WATER METABOLISM IN INDIGENOUS CATTLE, SHEEP AND GOATS IN ZARIA, NIGERIA

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THESIS APPROVAL

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DEDICATION

This thesis is dedicated to my parents, my wife and my children, for all they represent in life.

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ABSTRACT

INTRODUCTION

In Nigeria, as in most countries, increased production of protein, especially of animal origin, has become a pressing problem. This is particularly important in tropical countries, where such problems are more numerous and less easily resolved than in temperate countries. Tropical countries have special, and often unique problems, limiting animal production: adverse climatic factors and their interaction with disease; parasites; and feed availability. Intensive investigations into various aspects of these complex interactions and their effects on productivity are urgently required. Measurements of water content and turnover are of interest apart from their possible relationship to body composition. Some significance in adaptation to tropical environments has been ascribed to such measurements (Bianca et al., 1965; MacFarlane and Howard, 1966).

Water metabolism in different species and breeds of livestock and under different environmental

conditions, has been investigated in many parts of the world, but information related specifically to Nigeria is lacking. The objective of this study was to fill this gap. The work described below was therefore designed to investigate any environmentally - induced, adaptive physiologic characteristics in water requirements and metabolism that may be present in cattle, sheep and goats indigenous to the environs of Zaria, Kaduna State, Nigeria. The specific objectives were to investigate the:

1. Seasonal variations in water metabolism in penned indigenous cattle, sheep and goats;
2. Seasonal variations in water metabolism in grazing indigenous cattle, sheep and goats;
3. Influence of total water deprivation on water metabolism in indigenous cattle, sheep and goats; and
4. Physiologic responses of indigenous cattle, sheep and goats to water deprivation.

CHAPTER 1

REVIEW OF THE LITERATURE

A. WATER METABOLISM IN MAMMALS

1. Introduction

The distribution or survival of mammals is a function of both their genetic constitution and their environment. Environment consists of those physical and biotic variables which influence and program animal behavior and physiologic responses. The animal-environment interaction represents an open thermodynamic system, the animal body serving primarily for the flow-through of energy and matter. An animal is thus at the center of an ecosystem, affecting and being affected by its environment. A major environmental variable which governs the limits of any species is climate. Climate constitutes the summation, in time and space, of the average meteorological conditions in a given region.

2. The water environment

Another important factor in the environment of

animals is water. The importance of water in the environment of living things has been well-documented (Henderson, 1913; Coker, 1938; Rubey, 1951; Sykes, 1955; Robinson, 1957; Platt, 1964). Water serves many important functions in the physiologic economy of animals. As the extracellular fluid, it constitutes the internal environment, which Claude Bernard (1878) termed "le milieu interieur". This internal environment is maintained within narrow limits by an array of regulatory mechanisms, which enable an animal to adapt to a wide range of external conditions.

Water makes up to 55-65% of active protoplasm. The physical and chemical properties of water make it uniquely suited as an external or internal medium for life. It has a high heat capacity, and is therefore capable of transferring large amounts of heat. This provides an immediate thermal buffer as the first line of defense against damaging local increases in the temperature of active tissues. This helps to maintain relatively uniform temperatures, an important requirement, especially in homeotherms. Water possesses a high dielectric constant, which makes it an ideal

solvent and medium for molecules and ions that take part in biochemical reactions in the body. In addition, water is an obligatory chemical requirement for all hydrolysing enzymes in the body.

Water and energy metabolism in mammals are interdependent, and both are influenced by the animal's immediate environment. Most arid and semi-arid tropical environments are characterized by wide ranges of temperature, scanty and irregular precipitation, and poor vegetation, which contribute to the slow growth rate and poor productivity of animals in these regions. The Sahelian vegetation zone possesses most of these features. In such extreme biotopes, only those animals which possess effective mechanisms that enable them to adapt to such ecological niches, are able to survive.

Water requirement and its metabolism in farm animals are governed by such factors as ambient temperature, level of feed, age, body size, milk yield and the degree of salinity of the water. Water intake, at a given temperature, is related to the amount and type of feed consumed. Steers on a high protein feed consumed significantly more water than those on low

protein rations (Ritzman and Benedict, 1924; Sykes, 1955). Castle (1950) has also reported that the amount of water consumed by grazing dairy cows was positively correlated with the dry matter content of the herbage. This relationship, however, is affected by the water content of the feed. The higher the water content of feed, the less the water requirement, and cattle consuming succulent pastures have been observed not to drink at all (Church et al, 1972).

Sheep and cattle tolerate moderate degrees of salinity (less than 1% of their feed) but they will increase their water intake when the salt concentration in their diet increases (Wilson, 1966). Thus the addition of salt to protein supplements increased water consumption in cattle by as much as 22-100% (MacIlvain, 1953; Riggs et al., 1953; Kelly et al., 1955). These findings were supported by observations of Schmidt-Nielsen (1964) who reported that desert-adapted animals increased the amount and frequency of drinking water when they were forced to consume plants high in salt content.

In all homeotherms, food intake is negatively correlated, and water intake positively correlated, with the ambient temperature (Brobeck, 1948, 1960; Kibler et al., 1949). The higher the temperature, the greater the amount of water consumed, due partly, to the increased need to dissipate heat by evaporation of water from the skin surface in order to maintain normal body temperature (Johnson et al., 1958; Chowdhruy and Sadhu, 1961; Kamal et al., 1962; Amakiri and Mordi, 1975).

Furthermore, high temperature and low relative humidity increase water consumption in sheep and cattle (Hoffman and Self, 1972; Olbrich et al., 1973; Bhattacharya and Hussain, 1974). Kamal (1965) considered these changes as evidence of physiologic and nutritional adaptations in response to heat stress.

With increasing environmental temperature above the comfort zone, animals dissipate the greatest part of their heat load through the most efficient system, i.e., evaporative cooling, mainly through sweat (Kamal et al., 1962). Breed differences in sweating rates have been observed in cattle (Johnson, 1970; Amakiri and

Mordi, 1975). Bos indicus and other breeds evolved in the tropics possess higher sweating rates than Bos taurus breeds, especially at higher temperatures. This is thought to be due to the greater activity of sweat glands of tropical cattle (Jenkinson and Nay, 1973).

B. USE OF TRITIATED WATER (^3H_2O) IN STUDYING WATER METABOLISM IN ANIMALS

1. Introduction

Recognition of the growing need for simple but dependable measurements of dynamic physiologic changes in developing animals, and the availability of sensitive tracer equipment and methodology, have contributed greatly to development of techniques for differential evaluation of body composition of animals without resort to slaughter (Hansard, 1964). Farm animals are especially adaptable to such studies because of their economic importance and the large size of their major metabolic pools.

Most studies of water metabolism in animals have employed the principle of indicator dilution technique. By this technique, it is theoretically possible to measure the size of each body fluid compartment by administering a marker substance which remains in only one compartment, and then calculating the volume of distribution of the marker. Volume of distribution can be calculated for any substance that can be injected, provided its concentrations in body fluids and amounts removed by excretion and metabolism can be accurately measured. Although the principle involved in such measurements is relatively simple, some important factors have to be considered. The material injected must be non-toxic, must mix evenly throughout the compartment being studied, and must have no inherent effects on the distribution of water or other substances in the body. In addition, it must be unchanged during the mixing period and must be relatively easy to measure.

Wellington et al. (1956) compared the estimation of body water using antipyrine (AP) and by tissue analysis, and found a correlation coefficient of 0.94

between the two methods. In contrast to this, however, Garret et al. (1959) made 45 direct comparisons in cattle between body water calculated from antipyrine and from specific gravity methods, and found the results too variable to be useful. A combination of antipyrine and N-acetyl-4-amino-antipyrine (NAAP) was used to estimate body water in sheep (Bensadoun et al., 1963). NAAP is excreted slowly into the gastrointestinal tract of sheep, and thus could be used only to estimate an ingesta-free body composition. It was not reliable in estimating body water in the intact animal. Deuterium, labelled and stable pyrazolones, thiocyanates, and numerous other substances have been employed in estimating body water, but none has been found to be satisfactory (Kraybill et al., 1953; Reid et al., 1955; Wellington et al., 1956; Garret et al., 1959).

Among markers that have been used to study water metabolism, tritiated water (^3H_2O) has been found to be the most satisfactory. Since its discovery in 1939, tritium has largely replaced other substances as the marker of choice for studying water metabolism in intact animals (Panaretto, 1963). Tritiated water

appears to be handled essentially like normal water. When injected in low concentrations, it fulfils most of the requirements for an ideal marker (MacFarlane et al., 1972).

2. Administration

Although $^{3}H_2O$ may be given by mouth, it is more difficult to obtain quantitative injestion than by parenteral administration. During efforts to get an animal to drink or to administer the tracer via a stomach tube, there may be struggling, rejection of fluid by the tongue or spillage of part of the dose. One advantage of oral administration, however, is that, if reasonable rumen samples can be obtained subsequently, rumen volume and rate of passage of material from the rumen can be measured (MacFarlane et al., 1972).

Injection of $^{3}H_2O$ in sterile isotonic solution (150 mM sodium chloride) is the most expeditious and accurate approach. The tracer can be injected intravenously, intramuscularly, intraruminally or subcutaneously. In addition to being the easiest way to

administer a quantitative dose, the intramuscular route also gives a slightly slower rate of uptake compared to the intravenous route. This means that the initial plasma levels of the tracer are lower than they would be following intravenous injection. As a result, renal loss, particularly in animals like cattle with fast urine flow, is less over equilibration time. The usual loss through urine, feces, sweat and respiratory water output before equilibration is less than 1% of the injected dose (MacFarlane et al., 1972).

3. Equilibration

An important assumption underlying the tritium dilution technique is that the injected tracer mixes instantly and uniformly with the body water pool, but the time taken for equilibration to occur is variable and depends to a great extent on the species. In non-ruminants such as man, dog or pig, tracer water distributes to extracellular, transcellular, and intracellular water spaces in one to two hours (MacFarlane, 1968;

MacFarlane et al., 1969). This is also true for neonatal lambs and calves. As the rumen develops, however, mixing time increases because of the relatively large ruminal volume which has to be equilibrated with tracer, mainly through salivary flow. Transruminal passage contributes only a small amount of water. When animals have good salivary flow, and are well-hydrated, time for equilibration in sheep and goats is five to six hours, cattle seven to eight and camels eight to ten hours (Stepankina and Tashenov, 1958; Morris et al., 1962; MacFarlane and Howard, 1970). Reduction in salivary flow as occurs during dehydration, prolongs the equilibration time. Once equilibration has occurred, there is theoretically no difference between the ratio of tritium to protium in any of the body fluids at any given time.

4. Calculation

In steady state, body water behaves as a single pool, in which injected tritium undergoes simple dilution after mixing time. The concentrations of tritium in blood samples taken after mixing time decrease exponentially with time, and individual values fit closely the linear regression calculated by the method of least squares. The rate of disappearance of marker is expressed as a "half-life" value, $T_{\frac{1}{2}}$, i.e., the time taken for the plasma activity to fall by 50%. The mathematical equation that describes this relationship is:

$Y = a + bX$, where Y = log of specific activity of tritium

a = intercept (log)

b = slope constant

X = time (days)

The Y intercept (or equilibration count rate) gives the theoretical value of specific activity at zero time, which should have been obtained if the injected marker had been distributed instantly throughout the pool. This value can be obtained by regression

analysis and is used to calculate total body water (TBW) as follows:

$$\text{Total injected activity} = \frac{\text{Net count rate of "standard" x weight of tracer injected}}{\text{Weight of "standard"}}$$

$$\text{TBW (ml)} = \frac{\text{Total injected activity}}{\text{Equilibration count rate}}$$

$$\text{TBW (\% body wt.)} = \frac{\text{TBW (kg)}}{\text{wt. of animal (kg)}} \times \frac{100}{1}$$

The slope of the regression line (b), multiplied by 2.3 (to convert Briggsian to natural logarithm) represents the rate of turnover of body water pool, (k).

The half-life and daily turnover of body water can be calculated from the following relationships:

$$T_{\frac{1}{2}} \text{ (days)} = \frac{0.693}{k}$$

$$\text{Daily turnover (ml)} = k \times \text{TBW}$$

Anand, R.S., and H.R. Parker. Total body water and water turnover in sheep. Am. J. Vet. Res. 27: 899-902, 1966

Chase, G.D. and J.L. Rabinowitz. In: Principles of Radioisotope Methodology. 3rd ed. Burgess Publishing Company, Minneapolis, p. 458, 1970.

Hansard, S.L. Total body water in farm animals. Am. J. Physiol. 206: 1369-1372, 1964.

5. Expressing water turnover

Water turnover has been expressed in terms of ml/kg/24 hours but this has two disadvantages:

(1) Body weight may contain various proportions of fat or rumen content. It is, therefore, more relevant to physiologic processes to express water turnover in terms of ml/l of body water/24 hours.

(2) The second disadvantage arises from the effects of body size on functional processes. The empirical relationship between size and energy turnover is given as $\text{mass}^{0.75}$ (Brody, 1945; Kleiber, 1961). For water, there is a different empirical relationship, namely, $\text{mass}^{0.82}$ (Richmond et al., 1962, MacFarlane and Howard, 1970). For comparing the rate of water use by animals of different sizes, this exponential provides a useful baseline.

6. Limitations of the technique

Although tritiated water has been considered to be more reliable than most substances in studying water

metabolism, the technique possesses some limitations: exchange with protium, and differential rate of equilibration.

7. Exchange of tritium with protium in the body

Total body water and tritiated water spaces are usually equated, despite the fact that injected tritium exchanges with labile protium in the body, thus overestimating the extent of dilution that would have occurred. Although the amount of such exchange has been estimated variously at 0.5-2% (Pinson and Langham, 1957; Panaretto and Till, 1963; Springell, 1968), the exact magnitude of this factor is uncertain as it is difficult to determine experimentally. The principal source of labile protium is body protein (Springell, 1968). Other tissues such as fat and bone contain little, if any, labile hydrogen. Rumen contents on a dry weight basis represent only a minor proportion of the body. Nevertheless, the hydrogen-tritium exchange potential of the major ruminal components,

cellulose and protein of the flora, is similar to that of body protein (Lang and Mason, 1960). Although exchange conditions are dependent on the nature of the protein, model studies with insulin have found that, under physiologic conditions, only about 1.5% of dry protein by weight is available for exchange (Leach and Springell, 1962).

8. Differential rate of equilibration

The tritium dilution technique assumes that, once equilibration has occurred, the tracer water should be evenly mixed in all body fluids. This has been proved not to be so (Robertshaw, 1975). Movement of water into fluid compartments follow ionic transfer and is determined by the relative blood flow, e.g. into cartilage and bone, and by the presence of a taxie e.g. the blood-brain barrier. Equilibration thus occurs at different rates in body tissues. As a result, body water is likely to be underestimated, although the extent of such an error is small.

In spite of these limitations, the tritium dilution technique is regarded generally as the most reliable method for studying water metabolism in domestic animals. MacFarlane and Howard (1966) achieved a high degree of reproducibility of water content and turnover between identical twin cattle using tritiated water, and considered this to be good evidence for the validity of the technique.

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CHAPTER II

SEASONAL VARIATIONS IN WATER METABOLISM IN PENNED INDIGENOUS CATTLE, SHEEP AND GOATS IN ZARIA, NIGERIA.

INTRODUCTION

Most tropical and sub-tropical climates are characterized by prolonged periods of high ambient temperatures, irregular and scanty precipitation, and low quantity and quality of available feed. Animals indigenous to such unfavorable environments often have to contend with two major physiologic problems: obtaining sufficient food and water, and maintaining body temperature within limits optimum for normal function. Such environments may be responsible for decreased productivity either indirectly by enhancing susceptibility to disease, or directly by precipitating nutritional stress.

Within wild and domestic mammals, a range of mechanisms have evolved for adaptation of body processes to cope with high ambient temperatures. These adaptations vary from a high degree of control of body temperature using much water, to a relatively labile body temperature associated with thrifty and economical water use.

Water metabolism in animals under defined environ-

mental conditions has been widely studied. There is, among animals, a hierarchy of water turnover rates (MacFarlane et al., 1972). High rates of water turnover are found in animals in the tropics such as water buffaloes, Banteng, cattle, elands and pigs. In cattle, the Hereford breed has the highest rate of water turnover and also the highest content of body solids, while Zebu-type animals use less water under similar conditions (MacFarlane et al., 1972). Rates of turnover are intermediate in the donkey, low in sheep and goats, and lowest in desert mamals like the camel (MacFarlane, 1968; MacFarlane and Howard, 1970; MacFarlane et al., 1972).

Kinetics of water metabolism in penned animals have been studied by many workers. The biologic half-life of tritiated water in cattle was reported to be 3.5 days in both lactating and non-lactating cows, and 3.4 days in mature bulls (Black et al., 1964). Aschbacher et al. (1965), however, obtained values of 2.9 and 3.1 days for two lactating, and 5.0 and 5.4 days for two non-lactating cows, respectively. On the other hand, Kamal (1975) compared data from lactating and non-lactating Red Danish cattle and water buffaloes,

and reported that the biologic half-life of injected tritium was significantly longer in lactating than in non-lactating animals.

The biologic half-life of tritiated water has also been compared in two groups of penned steers maintained on different planes of nutrition (Springell, 1968). In a well-fed group, the half-life was shorter (2.4 days) during warmer months, while it was generally longer, (6.1 days), and more constant, in undernourished steers. This author observed that the biologic half-life of tritium reported was dependent on the season and plane of nutrition.

The volume and rate of turnover of body water in stall-fed animals have been documented. Kamal (1975) found that total body water was significantly less in lactating cows and water buffaloes, while the rates of turnover were correspondigly higher than in heifers. In a series of comprehensive studies (Kamal and Seif, 1969; Kamal et al., 1972), water content and turnover rates were compared in camels, sheep, cattle and water buffaloes. Their data revealed that total body water,

as per cent of body solids, was highest in water buffaloes, followed by camels, sheep and cattle. Water turnover, as per cent of body weight, however, did not follow this order. Water buffaloes and sheep were similar in this respect, followed by cattle, while camels were found to have the lowest turnover rate.

A knowledge of water metabolism of various species and classes of herbivores in any environment is valuable in assessing their adaptation to that environment. Since no information is available on seasonal changes in water metabolism in farm animals in Nigeria, this study was designed to investigate such changes.

MATERIALS AND METHODS

Experimental Animals

The experimental animals consisted of six adult, clinically healthy, male Bunaji cattle, Yankassa sheep, and Sokoto Red goats (Appendix 2, Fig. 1-3). The cattle and sheep were obtained from the herd located at

the Ahmadu Bello University Farm, while the goats were purchased locally. All animals were castrated and preconditioned to the experimental environment for three months. Water and feed were available ad libitum, and the normal maintenance ration consisted of dry gamba hay, groundnut cake and cotton seed. The animals were examined routinely and treated for internal and external parasites[1]. Two steers sustained fractures and could not continue to be used, while one sheep died of pneumonia.

Environment

The investigation was conducted at the University Farm, located six kilometres from the main University campus at Samaru, Zaria (Appendix 1). The animals were housed in individual pens under a common roof (Appendix 2, Fig. 4). The cattle pens measured 1.8 x 3.7 metres, and the sheep or goat pen measured 1.8 x 1.8

[1]Thiabenzole-Thiabendazole, Merck Sharp & Dohme Ltd. Hoddeston, U.S.A., and Pfizona, Pfizer Products, Ltd; P.M.B. 111, Ikeja, Nigeria.

metres. The pens were located adjacent to a crush and weighing scales, where the steers were weighed and blood and other samples collected, after which they were returned to their individual pens. The trials were conducted during three periods of the year: March-April (hot season), July-August (rainy season), and December-January (cold season). Daily and monthly meteorological data were obtained from the Institute for Agricultural Research, Samaru (Appendix 3, Fig. 5-7).

Measurements

The animals were weighed daily for the duration of each trial, which lasted seven days. Daily rectal temperatures were taken. Amounts of feed and water consumed by each animal were measured daily as the net difference in weight between full containers and the weight of containers plus the balance of whatever remained on the next day. The net amount of water consumed by each animal was obtained by subtracting the amount due to evaporation, which was estimated as the

average difference in weight, within 24 hours, of two similar containers placed inside the barn. Hemoglobin (Hb), packed cell volume (PCV), total erythrocytes (RBC) and total protein concentrations were determined for the duration of each trial as described by Coles (1974). All measurement were performed at the same relative time each day.

Water metabolism trials were conducted using tritiated water[2]. This had a specific activity of 5 mc/ml. Tritiated water, in sterile isotonic saline, at the rate of 3 ml for cattle, and 1 ml for sheep or goat, was injected intramuscularly using a 19-gauge, 5-cm needle. The exact amount of tracer administered was determined by carefully weighing the syringe before and after injection. After the needle was inserted, a syringe containing the calculated amount of tracer, plus a small air bubble, was attached and the content carefully injected. The air bubble was used to force the last dose of tracer

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[2]Radiochemical Center, Amersham, England.

through the needle. The needle was withdrawn slowly while pressure applied over the insertion point to prevent any backflow of marker. The time of each injection was recorded.

Ten milliliters of blood were collected from the jugular vein of each animal before administration of tracer and daily for seven days thereafter. Disodium salt of ethylene diamine tetraacetic acid (EDTA) (0.8 mg/ml of blood) was used as the anticoagulant. The time of blood collection from each animal was recorded. Blood was centrifuged at 3500 rpm for 15 minutes and the plasma decanted into test-tubes. One milliliter of 20% trichloroacetic acid (TCA) was added to one milliliter of each supernatant to denature the proteins, the test tubes were then shaken in a shaker for one minute, centrifuged for 10 minutes, and the protein-free supernatant removed. Samples for counting were prepared in counting bottles by mixing 0.25 ml of deproteinised plasma with 4.0 ml of liquid scintillator[3] and 6.0 ml of absolute ethanol. Samples

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[3] PCS™ from Amersham Seale Corp.

were counted together with standards and blanks in a well-type liquid scintillation counter[4] at 4°C, for five minutes. Each sample was counted four times. Standards were prepared by adding a carefully weighed volume of the original stock solution of tracer into a two-litre volumetric flask and making up to mark with distilled water. The solution was well-mixed and one millilitre removed and treated as above. Blanks were similarly prepared by treating pre-injection blood samples as described above.

Calculation

Mean count rates of the blanks were substracted from the counts of both the standard and the unknown samples. This gave the mean net count rates which were used for calculations as described in Chapter I. Statistical analyses using analysis of variance and student t-test were performed as described by Snedecor and Cochran (1973).

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[4] Scaler Ratemeter SR 3, model NE5503 No. 022, Nuclear Enterprises Limited, U.K. 1974.

RESULTS

Water intake by penned animals is shown in Table 1 and Appendix 4 (Tables 1-3). Intake in the three species, either as absolute (kg) or as relative (ml/kg or ml/$kg^{0.82}$) value, is significantly different ($P < 0.01$) between any two seasons. It was highest during the hot season and lowest during the cold season. In any season, there was a hierarchy of water intake, cattle consumed the largest amount, followed by sheep and goats, respectively. In all species, seasonal differences were most apparent when intake was expressed as $mass^{0.82}$.

Seasonal variations in feed intake are presented in Table 2 and Appendix 4 (Tables 4-6). Amount of feed consumed by each species was greatest ($P < 0.01$) during the cold season, with goats consuming relative more feed ($P < 0.01$).

Water turnover by penned animals is presented in Tables 3-5 and Appendix 5 (Tables 7-15). Seasonal variations in total body water are shown in Table 3. Significant differences ($P < 0.05$) in absolute total

body water were observed between the hot and rainy seasons in both sheep and goats. In all species, water content tended to be highest during the hot season, followed by the cold and rainy seasons, respectively.

In cattle, total body water as per cent body weight was significantly higher ($P < 0.05$) in the hot season than in either the rainy or the cold season, while in sheep and goats, it was significantly higher ($P < 0.05$) in the hot and cold seasons than in the rainy season. Intra-species seasonal variations were also observed between the hot and rainy seasons between cattle on one hand, and sheep and goats on the other. Total body water as per cent body weight was significantly higher ($P < 0.05$) in cattle during either hot or rainy season compared to sheep or goats.

Mean biologic half-life of tritiated water and pool turnover rates are presented in Table 4. Species and seasonal variations in biologic half-life were observed. The half-life was shortest in all species during the hot season, and longest during the cold season. In any season, significant ($P < 0.01$) species

variations were also observed, cattle having the shortest half-life, followed by sheep and goats, respectively.

Variations in pool turnover rates generally followed an inverse relationship to half-life. In all species, pool turnover rate was highest ($P < 0.01$) during the hot season, followed by the rainy and cold seasons, respectively. Goats had the lowest ($P < 0.01$) rate during the hot and rainy seasons and cattle the highest. No significant difference was observed in turnover rates between sheep and goats during the cold season, but their turnover rates were significantly lower ($P < 0.01$) than those obtained for cattle during the same season.

Daily water turnover is shown in Table 5. Significant ($P < 0.01$) seasonal variations were evident in the daily amount of water turned over by cattle. Turnover was least during the cold season, and largest during the hot season. In either sheep or goats, however, no significant differences were observed between the cold and rainy seasons, but values

during these two seasons were significantly lower ($P<0.05$) compared to the hot season. In any season, significant differences ($P<0.01$) were observed between all species. Cattle turned over the largest amount, and goats the least.

Data on seasonal variations in hematologic parameters and in total protein concentrations are presented in Table 6 and Appendix 6 (Tables 16-27). Significant seasonal variations were not observed, but in all species, values tended to be higher during the rainy season.

DISCUSSION

Results of seasonal and species variations in water intake by penned animals parallel those previously reported by several workers (Brobeck, 1948, 1960; Kibler et al., 1949; Johnson et al., 1958; Kamal et al., 1962). The significant increase in water intake by all species during the hot season reflects the physiologic cost of maintaining homeokinesis with

particular reference to water metabolism. Water is the most important means of regulating body temperature when ambient temperature rises above the body temperature (Johnson et al., 1958; Kamal et al., 1962; Hainsworth et al., 1968). Thus, at the ambient temperatures occuring during the hot season in Zaria (average air temperature 36.6°C), more water is consumed by animals to replace that lost through evaporative cooling.

Decrease in feed intake by all species during the hot season is also in agreement with published data (Ragsdale et al., 1948; Brobeck, 1948, 1960; Hamilton, 1963). Under stress, in this case thermal stress, the major responses are directed towards maintaining the "constancy" of body functions and reducing the physiologic impact of the stress. Thus, at temperatures above the zone of thermoneutrality i.e., upper critical temperature, feed intake is reduced, because of difficulty in heat dissipation, since any extra heat obtained from feed may embarrass the system, resulting in hyperthermia (Brobeck, 1960).

During colder months (average air temperature 20.8°C), however, when ambient temperature is lower than body temperature, animals lose heat to the environment, and physiologic emphases shift from dissipating to conserving heat (Schmidt-Nielsen, 1964). Metabolic rate rises, and feed intake is increased. The relatively greater feed intake in goats and sheep compared to cattle emphasises the effect of metabolic body size ($mass^{0.75}$) on functional processes. The influence of temperature on both feed and water intake appears to be central and is mediated by hypothalamic receptors (Anand, 1961).

Water metabolism data obtained from this study are similar to those already reported (Kraybill et al., 1953; Anand, 1961; Till and Downes, 1962; Hansard, 1964; MacFarlane, 1964; MacFarlane and Howard, 1966; Springell, 1968; Kamal et al., 1972). Lack of seasonal variation in total body water observed in this study differs from data previously published (MacFarlane and Howard, 1966; Maloiy, 1970; Springell, 1968). Water content of animals is influenced by factors such as

species, age, sex, ambient temperature and plane of nutrition. In the present study, ambient temperature was an important contributory factor to the seasonal pattern of total body water observed in the test animals. It is well established that body water and body fat are inversely related (Shumway et al., 1956; Panaretto and Till, 1963; Reid et al., 1955; Cameron and Luick, 1972). Temperature affects body fat content by decreasing feed intake (Cameron and Luick, 1972), and therefore decreasing the amount of fat that an animal lays down. Seasonal variations in total body water observed in these animals is, therefore, probably an indication of seasonal variations in their relative fat content; animals putting on more fat and therefore having less water during the rainy season, when environmental conditions of weather and nutrition are considered more favorable, as indicated by generally higher blood values and total protein concentrations.

Seasonal and species variations in biologic half-life of tritium, pool turnover rate and daily water turnover are in agreement with findings of several workers working with penned animals (Till and Downes,

1962; Black et al., 1964; Hansard, 1964; MacFarlane and Howard, 1966; Springell, 1968). Water requirements and its metabolism by these animals appear to be greatly influenced by seasonal changes in environmental conditions, such as temperature. The harsh conditions prevailling during the hot season induces appropriate physiologic responses, which are reflected in the kinetics of water metabolism in these animals. In any season, goats required the least amount of water, followed by sheep and then cattle. This is probably indicative of the order of adaptation of these animals to their native environment.

SUMMARY

Seasonal variations in water and feed intake and in water metabolism were investigated in penned, castrated male Bunaji cattle, Yankassa sheep and Sokoto Red goats during the hot, rainy and cold seasons in the Samaru environment of Zaria, Nigeria. Water

metabolism was studied using tritiated water. Results indicated that water intake by all species was strongly influenced by season; the greatest intake occurred during the hot season, and the least during the cold season. Cattle consumed relatively more water than the smaller ruminants, regardless of season, and goats consumed the least. Feed intake was more variable and did not follow any pattern. In all animals, however, the greatest intake occurred during the cold season, goats consuming relatively more, followed by sheep and cattle, respectively.

Water metabolism varied with species and season. Water content appeared to be strongly affected by temperature and plane of nutrition. Data on biologic half-life of tritiated water, pool turnover rate and daily water turnover indicated that water requirement of all the animals was greatest during the hot season, and in any season there existed a hierarchy of water metabolism, cattle requiring the greatest amount of water, followed by sheep and then goats.

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Table 1. Seasonal variations in water intake in penned indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1]	Body weight (kg)	Mean water intake/24 hours (kg)	(ml/kg)	(ml/kg$^{0.82}$)
			HOT SEASON		
Cattle	4	383.2	28.2±6.1[2]	74.1±17.4	215.8±31.9
Sheep	5	44.2	2.4±1.5	48.6±13.5	108.0±29.9
Goat	6	31.9	1.2±0.3	38.0±8.5	70.9±16.0
			RAINY SEASON		
Cattle	5	375.4	14.9±3.6	39.7±9.9	115.9±12.4
Sheep	5	36.9	1.4±0.5	36.6±12.9	70.6±12.5
Goat	6	28.2	0.6±0.3	20.1±10.0	31.4±9.8
			COLD SEASON		
Cattle	5	378.1	7.5±1.7	20.0±5.2	61.3±4.1
Sheep	5	40.0	0.4±0.2	9.9±6.2	18.6±3.9
Goat	6	30.6	0.2±0.1	4.6±3.9	9.1±3.2

1/ n is number of animals

2/ Mean ± standard deviation

Table 2. Seasonal variations in daily feed intake in penned indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1]	Mean feed intake/24 hours		
		kg	g/kg	$g/kg^{0.75}$
		HOT SEASON		
Cattle	4	5.9±1.5[2]	15.4±4.2	68.0±13.0
Sheep	5	0.8±0.2	17.7±6.5	46.4±8.2
Goat	6	0.8±0.2	23.0±8.8	58.6±13.2
		RAINY SEASON		
Cattle	5	5.6±0.6	15.1±5.1	66.7±10.2
Sheep	5	0.8±0.4	21.3±8.7	52.4±3.6
Goat	6	0.5±0.1	19.0±7.1	43.8±9.6
		COLD SEASON		
Cattle	5	9.8±0.6	26.2±4.7	114.9±10.1
Sheep	5	2.3±0.2	59.3±15.4	148.7±21.8
Goat	6	2.4±0.2	77.3±19.3	181.7±11.2

1/ n is number of animals

2/ Mean ± standard deviation

Table 3. Seasonal variations in total body water (TBW) in penned indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	Total body water	
		kg	% body weight
		HOT SEASON	
Cattle	4	260.5±11.2[2/]	68.4±2.8
Sheep	5	28.0±2.4	63.4±1.7
Goat	6	21.7±2.8	64.4±1.8
		RAINY SEASON	
Cattle	5	244.3±30.4	65.0±2.1
Sheep	5	22.8±2.6	61.8±1.2
Goat	6	17.3±2.9	61.2±1.4
		COLD SEASON	
Cattle	5	245.2±26.4	64.8±1.6
Sheep	5	26.0±3.0	64.9±1.0
Goat	6	19.3±2.3	63.2±1.4

1/ n is number of animals

2/ Mean ± standard deviation

Table 4. Seasonal variations in biologic half-life of tritiated water(^3H_2O) and pool turnover rates in penned indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	^3H_2O half-life (days)	Pool turnover rate (fraction/ 24 hours)
		HOT SEASON	
Cattle	4	4.4±0.6[2/]	0.160±0.019
Sheep	5	5.4±0.6	0.130±0.015
Goat	6	6.8±0.4	0.102±0.002
		RAINY SEASON	
Cattle	5	5.3±0.3	0.131±0.008
Sheep	5	6.2±0.7	0.113±0.013
Goat	6	7.3±0.8	0.096±0.010
		COLD SEASON	
Cattle	5	6.7±0.3	0.103±0.005
Sheep	5	7.7±0.8	0.091±0.008
Goat	6	8.1±0.8	0.087±0.008

1/ n is number of animals

2/ Mean ± standard deviation

Table 5. Seasonal variations in daily body water turnover in penned indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	Water turnover/24 hours		
		kg	ml/kg	$ml/kg^{0.82}$
		HOT SEASON		
Cattle	4	41.6±4.9[2/]	109.1±13.4	317.6±36.9
Sheep	5	3.6±0.5	81.8±8.9	161.7±17.7
Goat	6	2.2±0.3	71.8±13.7	129.3±20.2
		RAINY SEASON		
Cattle	5	32.0±3.4	85.3±3.5	250.2±13.2
Sheep	5	2.6±0.6	69.3±9.3	125.7±13.6
Goat	6	1.7±0.3	58.7±6.0	106.8±11.8
		COLD SEASON		
Cattle	5	25.3±2.5	67.0±3.1	194.1±9.8
Sheep	5	2.4±0.5	62.7±10.7	115.0±10.5
Goat	6	1.7±0.2	54.5±5.2	101.0±9.2

1/ n is number of animals

2/ Mean ± standard deviation.

Table 6. Seasonal variations in selected hematologic parameters and total protein in penned cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	PCV (%)	Hb (g/dl)	RBC ($X10^6/mm^3$)	Total Protein (g/dl)
			HOT SEASON		
Cattle	4	33.5±3.5[2/]	9.3±1.4	6.9±0.9	7.6±1.4
Sheep	5	36.0±2.6	8.5±1.2	8.0±1.2	7.1±1.2
Goat	6	30.3±2.9	7.4±1.1	9.3±0.9	7.2±1.2
			RAINY SEASON		
Cattle	5	39.0±3.1	10.8±1.3	7.9±0.7	8.1±0.9
Sheep	5	37.5±2.5	9.7±1.1	8.7±0.8	7.8±1.0
Goat	6	34.6±2.9	9.3±0.9	10.1±1.1	7.4±1.1
			COLD SEASON		
Cattle	5	36.2±3.2	10.9±0.9	7.3±0.8	8.0±1.3
Sheep	5	37.6±3.5	9.5±1.5	9.1±1.0	7.6±1.0
Goat	6	32.9±2.0	8.5±0.8	9.5±1.6	7.5±1.1

1/ n is number of animals

2/ Mean ± standard deviation

CHAPTER III

SEASONAL VARIATIONS IN WATER METABOLISM IN GRAZING INDIGENOUS CATTLE, SHEEP AND GOATS IN ZARIA, NIGERIA.

INTRODUCTION

Exact simulation of the natural environment cannot be readily or successfully accomplished, thus most studies concerning adaptation of animals to particular environments are often carried out in mobile or stationary climatic chambers. Under such laboratory conditions, the effects of specific meteorological variables can be identified and investigated and results can be more reliably interpreted in terms of cause and effect. In relation to animal-environment interaction, however, this procedure is artificial, because in the environments in which most animals live, a single factor is often affected by one or more related variable e.g. heat exposure may be associated with high humidity.

Physiologic and other adaptations are best studied in animals in their natural habitat. Under such conditions, animals are exposed simultaneously to all meteorological factors which define a particular climate. These factors not only interact with one

another, but they are, singly or severally, constantly changing, and these changes affect and modify physiologic responses of animals. Measurements of content and turnover of water in animals under grazing conditions can thus be a useful approach to their physiological ecology.

Water metabolism in grazing animals has been widely investigated. On the equator, in the cool moist highlands of Kenya, comparisons were made between cattle, sheep, donkeys and goats grazing Cynodon pasture (MacFarlane et al., 1972). A hierarchy of function was apparent, Hereford cattle having the highest rate of water turnover, followed in decreasing order by Zebu-type cattle, donkeys, sheep and goats.

Robertshaw (1975) also compared mean total body water, tritiated water turnover, and free water intake of grazing sheep and goats in East Africa. He found that mean total body water was 726 ml/kg in goats and 718 ml/kg in sheep; free drinking water was 23 ml/kg/24 hours in goats and 26 ml/kg/24 hours in sheep, while

body water turnover was 144ml/kg/24 hours in goats and 171 ml/kg/24 hours in sheep.

Seasonal variations in water content in grazing cattle in temperate climates have been found to be highly significant (Springell, 1968). Water content was reported to be minimum in winter and maximum in summer, while the biologic half-life of tritium was shorter in warmer months, being 58 hours in summer compared to 128 hours during winter. Water turnover followed similar patterns.

In an attempt to assess the most suitable types of animals for hot dry regions, MacFarlane and Howard (1966) studied water metabolism in identical twin cattle and in the Oryx under different conditions. Under grazing conditions, they reported that the biologic half-life of tritiated water ranged from 3.6 days in Zebu to 16.8 days in the Oryx, while the turnover rate was 70.5 $ml/kg^{0.82}/24$ hours in the Oryx and 359 $ml/kg^{0.82}/24$ hours in the Zebu. They concluded that the Oryx was able to conserve water more than the Zebu, and so, was better adapted to hot arid environments.

Grazing animals have been reported to turn over about three times more water than stall-fed animals (261-364 ml/$kg^{0.82}$/24 hours and 74-132 ml/$kg^{0.82}$/24 hours respectively), MacFarlane and Howard (1966). Kamal (1975), however, studying water metabolism in camels, cattle, sheep and water-buffaloes under different grazing conditions, reported that the water requirement of stall-fed animals was higher than those under grazing conditions. Total body water either as absolute value, or as per cent of body weight or of body solids, decreased in heifers and lactating cows after they had been turned to pasture, but water turnover decreased in all four species of animals studied. He considered that the variations observed might have been due to lack of free air movement inside the barn.

Water metabolism in farm animals is a sensitive index of their physiologic status and is greatly affected by season, especially under grazing conditions. Although seasonal variations in water metabolism in grazing farm animals have been investigated in many

parts of the world, no information is available about livestock indigenous to Nigeria. The aim of this study was to determine the characteristics and seasonal variations in water metabolism in cattle, sheep and goats under grazing conditions in Zaria, Nigeria.

MATERIALS AND METHODS

Experimental animals

Six adult, healthy, male Bunaji cattle, Yankassa sheep and Sokoto Red goats were used. The cattle and sheep belonged to the herd at the University Farm, while the goats were purchased locally. The animals were castrated three months before the trials began. They grazed on native pastures on the farm during the day, and were herded at night. Water was freely available at all times. They were dipped for ticks once every month[1].

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[1] Pfizona, Pfizer Products Ltd., P.M.B. 111, Ikeja, Nigeria.

Environment

The investigations were conducted under the same climatic environment as described in Chapter II, with the animals grazing freely.

Measurements

All measurements were made as previously described (Chapter II). The amounts of feed and water consumed were not measured.

RESULTS

Seasonal variations in total body water in grazing animals are given in Table 1 and Appendix 7 (Tables 28-36). There were no significant differences in absolute total body water in cattle during the three seasons; it was, however, highest during the hot season and lowest during the rainy season. In sheep, total body water was significantly lower ($P < 0.01$) during the rainy season than during the hot and cold seasons. In goats, on the other hand, total body water was significantly lower ($P < 0.05$) during either the cold or rainy season than during the hot season.

Total body water as per cent body weight showed significant seasonal variations in the three species; the values were lowest during the rainy season, and highest during the hot season ($P < 0.05$). During the hot and rainy seasons, TBW as per cent body wight was significantly higher in cattle and sheep than in goats ($P < 0.05$), but lower in the smaller ruminants ($P < 0.01$) during the cold season.

Seasonal and species variations in biologic half-life of tritium, pool turnover rates and daily water turnover are presented in Tables 2 and 3. In all species, half-life was shortest ($P < 0.01$) during the hot season, followed by the rainy and cold seasons, respectively. In any season, significant species variations ($P < 0.01$) were observed. Cattle had the shortest half-life, followed by sheep and then goats. Pool turnover rates generally followed an inverse relationship to half-life. In all species, pool turnover rates were highest ($P < 0.01$) during the hot season, followed by rainy and cold seasons, respectively. Goats had the lowest rate ($P < 0.01$) during the hot season, followed by sheep and then cattle. No significant differences were observed in turnover rates between sheep and goats during both rainy and cold seasons, but values during these periods were significantly lower ($P < 0.01$) in both species than in cattle.

Seasonal variations in hematologic parameters are presented in Table 4 and Appendix 8 (Tables 37-48).

In all species, hematologic values were lowest during the hot season.

DISCUSSION

The pattern of water metabolism found in grazing animals agree with published data (Kraybill et al., 1953; Garret et al., 1959; Hansard, 1964; MacFarlane and Howard, 1966; Springell, 1968; Kamal and Seif, 1969; MacFarlane et al., 1972; King, 1975; Robertshaw, 1975). In all seasons and in all animals, total body water as per cent body weight was significantly higher ($P < 0.01$) in grazing compared to penned animals. Variations in biologic half-life of tritium, pool turnover rates and daily water turnover in grazing animals followed a similar pattern to corresponding values for penned animals. Biologic half-life was significantly shorter ($P < 0.01$), while pool turnover rate and daily water turnover significantly higher

($P < 0.01$) in grazing than in penned animals.

Although the seasonal pattern of water use was similar in both penned and grazing animals, grazing animals generally required more water. This is in contrast to the report by Kamal (1975), that penned animals required more water. These animals, however, were housed in open stalls without free air movement. This could have increased the heat load on them to such an extent that they required more water to offset this extra heat.

MacFarlane and Howard (1966) associated high water content in animals with undernourishment as would occur in animals grazing in a hot climate with low quantity and quality of available feed. In addition, grazing animals are exposed to, and are more directly affected by such environmental variables as temperature and solar radiation (Cameron and Luick, 1972). Therefore, they require more water to replace that lost by evaporative cooling. This is reflected in the altered kinetics of their body water pool, viz: shorter half-life, higher turnover rate and greater daily water turnover. The greater amount of total

body water in grazing compared to penned animals is primarily due to changes in body fat reserves, which reflect contrasting nutritional circumstances between seasons.

SUMMARY

Seasonal variations in water metabolism in grazing, castrated, male Bunaji cattle, Yankassa sheep and Sokoto Red goats, were investigated, using tritiated water. The results indicated that the pattern of water metabolism in grazing animals was similar to that in penned animals, but grazing animals required more water as reflected in their higher water metabolism. This was thought to be primarily due to exaggerated effects of environmental factors such as temperature and solar radiation.

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Table 1. Seasonal variations in total body water (TBW) in grazing indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	Body wt. (kg)	Total body water	
			kg	% body weight
		HOT SEASON		
Cattle	6	363.5	275.5±35.1[2/]	75.7±1.4
Sheep	6	40.0	29.8±4.4	74.5±1.6
Goat	6	31.9	22.0±4.2	69.2±1.6
		RAINY SEASON		
Cattle	6	358.8	243.4±28.9	67.8±1.8
Sheep	6	34.3	22.5±2.4	65.8±1.2
Goat	6	27.8	17.3±3.8	62.0±2.1
		COLD SEASON		
Cattle	6	362.7	254.4±29.0	70.2±1.6
Sheep	6	42.4	28.7±2.2	67.7±0.9
Goat	6	28.1	18.8±1.5	66.9±2.8

1/ n is number of animals

2/ Mean ± standard deviation

Table 2. Seasonal variations in biologic half-life of tritiated water (^3H_2O) and pool turnover rates in grazing indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	^3H_2O half-life (days)	pool turnover (fraction/24 hours)
		HOT SEASON	
Cattle	6	2.8±0.5[2/]	0.250±0.038
Sheep	6	3.7±0.6	0.193±0.028
Goat	6	4.8±0.6	0.146±0.018
		RAINY SEASON	
Cattle	6	4.9±0.5	0.145±0.015
Sheep	6	5.7±0.6	0.122±0.013
Goat	6	5.4±0.9	0.132±0.026
		COLD SEASON	
Cattle	6	6.4±0.3	0.108±0.005
Sheep	6	7.3±0.6	0.096±0.009
Goat	6	8.1±1.1	0.087±0.011

1/ n is number of animals

2/ Mean ± standard deviation

Table 3. Seasonal variations in daily water turnover in grazing indigenous cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	Water turnover/24 hours		
		kg	ml/kg	$ml/kg^{0.82}$
		HOT SEASON		
Cattle	6	68.0±6.5[2/]	188.9±27.5	544.5±71.6
Sheep	6	5.7±0.8	143.6±20.1	278.0±35.6
Goat	6	3.2±0.8	100.7±11.6	187.6±23.1
		RAINY SEASON		
Cattle	6	35.2±4.9	98.0±8.3	282.3±24.4
Sheep	6	2.7±0.4	79.8±7.3	150.7±14.6
Goat	6	2.3±0.7	81.7±17.6	148.4±32.9
		COLD SEASON		
Cattle	6	27.4±2.6	75.8±4.6	208.4±11.6
Sheep	6	2.7±0.3	65.0±5.3	127.4±9.8
Goat	6	1.6±0.2	58.4±7.4	106.5±13.3

1/ n is number of animals

2/ Mean ± standard deviation

Table 4. Seasonal variations in selected hematologic parameters and total protein in grazing cattle, sheep and goats in Zaria, Nigeria.

Species	n[1/]	PCV (%)	Hb (g/dl)	RBC (x106/mm^3)	Total Protein (g/dl)
			HOT SEASON		
Cattle	6	33.4±3.8[2/]	8.6±1.1	6.3±0.8	7.1±1.8
Sheep	6	34.6±1.9	7.9±0.9	7.3±1.0	6.7±1.0
Goat	6	28.6±3.0	6.4±0.8	8.2±1.0	6.8±0.9
			RAINY SEASON		
Cattle	6	38.4±1.6	10.7±1.0	7.4±1.0	8.2±1.2
Sheep	6	37.3±1.9	9.3±1.0	9.1±0.9	7.5±0.9
Goat	6	33.5±2.3	8.8±0.7	10.5±1.1	7.1±1.0
			COLD SEASON		
Cattle	6	35.5±1.2	10.1±1.1	6.7±0.9	8.0±1.2
Sheep	6	36.8±1.3	8.9±1.3	8.5±0.8	6.8±0.9
Goat	6	31.4±1.8	8.3±1.1	9.4±1.0	7.2±0.9

1/ n is number of animals

2/ Mean ± standard deviation

CHAPTER IV

INFLUENCE OF TOTAL WATER DEPRIVATION ON WATER METABOLISM IN INDIGENOUS CATTLE, SHEEP AND GOATS DURING THE HOT SEASON IN ZARIA, NIGERIA.

INTRODUCTION

Water is essential for all processes governing life and must be supplied on an almost continuous basis. It is distributed throughout the animal and forms the ambient fluid that imparts to every functional cell those properties necessary for life. All nutrient and waste materials are transported to, and from the cell, dissolved in water; and apparently all biochemical reactions proceed in an aqueous environment. Water is the largest single constituent of the body, comprising about two-thirds of the total body mass of mammals (Cizek, 1968). Deviations in the volume of body water results in profound changes in physiologic function. Regulation of body water is achieved by a balance between forces responsible for water intake and loss (Selkurt, 1963). In times of stress, an animal is capable of conserving water in order to maintain a balance of critical body fluids (Gray, 1970). This ability is reflected in the pool size and in its kinetics.

Most tropical and sub-tropical animals tolerate high ambient temperatures, intense solar radiation, scarce and low quality roughage, and, above all, irregular and scanty supplies of drinking water. The physiologic problems associated with animal production in the tropics have been discussed (Schmidt-Nielsen, 1956; MacFarlane, 1964). Furthermore, water economy of desert-inhabiting vertebrates has been reviewed (Chew, 1961; Robertshaw and Taylor, 1970; Taylor, 1970; Maloiy and Taylor, 1971; Maloiy and Hopecraft, 1971). The general contention is that desert animals resist the effects of drought by a series of interrelated shifts of emphases in physiologic processes already present in temperate zone animals. Thus, input, production and dissipation of heat, are adjusted to econimise water.

MacFarlane and Howard (1966) conducted extensive investigations in identical twin cattle during periods of restricted water intake, and reported that intermmittent water supplies resulted in large differences in total water consumption and in reduced water turnover

rate. Bos indicus twins achieved the lower turnover rate compared to B. taurus. This finding confirmed earlier reports by Phillips (1960) and MacFarlane (1964). In all animals studied, the biologic half-life of injected tritiated water was prolonged from 3.5-5.5 days during control period to 15.0-18.2 days during water deprivation.

Animals inhabiting the drier parts of Nigeria are often subjected to prolonged periods of descreased availability of drinking water, especially during the hot, dry season, (March-April). During this period, they may have no access to drinking water for several days. The deleterious effects of such water lack are exercabated by trekking long distances under high ambient temperature in search of water and food.

Physiologic adaptations which permit farm animals to cope with high ambient temperatures during periods of decreased water supply have been investigated in various parts of the world, but similar information about livestock in Nigeria is lacking. The aim of this study was to investigate the effects of total water

deprivation on water metabolism in domestic ruminants indigenous to the Zaria environment of Nigeria.

MATERIALS AND METHODS

Experimental animals

Four Bunaji cattle, five Yankassa sheep, and six Sokoto Red goats were used. The animals were all adult males which had been castrated and preconditioned for three months. Normal maintenance ration of dry gamba hay and groundnut cake and cotton seed was provided ad libitum. Water was withheld for four days during the trial period.

Environment

These trials were conducted under the same environmental conditions as described previously (Chapter III).

Water metabolism studies

The animals were weighed daily for the duration of the study. The amount of feed consumed by each animal was measured for four days prior to water restriction. On the fourth day, after all measurements were recorded, water, but not feed, was withheld for the following four days, during which the amount of feed consumed was recorded. On the fifth day, pre-injection blood samples were obtained and a calculated amount of tritiated water injected into each animal. Serial blood samples were obtained every 12 hours for the four days of water restriction. The exact times of injection of tracer, and of subsequent blood samples, were recorded. The samples were prepared, counted for radio-activity and the data analysed as described previously (Chapter II).

RESULTS

Influence of total water deprivation on total body water (TBW) in penned animals during the hot season is shown in Table 1. Total body water, expressed either as absolute value or as per cent body weight, decreased significantly ($P<0.01$) when water was completely witheld from the three species studied. The decrease was most pronounced in cattle and least in goats.

The mean biologic half-life of tritiated water and pool turnover rates in water-deprived animals are presented in Table 2 and Appendix 9 (Tables 49-51; Fig. 8). In all three species, biologic half-life was significantly prolonged ($P<0.01$) during periods of total water deprivation. Per cent change over controls was least in goats and highest in sheep. The rate of body water pool turnover was also significantly lowered ($P<0.01$) during water deprivation.

In addition to water pool turnover rate, daily water turnover was also significantly decreased ($P < 0.01$) during water deprivation; it was least in goats and most in cattle (Table 3).

DISCUSSION

Water deprivation, especially in a hot environment, constitutes serious nutritional and metabolic stresses and physiologic defense mechanisms are mobilized to maintain normal functions (Schmidt-Nielsen, 1964). The most immediate of these defenses relate to water conservation. The physiologic cost of metabolism entails some obligatory water loss (urine, feces, sweat, and insensible water loss). With lack of input, as occurs during total water deprivation, such obligatory water loss leads in time to a decrease in total body water. The significantly prolonged half-life and low turnover rate of tritiated water

reflect attempts by the body to minimise the stress imposed by water deprivation. Similar changes have been reported (Schmidt-Nielsen and Schmidt-Nielsen, 1952; MacFarlane et al., 1958, 1961; MacFarlane, 1964; Springell, 1968; Kamal et al., 1972). Physiologic implications of these responses are to maintain normal body functions and thus preserve life. The relative ability of species to conserve water reflects their degree of adaptation to semi-arid environments. Goats tolerate dehydration better than sheep, and sheep withstand water deprivation more than cattle.

On the basis of findings from this study, and the necessity to increase production of animal protein in Nigeria, basic and applied research into adaptation of smaller ruminants, particularly goats, in the savanna zone of Nigeria, should be encouraged. Such information will be useful in expanding the goat industry in order to supplement animal protein requirements in Nigeria.

SUMMARY

The influence of total water deprivation on water metabolism was investigated in castrated male Bunaji cattle, Yankassa sheep and Sokoto Red goats during the hot season in Samaru, Zaria, using tritiated water. Results obtained indicated that total water deprivation constitutes a serious nutritional stress. Total body water was significantly reduced ($P \leq 0.01$) in all the animals leading to compensatory changes in biologic half-life of tritiated water, pool turnover rates and daily water turnover, all of which were aimed at conserving body water. Goats were better adapted to water scarcity than sheep and cattle.

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Table 1. Influence of total water deprivation on total body water (TBW) in penned cattle, sheep and goats during the hot season in Zaria, Nigeria.

TBW	Cattle (4)[1]			Sheep (5)			Goat (6)		
	Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
(kg)	260.5 ± 11.1[2]	208.4 ± 26.8	-20.0	28.0 ± 2.4	22.7 ± 2.2	-18.9	21.7 ± 2.8	18.2 ± 2.6	-16.1
(% Body wt.)	68.4 ± 5.0	63.0 ± 1.4	-7.9	63.4 ± 1.7	60.1 ± 2.8	-5.2	64.4 ± 1.8	61.9 ± 2.1	-3.9

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

Table 2. Influence of total water deprivation on biologic half-life of tritiated water (^3H_2O) and turnover rates in cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Cattle (4)[1]			Sheep (5)			Goat (6)		
	Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
Half-life (days)	4.4 ± 0.6[2]	11.9 ± 2.7	+170.5	5.4 ± 0.6	14.9 ± 1.4	+175.9	6.8 ± 0.4	17.9 ± 3.6	+163.2
Pool turnover rate (fraction/24 hours)	0.160 ± 0.019	0.061 ± 0.017	- 61.9	0.130 ± 0.015	0.047 ± 0.002	- 63.9	0.102 ± 0.002	0.040 ± 0.007	- 60.8

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

Table 3. Influence of total water deprivation on daily water turnover in penned cattle, sheep and goats during the hot season in Zaria, Nigeria.

Water turnover/24 hours	Cattle (4)[1]			Sheep (5)			Goat (6)		
	Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
Kg	41.6 ± 4.9[2]	12.7 ± 3.3	-69.5	3.6 ± 0.5	1.4 ± 0.3	-61.1	2.2 ± 0.3	1.0 ± 0.2	-54.5
ml/kg	109.1 ± 13.4	36.6 ± 11.7	-66.5	81.8 ± 8.9	34.2 ± 3.5	-57.5	71.8 ± 10.2	33.8 ± 3.5	-52.9
ml/kg$^{0.82}$	317.6 ± 36.9	105.1 ± 7.8	-66.9	161.7 ± 17.7	71.5 ± 7.8	-55.7	129.3 ± 20.2	63.8 ± 6.6	-50.7

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

CHAPTER V

PHYSIOLOGIC RESPONSES OF INDIGENOUS CATTLE, SHEEP AND GOATS TO TOTAL WATER DEPRIVATION DURING THE HOT SEASON IN ZARIA, NIGERIA.

INTRODUCTION

Homeokinesis, the maintenance of relatively constant bodily conditions, provides the dynamic equilibrium of the internal environment, which is necessary for normal cellular function and life. Thus, when an animal is exposed to one or more stressful or potentially stressful stimuli, metabolic, neuroendocrine and motor responses act together to maintain the status quo (Cannon, 1932). Such interrelated responses usually favor animal survival. Water deprivation constitutes a serious nutritional stress, which induces an array of protective physiologic responses in animals.

The physiologic responses of farm animals to varying degrees of water deprivation have been investigated. The relationship between water and food intake by cattle, African goats and haired-sheep has been investigated by Phillips (1960) and Horrocks and Phillips (1961), who reported that the first noticeable effect of moderate water restriction was a decrease

in feed intake. Phillips (1960) demonstrated that 50% reduction in water available to European and Zebu steers resulted in a slight decline in the consumption of dry hay, while Utley et al. (1969) reported that water restriction to 60% free choice resulted in significant reductions in voluntary feed intake by steers. Wilson (1970), studying water economy and food intake of sheep watered intermittently, reported that mean food intake declined to less than half by the third day.

Reduction in water intake not only results in decreased feed consumption but also affects feed utilization. Phillips (1960) observed that digestibility of dry matter, nitrogen and fiber in cattle tended to increase with water restriction of up to 60%, and suggested that the increased digestibility was probably an artifact, due, in part, to dry matter accumulation rather than to any increase in fermentation or digestion. Balch et al. (1953), considered that water restriction tended to reduce the passage of ingesta through the gastrointestinal tract, which would

result in higher digestibility.

Thornton and Yates (1969) reported a decrease in nitrogen retention in cattle when water was restricted, and suggested that this was associated with increased fecal nitrogen output and urinary urea excretion. Utley et al. (1969), however, observed increased nitrogen retention in steers when water was restricted. The increase was negatively correlated with total urinary nitrogen excretion, indicating increased nitrogen recycling. As Schmidt-Nielsen (1954) pointed out, this is a water-conserving adaptation to arid environments.

Other physiologic responses of farm animals to water restriction have been reported. Bianca et al. (1965) reported that cattle deprived of water at 40°C lost about 12% of their body weight in two days. He also reported marked diurnal variations in rectal temperature, decreased respiratory rates and decreased urinary output. Tajena (1965, 1966), studying sheep subjected to varying degrees of dehydration, observed

elevation in packed cell volume (PCV) up to 60%, accompanied by changes in plasma electrolytes, which were as severe as those reported by Watt (1967) in calves with diarrhea.

Water constitutes an important factor in the external environment of animals. In arid environments this leads, in time, to evolution of protective physiologic traits necessary for maintaining an internal environment that is compatible with life. Physiologic responses of indigenous livestock to water deprivation have not been reported. The purpose of this investigation was to determine the existence and the extent of such responses in cattle, sheep and goats in Zaria, Nigeria.

MATERIALS AND METHODS

Animals and Environment

Data reported here were obtained from the same animals as described previously (Chapter IV).

Measurements

The animals were weighed daily for the duration of the study, and the amount of feed consumed by each was measured. Rectal temperatures were recorded for each animal twice daily (9.00 A.M. and 4.00 P.M.) while respiratory rates were determined once (9.00 A.M.). Per cent fecal moisture content was determined daily by drying weighed fecal samples from each animal to constant weight at 105°C.

Serum sodium and potassium concentrations were determined by flame photometry (King and Wooton, 1959), while serum chloride levels was determined by the method described by Schales and Schales (1941). Blood urea nitrogen was estimated using the method described by Chaney and Marback (1962). Packed cell volume, hemoglobin, total red blood cells, and total protein concentrations were determined according to the methods described by Coles (1974). Control measurements were obtained for four days preceeding water withdrawal.

RESULTS

When water was withheld from cattle, sheep and goats for four days, there were elevations in hematologic parameters measured and in total protein as presented in Table 1 and Appendix 10 (Tables 52-55). Per cent increase in PCV, total RBC and total protein was highest ($P < 0.01$) in cattle, but the increase in Hb concentration was lowest in this species and highest in sheep.

The effects of total water deprivation on rectal temperature, respiratory rate and fecal moisture content are presented in Table 2 and Appendix 10 (Tables 56-59). Significant elevation ($P < 0.01$) in rectal temperature occurred during the late afternoon (1600 Hours) in all species during water deprivation. Respiratory rate and fecal moisture content, on the other hand, were significantly decreased ($P < 0.01$) in all species. The highest per cent decrease in respiratory rate occurred in cattle and sheep had the greatest decrease in fecal moisture content.

The influence of four days of total water deprivation on body weight and feed intake are shown in Table 3 and in Appendix 10 (Tables 60-61). Goats lost the least weight, and sheep lost the most. There was also a highly significant reduction ($P < 0.01$) in the amount of feed consumed by all species.

The effects of total water deprivation on serum electrolytes and blood urea nitrogen (BUN) are given in Table 4 and in Appendix 10 (Tables 62-65). BUN, serum sodium, potassium and chloride were significantly elevated ($P < 0.01$) following water deprivation. The relative increase in sodium ion concentration was more in sheep than in the other species. Cattle on the other hand, had a higher increase in BUN and chloride ion concentration than either sheep or goats.

DISCUSSION

Physiologic changes observed in the three species following total water deprivation parallel reported

data (Clark and Quin, 1949; Schmidt-Nielsen, 1954; Taneja, 1965, 1966; English, 1966; Gray, 1970; Olbrich et al., 1973). When an animal is subjected to dehydration by water withdrawal, the immediate source of water lost from the body is extracellular fluid, the volume of which becomes consequently reduced. The severity of the ensuing hemoconcentration depends on the degree of tolerance of the animal to dehydration, as well as to the rapidity of water loss. Moderate physiologic hemoconcentration is compatible with life, but as dehydration progresses, hemoconcentration becomes more severe, leading to increased viscosity, hypovolemia and eventually shock due to circulatory failure. The degree of hemoconcentration in an animal deprived of water reflects its ability to conserve water, and therefore, to adapt to an environment of water scarcity. This finding, as well as the observations that goats lost the least weight and had the lowest rise in rectal temperature following the stress of water deprivation, suggests that goats are better adapted to the environment of the northern

savanna zone of Nigeria, while cattle appear to be the least adapted.

Diurnal variation in body temperature, as observed in this study, is characteristic of animals inhabiting semi-arid environments, as is most evident in camels (French, 1956; Schmidt-Nielsen et al., 1957; Schmidt-Nielsen, 1964). The advantage of such thermolability is that, if body temperature is permitted to rise during the day, all heat that goes into warming the body can be considered as stored, and dissipated in the cool of the night by a thermal gradient of conduction and radiation, thus conserving water. Reduction in feed intake is a thermoregulatory response in defense against hyperthermia.

In the hot weather conditions under which this experiment was conducted, an animal exposed to the stress of water deprivation, responds to counteract or minimise the deleterious effects of stress. The primary physiologic defense is aimed at reducing water loss (Phillips, 1960; Horrocks and Phillips, 1961; Schmidt-Nielsen, 1964). Water loss via the respiratory

and intestinal tract is reduced by decreasing the respiratory rate and fecal moisture content. The degree of these water conserving measures may be a physiologic index of the relative adaptation which enable these animals to survive in their habitat.

SUMMARY

Physiologic changes, resulting from total water deprivation for four days were studied in castrated male Bunaji cattle, Yankassa sheep and Sokoto Red goats during the hot season in Zaria, Nigeria. Total body water was decreased and there was evidence of hemoconcentration, reflected in increased PCV, total red blood cells, and in increased hemoglobin, total proteins, electrolytes and BUN. Total water deprivation also induced lability in body temperature, which rises during the day while the stored heat is dissipated during the cool of the night. Physiologic

defense mechanisms were initiated to reduce or eliminate the effects of water-deprived stress. Respiratory rate and fecal moisture content were reduced to minimise water loss.

The extent of such water conserving measures may be a physiologic index of the ability of ruminants to survive in a hot semi-arid environment.

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Table 1. Influence of total water deprivation on packed cell volume (PCV), total red blood cells (RBC), hemoglobin (Hb) and total protein in cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Cattle (4)[1]			Sheep (5)			Goat (6)		
	Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
PCV (%)	33.2 ± 3.5[2]	46.2 ± 10.3	+39.2	36.0 ± 2.4	48.0 ± 8.3	+33.3	30.3 ± 2.8	41.1 ± 7.8	+35.6
RBC ($X10^6/mm^3$)	5.6 ± 0.7	8.7 ± 1.9	+55.4	7.2 ± 0.8	10.5 ± 2.1	+45.8	8.7 ± 0.6	10.5 ± 1.7	+20.7
Hb (g/dl)	9.6 ± 1.4	13.1 ± 2.2	+36.5	7.5 ± 1.0	10.5 ± 2.7	+40.0	7.4 ± 0.9	10.3 ± 2.5	+39.2
Total protein (g/dl)	6.6 ± 0.4	10.2 ± 2.1	+54.6	6.5 ± 0.9	8.8 ± 1.7	+35.4	6.7 ± 1.0	10.1 ± 1.9	+50.8

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

Table 2. Influence of total water deprivation on rectal temperature, respiratory rate and per cent fecal moisture content in cattle, sheep and goats during the hot season in Zaria, Nigeria.

		Cattle (4)[1/]			Sheep (5)			Goat (6)		
		Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
Rectal temperature (^{o}C)	A.M.	38.6 ± 0.2[2/]	38.6 ± 0.2	+ 0.5	38.9 ± 0.3	38.8 ± 0.2	- 0.3	38.6 ± 0.3	38.7 ± 0.3	+ 0.3
	P.M.	38.8 ± 0.4	39.9 ± 0.3	+ 2.8	38.9 ± 0.2	39.9 ± 0.2	+ 2.6	39.0 ± 0.3	39.9 ± 0.2	+ 2.3
Respiration/minute		26.1 ± 1.5	15.0 ± 3.9	-74.0	35.9 ± 2.5	24.6 ± 2.5	-31.5	36.7 ± 3.5	26.0 ± 3.6	-29.2
Fecal moisture content (%)		78.7 ± 4.6	66.8 ± 8.0	-15.0	68.6 ± 2.1	53.9 ± 8.0	-21.3	71.6 ± 1.7	59.2 ± 8.5	-17.3

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

Table 3. Changes in body weight and feed intake in cattle, sheep and goats deprived of water for 4 days during the hot season in Zaria, Nigeria.

	Cattle (4)[1]			Sheep (5)			Goat (6)		
	Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
Body weight ($kg^{0.75}$)	86.6 ± 7.3[2]	80.3 ± 7.3	- 7.3	17.1 ± 1.3	15.2 ± 1.4	-11.8	13.4 ± 1.0	12.6 ± 1.4	- 5.7
Feed intake									
kg/24 hours	5.8 ± 1.7	1.6 ± 3.0	-72.9	0.8 ± 0.2	0.2 ± 0.2	-75.0	0.9 ± 0.3	0.2 ± 0.2	-75.0
g/kg/24 hours	15.4 ± 4.2	4.7 ± 8.8	-69.5	17.7 ± 6.5	5.5 ± 5.7	-68.9	23.0 ± 8.8	7.8 ± 8.1	-66.1
$g/kg^{0.75}$/24 hours	68.0 ± 13.0	20.8 ± 17.9	-69.4	46.4 ± 8.2	11.9 ± 2.8	-74.4	58.6 ± 13.2	16.4 ± 8.9	-72.0

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

Table 4. Influence of total water deprivation on serum electrolytes and blood urea nitrogen (BUN) in cattle, sheep and goats during the hot season in Zaria, Nigeria.

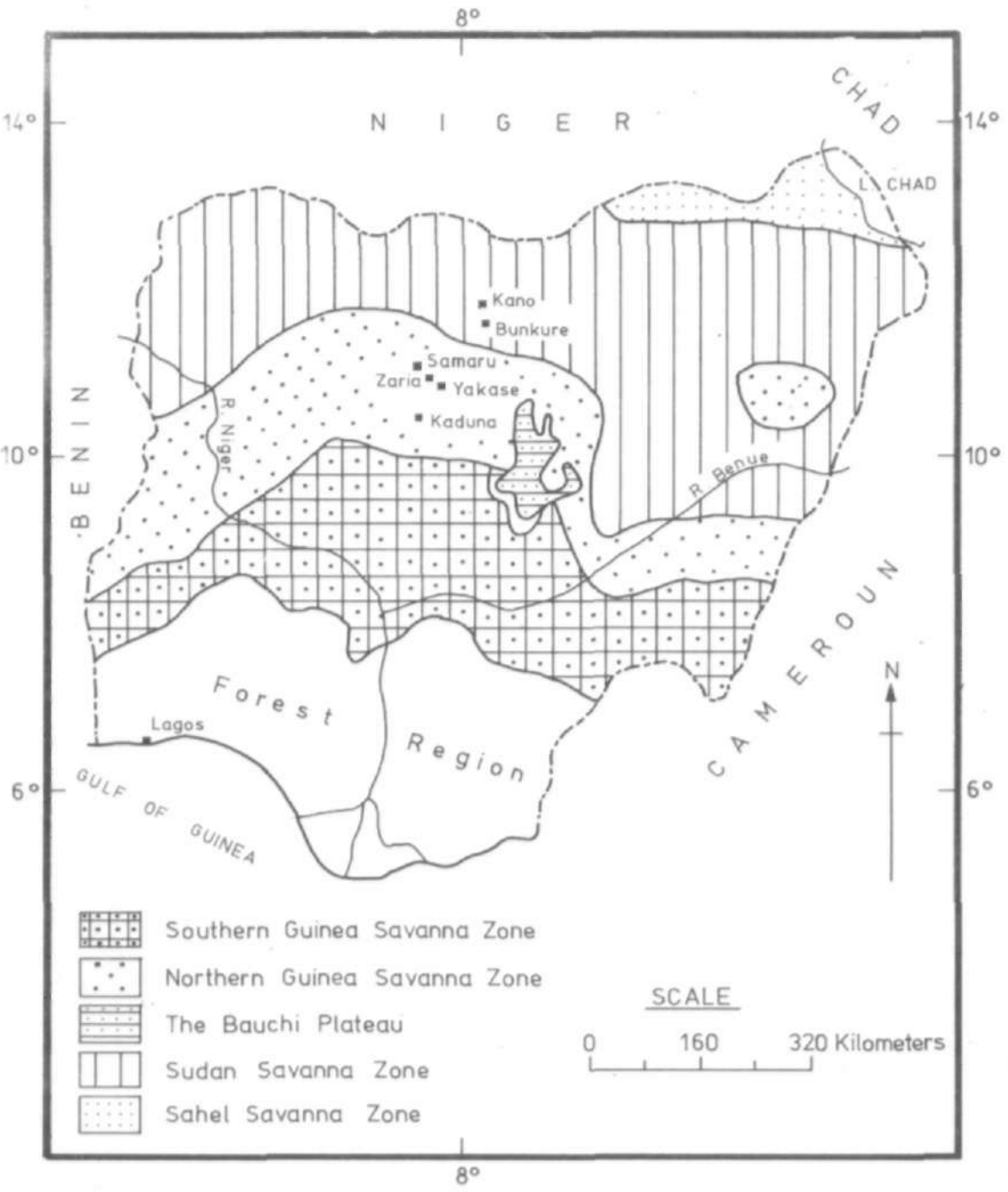
	Cattle (4)[1]			Sheep (5)			Goat (6)		
	Control	Water deprived	% change	Control	Water deprived	% change	Control	Water deprived	% change
Na^+ (mEq/l)	141.0 ± 1.7[2]	149.8 ± 7.6	+ 6.2	140.0 ± 2.2	150.7 ± 7.6	+ 7.6	140.8 ± 1.3	149.7 ± 7.0	+ 5.9
K^+ (mEq/l)	3.4 ± 0.3	3.9 ± 0.4	+12.8	3.2 ± 0.4	4.1 ± 0.4	+28.1	3.8 ± 0.4	4.3 ± 0.4	+15.8
Cl^- (mEq/l)	99.9 ± 2.0	120.1 ± 8.3	+20.2	96.7 ± 3.3	111.4 ± 8.5	+15.2	114.2 ± 2.0	124.5 ± 6.6	+ 9.0
BUN (g/dl)	11.5 ± 1.0	16.8 ± 1.7	+46.1	10.3 ± 0.7	14.1 ± 1.6	+36.9	16.4 ± 0.9	22.0 ± 3.8	+34.2

1/ Number in parenthesis is number of animals

2/ Mean ± standard deviation

Appendix 1

Map of Nigeria


8°
14°
10°
6°
NIGER
CHAD
L. CHAD
BENIN
Kano
Bunkure
Samaru
Zaria
Yakase
Kaduna
R. Niger
R. Benue
Forest
Region
Lagos
GULF OF GUINEA
CAMEROUN
N
Southern Guinea Savanna Zone
Northern Guinea Savanna Zone
The Bauchi Plateau
Sudan Savanna Zone
Sahel Savanna Zone
SCALE
0 160 320 Kilometers

Appendix 2

Experimental Animals and pens used

Fig. 1 - 4



Fig. 1. Sokoto Red Goat



Fig. 2. Bunaji (white Fulani) Cattle

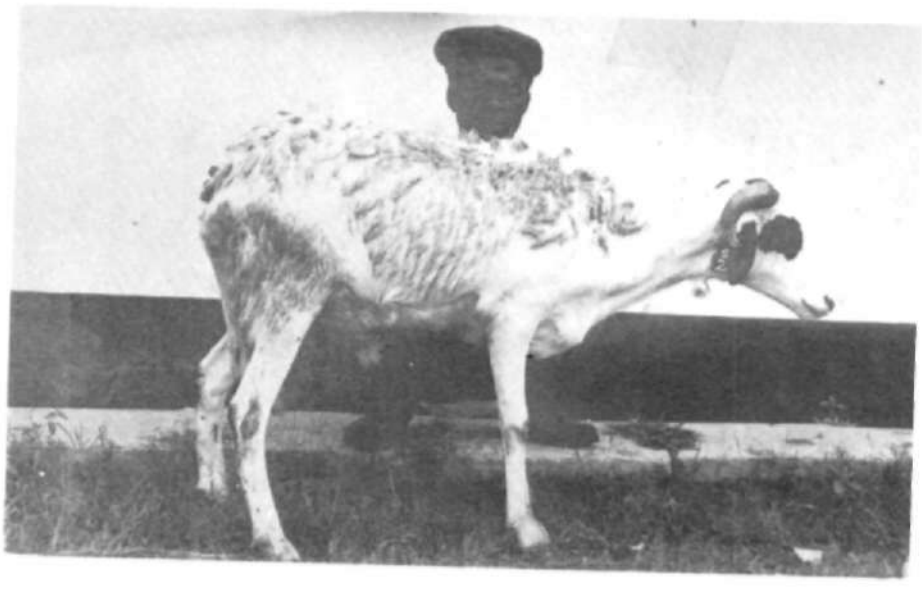


Fig. 3. Yankassa Sheep

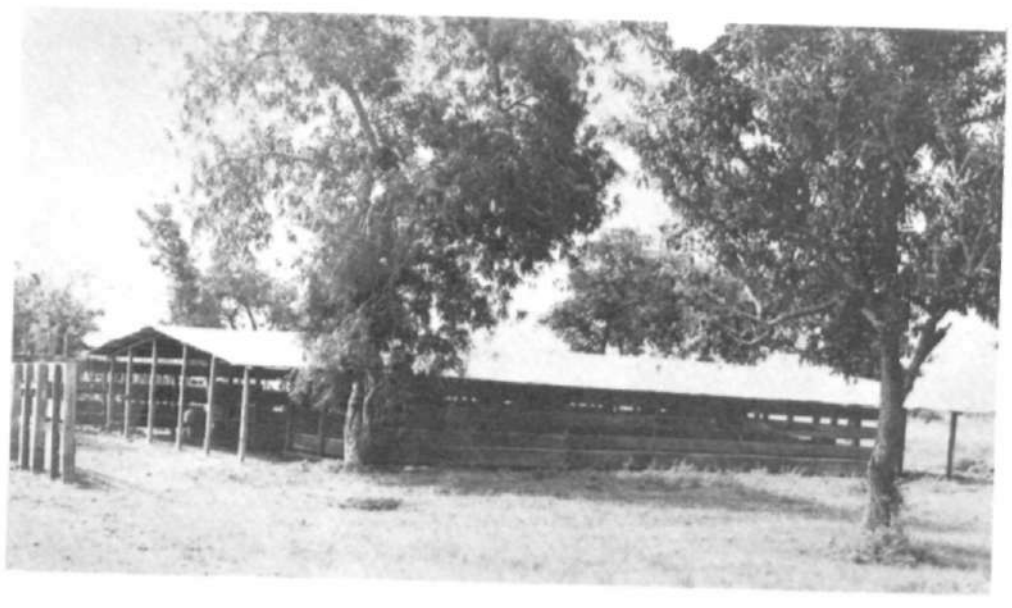


Fig. 4. Experimental Pens

Appendix 3

Meteorological data at Samaru-January 1975 to May 1976

Fig. 5 - 7

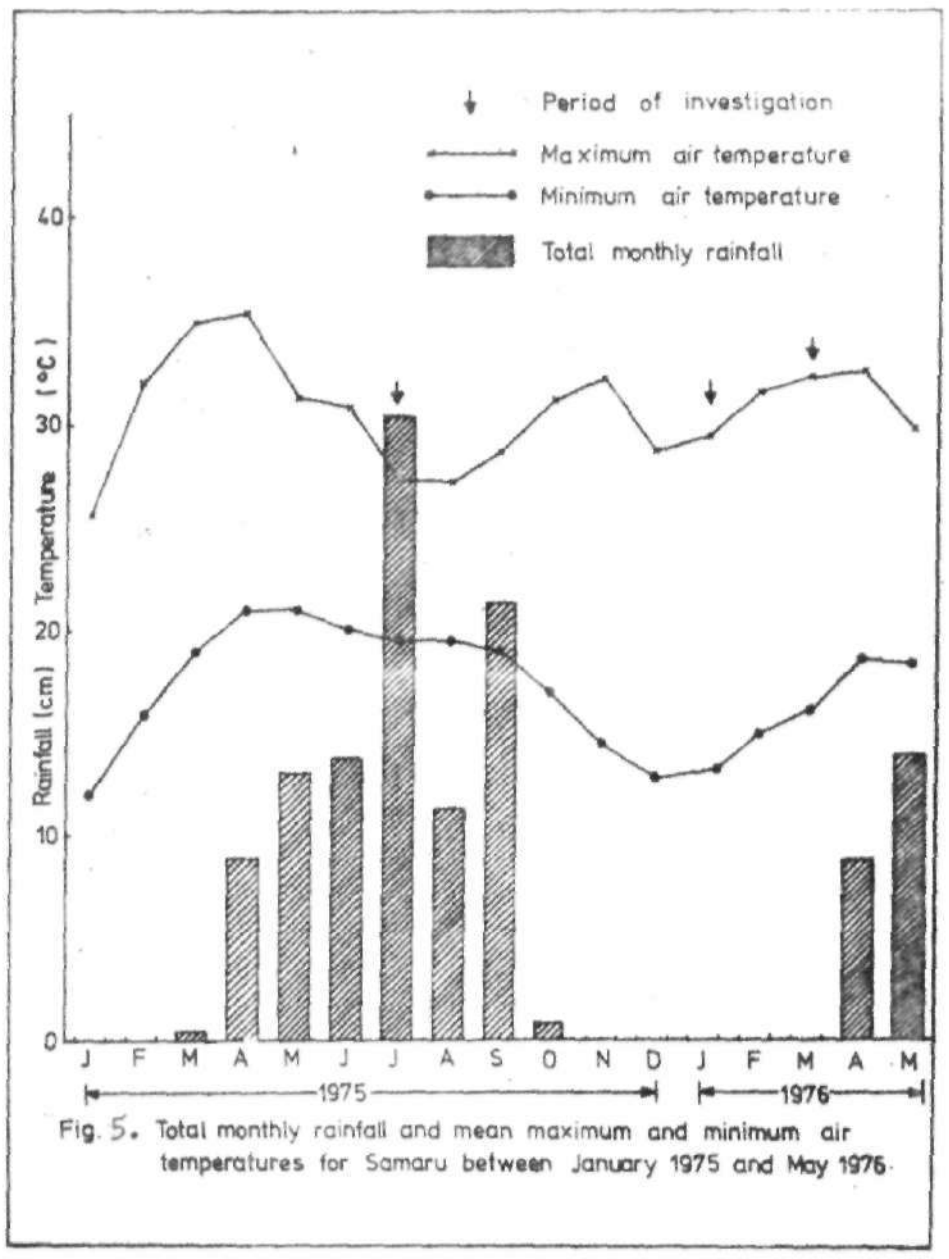


Fig. 5. Total monthly rainfall and mean maximum and minimum air temperatures for Samaru between January 1975 and May 1976.

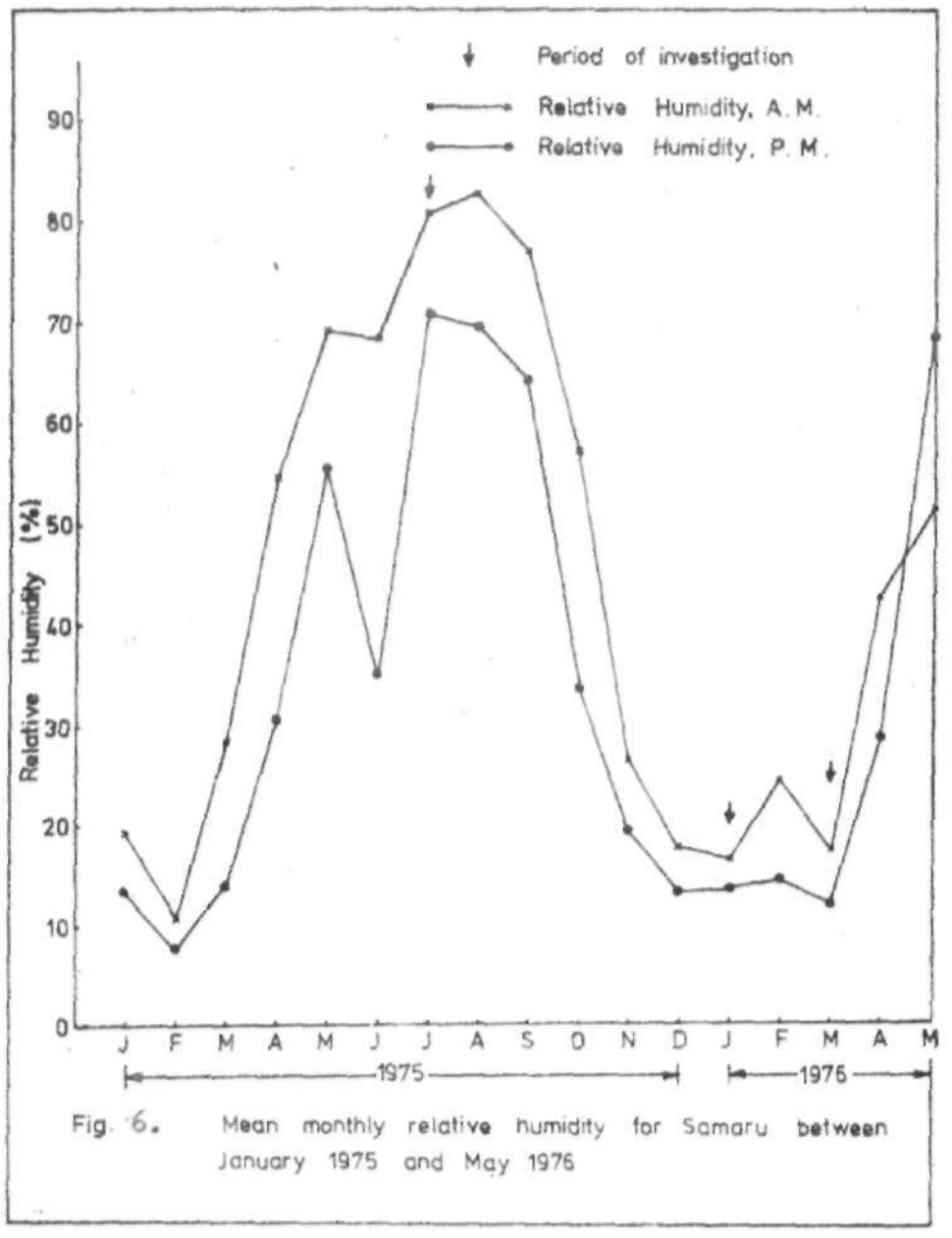


Fig. 6. Mean monthly relative humidity for Samaru between January 1975 and May 1976



Fig. 7. Mean monthly sunshine for Samaru between January 1975 and May 1976.

Appendix 4

Seasonal variations in water and feed intake in penned animals.

Tables 1 - 6

Table 1. Daily water intake (kg) in penned indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	3	4	6
1	43.5	20.9	38.5	29.1
2	36.5	36.6	27.3	24.9
3	32.5	31.1	22.5	26.7
4	30.8	22.7	19.3	25.4
5	20.2	25.0	29.4	26.2
6	32.6	24.8	24.0	24.6
7	36.4	20.6	28.2	27.8

GRAND MEAN = 28.2 S.D. = 6.1

	Sheep 1	2	3	5	6
1	2.9	2.7	10.0	3.8	2.0
2	2.8	1.9	3.7	1.9	1.3
3	1.7	2.2	2.7	2.3	1.4
4	2.5	2.6	2.8	2.1	1.0
5	1.8	2.2	2.7	1.6	1.2
6	2.4	2.8	2.6	2.0	1.4
7	2.0	2.4	2.8	1.8	1.0

GRAND MEAN = 2.4 S.D. = 1.5

	Goat 1	2	3	4	5	6
1	1.8	2.0	1.0	1.5	1.1	0.7
2	1.5	1.9	2.2	1.3	1.9	1.5
3	1.0	0.6	0.7	1.5	0.8	1.1
4	1.6	0.6	1.0	1.1	0.9	1.3
5	2.0	0.5	0.6	2.3	0.6	2.1
6	1.6	0.5	0.6	0.9	0.8	1.5
7	1.0	0.6	0.8	2.1	0.4	2.3

GRAND MEAN = 1.2 S.D. = 0.3

Table 2. Daily water intake (kg) in penned indigenous cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	24.4	16.8	15.6	12.2	15.9
2	16.1	16.0	11.8	14.5	12.5
3	14.2	14.2	9.1	11.5	8.3
4	11.3	18.4	15.4	13.5	17.5
5	9.5	16.4	9.0	12.1	16.0
6	15.5	16.2	13.1	12.9	16.1
7	22.8	15.8	17.1	20.4	18.8
	GRAND MEAN = 14.9		S.D. = 3.6		
	Sheep 1	2	3	5	6
1	1.9	2.0	1.2	1.8	1.0
2	1.1	1.4	0.6	0.5	0.5
3	1.0	1.4	0.6	1.0	1.0
4	1.6	1.5	1.6	1.2	0.8
5	1.3	1.7	1.5	1.4	1.0
6	1.9	1.8	2.0	0.7	2.1
7	1.6	2.0	2.1	1.3	1.1
	GRAND MEAN = 1.4		S.D. = 0.5		
	Goat 1	2	3	4	5	6
1	0.9	0.8	0.2	0.3	0.3	0.6
2	0.4	0.5	0.4	0.4	0.3	0.3
3	0.5	0.3	0.3	0.2	0.4	0.4
4	1.1	0.8	0.6	1.1	0.8	1.2
5	0.8	0.8	0.3	0.1	0.7	0.6
6	0.8	0.7	0.3	0.3	1.1	0.8
	GRAND MEAN = 0.6		S.D. = 0.3			

Table 3. Daily water intake (kg) in penned indigenous cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	10.6	6.4	8.6	6.4	7.4
2	6.6	8.0	10.4	8.0	5.8
3	8.0	10.6	6.0	6.0	8.8
4	10.6	5.5	4.8	5.5	5.2
5	5.8	6.8	9.2	6.8	6.4
6	8.8	8.0	8.4	8.0	7.0
7	9.2	6.0	6.5	9.6	5.6

GRAND MEAN = 7.5 S.D. = 1.7

	Sheep 1	2	3	5	6
1	0.8	0.4	1.0	0.4	0.8
2	0.4	0.3	0.6	0.2	0.4
3	0.5	0.4	0.5	0.1	0.6
4	0.3	0.2	0.6	0.2	0.2
5	0.6	0.6	0.2	0.4	0.2
6	0.2	0.1	0.2	0.6	0.1
7	0.2	0.4	0.1	0.4	0.2

GRAND MEAN = 0.4 S.D. = 0.2

	Goat 1	2	3	4	5	6
1	0.2	0.3	0.0	0.1	0.0	0.3
2	0.1	0.0	0.2	0.2	0.2	0.1
3	0.4	0.3	0.1	0.0	0.1	0.1
4	0.2	0.2	0.0	0.2	0.0	0.1
5	0.1	0.1	0.2	0.0	0.2	0.2
6	0.4	0.4	0.2	0.1	0.1	0.0
7	0.3	0.2	0.1	0.0	0.0	0.2

GRAND MEAN = 0.2 S.D. = 0.1

Table 4. Daily feed intake (kg) in penned indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	3	4	6
1	9.8	2.5	5.5	10.4
2	6.4	4.0	7.5	5.7
3	5.0	6.3	4.2	5.3
4	7.2	5.0	4.9	8.2
5	7.0	3.2	4.4	7.6
6	6.8	5.2	3.6	6.2
7	7.0	4.8	4.0	8.4

GRAND MEAN = 5.9 S.D. = 1.5

	Sheep 1	2	3	5	6
1	2.0	1.0	1.1	0.9	0.6
2	0.6	0.3	0.6	0.5	0.3
3	0.8	0.7	0.7	0.6	0.6
4	0.9	0.6	1.2	0.6	0.3
5	0.9	1.0	0.8	0.9	0.8
6	0.8	0.8	1.0	1.0	0.4
7	0.9	1.0	0.8	1.0	0.6

GRAND MEAN = 0.8 S.D. = 0.2

	Goat 1	2	3	4	5	6
1	0.8	0.6	0.8	0.4	0.4	0.6
2	0.8	0.9	0.8	0.2	0.9	0.4
3	0.8	0.8	0.8	0.4	0.6	0.6
4	1.6	0.6	0.8	0.6	0.8	0.8
5	1.5	1.0	1.2	0.4	1.0	0.6
6	1.0	1.0	0.6	0.8	0.8	0.9
7	0.8	0.6	1.0	0.4	1.0	0.8

GRAND MEAN = 0.8 S.D. = 0.2

Table 5. Daily feed intake (kg) in penned indigenous cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	9.0	8.6	6.6	6.8	5.8
2	4.6	5.2	4.3	5.3	3.7
3	2.0	4.0	5.9	6.2	4.7
4	2.2	4.6	7.3	6.8	9.4
5	5.7	6.4	5.3	6.6	3.7
6	4.0	5.0	4.7	5.4	3.1
7	7.9	4.2	6.5	8.9	7.0
	GRAND MEAN = 5.6		S.D. = 0.6		
	Sheep 1	2	3	5	6
1	0.8	0.8	0.9	0.9	1.0
2	0.4	0.2	0.2	1.0	0.1
3	0.9	0.9	0.9	0.9	1.4
4	1.0	0.9	0.9	0.9	0.8
5	1.0	0.9	0.9	1.1	0.8
6	0.7	0.6	0.8	0.5	0.2
7	0.8	0.7	0.7	0.6	0.7
	GRAND MEAN = 0.8		S.D. = 0.4		
	Goat 1	2	3	4	5	6
1	0.7	0.6	0.4	0.5	0.6	0.8
2	0.3	0.3	0.2	0.2	0.3	0.4
3	0.7	0.5	0.5	0.4	0.8	0.4
4	0.8	0.7	0.5	0.6	1.0	0.6
5	0.8	0.9	0.3	0.4	0.7	0.3
6	0.6	0.4	0.6	0.3	0.8	0.4
7	0.5	0.5	0.3	0.6	0.4	0.6
	GRAND MEAN = 0.5		S.D. = 0.1			

Table 6. Daily feed intake (kg) in penned indigenous cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	12.6	10.4	10.6	8.8	10.2
2	10.8	8.6	9.6	9.4	8.9
3	8.4	10.0	10.0	8.6	9.6
4	6.0	9.6	10.8	10.6	10.4
5	9.8	8.2	8.0	8.6	10.8
6	8.8	6.6	10.2	12.2	12.8
7	10.4	8.6	12.4	12.6	8.6

GRAND MEAN = 9.8 S.D. = 0.6

	Sheep 1	2	3	5	6
1	2.2	2.0	3.0	2.8	3.2
2	1.8	2.2	1.6	2.4	2.0
3	3.4	2.0	1.8	2.6	2.0
4	2.0	1.8	2.2	2.0	3.0
5	2.8	2.2	2.0	2.2	2.8
6	2.4	2.0	2.4	2.4	2.6
7	3.1	2.4	2.2	2.2	2.0

GRAND MEAN = 2.3 S.D. = 0.2

	Goat 1	2	3	4	5	6
1	1.8	1.0	1.6	3.2	2.8	2.4
2	2.0	2.4	1.8	3.0	2.0	2.0
3	2.0	2.0	1.8	1.8	2.2	1.8
4	2.2	1.8	2.4	2.4	2.2	3.6
5	2.0	2.8	2.0	2.0	2.6	2.8
6	3.2	3.4	2.2	2.2	2.0	2.8
7	2.8	3.6	2.8	1.8	3.0	2.6

GRAND MEAN = 2.4 S.D. = 0.2

Appendix 5

Seasonal variations in tritium retention by penned animals.

Tables 7 - 15

Table 7. Tritium retention by penned indigenous cattle during the hot season in Zaria, Nigeria.

Cattle 1	Time (days)	0.9	1.9	2.7	3.6	4.4	5.3	6.1
	Plasma activity (cpm)	12,117	10,434	8,771	7,497	6,515	5,601	4,892
3		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		12,769	11,014	9,893	8,815	7,821	6,901	6,453
4		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		12,180	10,241	8,809	7,650	6,679	5,743	4,987
6		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		11,457	9,701	8,629	7,454	6,522	5,691	5,089

Table 8. **Tritium retention** by penned indigenous cattle during the rainy season in Zaria, Nigeria.

Cattle 1	Time (days)	0.8	1.8	2.8	3.8	4.8	5.8	6.8
	Plasma activity (cpm)	13,304	11,750	10,327	9,096	8,017	7,105	6,253
2		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		14,011	12,350	10,743	9,419	8,284	7,213	6,305
3		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		15,213	13,108	11,267	9,717	8,419	7,308	6,411
4		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		13,418	11,871	10,524	9,255	8,428	7,219	6,334
5		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		10,614	9,347	8,233	7,259	6,341	5,563	4,909

Table 9. Tritium retention by penned indigenous cattle during the cold season in Zaria, Nigeria.

Cattle 1	Time (days)	0.9	1.9	2.9	3.7	4.6	5.6	6.5
	Plasma activity (cpm)	13,105	12,113	10,815	10,124	9,216	8,344	7,737
2		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		14,217	12,829	11,511	10,730	9,705	8,819	7,987
3		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		15,250	13,737	12,321	11,304	10,211	9,198	8,341
4		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		14,024	12,515	11,256	10,327	9,441	8,432	7,609
6		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		11,517	10,311	9,287	8,548	7,832	7,097	6,425

Table 10. Tritium retention by penned indigenous sheep during the hot season in Zaria, Nigeria.

Sheep 1	Time (days)	0.9	1.9	2.7	3.6	4.4	5.3	6.1
	Plasma activity (cpm)	32,392	27,940	24,594	21,503	18,372	17,104	16,016
2		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		31,873	27,155	24,836	22,300	20,212	18,548	16,704
3		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		28,227	25,014	23,248	20,502	18,760	16,801	15,254
5		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		32,194	26,506	23,803	21,272	18,558	16,496	14,500
6		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		36,273	32,192	29,352	26,101	24,534	21,836	19,668

Table 11. Tritium retention by penned indigenous sheep during the rainy season in Zaria, Nigeria

Sheep 1	Time (days)	0.8	1.8	2.8	3.8	4.8	5.8	6.8
	Plasma activity (cpm)	41,860	37,132	34,121	28,944	27,187	24,278	21,884
2		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		39,343	34,596	30,201	27,842	24,424	21,595	18,510
3		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		33,793	29,337	25,468	22,516	19,644	17,579	15,282
5		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		41,534	37,816	34,740	31,920	28,182	25,274	23,067
6		0.8	1.8	2.8	3.8	4.8	5.8	6.8
		46,243	41,192	37,370	33,283	29,564	26,537	24,909

Table 12. Tritium retention by penned indigenous sheep during the cold season in Zaria, Nigeria.

Sheep 1	Time (days)	0.9	1.9	2.9	3.7	4.6	5.6	6.5
	Plasma activity (cpm)	36,884	33,672	32,010	27,848	25,165	23,747	21,899
2		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		33,868	30,974	28,383	26,776	24,262	22,513	20,834
3		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		29,594	26,662	24,933	22,478	20,315	18,532	16,879
5		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		34,286	31,452	28,550	26,484	24,512	22,301	20,561
6		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		41,397	37,264	34,195	34,197	32,248	27,749	25,976

Table 13. Tritium retention by penned indigenous goats during the hot season in Zaria, Nigeria.

Goat 1	Time (days)	0.9	1.9	2.7	3.6	4.4	5.3	6.1
	Plasma activity (cpm)	41,988	37,852	34,644	31,808	29,179	26,492	24,835
2		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		41,824	37,997	34,578	31,342	29,833	26,765	24,886
3		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		51,064	45,739	41,906	38,652	35,897	32,718	31,019
4		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		46,445	40,286	37,807	34,819	30,892	28,760	25,031
5		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		35,873	32,014	29,946	27,567	25,948	22,519	20,873
6		0.9	1.9	2.7	3.6	4.4	5.3	6.1
		37,665	33,917	30,049	29,117	26,722	24,554	22,547

Table 14. Tritium retention by penned indigenous goats during the rainy season in Zaria, Nigeria.

Goat 1	Time (days)	0.8	1.7	2.8	3.8	4.8	5.7	6.8
	Plasma activity	49,778	46,352	42,114	39,676	36,538	33,819	30,330
2		0.8	1.7	2.8	3.8	4.8	5.7	6.8
		65,512	61,233	53,474	48,897	43,469	39,536	35,771
3		0.8	1.7	2.8	3.8	4.8	5.7	6.8
		65,012	60,464	54,130	49,789	45,942	41,225	37,867
4		0.8	1.7	2.8	3.8	4.8	5.7	6.8
		53,018	49,374	44,552	40,694	36,586	33,017	30448
5		0.8	1.7	2.8	3.8	4.8	5.7	6.8
		44,569	40,454	37,995	33,716	31,354	28,160	25,112
6		0.8	1.7	2.8	3.8	4.8	5.7	6.8
		45,047	40,968	36,846	32,130	29,970	26,112	23,254

Table 15. Tritium retention by penned indigenous goats during the cold season in Zaria, Nigeria.

Goat 1	Time (days)	0.9	1.9	2.9	3.7	4.6	5.6	6.5
	Plasma activity (cpm)	49,776	46,724	40,110	38,512	35,495	32,846	30,248
2		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		47,354	43,242	40,770	37,138	34,584	32,197	29,712
3		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		54,204	49,175	44,156	40,017	37,438	34,574	31,445
4		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		52,713	49,034	45,216	43,472	40,167	37,118	34,980
5		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		40,875	37,227	34,596	32,833	29,504	27,067	25,712
6		0.9	1.9	2.9	3.7	4.6	5.6	6.5
		42,343	38,624	35,097	33,416	30,273	27,802	25,591

APPENDIX 6

Seasonal variations in daily hematologic parameters
in penned animals.

Tables 16 - 27

Table 16. Daily values (%) for PCV in penned cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	3	4	6
1	30.0	30.6	38.5	40.0
2	32.8	34.2	30.7	37.6
3	31.2	34.1	30.4	37.5
4	31.6	35.0	28.8	38.5
5	32.0	31.3	29.8	39.3
6	31.2	33.7	29.7	37.5
7	31.0	33.1	29.7	38.4

GRAND MEAN = 33.5 S.D. = 3.5

	Sheep 1	2	3	5	6
1	35.3	34.8	40.7	34.0	30.8
2	36.5	39.0	39.5	32.8	35.6
3	36.1	38.6	39.4	31.8	37.4
4	38.1	38.5	38.6	32.9	35.2
5	35.2	38.5	38.9	32.8	34.0
6	35.6	39.1	39.3	33.0	34.8
7	36.3	35.7	37.8	31.7	34.4

GRAND MEAN = 36.0 S.D. = 2.6

	Goat 1	2	3	4	5	6
1	29.7	30.1	34.1	26.0	31.7	30.4
2	26.1	30.3	36.0	26.1	30.9	29.8
3	32.4	32.2	35.2	26.5	30.0	29.6
4	27.3	29.7	35.3	27.0	30.6	28.7
5	31.5	31.1	34.3	26.4	32.0	27.3
6	29.8	33.0	36.0	25.3	30.6	31.5
7	29.0	30.6	32.4	26.1	30.7	29.9

GRAND MEAN = 30.3 S.D. = 2.9

Table 17. Daily values (%) for PCV in penned cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	46.6	34.7	42.0	39.8	36.1
2	42.7	35.1	41.0	37.9	35.4
3	43.3	36.2	38.4	37.8	38.3
4	42.4	36.4	37.1	37.2	39.0
5	42.9	34.6	40.5	36.8	39.0
6	43.8	37.0	39.3	36.9	39.2
7	43.5	33.8	41.1	39.7	39.0

GRAND MEAN = 39.0 S.D. = 3.1

	Sheep 1	2	3	5	6
1	40.2	35.7	35.0	40.1	36.1
2	40.1	37.5	36.0	40.0	36.7
3	39.3	37.4	37.6	41.0	34.4
4	39.0	33.4	37.7	31.3	35.3
5	39.4	34.8	36.5	42.0	34.5
6	38.0	34.7	34.3	40.9	36.0
7	37.0	35.7	35.5	43.1	35.8

GRAND MEAN = 37.5 S.D. = 2.5

	Goat 1	2	3	4	5	6
1	30.1	38.0	38.3	31.4	34.4	34.1
2	30.0	37.3	39.5	30.6	34.5	34.5
3	32.2	36.0	39.0	30.3	35.0	35.0
4	33.4	38.1	38.6	28.7	36.1	34.4
5	33.3	37.0	37.6	28.9	35.4	34.5
6	32.0	37.2	38.3	31.1	36.0	33.2
7	32.4	38.1	37.5	31.5	35.3	34.4

GRAND MEAN = 34.6 S.D. = 2.9

Table 18. Daily values (%) for PCV in penned cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	35.4	39.0	39.6	30.9	35.0
2	35.2	38.1	39.8	30.1	35.1
3	36.0	38.0	41.7	32.4	34.7
4	36.0	36.5	40.8	32.6	32.8
5	35.3	37.4	41.6	33.3	31.6
6	34.5	39.0	40.5	33.8	35.1
7	34.1	39.4	40.9	32.4	36.5

GRAND MEAN = 36.2 S.D. = 3.2

	Sheep 1	2	3	5	6
1	36.1	37.0	41.2	41.6	33.4
2	36.1	38.7	39.9	40.2	33.2
3	35.8	38.5	40.6	40.4	32.0
4	35.9	39.0	40.8	41.1	31.6
5	34.6	39.0	40.8	42.6	31.1
6	34.7	37.9	39.7	42.2	32.8
7	35.3	38.7	41.9	41.0	32.0

GRAND MEAN = 37.6 S.D. = 3.5

	Goat 1	2	3	4	5	6
1	32.9	31.4	31.6	33.8	36.0	29.9
2	34.0	30.6	31.0	34.2	36.0	30.8
3	34.0	29.9	30.0	34.4	35.1	30.7
4	35.2	32.0	31.5	35.6	34.4	31.5
5	35.4	32.8	32.4	35.5	34.5	28.7
6	35.5	32.8	31.5	33.3	35.0	32.8
7	33.2	31.4	31.1	34.2	35.4	30.4

GRAND MEAN = 32.9 S.D. = 2.0

Table 19. Daily hemoglobin concentrations (g/dl) in penned cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	2	4	6
1	7.6	10.7	7.8	9.1
2	10.9	9.1	6.7	8.3
3	8.3	10.3	8.9	8.2
4	9.1	11.5	8.9	10.0
5	9.0	8.6	9.8	7.4
6	9.9	10.3	9.6	9.1
7	7.8	12.3	9.2	12.3

GRAND MEAN = 9.3 S.D. = 1.4

	Sheep 1	2	3	5	6
1	10.0	7.3	8.9	8.4	10.1
2	10.1	6.0	9.1	8.1	8.9
3	8.7	8.1	9.0	6.6	9.3
4	9.0	7.4	6.9	7.0	10.7
5	9.6	9.0	7.6	6.4	8.6
6	9.1	10.1	8.7	7.0	8.5
7	8.5	9.3	9.3	6.5	10.4

GRAND MEAN = 8.5 S.D. = 1.2

	Goat 1	2	3	4	5	6
1	6.2	6.6	8.2	7.3	6.9	9.1
2	6.1	6.9	7.4	7.3	6.7	9.0
3	5.5	6.9	7.3	6.6	5.9	6.3
4	8.0	7.3	7.1	5.8	6.8	8.2
5	7.4	9.1	9.0	6.0	6.5	8.2
6	8.1	7.9	8.6	6.1	6.9	8.0
7	8.1	8.9	10.5	5.7	7.8	7.2

GRAND MEAN = 7.4 S.D. = 1.1

Table 20. Daily hemoglobin concentrations (g/dl) in penned cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	9.2	12.0	10.8	10.0	10.1
2	9.3	12.1	10.4	9.4	10.6
3	10.1	11.4	9.3	9.3	11.4
4	11.0	10.6	12.9	10.0	10.2
5	12.4	11.0	11.8	8.4	12.3
6	11.3	11.0	12.5	8.2	12.5
7	8.6	10.3	13.5	10.1	12.1

GRAND MEAN = 10.8 S.D. = 1.3

	Sheep 1	2	3	5	6
1	8.5	9.3	9.4	10.3	8.4
2	10.3	8.5	9.2	9.2	8.2
3	9.7	10.2	10.5	8.3	9.1
4	9.4	9.1	10.1	8.1	9.4
5	9.5	8.4	11.0	11.2	9.3
6	11.5	9.0	10.4	11.0	8.5
7	12.0	9.3	11.5	12.0	10.0

GRAND MEAN = 9.7 S.D. = 1.1

	Goat 1	2	3	4	5	6
1	8.3	9.3	8.3	10.1	8.4	9.6
2	8.2	9.0	8.7	9.5	8.1	9.8
3	9.1	8.6	8.7	9.0	9.0	8.9
4	9.2	10.2	7.5	10.6	9.1	9.5
5	10.0	9.4	8.5	11.2	10.0	10.7
6	8.1	9.0	8.8	10.5	9.1	9.6
7	10.1	8.3	9.2	11.2	10.0	9.8

GRAND MEAN = 9.3 S.D. = 0.9

Table 21. Daily hemoglobin concentrations (g/dl) in penned cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	11.3	10.2	9.4	11.5	11.3
2	10.0	10.6	10.2	10.6	12.5
3	11.0	10.1	10.0	11.3	12.4
4	11.3	9.7	10.3	11.1	12.4
5	12.1	10.3	11.0	10.5	12.6
6	9.4	10.6	10.1	11.4	10.2
7	11.3	11.3	9.2	11.1	12.6

GRAND MEAN = 10.9 S.D. = 0.9

	Sheep 1	2	3	5	6
1	9.0	9.6	9.5	8.1	10.3
2	10.4	8.0	9.5	7.3	11.1
3	10.1	9.4	10.6	7.3	11.2
4	10.3	9.2	9.7	6.6	12.2
5	11.0	9.3	10.8	7.1	11.4
6	10.1	9.0	10.2	7.0	11.0
7	9.2	8.6	10.5	6.5	10.2

GRAND MEAN = 9.5 S.D. = 1.5

	Goat 1	2	3	4	5	6
1	8.5	7.5	8.0	9.4	7.3	9.4
2	9.4	7.3	8.6	9.6	8.0	9.3
3	9.6	8.4	7.3	7.8	8.1	8.5
4	8.9	8.4	8.2	9.1	9.0	9.3
5	7.8	7.2	8.6	9.4	8.1	8.6
6	10.1	8.5	8.3	9.2	8.2	9.2
7	9.2	7.7	7.4	8.7	7.4	9.2

GRAND MEAN = 8.5 S.D. = 0.8

Table 22. Daily values ($X10^6/mm^3$) for RBC in penned cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	3	4	6
1	6.4	7.3	6.2	7.3
2	6.4	6.4	6.2	7.7
3	7.3	7.2	5.3	7.2
4	7.2	7.4	5.5	8.8
5	6.7	6.8	7.0	7.5
6	7.6	6.0	6.3	7.1
7	8.4	5.4	8.1	6.9

GRAND MEAN = 6.9 S.D. = 0.9

	Sheep 1	2	3	5	6
1	8.2	8.4	6.2	9.3	7.4
2	9.0	8.0	7.0	9.3	7.4
3	9.1	7.6	7.4	9.2	6.7
4	9.0	8.1	8.6	10.4	7.1
5	8.2	8.3	7.1	10.0	6.4
6	6.8	9.0	8.2	9.0	6.0
7	8.0	9.2	7.4	8.9	5.8

GRAND MEAN = 8.0 S.D. = 1.2

	Goat 1	2	3	4	5	6
1	8.5	9.3	9.0	8.9	9.3	8.2
2	9.1	10.0	8.4	8.9	8.5	7.4
3	10.0	10.1	9.3	9.8	8.1	7.2
4	9.3	11.0	9.1	10.6	9.2	8.0
5	10.2	10.3	10.0	9.7	9.4	8.3
6	9.4	10.3	9.3	10.9	9.3	9.0
7	8.6	11.1	10.1	9.8	10.0	8.3

GRAND MEAN = 9.3 S.D. = 0.9

Table 23. Daily values ($X10^6/mm^3$) for RBC in penned cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	8.0	6.4	7.9	8.3	8.3
2	7.4	7.0	7.7	8.3	9.0
3	8.3	7.2	7.7	8.4	8.2
4	8.0	6.5	6.9	9.2	7.6
5	8.0	7.3	7.9	8.0	7.5
6	9.1	8.1	8.8	7.1	8.0
7	8.3	8.0	7.7	6.8	8.2

GRAND MEAN = 7.9 S.D. = 0.7

	Sheep 1	2	3	4	6
1	9.3	8.4	8.2	8.2	8.0
2	9.0	9.0	8.0	8.2	8.4
3	8.4	9.2	9.1	6.4	9.2
4	9.1	10.1	8.5	9.0	9.1
5	10.1	9.0	8.1	8.3	9.3
6	8.6	9.0	9.0	7.3	9.6
7	9.1	8.3	7.6	9.1	10.2

GRAND MEAN = 8.7 S.D. = 0.8

	Goat 1	2	3	4	5	6
1	10.1	8.4	10.4	11.2	8.0	11.3
2	9.5	9.2	10.0	10.4	9.4	11.3
3	9.0	9.0	9.4	11.0	8.2	12.0
4	10.2	10.0	8.1	12.1	8.2	10.4
5	11.3	9.3	9.5	10.3	10.3	11.1
6	10.5	9.2	11.2	11.3	9.4	11.1
7	10.2	8.8	12.1	11.1	10.1	10.6

GRAND MEAN = 10.1 S.D. = 1.1

Table 24. Daily values ($X10^6/mm^3$) for RBC in penned cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle	2	3	4	6
1	8.0	6.5	7.2	6.6	6.3
2	7.4	6.1	7.2	6.2	7.1
3	7.2	7.0	8.0	7.0	7.2
4	8.1	8.2	9.3	6.0	8.0
5	7.0	8.2	8.0	7.3	8.0
6	7.2	7.3	8.4	6.5	7.1
7	6.4	7.2	8.3	5.1	7.3

GRAND MEAN = 7.3 S.D. = 0.8

	Sheep 1	2	3	5	6
1	9.3	8.0	8.2	7.5	10.2
2	9.3	8.2	9.2	8.0	9.4
3	8.0	9.3	9.0	8.0	10.0
4	8.4	11.0	10.4	8.2	11.1
5	9.0	10.0	10.1	8.1	10.0
6	7.5	10.2	9.3	7.7	10.3
7	7.4	9.4	9.2	9.1	9.0

GRAND MEAN = 9.1 S.D. = 1.0

	Goat 1	2	3	4	5	6
1	8.4	11.0	11.0	10.2	10.2	11.2
2	9.0	11.2	11.0	10.2	9.4	10.0
3	10.0	10.4	10.3	9.0	9.0	10.4
4	10.1	10.1	10.1	9.4	8.1	10.1
5	9.0	10.0	10.0	9.3	9.1	10.3
6	9.2	10.2	10.2	1.1	9.0	10.0
7	9.3	9.7	9.4	8.4	7.4	8.4

GRAND MEAN = 9.5 S.D. = 1.6

Table 25. Daily total protein concentrations (g/dl) in penned cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	3	4	6
1	7.1	8.4	9.0	6.1
2	7.3	7.8	8.4	6.1
3	8.4	7.5	8.1	5.4
4	6.0	8.9	8.3	6.0
5	7.1	8.8	10.0	6.3
6	8.1	6.7	10.1	6.3
7	6.0	6.5	10.5	7.2

GRAND MEAN = 7.6 S.D. = 1.4

	Sheep 1	2	3	5	6
1	8.3	9	7.0	6.8	6.4
2	8.5	9.3	7.1	7.2	6.8
3	7.6	8.5	7.2	7.3	7.5
4	6.2	7.7	7.0	6.7	6.7
5	6.7	7.3	5.7	5.8	5.3
6	7.2	9.4	5.6	6.4	7.7
7	6.3	7.5	4.8	5.3	6.8

GRAND MEAN = 7.1 S.D. = 1.2

	Goat 1	2	3	4	5	6
1	8.1	6.3	7.2	7.3	8.3	7.0
2	8.2	6.5	5.6	6.6	8.7	7.2
3	7.0	6.7	7.0	5.9	9.4	6.4
4	6.4	5.1	7.8	5.5	8.6	5.3
5	7.3	7.0	8.0	9.8	7.7	5.3
6	6.0	7.6	7.4	8.7	8.8	7.0
7	6.0	5.6	8.8	8.4	7.0	5.7

GRAND MEAN = 7.2 S.D. = 1.2

Table 26. Daily total protein concentrations (g/dl) in penned cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	9.0	8.0	7.9	8.5	8.1
2	8.3	7.1	8.3	9.7	7.3
3	8.3	9.2	7.6	7.4	8.1
4	8.6	9.0	7.6	7.8	8.1
5	7.8	8.0	8.4	9.6	8.3
6	10.2	8.1	6.5	8.3	7.0
7	6.6	6.6	6.7	8.9	9.2
	GRAND MEAN = 8.1		S.D. = 0.9		
	Sheep 1	2	3	5	6
1	8.4	7.3	7.3	7.3	8.0
2	8.2	7.5	9.0	7.0	8.4
3	8.4	6.6	7.5	8.1	8.1
4	7.0	5.4	7.8	9.0	9.1
5	7.3	7.3	8.9	9.1	9.0
6	9.0	8.2	6.8	8.3	6.3
7	9.1	9.6	5.9	7.2	6.5
	GRAND MEAN = 7.8		S.D. = 1.0		
	Goat 1	2	3	4	5	6
1	8.2	7.1	8.0	6.7	6.0	7.7
2	8.6	7.9	8.8	6.9	6.3	7.6
3	8.6	6.9	8.1	5.8	7.3	7.5
4	6.1	6.9	7.7	5.8	7.0	8.9
5	7.3	9.1	8.2	8.1	6.4	8.9
6	6.5	7.8	8.9	6.9	5.3	7.9
7	6.5	7.6	9.1	6.8	5.1	5.8
	GRAND MEAN = 7.4		S.D. = 1.1			

Table 27. Daily total protein concentrations (g/dl) in penned cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	6
1	8.2	8.4	7.3	7.0	9.6
2	8.6	8.9	7.5	7.1	10.0
3	8.0	8.3	7.5	7.2	10.2
4	8.8	7.7	8.3	6.5	7.4
5	9.7	6.4	7.6	6.0	9.3
6	9.1	9.6	6.4	5.0	9.4
7	6.5	9.2	5.7	6.2	9.0

GRAND MEAN = 8.0 S.D. = 1.3

	Sheep 1	2	3	5	6
1	7.1	8.8	6.3	7.6	8.1
2	8.3	7.7	6.7	9.0	8.1
3	9.0	7.9	7.7	9.0	8.4
4	9.0	8.9	6.2	9.0	7.6
5	8.2	6.0	6.6	6.1	6.9
6	7.3	6.8	5.5	8.3	6.9
7	7.3	7.8	6.5	8.2	7.5

GRAND MEAN = 7.6 S.D. = 1.0

	Goat 1	2	3	4	5	6
1	9.0	8.5	7.2	7.4	7.3	8.0
2	9.1	8.1	7.0	7.3	7.5	8.0
3	8.0	7.3	7.2	7.1	7.7	7.3
4	6.4	6.6	7.1	6.1	7.1	7.0
5	7.3	9.0	6.1	5.3	8.0	6.4
6	9.2	9.1	5.5	9.0	7.6	6.1
7	7.1	9.5	9.0	8.2	6.6	6.2

GRAND MEAN = 7.5 S.D. = 1.1

Table 28. Tritium retention by grazing indigenous cattle during the hot season in Zaria, Nigeria.

Cattle 1	Time (days)	0.7	1.6	2.6	3.6	4.5	5.4	6.3
	Plasma activity (cpm)	11,106	8,944	6,987	5,700	4,645	3,887	3,121
2		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		11,205	8,613	6,437	4,853	3,709	2,817	2,261
3		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		12,233	9,657	7,439	5,717	4,526	3,691	2,907
4		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		12,258	9,347	6,981	5,673	3,916	2,985	2,335
5		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		9,796	8,212	6,787	5,401	4,623	3,811	3,217
6		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		9,882	7,367	6,179	4,755	3,813	3,674	2,415

Appendix 7

Seasonal variation in tritium retention by grazing animals.

Tables 28 - 36

Table 29. Tritium retention by grazing indigenous cattle during the rainy season in Zaria, Nigeria.

Cattle 1	Time (days)	0.8	1.7	2.5	3.4	4.3	5.1	6.0
	Plasma activity (cpm)	13,187	11,613	10,554	9,267	8,185	7,301	6,514
2		0.8	1.7	2.5	3.4	4.3	5.1	6.0
		13,569	11,754	10,418	9,027	7,819	6,922	6,097
3		0.8	1.7	2.5	3.4	4.3	5.1	6.0
		15,184	13,027	11,349	9,721	8,445	7,361	6,355
4		0.8	1.7	2.5	3.4	4.3	5.1	6.0
		15,120	13,500	12,259	11,043	9,729	8,819	7,927
5		0.8	1.7	2.5	3.4	4.3	5.1	6.0
		11,833	10,567	9,385	8,372	7,390	6,531	5,833
6		0.8	1.7	2.5	3.4	4.3	5.1	6.0
		11,865	10,256	9,134	8,049	7,072	6,208	5,416

Table 30. Tritium retention by grazing indigenous cattle during the cold season in Zaria, Nigeria.

Cattle 1	Time (days)	0.9	1.8	2.6	3.4	4.2	5.1	6.0
	Plasma activity (cpm)	12,565	11,301	10,435	9,689	8,877	8,102	7,211
2		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		14,179	12,516	11,507	10,522	9,538	8,649	7,741
3		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		13,207	11,634	10,671	9,785	8,963	8,421	7,218
4		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		14,495	13,318	12,113	11,022	10,215	9,344	8,557
5		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		12,167	11,097	9,894	9,321	8,546	7,837	7,189
6		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		11,176	10,177	9,348	8,513	7,974	7,151	6,592

Table 31. Tritium retention by grazing indigenous sheep during the hot season in Zaria, Nigeria.

Cattle 1	Time (days)	0.7	1.6	2.6	3.6	4.5	5.4	6.3
	Plasma activity (cpm)	28,233	24,170	21,842	18,924	15,568	13,586	11,769
2		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		27,542	23,711	19,034	15,575	13,666	11,818	9,034
3		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		25,117	21,586	18,162	15,354	13,100	11,744	9,576
4		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		28,693	23,244	18,393	14,532	11,981	9,744	8,050
5		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		30,958	25,757	21,088	17,299	14,756	12,272	10,804
6		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		38,234	31,455	25,022	21,083	16,430	13,036	11,447

Table 32. Tritium retention by grazing indigenous sheep during the rainy season in Zaria, Nigeria.

Sheep 1	Time (days)	0.8	1.7	2.5	3.4	4.3	5.1	6.1
	Plasma activity (cpm)	42,387	39,764	35,430	32,178	29,352	27,331	24,345
2		0.8	1.7	2.5	3.4	4.3	5.1	6.1
		41,084	35,576	31,246	27,917	24,534	21,963	19,052
3		0.8	1.7	2.5	3.4	4.3	5.1	6.1
		35,340	31,171	28,534	25,545	23,084	21,376	18,532
4		0.8	1.7	2.5	3.4	4.3	5.1	6.1
		35,038	31,796	28,554	25,310	23,873	20,545	18,176
5		0.8	1.7	2.5	3.4	4.3	5.1	6.1
		41,835	37,327	33,476	30,478	26,879	24,096	21,142
6		0.8	1.7	2.5	3.4	4.3	5.1	6.1
		45,075	41,274	37,560	33,882	30,411	28,734	24,913

Table 33. Tritium retention by grazing indigenous sheep during the cold season in Zaria, Nigeria.

Sheep 1	Time (days)	0.9	1.8	2.6	3.4	4.2	5.1	6.0
	Plasma activity (cpm)	32,362	29,487	27,556	24,734	22,540	20,315	18,574
2		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		34,507	31,898	29,139	27,062	25,174	23,320	21,186
3		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		37,353	33,774	31,212	29,071	27,118	25,344	23,290
4		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		31,662	29,750	26,624	24,787	22,844	20,933	19,072
5		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		28,226	26,645	24,173	22,507	21,438	19,272	17,714
6		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		27,297	24,766	22,632	20,814	19,705	17,544	15,859

Table 34. Tritium retention by grazing indigenous goats during the hot season in Zaria, Nigeria.

Goat 1	Time (days)	0.7	1.6	2.6	3.6	4.5	5.4	6.3
	Plasma activity (cpm)	42,752	36,334	30,106	26,567	25,858	19,075	17,289
2		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		41,154	36,912	32,174	28,953	25,062	22,438	20,018
3		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		48,576	41,932	35,263	31,864	26,557	22,478	19,284
4		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		52,183	46,565	41,596	36,478	32,520	29,502	26,481
5		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		32,964	29,753	25,856	22,187	19,578	17,457	15,554
6		0.7	1.6	2.6	3.6	4.5	5.4	6.3
		32,956	27,870	23,532	21,871	17,258	15,463	12,947

Table 35. Tritium retention by grazing indigenous goats during the rainy season in Zaria, Nigeria.

Goat 1	Time (days)	0.9	1.7	2.5	3.4	4.3	5.1	5.9
	Plasma activity (cpm)	46,250	40,502	35,778	29,914	26,115	21,746	18,537
2		0.9	1.7	2.5	3.4	4.3	5.1	5.9
		59,893	53,612	48,874	44,250	39,421	36,526	32,887
3		0.9	1.7	2.5	3.4	4.3	5.1	5.9
		56,074	50,927	45,182	42,134	35,516	32,062	28,618
4		0.9	1.7	2.5	3.4	4.3	5.1	5.9
		71,296	65,572	60,855	54,927	49,796	45,113	39,562
5		0.9	1.7	2.5	3.4	4.3	5.1	5.9
		41,875	37,837	34,659	30,586	27,222	24,704	22,098
6		0.9	1.7	2.5	3.4	4.3	5.1	5.9
		39,920	35,914	33,562	30,495	27,856	24,907	22,670

Table 36. Tritium retention by grazing indigenous goats during the cold season in Zaria, Nigeria.

Goat 1	Time (days)	0.9	1.8	2.6	3.4	4.2	5.1	6.0
	Plasma activity (cpm)	45,667	41,252	38,534	35,866	33,898	30,110	28,516
2		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		51,852	46,514	43,715	39,928	36,814	33,501	30,562
3		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		47,067	44,768	40,122	38,194	35,553	33,456	30,532
4		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		50,820	47,818	45,472	42,756	40,107	38,138	35,579
5		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		44,676	40,212	38,374	35,516	33,442	30,528	28,914
6		0.9	1.8	2.6	3.4	4.2	5.1	6.0
		53,256	49,174	45,062	42,715	39,326	36,490	33,818

APPENDIX 8

Seasonal variations in daily hematologic parameters in grazing animals.

Tables 37-48

Table 37. Daily values (%) for PCV in grazing cattle, sheep and goats during the host season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	36.2	29.7	29.1	36.0	38.0	29.2
2	36.5	30.9	28.3	26.1	39.2	30.0
3	35.5	30.8	30.0	38.3	39.0	30.1
4	35.0	32.4	31.0	37.5	37.1	28.3
5	34.8	33.1	28.2	38.1	36.3	28.2
6	36.1	32.8	28.3	38.3	39.0	30.1
7	33.7	32.9	28.3	36.1	37.4	28.3
	GRAND MEAN = 33.4		S.D. = 3.8			
	Sheep 1	2	3	4	5	6
1	33.5	37.9	34.3	35.8	33.6	36.1
2	33.4	36.1	34.1	36.2	34.7	37.3
3	33.0	36.3	32.0	37.4	32.9	37.0
4	31.6	35.7	34.4	35.6	31.7	35.0
5	31.3	34.4	34.1	34.4	32.9	35.2
6	33.4	37.7	35.0	35.7	31.8	34.1
7	31.8	37.4	34.1	34.4	31.5	37.3
	GRAND MEAN = 34.6		S.D. = 1.9			
	Goat 1	2	3	4	5	6
1	32.6	29.4	27.0	26.0	27.4	31.4
2	32.8	28.7	27.4	26.0	27.2	38.6
3	29.5	30.7	28.0	25.3	27.5	30.5
4	31.9	31.5	29.0	24.2	26.1	29.5
5	30.7	28.7	26.3	24.0	25.0	30.8
6	31.8	28.9	26.4	24.1	26.2	31.1
7	32.6	28.3	26.3	26.1	24.7	29.6
	GRAND MEAN = 28.6		S.D. = 3.0			

Table 38. Daily values (%) for PCV in grazing cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	38.0	39.4	39.2	41.0	34.4	39.1
2	39.2	38.9	40.0	42.2	36.2	38.5
3	37.1	37.6	40.1	40.4	37.1	38.0
4	37.0	37.1	38.3	40.1	37.5	37.6
5	36.3	36.6	40.2	39.0	36.6	38.2
6	39.2	39.6	38.1	39.1	35.1	38.2
7	39.4	40.3	37.2	38.2	37.2	38.5
	GRAND MEAN = 38.4		S.D. = 1.6			
	Sheep 1	2	3	4	5	6
1	37.0	38.1	38.1	36.3	38.0	37.4
2	37.0	40.3	37.4	36.5	38.3	37.6
3	35.1	39.0	37.6	36.1	37.4	36.2
4	36.3	39.1	38.0	37.6	37.1	35.8
5	36.0	40.2	39.2	36.3	38.0	38.8
6	36.1	29.0	39.4	38.1	36.1	37.2
7	35.2	37.3	38.0	39.0	35.1	39.5
	GRAND MEAN = 37.3		S.D. = 1.9			
	Goat 1	2	3	4	5	6
1	36.2	30.0	35.8	31.9	34.0	34.0
2	35.4	30.0	36.6	31.5	35.8	34.1
3	35.3	32.2	36.4	29.8	34.2	34.0
4	35.2	31.2	35.9	29.6	34.6	33.3
5	37.4	31.1	34.3	29.6	35.3	32.5
6	37.6	31.2	34.8	30.9	33.7	32.0
7	37.0	31.0	35.4	31.6	33.2	32.5
	GRAND MEAN = 33.5		S.D. = 2.3			

Table 39. Daily values (%) for PCV in grazing cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	37.3	35.1	34.0	36.6	35.2	37.2
2	35.5	35.3	33.4	37.1	35.8	37.1
3	35.2	35.0	34.1	36.6	36.8	36.0
4	36.6	34.4	35.0	35.9	34.1	35.4
5	36.1	36.1	34.0	34.6	34.7	35.1
6	36.6	36.1	35.0	34.7	34.5	36.0
7	37.5	34.4	33.2	33.9	37.5	35.2
	GRAND MEAN = 35.5		S.D. = 1.2			
	Sheep 1	2	3	4	5	6
1	38.1	35.1	38.4	37.3	36.1	37.0
2	37.3	36.5	37.0	37.7	38.1	37.2
3	38.1	36.0	37.1	36.2	38.4	35.9
4	38.1	34.3	39.0	34.6	38.0	36.5
5	37.0	35.0	39.1	37.4	36.3	35.4
6	36.0	34.0	39.2	37.8	37.0	36.2
7	35.6	35.9	36.3	37.0	35.2	36.6
	GRAND MEAN = 36.8		S.D. = 1.3			
	Goat 1	2	3	4	5	6
1	33.2	29.4	34.1	33.8	31.5	29.1
2	33.4	29.6	32.0	33.2	31.7	28.3
3	32.1	29.3	34.3	31.1	30.9	28.0
4	33.5	30.7	34.6	32.9	29.3	28.4
5	31.6	31.5	32.0	32.3	29.8	31.2
6	31.1	31.9	33.0	30.9	31.5	31.3
7	31.2	31.1	32.4	33.3	29.5	28.1
	GRAND MEAN = 31.4		S.D. = 1.8			

Table 40. Daily hemoglobin concentrations (g/dl) in grazing cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	9.4	8.6	9.7	7.4	8.5	8.7
2	8.5	8.6	9.9	7.4	8.5	8.3
3	8.5	9.3	10.4	7.3	9.3	8.1
4	7.2	9.4	9.8	6.8	9.4	7.9
5	7.4	9.3	10.1	7.1	9.6	6.8
6	8.6	9.3	10.2	7.2	9.4	8.2
7	7.2	8.6	10.2	6.6	8.9	8.4
	GRAND MEAN = 8.6		S.D. = 1.1			
	Sheep 1	2	3	4	5	6
1	7.3	7.5	6.8	8.2	8.4	7.5
2	8.3	7.8	6.8	9.4	8.4	7.5
3	6.2	8.4	7.3	8.6	7.6	6.9
4	9.1	7.2	6.5	9.0	7.6	6.4
5	9.3	8.0	7.2	9.1	8.2	7.5
6	8.2	8.6	7.2	9.4	8.3	7.2
7	7.7	8.8	7.5	9.3	8.3	6.8
	GRAND MEAN = 7.9		S.D. = 0.9			
	Goat 1	2	3	4	5	6
1	6.4	4.4	6.3	7.3	5.4	6.3
2	7.3	7.0	7.4	7.2	5.2	6.3
3	7.5	6.1	6.7	7.1	4.9	6.0
4	6.8	6.0	7.2	6.8	5.0	5.2
5	7.0	5.3	7.1	7.0	5.3	6.2
6	7.4	6.0	8.0	7.1	5.2	6.4
7	7.4	6.2	6.3	7.2	5.1	6.0
	GRAND MEAN = 6.4		S.D. = 0.8			

Table 41. Daily hemoglobin concentrations (g./dl) in grazing cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	11.3	9.2	10.4	10.5	11.7	9.2
2	12.2	9.2	10.4	12.4	11.7	11.0
3	12.0	10.0	9.3	11.5	10.9	10.1
4	11.4	10.4	10.0	11.6	12.5	9.5
5	10.4	10.2	10.3	10.9	12.5	10.0
6	10.1	11.1	10.5	11.4	12.7	10.0
7	10.4	10.3	9.9	9.9	11.9	9.6
	GRAND MEAN = 10.7			S.D. = 1.0		
	Sheep 1	2	3	4	5	6
1	11.0	8.3	8.4	10.2	8.4	9.5
2	11.0	9.4	8.4	9.4	8.5	9.6
3	10.3	8.2	9.2	10.0	10.3	8.6
4	10.3	8.3	7.6	8.1	9.0	9.4
5	10.0	9.6	8.0	10.4	9.1	8.3
6	10.4	10.2	8.4	11.0	9.2	8.8
7	9.6	9.4	6.8	11.4	8.8	9.4
	GRAND MEAN = 9.3			S.D. = 1.0		
	Goat 1	2	3	4	5	6
1	9.6	8.3	8.5	9.3	9.4	7.5
2	9.7	8.3	8.9	9.4	8.4	7.5
3	8.8	9.1	7.4	9.0	8.8	8.1
4	9.6	9.5	7.5	8.7	8.3	7.9
5	7.9	10.0	8.8	9.5	9.6	8.5
6	8.5	9.2	8.7	9.3	9.3	8.3
7	9.0	8.7	7.5	8.4	10.0	8.6
	GRAND MEAN = 8.8			S.D. = 0.7		

Table 42. Daily hemoglobin concentrations (g/dl) in grazing cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	10.2	8.4	10.3	9.4	9.2	10.8
2	9.4	8.1	10.3	10.4	9.6	10.0
3	11.0	9.1	10.4	10.3	9.4	11.6
4	11.1	8.4	11.0	10.4	8.4	11.2
5	11.1	10.0	9.6	11.1	9.4	10.4
6	12.3	10.1	9.3	9.7	9.0	11.7
7	12.3	9.3	9.3	9.0	8.8	11.1
	GRAND MEAN = 10.1		S.D. = 1.1			
	Sheep 1	2	3	4	5	6
1	9.0	8.6	7.6	10.3	8.5	9.5
2	9.0	9.2	7.6	9.3	9.4	9.0
3	8.8	8.4	8.8	10.6	9.6	8.9
4	9.4	8.8	8.4	10.0	8.9	9.6
5	9.4	9.2	7.3	10.2	9.1	8.7
6	9.8	9.4	7.9	10.4	9.5	8.3
7	8.4	9.3	8.6	9.3	8.5	9.5
	GRAND MEAN = 8.9		S.D. = 1.3			
	Goat 1	2	3	4	5	6
1	8.1	8.4	8.5	6.2	8.1	8.9
2	9.0	8.6	9.4	6.2	7.9	8.2
3	7.3	9.2	10.6	7.1	7.5	7.5
4	7.6	9.6	10.5	7.3	8.5	7.5
5	6.0	10.2	7.5	8.0	8.5	8.6
6	9.4	9.5	9.4	7.1	8.2	7.7
7	9.0	7.7	8.6	7.7	7.8	8.4
	GRAND MEAN = 8.3		S.D. = 1.1			

Table 43. Daily values ($X10^6/mm^3$) for RBC in grazing cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	7.0	7.2	7.1	5.2	7.0	6.3
2	7.0	7.2	6.0	6.0	6.3	6.5
3	7.2	8.0	6.2	5.1	6.1	7.0
4	6.1	7.4	7.0	5.1	6.1	7.1
5	5.6	7.1	6.1	5.3	7.2	6.2
6	6.4	8.0	6.1	6.0	5.4	6.0
7	5.5	6.3	5.6	4.7	6.0	5.6
	GRAND MEAN = 6.3		S.D. = 0.8			
	Sheep 1	2	3	4	5	6
1	8.1	6.2	7.3	7.3	7.2	5.4
2	9.0	6.0	7.2	7.0	8.0	5.2
3	8.0	7.1	6.1	7.2	8.4	6.0
4	7.4	7.1	7.3	8.0	7.0	6.1
5	9.1	8.2	8.0	7.1	8.1	7.0
6	9.0	7.3	7.1	7.3	8.7	7.2
7	7.6	7.2	6.7	6.9	9.2	5.6
	GRAND MEAN = 7.3		S.D. = 1.0			
	Goat 1	2	3	4	5	6
1	9.1	10.1	7.1	6.4	9.2	8.0
2	8.3	9.0	7.3	7.0	9.0	8.0
3	7.0	9.3	8.0	7.0	10.4	8.6
4	8.2	8.5	8.0	8.1	9.1	7.4
5	9.0	9.0	9.1	7.1	9.3	8.3
6	7.3	9.0	9.1	7.1	8.0	8.1
7	7.4	8.3	7.4	6.3	8.4	8.2
	GRAND MEAN = 8.2		S.D. = 1.0			

Table 44. Daily values ($X10^6/mm^3$) for RBC in grazing cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	6.1	7.3	6.0	8.1	7.2	9.0
2	7.1	7.3	6.3	7.0	7.0	8.2
3	6.2	8.1	6.0	8.3	6.4	8.1
4	7.2	7.5	7.1	9.0	8.1	7.0
5	7.3	8.0	6.2	8.4	7.0	8.3
6	8.0	9.2	5.4	8.1	7.1	8.1
7	7.3	8.7	5.5	7.5	6.5	7.3

GRAND MEAN = 7.4 S.D. = 1.0

	Sheep 1	2	3	4	5	6
1	8.2	8.6	8.0	9.3	9.1	8.1
2	8.2	9.0	7.4	9.3	9.0	9.3
3	9.0	10.3	8.2	10.1	8.3	8.2
4	8.4	8.4	8.2	9.5	9.1	10.0
5	9.3	9.2	9.1	11.0	10.0	10.1
6	10.1	9.1	8.1	10.6	9.1	9.3
7	10.0	8.3	7.6	11.3	8.4	8.7

GRAND MEAN = 9.1 S.D. = 0.9

	Goat 1	2	3	4	5	6
1	11.0	10.4	11.2	9.0	11.4	8.4
2	9.2	11.3	11.2	9.4	11.0	8.2
3	10.3	12.0	12.0	10.2	10.2	8.6
4	10.0	12.0	11.3	11.1	11.3	9.0
5	8.1	12.3	10.3	11.3	12.1	10.1
6	10.3	11.4	11.0	10.0	11.2	9.6
7	11.1	12.1	10.4	9.4	10.5	10

GRAND MEAN = 10.5 S.D. = 1.1

Table 45. Daily values ($X10^6/mm^3$) for RBC in grazing cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	5.4	7.2	6.2	5.3	7.3	9.0
2	5.2	7.2	6.1	5.2	7.0	8.2
3	6.0	7.2	6.3	6.0	7.1	8.2
4	6.1	6.4	5.4	6.0	8.2	8.0
5	6.3	7.1	6.0	7.2	7.0	7.4
6	7.1	8.0	6.1	6.1	6.7	8.0
7	6.8	6.3	6.3	6.2	6.5	7.3

GRAND MEAN = 6.7 S.D. = 0.9

	Sheep 1	2	3	4	5	6
1	7.3	8.5	8.3	10.0	8.3	8.0
2	8.0	9.4	7.6	9.6	9.1	8.4
3	8.0	9.5	8.0	9.3	9.4	7.2
4	6.9	8.9	8.1	9.3	8.6	8.2
5	8.1	9.3	8.4	8.9	9.0	9.1
6	8.4	9.9	8.1	9.0	9.0	8.1
7	9.3	8	7.7	8.4	8.6	7.4

GRAND MEAN = 8.5 S.D. = 0.8

	Goat 1	2	3	4	5	6
1	9.3	8.2	8.1	10.1	7.5	9.3
2	9.0	9.4	8.5	10.3	8.3	9.3
3	10.3	8.5	9.0	9.0	7.8	10.1
4	10.4	10.1	8.6	10.2	8.4	10.4
5	10.3	10.0	10.2	11.1	9.0	11.3
6	11.5	8.6	9.4	10.3	8.1	10.0
7	9.6	8.3	9.3	9.6	7.5	9.6

GRAND MEAN = 9.4 S.D. = 1.0

Table 46. Daily total protein concentrations (g/dl) in grazing cattle, sheep and goats during the hot season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	8.0	7.7	6.3	8.6	9.2	5.6
2	7.3	7.8	6.0	8.7	10.0	6.9
3	5.2	7.6	6.0	7.9	10.0	3.4
4	7.1	6.5	4.5	8.8	7.9	6.3
5	6.0	8.4	5.1	8.9	8.4	4.7
6	6.3	8.7	5.0	9.3	10.3	6.4
7	5.1	6.9	5.1	8.1	9.2	3.6

GRAND MEAN = 7.1 S.D. = 1.8

	Sheep 1	2	3	4	5	6
1	6.8	7.0	8.2	7.9	5.9	6.0
2	7.0	7.0	8.0	7.1	4.8	5.6
3	7.2	6.3	7.3	7.5	4.9	5.3
4	8.6	5.5	7.1	8.2	4.9	6.0
5	7.5	7.2	6.4	7.6	6.3	7.1
6	7.7	6.0	6.0	6.5	7.2	7.3
7	7.0	4.4	7.0	7.4	5.2	6.0

GRAND MEAN = 6.7 S.D. = 1.0

	Goat 1	2	3	4	5	6
1	6.6	7.0	8.0	6.4	5.9	7.1
2	7.4	7.6	7.3	6.9	5.5	7.4
3	7.3	8.1	8.1	6.8	4.9	8.0
4	5.7	7.5	8.0	7.2	4.8	7.6
5	7.2	7.2	8.0	7.1	6.7	7.2
6	6.4	7.4	8.0	4.9	6.4	7.0
7	4.9	6.3	6.5	6.5	5.8	6.7

GRAND MEAN = 6.8 S.D. = 0.9

Table 47. Daily total protein concentrations (g./dl) in grazing cattle, sheep and goats during the rainy season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	8.3	8.9	9.3	8.6	7.0	9.2
2	8.0	7.9	8.1	8.5	6.8	10.1
3	8.2	9.8	10.0	7.7	5.9	9.9
4	7.0	9.4	8.0	6.4	6.9	10.0
5	7.3	6.3	9.4	6.8	6.7	9.6
6	8.2	8.7	10.1	8.3	6.8	9.4
7	9.1	8.3	8.1	6.9	7.0	9.3
	GRAND MEAN = 8.2		S.D. = 1.2			
	Sheep 1	2	3	4	5	6
1	8.0	7.4	8.3	6.7	7.8	5.6
2	8.4	8.0	8.5	6.8	7.0	8.0
3	7.2	8.0	8.6	8.8	8.0	8.1
4	7.1	6.0	7.2	6.9	6.6	7.0
5	9.3	8.1	8.1	7.9	7.4	7.0
6	8.4	8.1	8.2	5.9	7.7	8.3
7	8.0	5.5	6.9	6.7	6.8	8.2
	GRAND MEAN = 7.5		S.D. = 0.9			
	Goat 1	2	3	4	5	6
1	8.3	5.8	7.1	6.9	7.8	7.0
2	9.1	7.9	7.6	6.7	7.8	6.2
3	9.0	6.5	8.0	5.4	6.9	8.1
4	9.0	6.6	8.0	6.8	8.7	7.3
5	7.1	6.7	6.3	5.9	5.8	7.0
6	8.2	6.4	8.4	6.7	6.7	8.0
7	6.8	6.9	6.0	5.8	6.4	6.3
	GRAND MEAN = 7.1		S.D. = 1.0			

Table 48. Daily total protein concentrations (g/dl) in grazing cattle, sheep and goats during the cold season in Zaria, Nigeria.

Days	Cattle 1	2	3	4	5	6
1	6.9	8.5	9.0	7.3	6.9	8.5
2	7.7	7.6	9.0	7.5	6.7	8.7
3	7.6	8.3	10.4	6.6	5.9	9.3
4	8.9	8.0	9.1	5.2	7.8	10.6
5	7.6	8.4	9.3	8.0	7.8	7.7
6	7.5	7.8	9.4	7.8	6.9	6.9
7	6.9	8.5	8.0	9.4	5.8	8.5

GRAND MEAN = 8.0 S.D. = 1.2

	Sheep 1	2	3	4	5	6
1	9.0	6.8	6.3	7.2	7.5	7.0
2	9.0	5.9	6.4	7.4	7.7	6.3
3	8.3	5.6	7.5	6.3	5.7	6.5
4	7.3	7.0	7.1	6.5	7.8	6.4
5	8.2	7.5	7.3	7.0	6.4	7.2
6	8.0	6.9	6.4	7.6	7.4	7.1
7	7.6	5.8	7.2	8.1	6.9	9.0

GRAND MEAN = 6.8 S.D. = 0.9

	Goat 1	2	3	4	5	6
1	6.3	7.3	6.9	6.4	7.2	5.8
2	5.0	7.4	6.7	5.8	7.3	5.0
3	6.1	6.2	7.8	5.3	6.2	6.7
4	7.3	7.3	5.3	7.9	8.0	5.1
5	8.1	7.5	7.9	6.9	7.4	6.3
6	8.0	7.1	7.8	6.4	7.7	7.4
7	5.2	6.3	6.9	6.5	6.9	8.5

GRAND MEAN = 7.2 S.D. = 0.9

Appendix 9

Tritium retention by animals deprived of water.

Tables 49-51; Fig. 8.

Table 49. Tritium retention by indigenous cattle deprived of water during the hot season in Zaria, Nigeria.

Cattle 1	Time (days)	0.3	0.9	1.3	1.9	2.3	2.9
	Plasma activity (cpm)	15,625	15,150	14,911	14,323	14,110	13,501
3		0.3	0.9	1.3	1.9	2.3	2.9
		18,203	18,012	17,615	17,201	16,932	15,719
4		0.3	0.9	1.3	1.9	2.3	2.9
		17,250	16,331	15,727	15,034	14,491	13,729
6		0.3	0.9	1.3	1.9	2.3	2.9
		14,211	13,753	13,501	13,079	12,821	12,544

Table 50. Tritium retention by indigenous sheep deprived of water during the hot season in Zaria, Nigeria.

Sheep 1	Time (days)	0.3	0.9	1.3	1.9	2.3	2.9
	Plasma activity (cpm)	45,034	44,250	43,126	42,348	41,504	40,511
2		0.3	0.9	1.3	1.9	2.3	2.9
		39,964	39,357	38,019	37,240	37,082	36,114
3		0.3	0.9	1.3	1.9	2.3	2.9
		35,015	34,246	33,032	31,234	31,768	30,109
5		0.3	0.9	1.3	1.9	2.3	2.9
		40,337	39,133	38,745	37,276	37,084	36,013
6		0.3	0.9	1.3	1.9	2.3	2.9
		50,453	49,514	48,732	47,227	46,931	45,340

Table 51. Tritium retention by indigenous goats deprived of water during the hot season in Zaria, Nigeria.

Goat 1	Time (days)	0.3	0.9	1.3	1.9	2.3	2.9
	Plasma activity (cpm)	56,338	55,072	54,114	43,233	42,046	41,114
2		0.3	0.9	1.3	1.9	2.3	2.9
		55,192	53,906	53,338	52,150	51,202	49,256
3		0.3	0.9	1.3	1.9	2.3	2.9
		71,234	70,126	69,147	67,239	65,822	65,118
4		0.3	0.9	1.3	1.9	2.3	2.9
		53,978	52,517	51,713	50,174	49,652	48,241
5		0.3	0.9	1.3	1.9	2.3	2.9
		45,747	44,734	44,006	42,750	42,212	41,021
6		0.3	0.9	1.3	1.9	2.3	2.9
		50,518	50,244	49,317	48,352	48,147	47,065

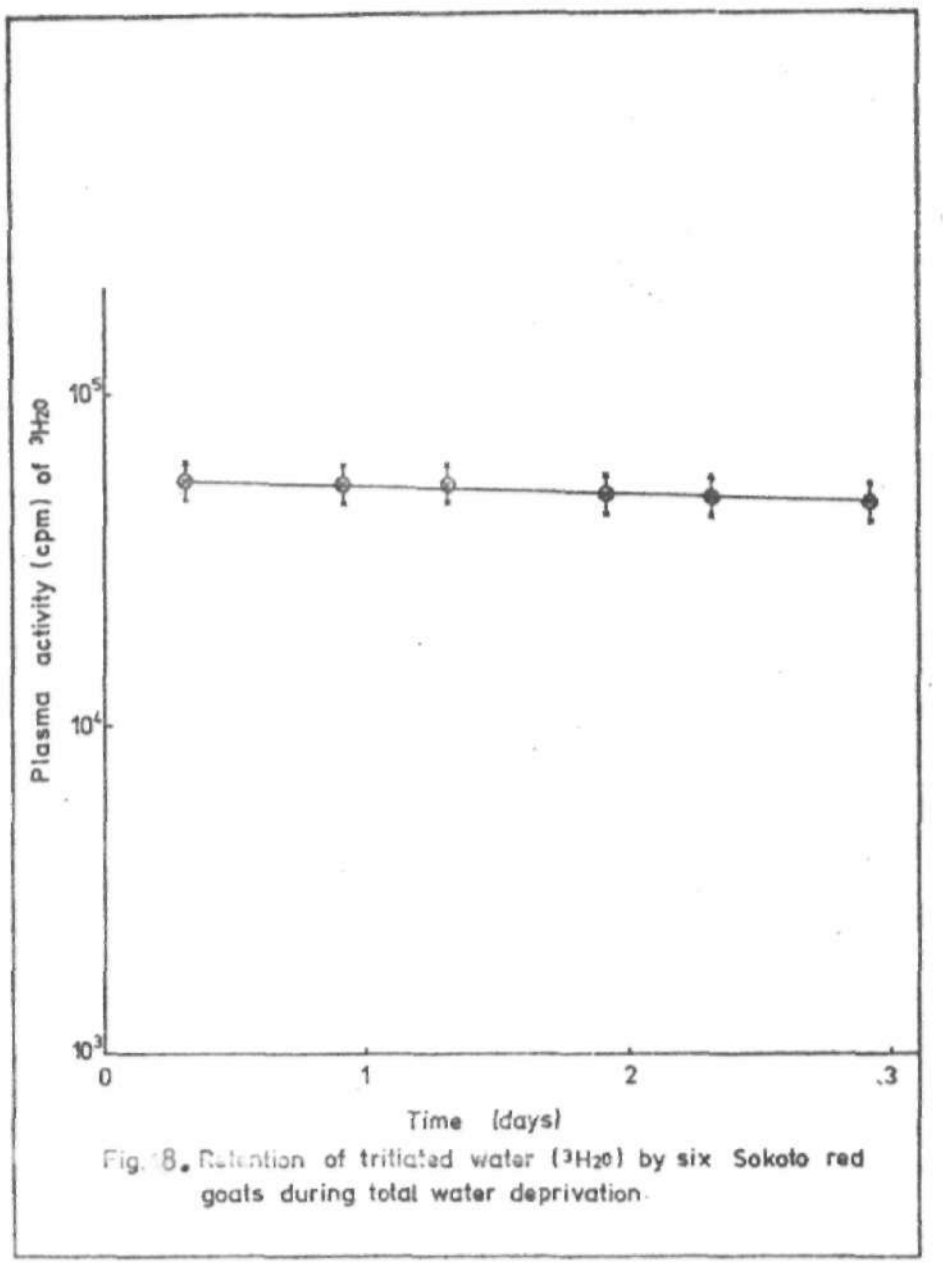


Fig. 18. Retention of tritiated water (^3H_2O) by six Sokoto red goats during total water deprivation.

Appendix 10

Daily values for physiologic parameters in control and water deprived cattle, sheep and goats.

Tables 52 - 65

Table 52. Daily values (%) for PCV in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	31.6	35.0	28.8	38.6	30.8	32.2	32.6	30.2
2	32.0	31.2	29.8	39.2	48.6	41.4	41.8	45.8
3	31.2	33.8	29.8	37.6	52.8	48.0	53.8	50.4
4	31.0	33.0	29.6	38.4	58.8	56.4	59.6	55.6
	GRAND MEAN = 33.2 S.D. = 3.5				GRAND MEAN = 46.2 S.D. = 10.3			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	38.0	38.6	38.6	32.8	35.2	37.2	33.2	35.0	35.6	36.0
2	35.2	38.6	38.8	32.8	34.0	50.4	48.0	45.4	48.0	50.4
3	35.6	39.2	38.0	33.0	34.8	53.6	50.4	50.2	53.2	52.2
4	36.2	35.8	37.8	31.8	34.4	55.0	54.6	54.4	59.4	58.4
	GRAND MEAN = 36.0 S.D. = 2.4					GRAND MEAN = 48.0 S.D. = 8.3				

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	27.2	29.8	35.2	27.0	30.6	28.8	30.2	26.2	30.8	30.2	30.6	28.4
2	31.6	31.0	34.2	26.4	32.0	27.2	40.2	41.0	40.0	43.2	42.0	38.0
3	29.8	33.0	36.0	25.2	30.6	31.6	46.4	46.4	44.0	48.2	44.2	42.2
4	29.0	30.6	32.4	26.4	30.6	29.8	52.6	48.2	48.4	51.0	49.2	45.6
	GRAND MEAN = 30.3 S.D. = 2.8						GRAND MEAN = 41.1 S.D. = 7.8					

Table 53. Daily values ($x10^6/mm^3$) for RBC in control and water deprived cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	5.2	4.4	5.5	6.0	7.0	7.2	7.4	6.0
2	6.7	5.8	6.2	5.8	8.2	7.0	7.8	7.2
3	5.0	6.0	6.3	4.3	10.4	8.4	8.0	10.0
4	6.4	5.4	5.4	5.0	11.4	9.8	9.8	12.8
	GRAND MEAN = 5.6		S.D. = 0.7		GRAND MEAN = 8.7		S.D. = 1.9	

	Sheep 1	2	3	5	6	1	2	3	5	6
1	8.6	6.2	6.6	7.8	7.1	8.0	8.4	8.6	9.2	7.4
2	8.2	6.8	7.1	7.8	6.4	9.4	10.0	8.0	10.4	8.0
3	6.8	8.0	6.2	8.0	6.0	11.2	11.6	10.6	12.0	10.6
4	8.0	8.0	7.4	7.8	5.8	12.6	14.0	12.2	13.6	14.0
	GRAND MEAN = 7.2		S.D. = 0.8			GRAND MEAN = 10.5		S.D. = 2.1		

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	8.8	8.4	9.1	8.6	9.2	8.0	8.0	9.0	8.4	8.8	9.2	9.4
2	8.4	9.0	7.8	9.7	9.4	8.3	10.2	9.2	9.0	9.4	9.0	10.2
3	9.4	8.0	9.3	8.6	9.3	9.0	11.0	10.4	10.2	11.2	11.4	12.4
4	8.6	8.4	9.0	9.8	7.4	8.3	13.4	11.2	11.4	13.6	12.4	14.6
	GRAND MEAN = 8.7		S.D. = 0.6				GRAND MEAN = 10.5		S.D. = 1.7			

Table 54. Daily hemoglobin concentrations (g/dl) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	9.0	11.6	8.8	10.6	10.8	10.2	10.6	9.4
2	9.0	8.6	9.8	7.4	13.4	12.0	12.0	12.2
3	9.8	10.2	9.6	9.0	14.2	14.6	13.2	13.8
4	7.8	12.2	9.2	12.2	17.8	15.8	14.8	14.0
	GRAND MEAN = 9.6		S.D. = 1.4		GRAND MEAN = 13.1		S.D. = 2.2	

	Sheep 1	2	3	5	6	1	2	3	5	6
1	6.8	7.4	6.9	7.0	6.8	8.2	8.4	8.6	7.4	8.4
2	7.6	7.8	7.6	6.4	8.6	9.4	8.8	10.2	8.2	9.0
3	7.0	6.4	8.7	7.0	8.6	12.0	11.0	13.0	9.8	10.6
4	8.6	9.2	8.8	6.6	5.8	14.8	13.2	13.8	16.2	12.2
	GRAND MEAN = 7.5		S.D. = 1.0			GRAND MEAN = 10.5		S.D.= 2.7		

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	8.0	7.2	7.0	5.8	6.8	8.2	7.2	8.0	8.0	8.6	8.4	7.0
2	7.4	7.4	7.2	6.0	6.6	8.2	8.0	8.2	9.8	10.6	10.4	7.4
3	8.0	7.8	8.6	6.0	6.8	8.0	10.4	9.6	10.4	12.8	11.8	8.6
4	7.6	8.8	8.4	5.8	7.8	7.2	14.8	11.4	14.6	14.8	13.4	12.6
	GRAND MEAN = 7.4		S.D. = 0.9				GRAND MEAN = 10.3		S.D. = 2.5			

Table 55. Daily total protein concentrations (g/dl) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	6.0	6.2	6.4	6.0	7.8	7.2	7.8	9.6
2	7.0	6.8	6.4	6.2	8.2	8.4	8.4	10.0
3	7.2	6.8	6.8	6.2	10.2	11.6	10.0	11.4
4	6.0	6.6	7.4	6.8	12.4	14.2	12.2	13.2
	GRAND MEAN = 6.6		S.D. = 0.4		GRAND MEAN = 10.2		S.D. = 2.1	

	Sheep 1	2	3	5	6	1	2	3	5	6
1	6.2	7.8	7.0	6.8	6.8	7.8	7.2	6.4	6.8	6.8
2	6.8	7.2	5.8	5.8	5.2	8.4	8.4	7.0	8.4	7.4
3	7.2	6.2	5.6	6.4	7.8	9.8	9.6	8.8	9.6	8.2
4	6.2	7.6	4.8	5.3	6.8	11.0	12.2	10.8	10.6	10.4
	GRAND MEAN = 6.5		S.D. = 0.9			GRAND MEAN = 8.8		S.D. = 1.7		

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	6.4	5.0	7.8	5.6	8.6	5.0	8.6	8.4	8.0	7.8	8.4	8.8
2	7.2	7.0	8.0	7.4	7.8	5.6	9.2	9.6	8.2	8.4	9.4	9.6
3	6.0	7.6	7.4	6.8	6.4	7.0	10.8	10.4	9.6	10.0	10.6	9.8
4	6.0	5.6	6.0	8.4	7.0	5.8	12.0	14.8	11.4	12.8	13.0	13.2
	GRAND MEAN = 6.7		S.D. = 1.0				GRAND MEAN = 10.1		S.D. = 1.9			

Table 56. Daily morning rectal temperature (°C) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	38.6	38.2	38.8	38.6	38.7	38.9	38.8	38.2
2	38.8	38.0	38.6	38.4	38.1	38.8	38.7	38.8
3	38.4	38.6	38.8	38.8	38.7	38.7	38.6	38.4
4	38.8	38.8	38.4	38.6	38.7	38.4	38.4	38.4
	GRAND MEAN = 38.6 S.D. = 0.2				GRAND MEAN = 38.6 S.D. = 0.2			
	Sheep 1	2	3	5	6	1	2	3	5	6
1	38.9	39.2	39.0	38.8	39.0	39.0	39.0	39.0	39.0	38.8
2	39.0	39.0	38.4	38.6	38.9	38.8	39.0	38.9	38.7	38.8
3	39.2	38.8	38.6	38.8	39.0	38.3	38.7	38.2	38.4	38.6
4	38.8	39.2	38.8	38.8	39.0	38.9	38.9	38.7	38.8	38.6
	GRAND MEAN = 38.9 S.D. = 0.3					GRAND MEAN = 38.8 S.D. = 0.2				
	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	39.0	38.6	38.4	38.8	38.6	39.2	38.6	38.7	39.2	38.8	38.8	38.6
2	38.8	38.8	39.0	38.6	39.0	38.4	39.0	38.8	38.8	39.0	38.7	38.8
3	38.0	38.4	39.0	38.7	38.4	38.0	38.7	38.4	38.6	38.2	38.4	39.2
4	38.2	38.6	38.2	38.8	38.6	38.8	39.0	38.4	39.0	39.0	38.7	38.0
	GRAND MEAN = 38.6 S.D. = 0.3						GRAND MEAN = 38.7 S.D. = 0.3					

Table 57. Daily noon rectal temperature (°C) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	39.3	38.8	39.5	39.3	39.4	39.9	39.6	39.9
2	38.9	39.2	39.1	38.7	40.4	39.4	39.7	40.1
3	38.7	38.4	38.8	38.3	39.7	39.9	39.9	39.9
4	38.6	38.4	38.3	38.6	39.8	40.1	40.0	40.0
	GRAND MEAN = 38.8 S.D. = 0.4				GRAND MEAN = 39.9 S.D. = 0.3			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	39.0	39.1	39.3	38.9	38.8	39.9	39.6	39.6	39.6	39.4
2	38.8	38.8	38.9	39.1	39.1	39.9	39.9	40.1	40.0	39.8
3	38 7	38.9	39.1	38.9	38.8	40.1	40.0	39.9	40.1	39.9
4	38.8	38.9	38.8	38.8	38.8	40.0	40.2	40.1	40.3	40.1
	GRAND MEAN = 38.9 S.D. = 0.2					GRAND MEAN = 39.9 S.D. = 0.2				

	Goat	2	3	4	5	6	1	2	3	4	5	6
1	39.4	39.3	39.2	39.4	39.6	38.9	39.6	39.6	39.7	39.9	39.7	39.9
2	38.9	39.1	38.9	39.0	39.2	38.8	40.0	40.1	40.0	39.9	40.1	40.0
3	38.8	38.8	38.9	38.8	38.9	38.8	40.1	40.0	39.6	40.0	39.8	40.1
4	38.9	38.8	38.8	38.9	38.8	38.6	40.1	40.2	40.1	40.1	39.9	40.1
	GRAND MEAN = 39.0 S.D. = 0.3						GRAND MEAN = 39.9 S.D. = 0.2					

Table 58. Daily respiratory rates in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	24	26	28	26	18	12	18	20
2	26	24	26	28	16	12	14	22
3	28	26	27	28	14	10	16	18
4	26	24	26	24	12	8	12	18
	GRAND MEAN = 26.1 S.D. = 1.5				GRAND MEAN = 15.0 S.D. = 3.9			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	34	36	42	30	34	28	24	28	26	28
2	37	35	34	33	35	26	22	24	24	28
3	36	36	38	36	38	24	24	26	26	26
4	38	34	36	38	38	20	22	20	22	24
	GRAND MEAN = 35.9 S.D. = 2.5					GRAND MEAN = 24.6 S.D. = 2.5				

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	40	30	30	36	36	34	28	24	32	36	28	26
2	40	36	36	40	34	36	30	22	24	28	28	24
3	42	40	40	42	40	36	29	20	26	26	26	26
4	38	36	38	30	36	34	26	20	24	24	24	24
	GRAND MEAN = 36.7 S.D. = 3.5						GRAND MEAN = 26.0 S.D. = 3.6					

Table 59. Daily per cent fecal moisture contents in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	73.4	85.2	84.5	78.6	72.7	83.3	78.6	72.2
2	74.9	78.3	80.2	76.1	67.5	71.0	72.0	64.7
3	70.6	87.7	78.8	74.9	64.7	67.8	56.3	61.8
4	75.7	81.4	82.0	76.7	61.3	62.1	52.7	59.2
	GRAND MEAN = 78.7 S.D. = 4.6				GRAND MEAN = 66.8 S.D. = 8.0			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	65.0	66.0	68.4	69.3	71.1	66.0	59.6	64.6	60.3	57.0
2	68.4	68.2	68.2	70.1	72.4	58.6	44.8	60.3	58.4	50.2
3	66.8	66.4	70.6	68.0	70.6	52.9	64.8	54.6	55.1	44.6
4	67.3	65.4	67.4	69.7	71.8	48.6	40.7	45.9	50.6	40.7
	GRAND MEAN = 68.6 S.D. = 2.1					GRAND MEAN = 53.9 S.D. = 8.0				

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	69.8	68.5	72.9	72.4	74.0	70.6	68.0	66.6	69.8	70.7	72.7	69.0
2	70.3	70.5	71.7	73.2	74.4	71.2	45.5	50.0	64.4	66.2	64.7	64.2
3	70.8	71.9	72.0	70.6	73.1	69.7	48.5	52.6	58.5	60.9	58.5	60.5
4	71.6	69.6	70.4	72.9	75.3	70.3	44.2	48.7	52.4	55.4	52.6	56.6
	GRAND MEAN = 71.6 S.D. = 1.7						GRAND MEAN = 59.2 S.D. = 8.5					

Table 60. Daily body weights (kg) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	376.6	348.7	354.6	444.0	378.2	327.3	335.0	422.7
2	377.8	350.1	358.2	448.0	357.7	311.4	319.1	402.3
3	379.9	354.3	357.1	445.1	345.5	302.3	310.9	394.6
4	380.5	352.5	355.7	447.3	343.2	300.0	305.5	390.5
	GRAND MEAN = 383.2 S.D. = 39.1				GRAND MEAN = 346.6 S.D. = 39.9			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	42.7	44.3	49.0	45.0	38.2	39.0	41.2	48.0	40.3	33.4
2	43.9	45.7	51.2	44.8	37.4	36.1	41.9	44.2	37.1	33.0
3	44.8	45.2	52.3	44.2	36.6	36.0	37.8	43.6	36.2	31.3
4	43.7	46.8	48.0	43.6	37.0	34.0	35.4	41.4	34.4	29.3
	GRAND MEAN = 44.2 S.D. = 4.3					GRAND MEAN = 37.7 S.D. = 4.7				

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	35.2	34.1	28.5	28.4	28.0	35.8	31.3	29.6	25.7	28.4	38.5	33.1
2	34.8	32.3	29.3	30.5	27.6	37.6	29.1	29.2	22.0	26.2	36.0	30.0
3	33.9	32.0	28.3	29.3	28.4	36.5	28.0	27.1	22.0	23.0	34.0	29.1
4	34.1	34.4	26.8	28.6	29.2	36.9	26.6	27.0	20.3	21.4	32.5	25.2
	GRAND MEAN = 32.1 S.D. = 3.7						GRAND MEAN = 28.2 S.D. = 4.7					

Table 61. Daily feed intake (kg) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control					Water deprived				
Days	Cattle 1	3	4	6		1	3	4	6	
1	7.2	5.0	4.9	8.2		7.0	0.0	10.9	1.6	
2	7.0	3.2	4.4	7.6		2.8	1.1	0.4	0.3	
3	6.8	5.2	3.6	6.2		0.1	0.2	0.4	0.1	
4	7.0	4.8	4.0	8.4		0.6	0.2	0.3	0.1	
	GRAND MEAN = 5.8 S.D. = 1.7					GRAND MEAN = 1.6 S.D. = 3.0				
	Sheep 1	2	3	5	6	1	2	3	5	6
1	0.9	0.6	1.2	0.6	0.3	0.3	0.4	0.7	0.5	0.5
2	0.9	1.0	0.8	0.9	0.8	0.3	0.0	0.0	0.2	0.1
3	0.8	0.8	1.0	1.0	0.4	0.0	0.2	0.3	0.2	0.0
4	0.9	1.0	0.8	1.0	0.6	0.0	0.0	0.0	0.0	0.0
	GRAND MEAN = 0.8 S.D. = 0.2					GRAND MEAN = 0.2 S.D. = 0.2				
	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	1.6	0.6	0.8	0.6	0.8	0.8	0.7	0.5	0.2	0.6	0.4	0.2
2	1.5	1.0	1.2	0.4	1.0	0.6	0.0	0.0	0.0	0.3	0.2	0.0
3	1.0	1.0	0.6	0.8	0.8	0.9	0.1	0.8	0.2	0.0	0.0	0.1
4	0.8	0.6	1.0	0.4	1.0	0.8	0.0	0.2	0.0	0.2	0.2	0.0
	GRAND MEAN = 0.9 S.D. = 0.3						GRAND MEAN = 0.2 S.D. = 0.2					

Table 62. Daily serum sodium ion concentrations (mEq/l) in control and water deprived *indigenous cattle, sheep and goats during the hot season* in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	142.2	140.8	138.0	138.8	140.0	142.2	141.0	141.8
2	139.6	142.6	139.4	140.0	142.4	148.2	150.6	142.0
3	143.8	140.2	140.2	142.4	150.8	154.2	156.0	149.4
4	143.4	141.4	142.4	140.8	158.0	160.4	162.4	156.6
	GRAND MEAN = 141.0 S.D. = 1.7				GRAND MEAN = 149.8 S.D. = 7.6			
	Sheep 1	2	3	5	6	1	2	3	5	6
1	142.2	139.8	137.0	140.0	138.4	140.2	140.2	141.2	140.8	142.0
2	143.4	138.6	138.8	141.8	136.8	144.0	150.8	150.0	148.4	146.0
3	144.8	140.0	136.4	141.2	138.2	150.4	158.0	158.6	153.8	153.8
4	142.6	140.8	138.6	140.4	139.4	156.0	160.6	161.4	158.2	160.4
	GRAND MEAN = 140.0 S.D. = 2.2					GRAND MEAN = 150.7 S.D. = 7.6				
	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	141.2	142.6	138.8	140.6	140.0	140.2	140.4	140.6	140.0	141.2	142.0	140.2
2	142.2	142.8	140.2	138.8	138.8	142.6	152.2	142.0	152.4	147.6	143.2	146.4
3	140.8	140.2	141.4	141.6	138.4	142.0	155.6	118.2	153.2	154.0	151	152.2
4	143.0	141.0	140.2	141.2	140.6	140.4	158.6	156.6	157.6	159.0	158.8	158.2
	GRAND MEAN = 140.8 S.D. = 1.3					GRAND MEAN = 149.7 S.D. = 7.0						

Table 63. Daily serum potassium ion concentrations (mEq/l) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	4.0	3.8	3.0	3.4	3.6	3.8	3.4	3.6
2	3.6	4.0	3.4	3.1	3.2	4.0	3.4	4.0
3	3.8	3.6	3.2	3.0	4.0	4.6	4.2	4.4
4	3.6	3.4	3.0	3.2	4.4	4.6	4.0	4.0
	GRAND MEAN = 3.4		S.D. = 0.3		GRAND MEAN = 3.9		S.D. = 0.4	

	Sheep 1	2	3	5	6	1	2	3	5	6
1	3.8	32.	2.8	4.0	2.8	4.2	3.6	3.8	4.2	3.4
2	4.2	3.0	2.8	3.8	2.8	4.6	3.4	4.0	4.6	3.8
3	3.6	3.0	3.0	3.0	3.0	4.4	3.8	4.2	4.8	4.0
4	3.0	3.1	3.4	3.0	3.0	4.6	4.0	3.8	4.0	4.2
	GRAND MEAN = 3.2		S.D. = 0.4			GRAND MEAN = 4.1			S.D. = 0.4	

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	4.4	4.2	3.6	3.8	4.4	3.4	3.8	3.4	3.8	3.8	4.0	4.4
2	4.2	4.0	3.8	4.0	3.8	3.0	4.2	3.8	3.6	4.2	4.4	4.6
3	3.6	4.1	4.0	3.6	3.8	3.0	4.8	4.2	4.4	4.4	4.8	4.0
4	3.8	4.0	3.8	3.8	3.4	3.6	4.2	4.8	4.8	5.8	4.8	4.2
	GRAND MEAN = 3.8		S.D. = 0.4				GRAND MEAN = 4.3		S.D. = 0.4			

Table 64. Daily serum chloride ion concentrations (mEq/l) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	98.4	98.4	98.8	102.0	96.2	98.0	98.0	96.8
2	98.6	100.2	102.2	96.2	120.4	122.2	127.2	122.2
3	102.8	102.2	98.0	98.4	129.0	128.4	120.8	125.4
4	100.4	100.6	102.8	98.6	138.0	136.0	134.0	131.4
	GRAND MEAN = 99.9 S.D. = 2.0				GRAND MEAN = 120.1 S.D. = 8.3			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	96.2	98.0	98.5	98.6	100.4	96.4	94.2	98.8	98.6	94.2
2	100.4	98.6	100.8	96.2	98.0	117.6	111.4	114.6	110.2	112.4
3	94.4	94.8	102.4	96.4	96.4	118.6	113.6	113.6	116.2	114.8	117.6
4	90.6	96.4	94.3	92.0	90.8	125.0	118.4	121.4	121.4	125.8
	GRAND MEAN = 96.7 S.D. = 3.3					GRAND MEAN = 111.4 S.D. = 8.5				

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	108.8	114.4	112.6	112.6	110.6	114.8	116.2	118.6	114.8	116.4	118.8	116.4
2	115.4	116.8	114.4	116.4	114.0	112.4	120.4	123.2	121.2	120.6	123.4	121.2
3	116.0	114.2	112.8	116.4	114.2	114.2	132.6	128.0	130.0	124.2	127.8	126.8
4	114.2	116.0	114.8	116.0	112.8	116.8	141.2	136.8	142.8	132.4	138.2	131.4
	GRAND MEAN = 114.2 S.D. = 2.0						GRAND MEAN = 124.5 S.D. = 6.6					

Table 65. Daily blood urea nitrogen concentrations (g/dl) in control and water deprived indigenous cattle, sheep and goats during the hot season in Zaria, Nigeria.

	Control				Water deprived			
Days	Cattle 1	3	4	6	1	3	4	6
1	13.4	11.4	11.6	12.6	14.6	13.2	15.8	14.2
2	12.2	10.2	13.0	10.6	16.4	14.8	16.0	16.8
3	10.4	10.6	10.2	11.9	16.8	16.2	16.8	16.0
4	11.3	10.0	12.2	10.2	18.0	17.6	19.6	18.8
	GRAND MEAN = 11.5 S.D. = 1.0				GRAND MEAN = 16.8 S.D. = 1.7			

	Sheep 1	2	3	5	6	1	2	3	5	6
1	10.0	10.2	9.4	9.8	10.0	12.4	11.8	14.6	13.8	12.6
2	9.9	10.0	9.9	10.2	11.4	11.8	12.2	13.8	14.0	14.4
3	10.2	11.1	11.2	10.0	11.0	13.2	12.8	15.2	14.8	15.8
4	10.4	8.4	11.0	11.0	11.0	14.8	13.6	16.8	16.2	16.6
	GRAND MEAN = 10.3 S.D. = 0.7					GRAND MEAN = 14.1 S.D. = 1.6				

	Goat 1	2	3	4	5	6	1	2	3	4	5	6
1	16.1	15.8	16.0	18.6	16.2	16.4	18.6	16.8	19.4	18.2	17.4	18.3
2	16.2	17.0	17.9	16.4	15.6	15.6	20.4	19.2	23.6	22.2	17.8	21.4
3	15.8	17.4	17.0	16.2	15.0	15.0	24.2	24.6	26.8	24.0	18.2	24.8
4	15.6	17.4	16.8	17.4	16.4	16.2	26.8	24.8	29.0	24.8	18.4	28.2
	GRAND MEAN = 16.4 S.D. = 0.9						GRAND MEAN = 22.0 S.D. = 3.8					

WATER METABOLISM IN INDIGENOUS CATTLE, SHEEP AND GOATS IN ZARIA, NIGERIA.

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In an attempt to elucidate environmental adaptations of indigenous cattle, sheep and goats to their native habitat of Zaria, the following investigations were conducted between January 1975 and May 1976:

1. Seasonal variations in water metabolism in penned and grazing cattle, sheep and goats;
2. Influence of total water deprivation on water metabolism in cattle, sheep and goats; and
3. Physiologic responses of cattle, sheep and goats to total water deprivation during the hot season.

Six castrated male Bunaji cattle, Yankassa sheep and Sokoto Red goats, in good physical condition, were used after a preconditioning period of three months. Water metabolism was studied during three different seasons (hot, rainy and cold) using tritiated water. Penned animals were kept in individual stalls under a common roof, while grazing animals grazed freely during the day and were herded at night. Seasonal changes in water and feed intake were determined in penned animals.

Results indicated seasonal and species differences in water and feed intake in penned animals and in water

metabolism in both penned and grazing animals. Seasonal variations in water intake were evident with the greatest amount of water being consumed during the hot season. Druing any season, cattle required the most water and goats the least. Feed consumption was significantly increased ($P < 0.01$) during the cold season in the three species but was significantly higher ($P < 0.01$) in the smaller ruminants than in cattle. This was probably due to the influence of metabolic body size ($Mass^{0.75}$) on functional processes. Total body water content was very similar in all species. Although seasonal changes in this parameter were inconstant, values obtained were generally lowest during the rainy season, which might indicate increased body fat content during this period, when feed and water were usually more abundant and the weather more favorable.

Marked seasonal and species variations were found in the kinetic parameters of the body water pool. The biologic half-life of tritiated water was shortest in all animals during the hot season, and longest ($P < 0.01$) during the cold season. Pool turnover rate and daily

water turnover were highest during the hot season, and least during the cold season ($P < 0.01$). Under penned or free-grazing conditions, the longest half-life was obtained in goats, and they also had the least turnover rate and daily water turnover. Total water deprivation decreased total body water, pool turnover rate and daily water turnover, while significantly ($P < 0.01$) prolonging the biologic half-life of tritiated water in all the animals. Goats appeared to be least affected and cattle the most.

Total water deprivation caused, in all species, hemoconcentration with resultant elevation in hematologic values, total protein, blood urea nitrogen and serum electrolytes. Respiratory rate, fecal moisture content, body weight and feed intake were all reduced, while late afternoon rectal temperatures were significantly elevated in all species.

Results from these investigations indicated the adaptive mechanisms in the animals studied, which enable them to adjust to their environment. While further findings are required to elucidate in greater

such adaptations, it may be concluded that goats and sheep appear to be better adapted than cattle to the semi-arid environment that prevails in the Zaria area.