Bicarbonate mEq/l	27	-	-	27	-	-	28

CALF NO. 27

Serum Immune Globulin 3.5 expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT						
	1	2	3	4	5	6	7
Body Weight in Kilograms	34	-	-	35	-	-	36
INTAKE							
Milk Millitres per day	3312	3312	3312	3312	3312	3312	3312
Total amount of water ingested mls/day	2947	2947	2947	2947	2947	2947	2947
Sodium mEq/day	92.73	92.73	92.73	92.73	92.73	92.73	92.73
Potassium mEq/day	109.29	109.29	109.29	109.29	109.29	109.29	109.29
OUTPUT							
FAECES							
Total output gms/day	74	105	282	282	282	282	170
Percentage dry matter	21.44	22.54	14.87	14.87	14.87	14.87	18.57
Percentage water	78.56	77.46	85.13	85.13	85.13	85.13	-
Total amount of water excreted mls/day	58.13	81.33	240.06	240.06	240.06	240.06	138.43
Sodium mEq/day	2.45	2.64	9.24	9.24	9.24	9.24	5.1
Potassium mEq/day	1.12	1.15	4.	4.	4.	4.	2.75
URINE							
Total output mls/day	2120	2420	2000	1410	1310	2300	2800
Sodium mEq/day	11.4	12.5	17	16	8.2	10	24
Potassium mEq/day	44	48	46	48	34	38	50
Osmolarity mOsm./l	290	235	210	300	265	270	230
PLASMA AND BLOOD PARAMETERS							
Sodium mEq/l	133	138	136	140	140	-	140
Potassium mEq/l	3.5	3.9	3.5	5.4	4.	-	3
Osmolarity mOsm./l	295	290	280	265	285	-	-
Urea mg/100 ml.	22	-	33	-	28	-	33
Packed Cell Volume	37	35	36	33	33	34	32
Blood pH.	7.37	7.37	7.33	7.42	7.37	7.40	7.38
Bicarbonate mEq/l	24.5	23	24.5	30	27.5	27	26

CALF NO. A1

Serum Immune Globulin 6
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT		
		1	2	3
Body Weight in Kilograms		35	30	27.3
INTAKE				
Milk Millitres per day		2365	2602	473.1
Total amount of water ingested mls/day		2104.8	2315	421
Sodium mEq/day		66.22	72.85	13.24
Potassium mEq/day		78.09	85.9	15.61
OUTPUT				
FAECES				
Total output gms/day		1155	5244	3494
Percentage dry matter		5.29	5.29	5.80
Percentage water		94.71	94.71	94.2
Total amount of water excreted mls/day		1093	4966	3291
Sodium mEq/day		53.13	241.2	150.9
Potassium mEq/day		11.08	50.34	49.61
URINE				
Total output mls/day		2470	1660	750
Sodium mEq/day		4.94	2.98	1.03
Potassium mEq/day		25.68	14.60	12.80
Osmolarity mOsm./l		205	608	700
PLASMA AND BLOOD PARAMETERS	First sample			
Sodium mEq/l	150	152	154	158
Potassium mEq/l	5.0	5.0	7.4	7.8
Osmolarity mOsm./l	276	280	324	329
Urea mg/100 ml.	24	24	79	175
Packed Cell Volume	27	27	36	38
Blood pH.	7.39	7.39	7.22	7.09
Bicarbonate mEq/l	30.5	30.5	16.5	12

CALF NO. 22

Serum Immune Globulin 9
expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT		
	1	2	3
Body Weight in Kilograms	37	33	30
INTAKE			
Milk Millitres per day	3548	3785	0
Total amount of water ingested mls/day	3157.7	3368	0
Sodium mEq/day	99.34	105.98	0
Potassium mEq/day	117.15	124.9	0
OUTPUT			
FAECES			
Total output gms/day	1612	6905	3147
Percentage dry matter	6.25	4.89	5.20
Percentage water	93.75	95.11	94.80
Total amount of water excreted mls/day	1511	6567	2983
Sodium mEq/day	68.35	290.9	125.6
Potassium mEq/day	18.38	75.96	32.04
URINE			
Total output mls/day	520	600	0
Sodium mEq/day	1.77	2.16	0
Potassium mEq/day	46.8	39.0	0
Osmolarity mOsm./l	420	1600	0
PLASMA AND BLOOD PARAMETERS First Sample			
Sodium mEq/l 142	146	146	150
Potassium mEq/l 510	5.0	7.4	6.6
Osmolarity mOsm./l 329	320	330	287
Urea mg/100 ml. 46	48	79	100
Packed Cell Volume 45	45	50	57
Blood pH. 7.40	7.30	7.18	6.92
Bicarbonate mEq/l 35	24.0	14.0	7.0

CALF NO. 63

Serum Immune Globulin 5.5
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT		
		1	2	3
Body Weight in Kilograms		31	30	28
INTAKE				
Milk Millitres per day		2839	946.3	0
Total amount of water ingested mls/day		2526	842.2	0
Sodium mEq/day		79.49	26.48	0
Potassium mEq/day		93.74	31.23	0
OUTPUT				
FAECES				
Total output gms/day		1679	1426	2188
Percentage dry matter		4.56	4.56	4.15
Percentage water		95.44	95.44	95.85
Total amount of water excreted mls/day		1602.43	1360.97	2097.19
Sodium mEq/day		73.9	55.9	122.5
Potassium mEq/day		17.1	18.3	23.2
URINE				
Total output mls/day		400	0	50
Sodium mEq/day		2.3	0	2.3
Potassium mEq/day		10.4	0	30.2
Osmolarity mOsm./l		340	0	1000.0
PLASMA AND BLOOD PARAMETERS	First Sample			
Sodium mEq/l	133	136	130	130
Potassium mEq/l	4.4	4.4	4.8	5
Osmolarity mOsm./l				
Urea mg/100 ml.	30	30	100	111
Packed Cell Volume	40	42	52	58
Blood pH.	7.38	7.36	7.19	7.0
Bicarbonate mEq/l	26	24	10.5	10.0

CALF NO. 64

Serum Immune Globulin 3
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT	
		1	2
Body Weight in Kilograms		36.7	33.18
INTAKE			
Milk Millitres per day		1892	1076
Total amount of water ingested mls/day		1683	957.6
Sodium mEq/day		52.97	30.12
Potassium mEq/day		62.47	35.52
OUTPUT			
FAECES			
Total output gms/day		1250	3452
Percentage dry matter		4.8	3.95
Percentage water		95.2	96.05
Total amount of water excreted mls/day		1190	3315
Sodium mEq/day		55	146.4
Potassium mEq/day		13.5	31.8
URINE			
Total output mls/day		100	640
Sodium mEq/day		.64	5.12
Potassium mEq/day		2.3	16
Osmolarity mOsm./l		560	600
PLASMA AND BLOOD PARAMETERS	First Sample		
Sodium mEq/l	133	133	128
Potassium mEq/l	4.2	4.7	10.4
Osmolarity mOsm./l	280	290	290
Urea mg/100 ml.	25	25	143
Packed Cell Volume	47	53	58
Blood pH.	-	-	-
Bicarbonate mEq/l	-	-	-

CALF NO. 4

Serum Immune Globulin 6 expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT 1	2
Body Weight in Kilograms		27	29.1
INTAKE			
Milk Millitres per day		1656	1419
Total amount of water ingested mls/day		1473.8	1262
Sodium mEq/day		46.36	39.73
Potassium mEq/day		54.68	46.85
OUTPUT			
FAECES			
Total output gms/day		1000	4157
Percentage dry matter		8.54	3.74
Percentage water		91.46	92.26
Total amount of water excreted mls/day		914	4001.5
Sodium mEq/day		42	182.9
Potassium mEq/day		5.6	37.0
URINE			
Total output mls/day		0	300
Sodium mEq/day		0	3.6
Potassium mEq/day		0	36
Osmolarity mOsm/l		0	905
PLASMA AND BLOOD PARAMETERS	First Sample		
Sodium mEq/l	148	178	128
Potassium mEq/l	6.2	6.7	8.0
Osmolarity mOsm./l	330	330	300
Urea mg/100 ml.	50	46	95
Packed Cell Volume	53	47	50
Blood pH.	7.30	7.28	7.16
Bicarbonate mEq/l	24	22	11

CALF NO. 214

Serum Immune Globulin 8 expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT			
		1	2	3	4
Body Weight in Kilograms		38.15	37	37.5	35
INTAKE					
Milk Millitres per day		3785	3785	3785	3785
Total amount of water ingested mls/day		3368	3368	3368	3368
Sodium mEq/day		105.98	105.98	105.98	105.98
Potassium mEq/day		124.9	124.9	124.9	124.9
OUTPUT					
FAECES					
Total output gms/day		1412	2518	3462	3735
Percentage dry mastter		3.69	3.57	2.80	4.80
Percentage water		96.31	96.43	97.2	95.18
Total amount of water excreted mls/day		1359	2428	3365	3554
Sodium mEq/day		67.7	110.7	146.7	156.8
Potassium mEq/day		18.6	30.7	38.0	39.5
URINE					
Total output mls/day		2400	1800	830	230
Sodium mEq/day		20.6	10.4	6.66	1.15
Potassium mEq/day		96	90	54.7	17.02
Osmolarity mOsm./l		190	260	499	742
PLASMA AND BLOOD PARAMETERS	First sample				
Sodium mEq/l	134	132	132	132	124
Potassium mEq/l	4	4.2	4.6	5.6	7.6
Osmolarity mOsm./l	272	272	275	280	254
Urea mg/100 ml.	40	40	98	137	285
Packed Cell Volume	38	38	38	42	43
Blood pH.	7.37	7.37	7.35	7.26	7.19
Bicarbonate mEq/l	26	26	22	19.0	10.5

CALF NO. 022

Serum Immune Globulin 8.25
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT 1	2
Body weight in Kilograms		33.6	31
INTAKE			
Milk Millimetres per day		300	0
Total amount of water ingested mls/day		267	0
Sodium mEq/day		8.4	0
Potassium mEq/day		9.9	0
OUTPUT			
FAECES			
Total output gms/day		1022	2156
Percentage dry matter		8,48	8.0
Percentage water		91.52	92
Total amount of water excreted mls/day		935	1983
Sodium mEq/day		40.6	41.1
Potassium mEq/day		11.9	13.6
URINE			
Total output mls/day		0	100
Sodium mEq/day		0	.48
Potassium mEq/day		0	8.4
Osmolarity mOsm./l		0	550
PLASMA AND BLOOD PARAMETERS	First Sample		
Sodium mEq/l	142	151	142
Potassium mEq/l	5.2	7.2	7.8
Osmolarity mOsm./l	310	320	300
Urea mg/100 ml.	56	56	180
Packed Cell Volume	58	56	70
Blood pH.	7.36	7.36/	6.9
Bicarbonate mEq/l	25.5	24	9.0

CALF NO. 019

Serum Immune Globulin 6
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT	
		1	2
Body Weight in Kilograms		28	25.2
INTAKE			
Milk Millitres per day		460	460
Total amount of water ingested mls/day		409	409
Sodium mEq/day		12.88	12.88
Potassium mEq/day		15.18	15.18
OUTPUT			
FAECES			
Total output gms/day		1483	1367
Percentage dry matter		3.62	3.0
Percentage water		96.38	97
Total amount of water excreted mls/day		1429.3	1325.0
Sodium mEq/day		49.8	50.3
Potassium mEq/day		21.0	19.6
URINE			
Total output mls/day		0	380
Sodium mEq/day		0	1.9
Potassium mEq/day		0	9.12
Osmolarity mOsm./l		0	575
PLASMA AND BLOOD PARAMETERS	First sample		
Sodium mEq/l	133.0	138	135
Potassium mEq/l	4.8	4.8	9.0
Osmolarity mOsm./l	310	310	300
Urea mg/100 ml.	50	50	224
Packed Cell Volume	52	50	60
Blood pH.	7.28	7.29	6.90
Bicarbonate mEq/l	20	21	7.0

CALF NO. 207

Serum Immune Globulin 7
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT		
		1	2	3
Body Weight in Kilograms		34	33	29
INTAKE				
Milk Millitres per day		3785	3785	0
Total amount of water ingested mls/day		3368	3368	0
Sodium mEq/day		105.98	105.98	0
Potassium mEq/day		124.98	124.98	0
OUTPUT				
FAECES				
Total output gms/day		3955	4661	3725
Percentage dry matter		4.95	5.54	4.08
Percentage water		95.05	94.46	95.92
Total amount of water excreted mls/day		3759	4402	3573
Sodium mEq/day		151.8	151	110.26
Potassium mEq/day		41.9	60.5	48.4
URINE				
Total output mls/day		0	0	175
Sodium mEq/day		0	0	1.29
Potassium mEq/day		0	0	9.45
Osmolarity mOsm./l		0	0	418
PLASMA AND BLOOD PARAMETERS	First sample			
Sodium mEq/l	138	138	142	127
Potassium mEq/l	5.4	5.6	6.4	7.4
Osmolarity mOsm./l	294	294	315	308
Urea mg/100 ml.	70	80	132	219
Packed Cell Volume	41	40	45	49
Blood pH.	7.38	7.38	7.06	6.94
Bicarbonate mEq/l	27	29	11.4	7.0

CALF NO. 061

Serum Immune Globulin 7
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT 1	2
Body Weight in Kilograms		33	31
INTAKE			
Milk Millitres per day		1419.5	946.3
Total amount of water ingested mls/day		1263	842.2
Sodium mEq/day		39.73	26.48
Potassium mEq/day		46.85	31.24
OUTPUT			
FAECES			
Total output gms/day		1545	2100
Percentage dry matter		4.95	3.70
Percentage of water		95.05	96.30
Total amount of water excreted mls/day		1468	2022
Sodium mEq/day		74.2	113.4
Potassium mEq/day		17.9	31.0
URINE			
Total output mls/day		0	350
Sodium mEq/day		0	1.89
Potassium mEq/day		0	28.9
Osmolarity m.Osm/l		0	570
PLASMA AND BLOOD PARAMETERS	First Sample		
Sodium mEq/l	136	110	128
Potassium mEq/l	5.4	5.6	6.2
Osmolarity mOsm./l	298	298	289
Urea mg/100 ml.	30	32	108
Packed Cell Volume	39	39	44
Blood pH.	7.30	7.30	7.01
Bicarbonate mEq/l	24	24	11

CALF NO. 35

Serum Immune Globulin 4
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT	
		1	3
Body Weight in Kilograms		26	23
INTAKE			
Milk Millitres per day		2836	0
Total amount of water ingested mls/day		2526	0
Sodium mEq/day		79.49	0
Potassium mEq/day		93.74	0
OUTPUT			
FAECES			
Total output gms/day		1000	3722
Percentage dry matter		11.66	4.96
Percentage water		88.34	99.04
Total amount of water excreted mls/day		883	3442
Sodium mEq/day		38.4	156.32
Potassium mEq/day		32	40
URINE			
Total output mls/day		1530	250
Sodium mEq/day		15.3	6.0
Potassium mEq/day		134.6	20
Osmolarity mOsm./l		400	830
PLASMA AND BLOOD PARAMETERS	First sample		
Sodium mEq/l	150	150	144
Potassium mEq/l	5.0	5.2	6.0
Osmolarity mOsm./l	2761	276	270
Urea mg/100 ml.	40	49	90
Packed Cell Volume	45	42	61
Blood pH.	7.39	7.38	7.02
Bicarbonate mEq/l	29.5	26.5	17

CALF NO. 26

Serum Immune Globulin 8.75
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT					
		1	2	3	4	5	6
Body Weight in Kilograms		33	32.5	32	32	30	27
INTAKE							
Milk Millitres per day		3312	3312	3312	3312	0	0
Total amount of water ingested mls/day		2947	2947	2947	2947	0	0
Sodium mEq/day		92.73	92.73	92.73	92.73	0	0
Potassium mEq/day		109.3	109.3	109.3	109.3	0	0
OUTPUT							
FAECES							
Total output gms/day		1000	3421	1301	1301	1500	3486
Percentage dry matter		6.48	6.87	6.61	6.61	5.71	5.71
Percentage water		93.52	93.13	93.39	93.39	94.29	94.29
Total amount of water excreted mls/day		935	3185	1215	1215	1414	3286
Sodium mEq/day		40	150.5	48.9	48.9	45.6	105.9
Potassium mEq/day		11.2	42.4	20	20	26.4	61.3
URINE							
Total output mls/day		1850	800	720	640	900	0
Sodium mEq/day		8.5	5.4	11.52	4.86	5.9	0
Potassium mEq/day		81.4	33.0	38.88	28.16	39.6	0
Osmolarity mOsm./l		290	400	480	560	530	0
PLASMA AND BLOOD PARAMETERS	First sample						
Sodium mEq/l	132	136	130	132	130	122	125
Potassium mEq/l	5.2	5.0	5.6	6.0	6.0	5.8	5.6
Osmolarity mOsm./l	280	280	285	270	290	270	280
Urea mg/100 ml.	30	30	76	100	100	100	190
Packed Cell Volume	39	39	43	42	41	40	45
Blood pH.	7.39	7.39	7.24	7.27	7.20	7.16	6.95
Bicarbonate mEq/l	25	25	14.5	15	13	11.5	7.4

CALF NO. 21

Serum Immune Globulin 7
expressed as $ZnSO_4$ Units

		DAY OF EXPERIMENT						
		1	2	3	4	5	6	7
Body Weight in Kilograms		31.25	28.9	28	27.9	27.5	27	26.6
INTAKE								
Milk Millitres per day		2839	2839	2839	2839	2839	1419	0
Total amount of water ingested mls/day		2526	2526	2526	2526	2526	1216	0
Sodium mEq/day		79.49	79.49	79.49	79.49	79.49	39.73	0
Potassium mEq/day		93.74	93.74	93.74	93.74	93.74	46.85	0
OUTPUT								
FAECES								
Total output gms/day		1746.5	1746.5	4501	1874	1811	864	542
Percentage dry matter		5.80	5.80	5.15	11.25	9.27	18.19	17.05
Percentage water		94.2	94.2	94.85	88.75	90.73	81.81	82.92
Total amount of water excreted mls/day		1644	1644	4269	1663	1643	709	449
Sodium mEq/day		76.8	76.8	165.6	53.22	47.8	18.38	11.27
Potassium mEq/day		15.36	15.36	45.91	24.7	36.2	19.07	11.9
URINE								
Total output mls/day		2150	950	370	0	610	800	700
Sodium mEq/day		20.6	6.08	1.63	0	5.37	2.56	3.08
Potassium mEq/day		107.5	45.6	22.2	0	32.9	20.8	17.5
Osmolarity mOsm./l		282	290	1600	0	900	910	900
PLASMA AND BLOOD PARAMETERS	First sample							
Sodium mEq/l	146	146	132	146	142	122	130	130
Potassium mEq/l	4.8	4.6	6.4	6.2	6.2	5.8	4.8	5
Osmolarity mOsm./l	334	330	271	330	320	270	275	295
Urea mg/100 ml.	27	26	67	63	76	51	50	50
Packed Cell Volume	32	34	39	41	38	38	37	40
Blood pH.	7.39	7.39	7.33	7.24	7.21	7.21	7.15	7.15
Bicarbonate mEq/l	27	27	21	13.8	11.4	12.0	9.8	9.0

DIARRHOEIC CALVES WHICH SURVIVED

CALF NO. 686

Serum Immune Globulin 15.25
expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT							
	1	2	3	4	5	6	7	8
Body Weight in Kilograms	38.90						4089	
INTAKE								
Milk Millitres per day	3785	3075	2839	2839	2602	2839	2839	2839
Total amount of water ingested mls/day	3368	2736	2526	2526	2315	2526	2526	2526
Sodium mEq/day	98.41	79.95	73.80	73.80	67.65	73.80	73.80	73.80
Potassium mEq/day	113.55	92.25	85.17	85.17	78.06	85.17	85.17	85.17
OUTPUT								
FAECES								
Total output gms/day	550	73	73	598	600	1000	101	170
Percentage dry matter	16%	25%	25%	19%	13%	9%	15%	20%
Percentage water	84%	75%	75%	86%	87%	91%	85%	80%
Total amount of water excreted mls/day	462	54.7	54.7	514.2	522	910	85.8	136%
Sodium mEq/day	2.3	2.3	2.3	38	21	65	3.0	4.0
Potassium mEq/day	14.18	3.9	3.9	15	10	30	3.2	3.5
URINE								
Total output mls/day	700	0	1850	900	850	600	650	600
Sodium mEq/day	39.9	0	9.25	18.00	9.45	4.0	9.23	7.2
Potassium mEq/day	45.5	0	39.3	28.00	19.25	45.00	60.45	50.4
Osmolarity mOsm./l	-	-	-	-	-	-	-	-
PLASMA AND BLOOD PARAMETERS								
Sodium mEq/l	130.5	150.0	-	146.0	140	140	146	144
Potassium mEq/l	5.5	5.5	-	4.5	5.0	5.0	4.5	5.0
Osmolarity mOsm./l	300	290	-	295	290	310	290	280
Urea mg/100 ml.	25	15	-	12	25	20	25	25
Packed Cell Volume	29.5	26.5	-	29	28	29	29	30
Blood pH.	7.41	7.39	-	7.39	7.36	7.30	7.30	7.34
Bicarbonate mEq/l	32	38	-	29	24	24	23	26

CALF NO. 018

Serum Immune Globulin 9
expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT							
	1	2	3	4	5	6	7	8
Body Weight in Kilograms	32.2							32.2
INTAKE								
Milk Millitres per day	2839	2839	2839	2839	2839	2839	2839	2839
Total amount of water ingested mls/day	2526	2526	2526	2526	2526	2526	2526	2526
Sodium mEq/day	70.72	70.72	70.72	70.72	70.72	70.72	70.72	70.72
Potassium mEq/day	98.51	98.51	98.51	98.51	98.51	98.51	98.51	98.51
OUTPUT								
FAECES								
Total output gms/day	479	350	608	510	510	326	246	166
Percentage dry matter	26.9	26.9	26.9	1.36	1.36	16.49	16.49	16.49
Percentage water	73.1	73.1	73.1	98.6	98.6	83.51	83.51	83.51
Total amount of water excreted mls/day	350.14	255.85	444.4	502.8	502.8	272.2	205.4	138.6
Sodium mEq/day	130	9.5	16,53	15.5	15.5	6.3	4.7	3.2
Potassium mEq/day	7.66	5.60	9.72	7.14	7.14	4.5	3.4	2.3
URINE								
Total output mls/day	1900	1200	1400	2000	2300	1850	2500	2000
Sodium mEq/day	12.56	13.12	5.88	8.80ø	-	21.82	30.00	24.00
Potassium mEq/day	68.4	45.6	7.5	8.0	-	7.77	7.50	36.0
Osmolarity mOsm./l	230	335	315	265	270	230	375	260
PLASMA AND BLOOD PARAMETERS								
Sodium mEq/l	130	-	136	136	-	130	-	135
Potassium mEq/l	4.6	-	4.2	6.6	-	4.2	-	4.5
Osmolarity mOsm./l	270	-	290	300	-	280	-	270
Urea mg/100 ml.	31	21	20	-	-	20	-	20
Packed Cell Volume	-	43	45	47	-	-	-	43
Blood pH.	7.39	-	7.38	7.40	-	7.37	-	7.39
Bicarbonate mEq/l	29	29	28.5	-	-	-	-	-

CALF NO. 619

Serum Immune Globulin 13.5 expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT							
	1	2	3	4	5	6	7	8
Body Weight in Kilograms	36.36							39
INTAKE								
Milk Millitres per day	2125	2500	2500	2500	2500	2500	2500	2500
Total amount of water ingested mls/day	1891	2225	2225	2225	2225	2225	2225	2225
Sodium mEq/day	49.16	57.85	57.85	57.85	57.85	57.85	57.85	57.85
Potassium mEq/day	63.53	74.76	74.76	74.76	74.76	74.76	74.76	74.76
OUTPUT								
FAECES								
Total output gms/day	705	2192.45	628	430	253	0	100	172
Percentage dry matter	14.6	5.83	15.05	10.01	15.20	-	11.92	11.92
Percentage water	85.4	94.17	84.95	89.99	84.80	-	88.08	88.08
Total amount of water excreted mls/day	602.07	2064.63	533.48	386.95	214.56	-	176.16	152.73
Sodium mEq/day	31.2	105.24	30.14	17.54	8.70	-	2.29	2.29
Potassium mEq/day	14.81	30.69	11.30	7.57	4.00	-	1.74	1.74
URINE								
Total output mls/day	-	2000	1020	1320	1850	1770	1500	1870
Sodium mEq/day	-	7.68	8.16	19.24	14.44	15.31	11.25	
Potassium mEq/day	-	56.6	20.4	31.68	92.50	63.72	75.0	-
Osmolarity mOsm./l	-	250	650	300	-	300	280	-
PLASMA AND BLOOD PARAMETERS								
Sodium mEq/l	144	139	127	128	-	151	136	140
Potassium mEq/l	4.9	3.4	5.0	4.4	-	6.0	4.6	4.8
Osmolarity mOsm./l	280	300	290	280	-	260	270	280
Urea mg/100 ml.	24	28	20	17	-	10	24	28
Packed Cell Volume	39	38	35	32	28.5	25	-	28
Blood pH.	7.39	7.36	7.35	7.4	-	-	-	7.36
Bicarbonate mEq/l	30	24	24	26.5	-	-	-	26.5

CALF NO. 4

Serum Immune Globulin 12
expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT					
	1	2	3	4	5	6
Body Weight in Kilograms	31.47					31.93
INTAKE						
Milk Millitres per day	2839	2839	2839	2839	2839	2839
Total amount of water ingested mls/day	2526	2526	2526	2526	2526	2526
Sodium mEq/day	65.67	65.67	65.67	65.67	65.67	65.67
Potassium mEq/day	85.88	85.88	85.88	85.88	85.88	85.88
OUTPUT						
FAECES						
Total output gms/day	268	279	/288	230	240	240
Percentage dry matter	30.86	23.56	6.56	10.5	19.0	19.0
Percentage water	69.14	76.44	93.44	89.2	81.0	81.0
Total amount of water excreted mls/day	185.29	213.26	1203.5	205.16	194.0	194.0
Sodium mEq/day	10.7	12.27	59.2	5.98	6.24	6.24
Potassium mEq/day	2.46	2.67	15.5	2.20	1.92	1.92
URINE						
Total output mls/day	1680	1600	1205	350	690	1300
Sodium mEq/day	19.48	19.92	4.82	1.960	16.14	13.26
Potassium mEq/day	33.6	33.6	21.6	5.9	11.04	27.3
Osmolarity mOsm./l	310	225	230	500	461	400
PLASMA AND BLOOD PARAMETERS						
Sodium mEq/l	142	133	128	133	139	140
Potassium mEq/l	4.6	5.0	4.8	4.5	4.6	4.4
Osmolarity mOsm./l	270	280	270	300	290	290
Urea mg/100 ml.	19	19	37	43	57	-
Packed Cell Volume	42	40	41	40	40	40
Blood pH.	-	7.37	7.38	7.41	7.39	-
Bicarbonate mEq/l	30	26	32	31	-	-

expressed as $ZnSO_4$ units

	DAY OF EXPERIMENT									
	1	2	3	4	5	6	7	8	9	10
Body Weight in Kilograms	31.13									31.8
INTAKE										
Milk Millitres per day	2839	2839	2839	2839	2839	2839	2839	2839	2839	2839
Total amount of water ingested mls/day	2526	2526	2526	2526	2526	2526	2526	2526	2526	2526
Sodium mEq/day	65.67	65.67	65.67	65.67	65.67	65.67	65.67	65.67	65.67	65.67
Potassium mEq/day	84.87	84.87	84.87	84.87	84.87	84.87	84.87	84.87	84.87	84.87
OUTPUT										
FAECES										
Total output gms/day	892	1600	2305	181	379	415	34	110	70	90
Percentage dry matter	6.0	9.48	6.35	3.81	16.00	10.6	15.0	19.6	19.6	19.6
Percentage water	94.00	90.60	93.65	96.2	84.00	89.4	85.0	81.4	81.4	81.4
Total amount of water excreted mls/day	838.48	1449.0	2158.63	174.12	318.36	371.0	28.9	89.54	56.98	93.26
Sodium mEq/day	39.68	44.8	99.11	6.0	4.24	10.6	0.57	2.68	1.70	2.19
Potassium mEq/day	16.94	30.4	22.1	2.71	6.13	5.4	0.58	1.38	0.88	1.13
URINE										
Total output mls/day	1060	1000	300	690	2550	2100	1950	2000	2000	2000
Sodium mEq/day	11.23	10.0	-	4.14	7.65	-	5.85	15.6	31.5	31.6
Potassium mEq/day	23.30	20.0	-	48.3	25.5	-	70.20	96.0	91.20	96.00
Osmolarity mOsm./l	385	225	680	500	260	395	260	345	270	260
PLASMA AND BLOOD PARAMETERS										
Sodium mEq/l	141	142	150	-	146	-	142	-	-	138
Potassium mEq/l	4.2	6.6	5.6	-	5.8	-	5.4	-	-	5.2
Osmolarity mOsm./l	285	280	300	290	270	-	275	-	-	280
Urea mg/100 ml.	30	28	44	-	-	-	19	-	-	14
Packed Cell Volume	47	48	53	50	48	47	48	47	48	46
Blood pH.	7.27	-	7.25	7.34	7.33	-	7.38	-	-	7.56
Bicarbonate mEq/l	19	15	17.5	29	29.5	-	31.0	-	-	39

CALF NO. 470

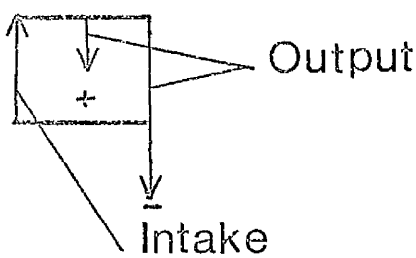
Serum Immune Globulin 10
expressed as $ZnSO_4$ Units

	DAY OF EXPERIMENT					
	1	2	3	4	5	6
Body Weight in Kilograms	35.4					33.7
INTAKE						
Milk Millitres per day	3312	3312	2602	946	1892	3312
Total amount of water ingested mls/day	2947	2947	2315	841.9	1683	2947
Sodium mEq/day	82.51	82.51	64.82	23.54	47.12	82.51
Potassium mEq/day	114.93	114.93	90.28	32.79	65.63	114.97
OUTPUT						
FAECES						
Total output gms/day	891	2421	1467	841	280	280
Percentage dry matter	14.57	8.26	11.93	13.48	10.98	10.98
Percentage water	85.43	91.74	88.07	86.52	89.02	89.02
Total amount of water excreted mls/day	761.18	2221.02	1291.98	727.63	249.25	249.25
Sodium mEq/day	32.07	87.15	43.42	21.86	5.04	5.04
Potassium mEq/day	7.48	30.2	24.05	6.39	2.52	2.52
URINE						
Total output mls/day	775	800	925	1710	1110	1200
Sodium mEq/day	-	1.68	3.88	1.98	13.75	12.24
Potassium mEq/day	-	12.80	24.05	18.46	23.10	21.60
Osmolarity mOsm./l	820	662	610	420	400	298
PLASMA AND BLOOD PARAMETERS						
Sodium mEq/l	145	136	130	136	127	-
Potassium mEq/l	5.0	5.0	5.2	6.0	5.0	-
Osmolarity mOsm./l	290	280	270	280	290	-
Urea mg/100 ml.	14	33	36	40	57	-
Packed Cell Volume	42	45	45	44	43	-
Blood pH.	7.37	7.26	7.33	7.30	7.34	-
Bicarbonate mEq/l	29.5	22.5	25	23	25	-

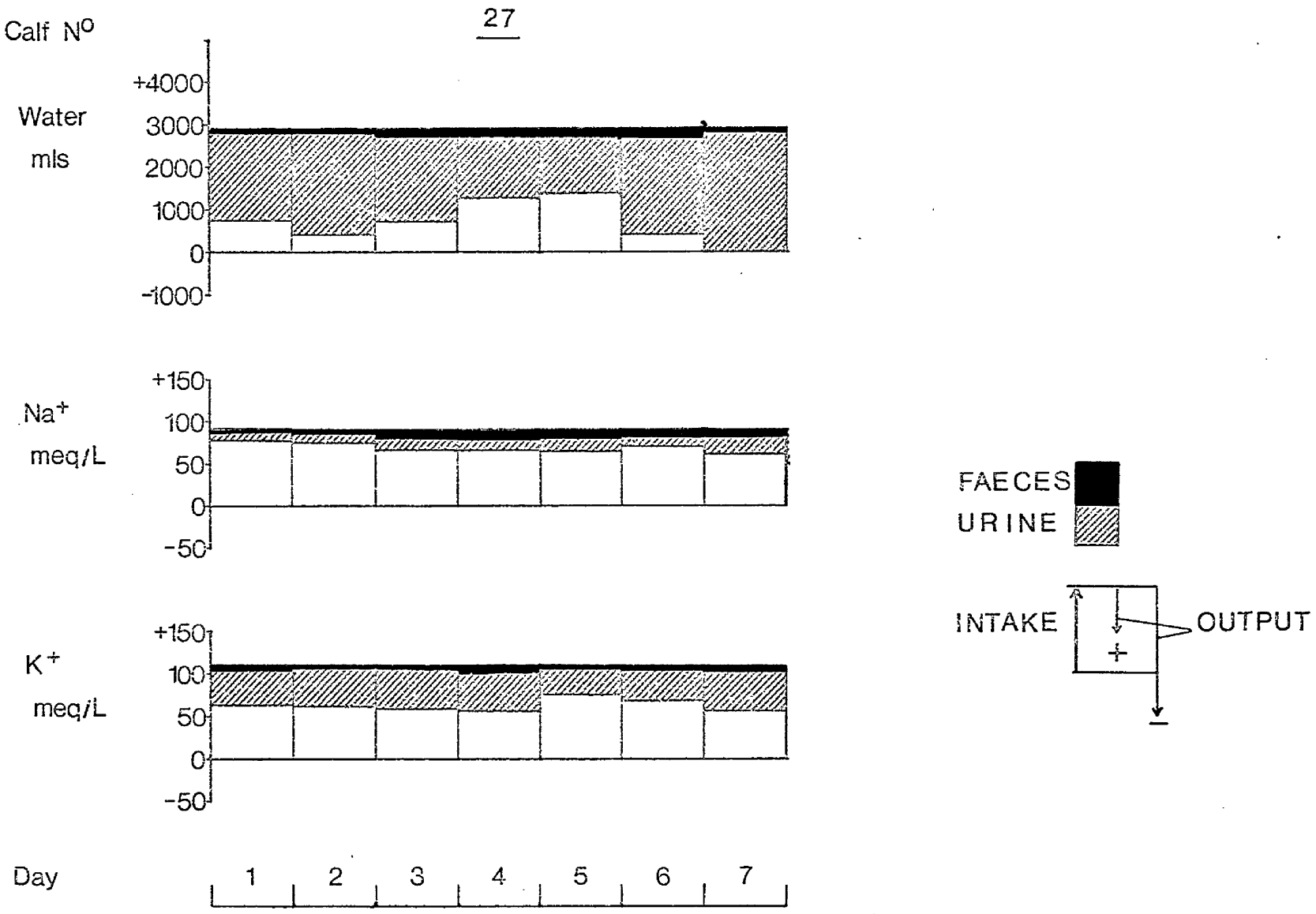
APPENDIX 4(a)

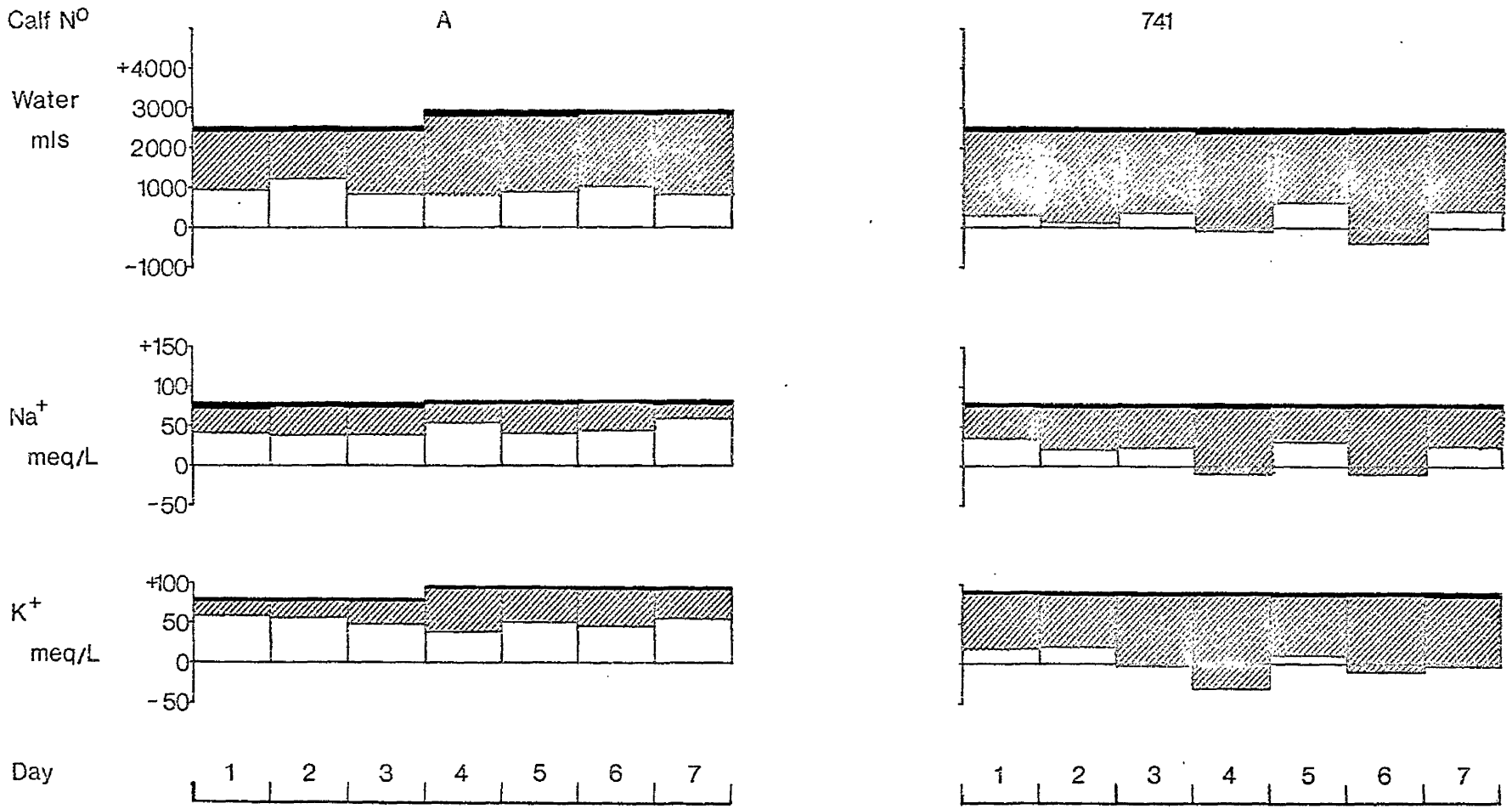
The graphs on the following pages illustrate the daily balance of sodium, potassium and water in normal and dying diarrhoeic calves. The graphs were drawn from the values reported in this appendix.

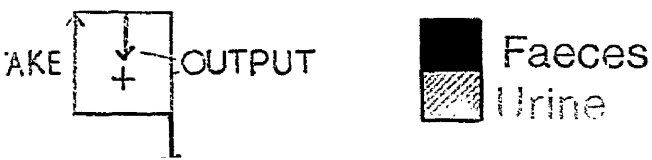
In the graphs, intake is plotted upward and output downward; resultant above the zero line represents a positive and below a negative balance. Faecal output is represented by a dark solid line in the normal calves, and by vertical lining in the dying diarrhoeic calves.



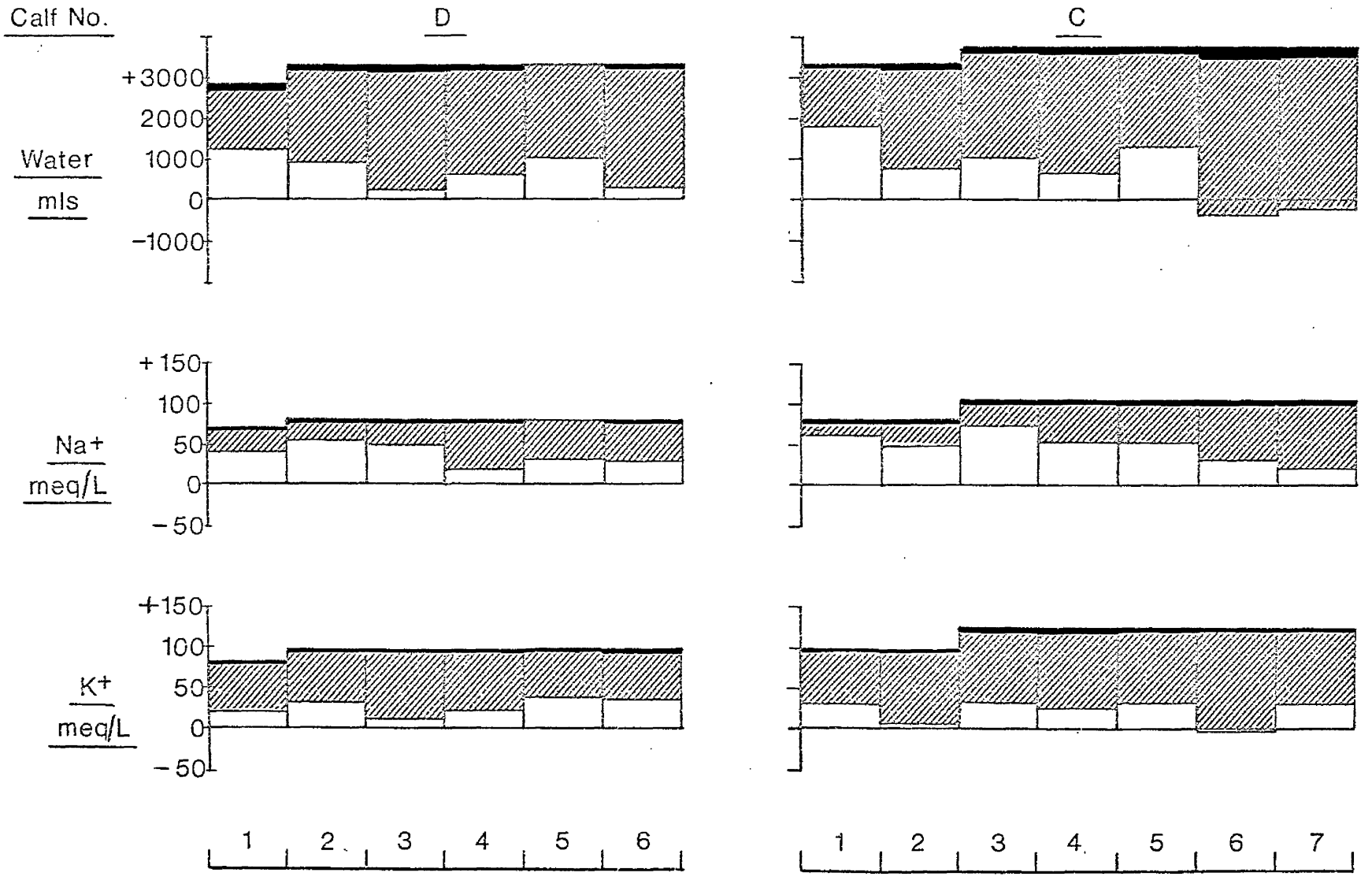
NORMAL CALVES

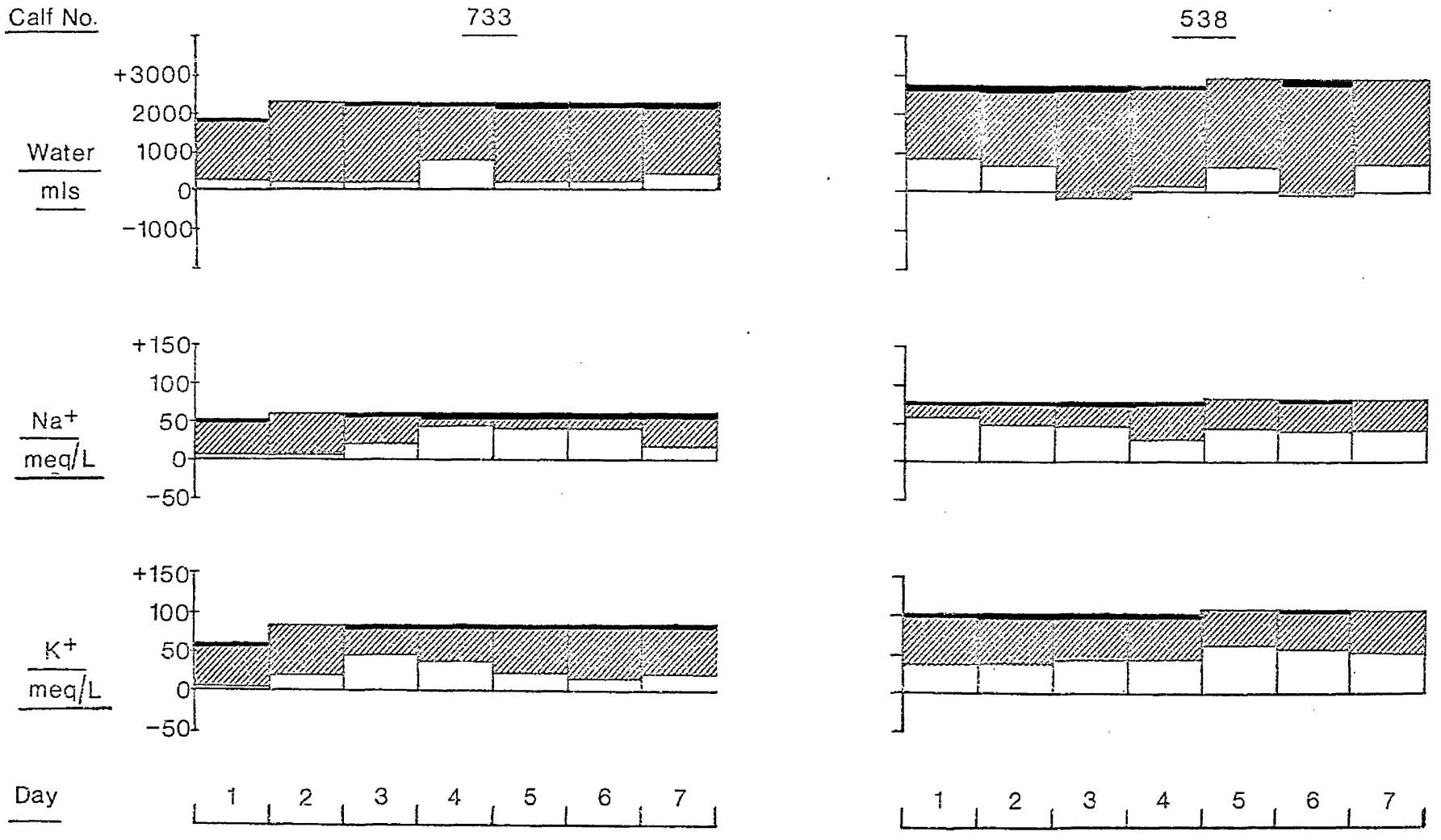

Calf N°
27
Water
mls
+4000
3000
2000
1000
0
-1000
Na+
meq/L
+150
100
50
0
-50
K+
meq/L
+150
100
50
0
-50
Day
1
2
3
4
5
6
7
FAECES
URINE
INTAKE
OUTPUT
+
-





Faeces
Urine


Calf No.
D
C
+3000
2000
1000
0
−1000
Water
mls
+150
100
50
0
−50
Na+
meq/L
+150
100
50
0
−50
K+
meq/L
1 2 3 4 5 6
1 2 3 4 5 6 7
INTAKE
+
OUTPUT
Faeces
Urine

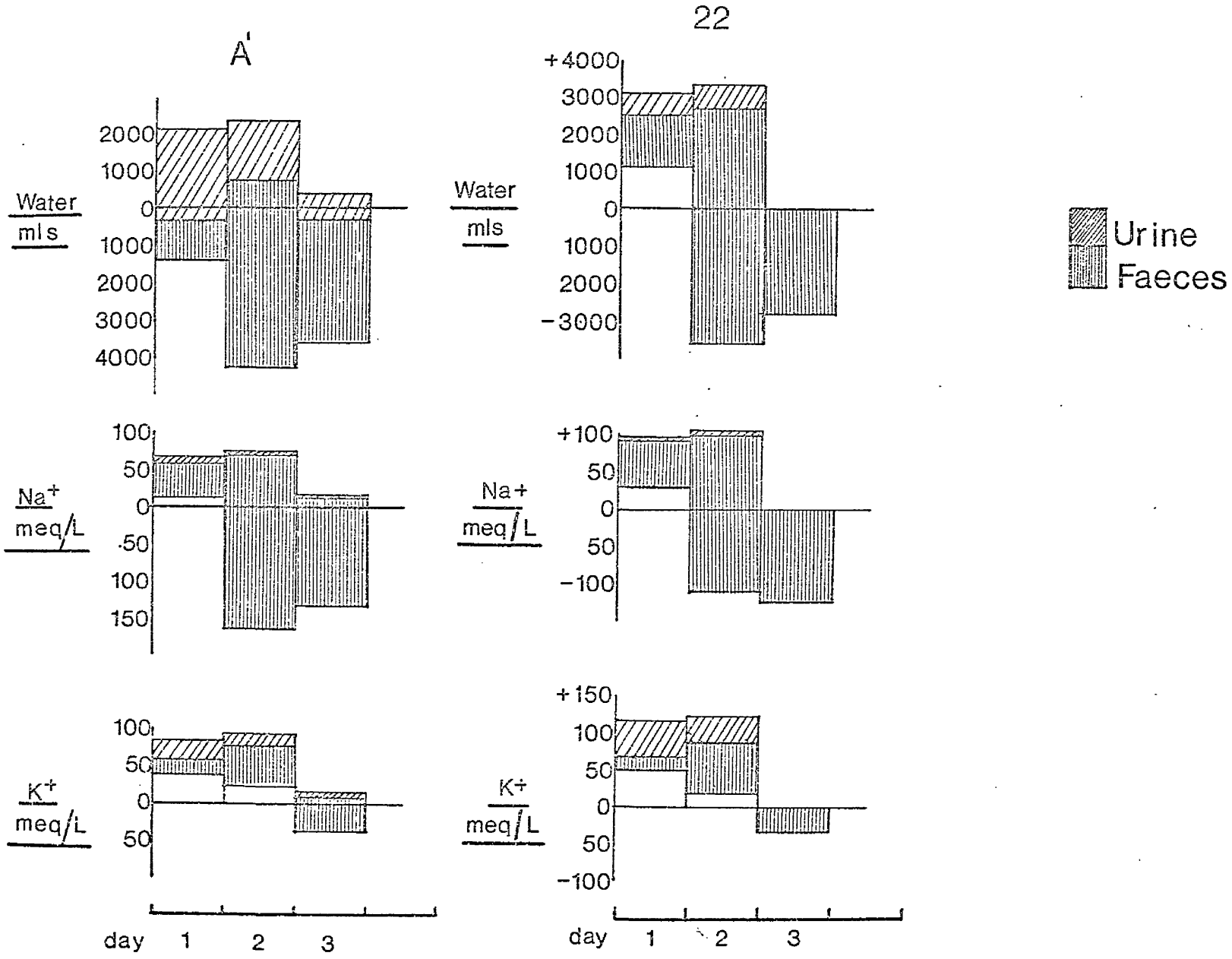


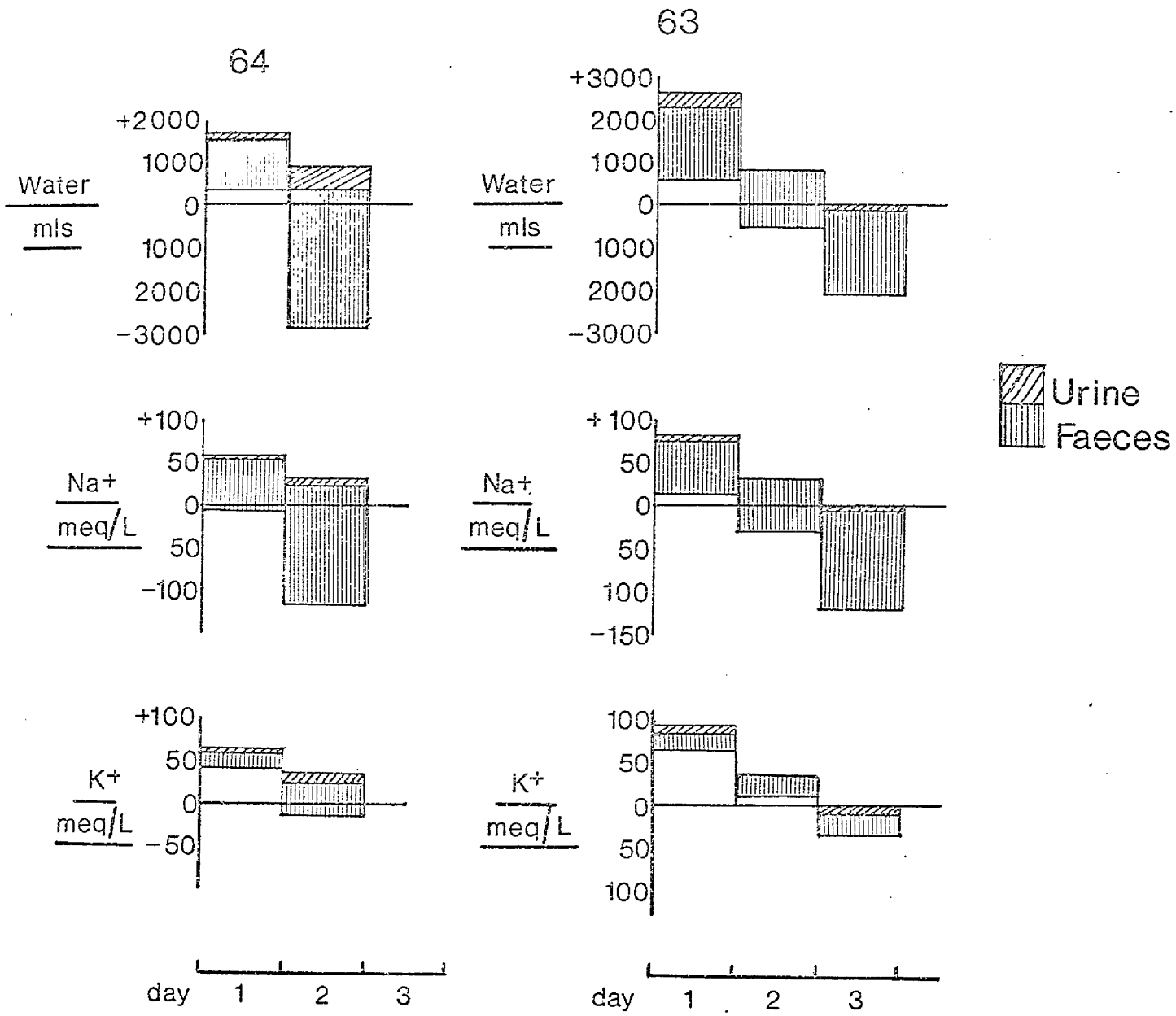
NTAKE + OUTPUT

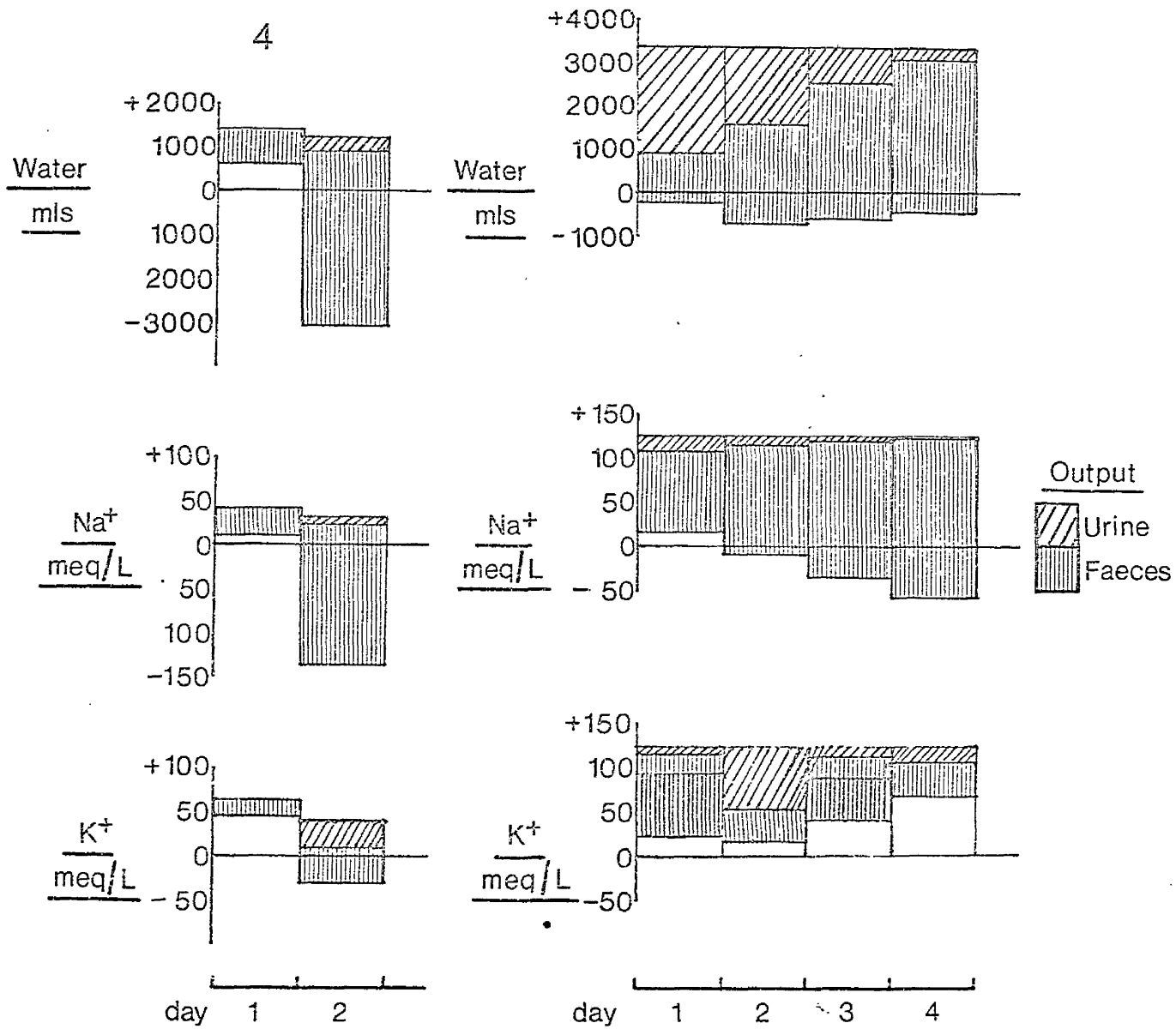
Faeces

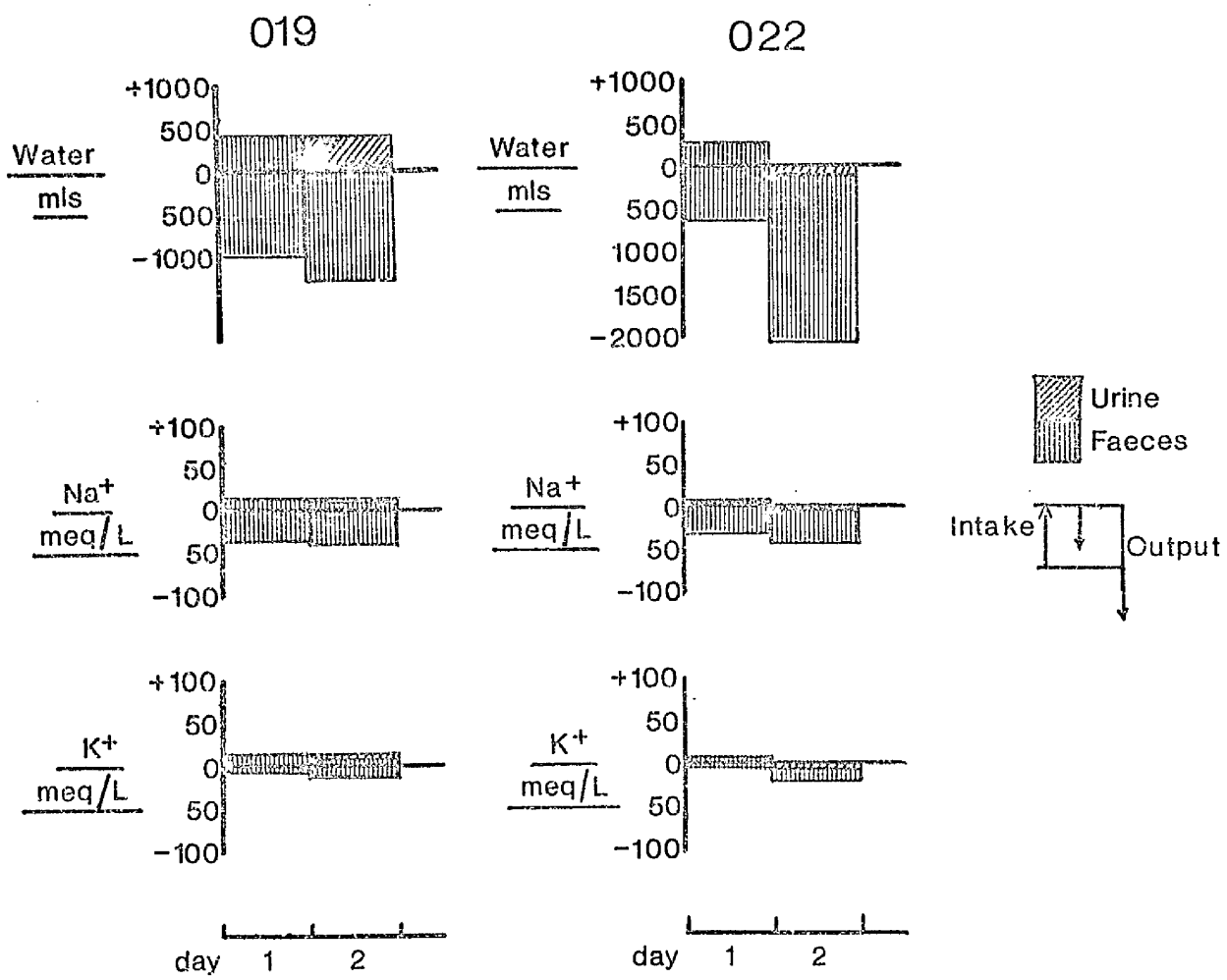
Urine

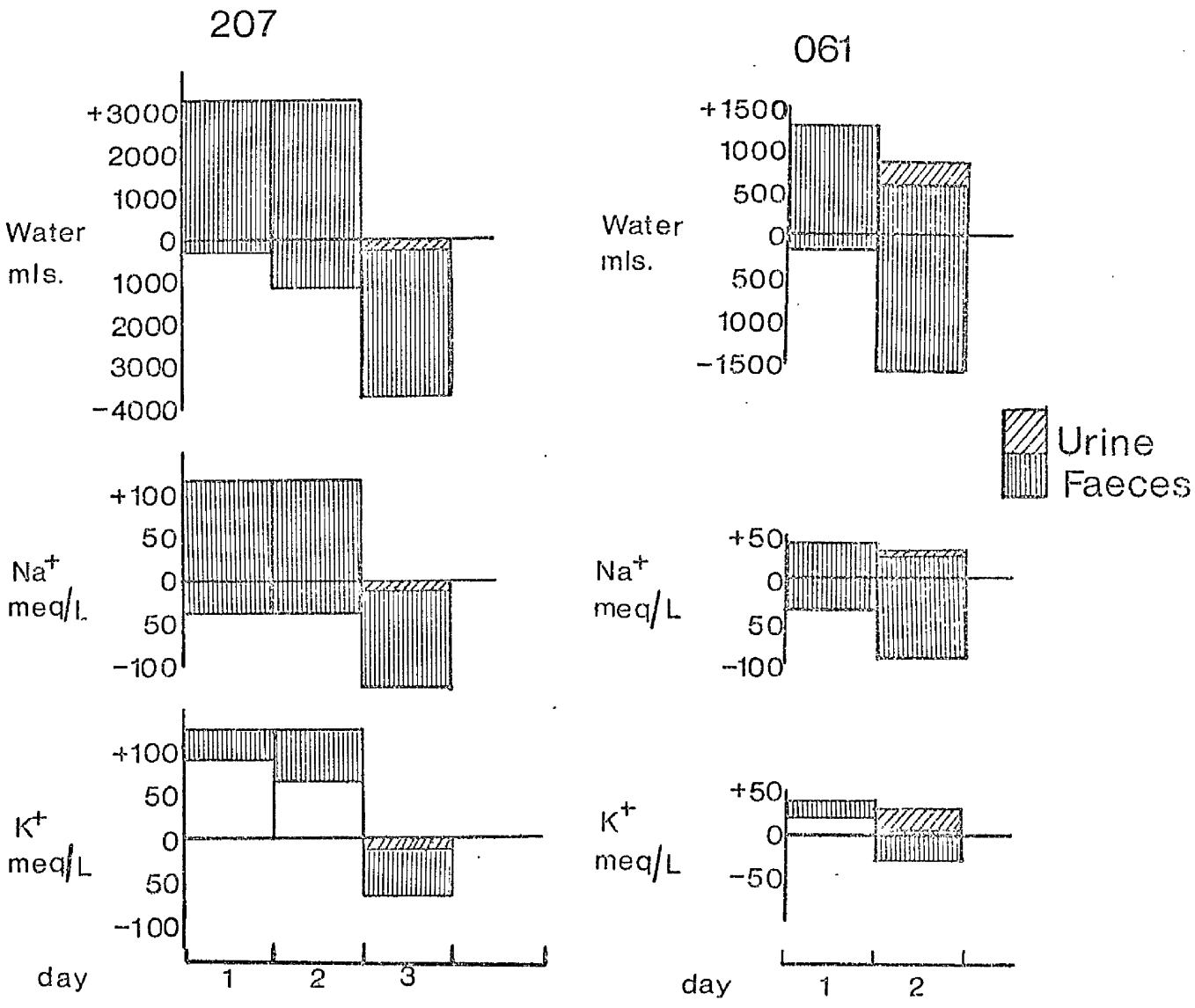
DIARRHOEIC CALVES WHICH DIED

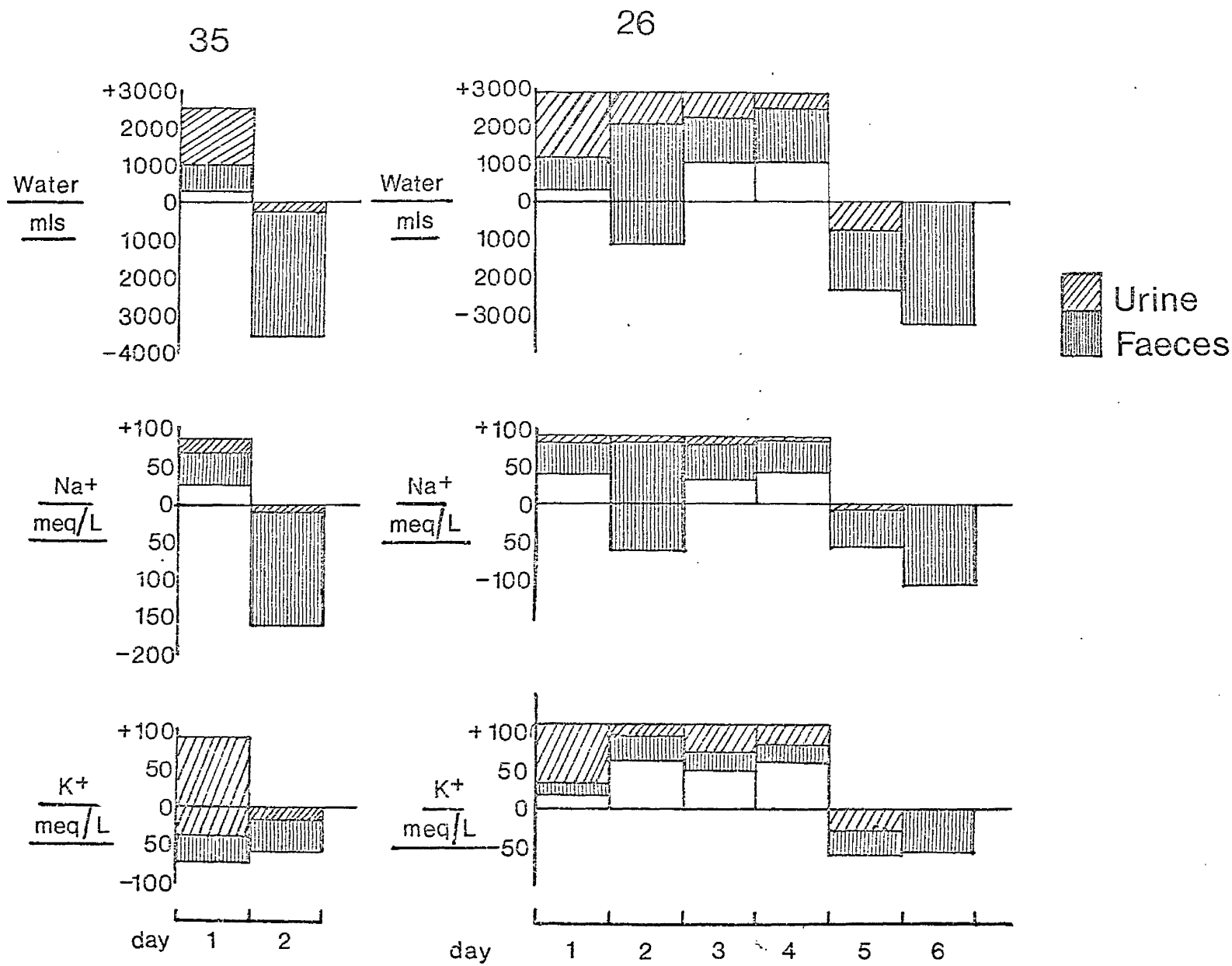

A'
Water
mls
2000
1000
0
1000
2000
3000
4000
Na+
meq/L
100
50
0
50
100
150
K+
meq/L
100
50
0
50
day 1 2 3
Water
mls
+4000
3000
2000
1000
0
1000
2000
−3000
Na+
meq/L
+100
50
0
50
−100
K+
meq/L
+150
100
50
0
50
−100
day 1 2 3
Urine
Faeces

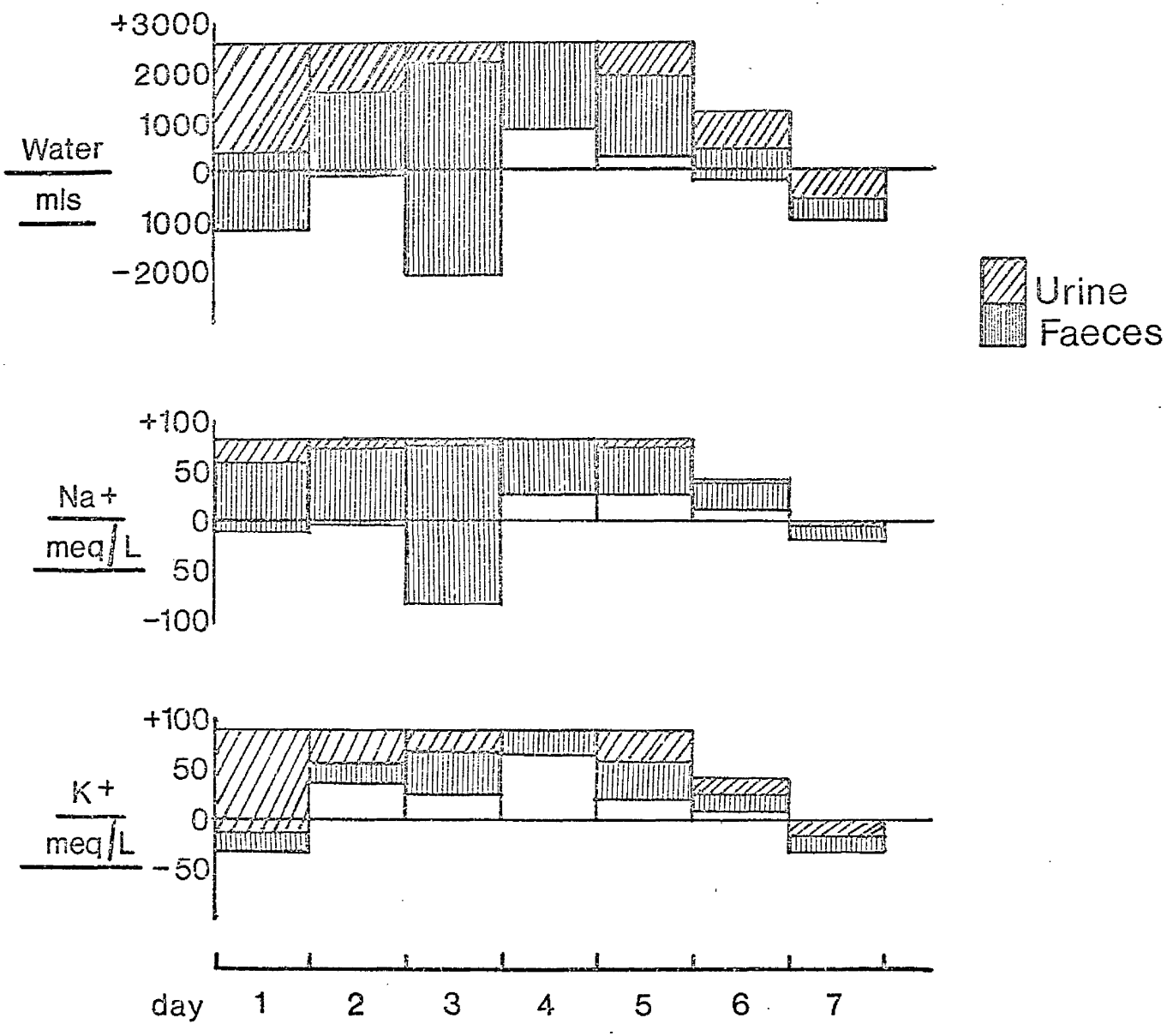

64
63
Water
mls
+2000
1000
0
1000
2000
-3000
+3000
2000
1000
0
1000
2000
-3000
Na+
meq/L
+100
50
0
50
-100
+100
50
0
50
100
-150
K+
meq/L
+100
50
0
-50
100
50
0
50
100
day 1 2 3
day 1 2 3
Urine
Faeces


4
Water
mls
+2000
1000
0
1000
2000
−3000
Na+
meq/L
+100
50
0
50
100
−150
K+
meq/L
+100
50
0
− 50
day 1 2
+4000
3000
2000
1000
0
−1000
Water
mls
+150
100
50
0
− 50
Na+
meq/L
+150
100
50
0
−50
K+
meq/L
day 1 2 3 4
Output
Urine
Faeces


019
022
Water
mls
+1000
500
0
500
−1000
1000
1500
−2000
Na+
meq/L
+100
50
−100
K+
meq/L
day
1
2
Urine
Faeces
Intake
Output


207
061
+3000
2000
1000
0
1000
2000
3000
−4000
Water
mls.
+1500
1000
500
0
500
1000
−1500
Water
mls.
Urine
Faeces
+100
50
0
50
−100
Na+
meq/L
+50
0
50
−100
Na+
meq/L
+100
50
0
50
−100
K+
meq/L
+50
0
−50
K+
meq/L
day
1
2
3
day
1
2


35
26
Water
mls
+3000
2000
1000
0
1000
2000
3000
−4000
Water
mls
+3000
2000
1000
0
1000
2000
−3000
Urine
Faeces
Na+
meq/L
+100
50
0
50
100
150
−200
Na+
meq/L
+100
50
0
50
−100
K+
meq/L
+100
50
0
50
−100
K+
meq/L
+100
50
0
−50
day 1 2
day 1 2 3 4 5 6


+3000
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Water
mls
Urine
Faeces
+100
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meq/L
+100
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1
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7

APPENDIX 5

The Plasma Concentrations of Sodium, Potassium, Bicarbonate, Urea and Osmolarity, Blood pH and Packed Cell Volume of Diarrhoeic Recovered Calves - First Sample

Calf No.	Plasma Osmolarity mOm./L.	pH	Bicarbonate mEq./L.	Packed Cell Volume %	Sodium mEq./L	Potassium mEq./L.	Urea mg/100
40	280	7.34	36	35	138	4.4	24
944	280	7.37	26	42	140	4.4	26
619	280	7.39	30	39	144	4.9	24
101	290	7.33	23	45	138	4.8	36
018	270	7.39	29	43	130	4.6	31
470	280	7.39	29.5	45	145	5.0	14
4	280	7.37	30	42	142	4.5	19
686	300	7.41	28	29.5	130	5.5	25
Mean	282.5	7.37	28.18	40.62	138.37	4.76	24.87
S.D.	±8.86	±0.024	±2.5	±5.38	±5.75	±0.37	±4.93

APPENDIX 6

The correlation between the total body water loss and the increase in packed cell volume per cent.
($r = 0.17$ p = not significant)

Calf No.	Total Body water Loss L.	Increase in P.C.V.
35	3.579	6
26	4.373	5
019	2.316	8
207	5.181	5
21	3.706	8
214	2.539	5
A1	9.390	11
061	1.734	5
022	2.751	12
4	2.480	3
64	2.605	5
22	5.566	12
63	2.144	18

APPENDIX 7

An example illustrating the volume of faeces that could be successfully collected using the method described in part III of this Thesis. S_2 has been detached from the calf, and S_3 is still attached to it. S_2 was the volume passed in 24 hours by this particular calf.

APPENDIX 8

Lateral view of the metabolic cage, used throughout the experiments performed, and reported in part III.

STUDIES ON NEONATAL CALF DIARRHOEA

Summary of a Thesis presented for the Degree

of Doctor of Philosophy of the University of Glasgow

by

Gonzalo Hector de la Fuente, M.V.Z.

The work described in this Thesis is concerned with the eff of diarrhoea on newborn calves of known serum immune globulin concentrations and the influence that such colostrum-derived passive immunity may have on the outcome of the condition. The work is divided into three parts as follows:-

Part 1

General Introduction and Review of the Literature

In this part a general review and criticism of the relevant literature concerned with the probable aetiology, pathogenesis, prophylaxis and treatment of neonatal calf diarrhoea is reported.

Part 2

Studies on the Influence of some environmental, therapeutic and managemental factors on the severity of diarrhoea, and upon the survival of newborn calves of known serum immune globulin concentration

A farm survey performed during the period from February to June 1968, investigating the serum immune globulin concentrations

of dairy heifer calves using the Zinc Sulphate Turbidity Test is reported. 327 dairy heifer calves of two to seven days of age retained in 47 closed dairy herds in the West of Scotland were sampled. Some aspects of the management prevailing on the farms were investigated and the possible effects of such management on the serum immune globulin concentrations attained by the newborn calves were looked into. The relationship between the serum immune globulin concentration and the incidence on these farms of death from E.coli septicaemia and diarrhoea is also discussed. The serum immune globulin concentrations were found to be influenced by the place of birth. Those calves born indoors, showed significantly lower values than those born out of doors. Furthermore, a significant difference was found amongst the calves born indoors, in that calves born in the byre showed significantly lower values than those born in boxes. The time of first feeding colostrum and whether the calves were left with or removed from their dams at the time of birth, also influenced the serum immune globulin concentrations. Calves born in the byre and fed colostrum within six hours of birth had significantly higher serum immune globulin concentrations than those fed after six hours, and calves born in boxes and left with their dams for more than 12 hours had significantly higher serum immune globulin concentrations than those removed from their dams at birth or when found.

The overall mortality rate for calves up to 1 month of age recorded in this survey was 11 per cent. The highest mortality rate was observed in the byre-born calves (calves with the lowest serum immune globulin concentrations) and the lowest mortality was seen in those calves born in the field (calves with the highest serum immune globulin concentrations).

It was demonstrated that by adopting a method of management whereby ingestion of colostrum by the calf occurred within six hours of birth while remaining with its mother for at least 12 hours, the serum immune globulin concentrations were increased significantly. As a result a marked decline in the mortality rate, and incidence of diarrhoea was achieved.

Experimental evidence was produced indicating that in hypogammaglobulinaemic calves, the parenteral administration of chloramphenicol, and the oral administration of Furazolidone used as treatment and as prophylactic measures, had little beneficial effect on the outcome of calf diarrhoea.

Using hypogammaglobulinaemic calves, with similar serum immune globulin concentrations no difference was found in mortality rate between diarrhoeic calves treated intravenously with fluid and electrolytes (Darrow's solution) and untreated diarrhoeic calves.

Experimental evidence was produced suggesting that the

protective properties of a high serum immune globulin concentrati was more effective against calf diarrhoea than any of the above mentioned therapies. The oral use of anticholinergic substances would appear to be contraindicated in the diarrhoeic syndrome observed in the present study.

Part 3.

Studies on the faecal water and electrolyte losses in normal diarrhoeic surviving and diarrhoeic dying newborn calves of known serum immune globulin concentrations, and the correlation of these losses with the changes in the plasma electrolytes, osmolarity, blood pH, urea and packed cell volume

Balance studies of water, sodium and potassium were perform on seven normal newborn calves, and on 21 newborn calves sufferin from different degrees of diarrhoea. This last group was divided into dying diarrhoeic (13 calves) and surviving diarrhoeic (8 calves).

Normal calves fed cow's milk at a rate of 10 per cent of their bodyweight, retained 42 per cent and 36 per cent respectively of the sodium and potassium ingested per day, and only 25 per cent of the water ingested. A very small amount of sodium and potassium was lost through the faeces, but a considerable amount was excreted by the kidneys. In the dying diarrhoeic calves and diarrhoeic recovered calves the excretion

of such substances was completely reversed, the main losses occurring through the faeces. The dying diarrhoeic calves, although capable of concentrating their urine, promptly fell into a negative balance of sodium and water. The deficits for sodium and water were the most impressive findings, potassium in the present study did not seem to be lost to such a great extent. No relationship could be shown between the continued ingestion of milk and the severity of diarrhoea. It became apparent that when the diarrhoeic calves refused to drink, an exacerbation of the deficits occurred. A wide variation in the total deficit of sodium and water was observed in the dying diarrhoeic calves, with a mean loss of 133 millilitres per kilogram per day of water and 4.2 m.Eq. per day of sodium.

A highly significant negative correlation was found between the serum immune globulin concentration and the severity of diarrhoea of calves kept in metabolic cages. This would suggest that the immunological status of the calf is not only essential in protecting against the septicaemic form of colibacillosis, but that it also plays a vital role in preventing death from diarrhoea. Further evidence indicating that this is the case was found when comparing the zinc sulphate values of the dying diarrhoeic, diarrhoeic recovered and normal calves. A significantly lower immune globulin concentration prevailed amongst the dying diarrhoeic calves.