MODELLING PRODUCTIVITY OF INDIGENOUS ZEBU CATTLE (*BOS INDICUS*) UNDER THE NATURAL FIELD CONDITIONS ON RUSINGA ISLAND, KENYA.

BY

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"If you want to acquire knowledge you must take part in the practice of changing reality.

If we have a correct theory, but merely talk about it, lay it aside, and fail to put it into practice, then that theory, however good, has no importance.

Knowledge begins with practice, reaches the theoretical level through practice, and then returns to practice".

MAO TSE-TUNG

On practice, 1937.

DECLARATIONS

I , Hezron Oranga, hereby declare that the work presented in this thesis is my own and has not been submitted for a degree in any other university.

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DEDICATION

To my beloved father, the late Mzee Ezekiel Oyugi Wangwe without whose inspiration and fatherly advice I would have not gone so far in my academic pursuit.

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ABSTRACT

The general objective of this study was to develop predictive models which could be used to determine productivity (liveweight gain) losses attributed to various causal factors that are specific to livestock production systems as found in typical communities of small-scale peasant farmers in Africa. Factors of special interest were infestations by heliminths, arthropod vectors and their associated parasites, notably ticks and *Theileria* spp of parasites, tsetse flies and *Trypanosoma* spp. It was also noted that in the absence of diseases, nutrition was most important in determining calf growth and development. The goal of the study was to develop models which could help managers and policy-makers in undertaking economic evaluation and monitoring of projects and programmes on tick control strategies in the tropical Africa, with particular emphasis on cost-benefit analysis. Africa's livestock production system is predominantly characterised by the zebu cattle (*B. indicus*) with the destructive ticks and tsetse flies as the common disease vectors.

The study was conducted on Rusinga Island on the eastern edge of Lake Victoria in western Kenya. The Island is typical of many tropical regions of Africa in relation to livestock production systems and their associated causal

factors that claim their toll on the animal's productivity. The major livestock ticks (Acarina: *Ixodidae*) are found on the Island. The farmers were randomly selected for the study. These farmers had a total of two hundred sixty five cattle by December, 1987. This study involved seventy four calves born in both 1986 and 1987.

The ten farms were visited every month to collect data on the number of adult ticks on each calf categorized by species and sex, calf weight, as well as pasture quality. Data on weather conditions was also monitored. Information on morbidity and epidemiology of cattle diseases on the Island were secured from other secondary sources. Generally, nutrition quality of pastures in terms of crude protein, phosphorus, potassium, calcium and magnesium was satisfactory in 1987. On the basis of crude protein, phosphorus and calcium contents of pastures, the ten farms could be divided into three broad nutrition regimes. Farms with the highest nutritious pastures were located to the southern and western parts while the poorest to the eastern and north-eastern sides of the Island.

The dominant tick was *Rhipicephalus appendiculatus*, followed by *Amblyomma variegatum*, *R. evertsi* and *Boophilus decoloratus* in that order of abundance. The spatial distribution of the ticks was found to conform to the pattern depicted by the nutrition regimes especially crude protein contents. Strong association was found between certain nutrients and tick species. It was revealed that

crude protein was the most important nutrient in increasing host resistance to *R. appendiculatus* and *B. decoloratus*; two very destructive vectors of tick-borne diseases. Also important were potassium and calcium.

No significant differences were detected in birth weights between farms and sexes. Observed birth weights varied between 11 kg and 23 kg. Mean birth weights were 16.5 kg and 15.2 kg for bullocks and heifers, respectively. Calf birth weights were found to be associated with crude protein contents of pastures in which the respective dams were grazed.

Calf growth was found to be significantly different between farms ($P < 0.0001$). Calf growth was, however, consistent to calf birth weight, pasture quality as well as tick burden. Calves with highest birth weights experienced greatest growth rates and vice versa. The relationship between nutrition and host resistance to ticks was compatible to calf growth patterns. Poor growth was found also to be the result of interplay of the two causal factors. No significant differences were detected in calf growth between the sexes and also between the months of birth.

Observed growth rates mostly varied between 0.0159 to 0.359 lbs per day, (i.e. 0.0072 kg to 0.1632 kg per day). This represented a mean annual growth of between 26 to 60 kgs. The lowest growth rate was 0.009 lbs per day (0.0041 kg per day) while the highest 0.409 lbs per day (0.1859 kg per

day). These calves experienced mean tick burden of between 65 to 91 ticks per calf.

The upper economic threshold levels were also determined and found to be dependent on the age of a calf. In this study, the oldest calf was 33 months for which the upper economic threshold was found to be about 145 ticks per calf and which was comparable to a figure of 158 for *B. taurus X B. indicus* steers found in Australia.

It was found that the best model for simulation of calf growth was the modified Gompertz model. The model was found to adequately describe the growth behaviour of *B. indicus* calves on the Island. The model was found to be flexible and comprehensively explained the major growth features such as growth rate, age at which maximum growth rate is attained, and maximum potential growth of a breed under given production system.

A relatively new apprach based on the minimum liveweights of calves for given ages, was used to develop a survivorship threshold model. The survivorship threshold model is the lowest liveweight for which a calf would be under the risk of dying due to starvation and ill-health. The exponential model was found to provide the best fit to the data. Because of its functional invariance, the model would be a useful tool in monitoring cattle productivity in similar agroecological zones in Africa.

The study showed that mean calf growth rate, r_{k+j}, was related to the mean age, u_k, and mean adult tick burden, m_k,

of a herd of calves as follows:

$$\log_e(r_{k+j}) = \alpha_j + \beta_j u_k + \tau_j m^*_k$$

$$k = 0, 1, 2, 3, \ldots, K$$

$$j = 0, 1, 2, \ldots\ldots\ldots$$

where rk+j is the predicted growth rate in j months to come given that the calves are aged k months today, $m^*_k = \sqrt{m_k}$, K is the maximum age in months of calves in the herd. Several models were developed for specific tick burdens and nutrition conditions on the Island. It was found that the relationship was strongest when the lag variable, j, was two months, i.e. j = 2. The usefulness of the models were then discussed specifically with reference to their applications in microeconomic and cost-benefit analyses of tick control and management projects and programmes in Africa.

CHAPTER 1

INTRODUCTION

1.1 General background

Many Third World countries are experiencing acute shortages of the supply of protein and fat, particularly in the form of meat and milk despite the fact that these countries have the highest densities of livestock and wild game. In the sub-Saharan Africa, based on Chigaru's figures (Chigaru, 1984) and 4% annual growth rate, total population of ruminant livestock (cattle, sheep and goats) is estimated to be about 350 million by 1990. In addition to meat and milk, ruminants in tropical Africa also provide hides, hair, traction, transportation, fertilizer, and fuel. They also serve as vehicles for investment, savings, and capital formation. In most societies, livestock also feature importantly in social relationships and rituals, like payment of bride-price, funeral festivities, e.t.c.

Many governments, particularly in Africa are very much concerned about the persistent decline in the per capita protein intake of their peoples. According to the FAO Report (FAO, 1975), it was estimated that developing countries account for about 75% of the world's population. Further, it was estimated that 65 to 70% of the world's livestock resources, estimated to be about 350 million

(Chigaru, 1984), exist in these regions, yet they accounted for only 30% of the world's meat output. This situation is even worse off during the current decade. As a result, politicians and research administrators are calling upon scientists to investigate ways of increasing food supply on the continent. It has been reckoned that any possible way discovered must be culturally, socially and economically acceptable to the small peasant farmer in the rural Africa. Majority of these small-holder farmers are resource-poor, illiterate, ignorant with very heavy dependancy burdens that present great obstacles to the implementation to those sophisticated technologies that are developed in the Industrialised West.

In particular, livestock in Africa is characterised by numerous diseases, poor nutritional regimes, ecto- and endoparasites as well as exposure to harsh social environment. It is true that the poor animal in such a harsh habitat is exposed to very many factors that are counting their toll on its survival and hence productivity, and reproduction potential and efficiency. In addition to ticks and tick-borne diseases the other factors include climate, nutrition in terms of quantity and quality, endoparasites, other diseases such as *nagana* e.t.c., and the social environment (that is, land tenure system, pasture management, cultural practices, e.t.c.). Gavora (1982) put it that a great deal of livestock losses are attributed to

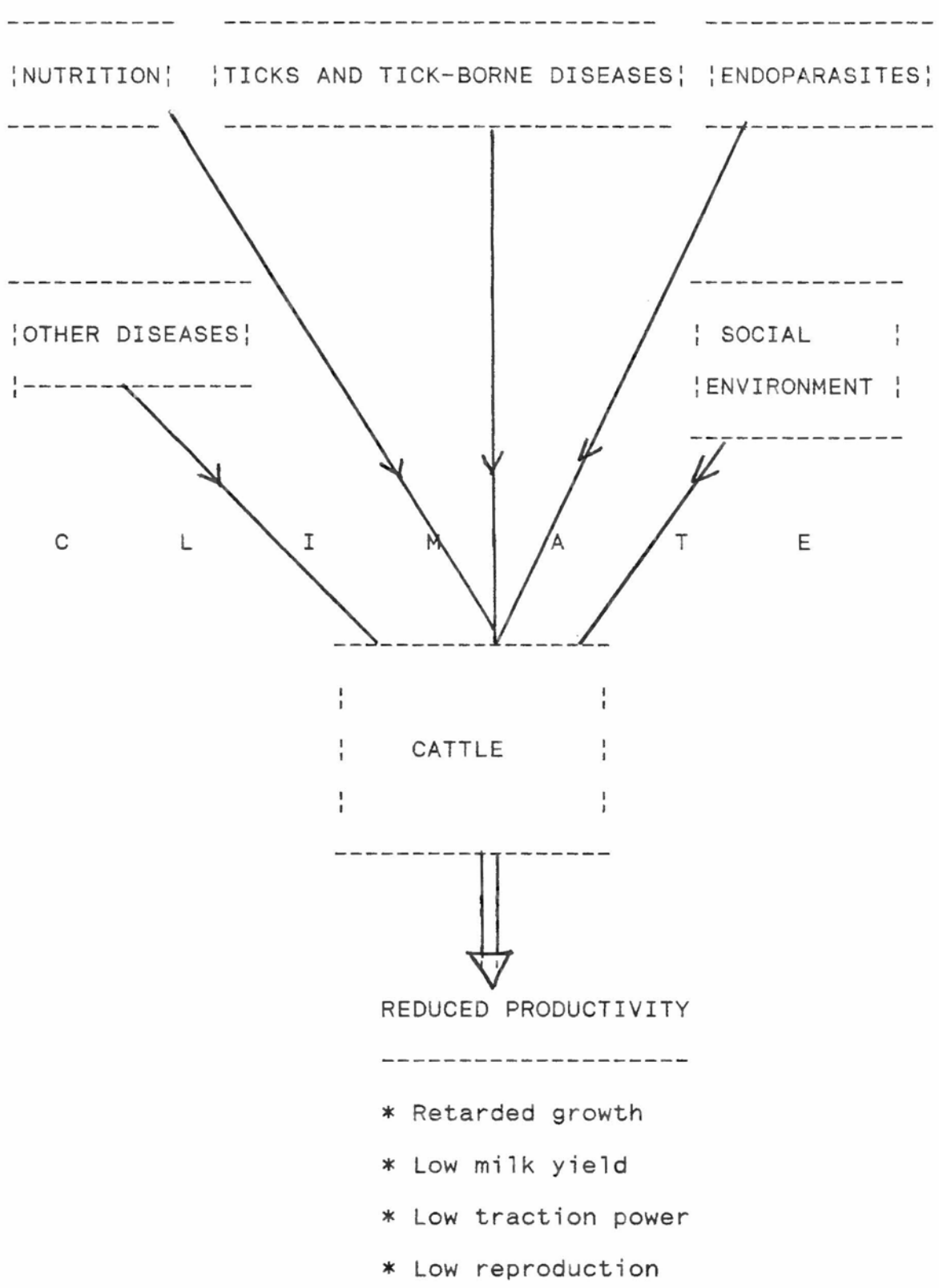


FIG 1.1 SCHEMATIC DIAGRAM OF FACTORS AFFECTING CATTLE PRODUCTIVITY

diseases and if the disease pressure could be reduced by just 2%, recovery would provide food for an additional 80 million people. These statistics only highlight the tip of the iceberg. For more details see Figure 1.1.

The aim of this study is to identify the relevant causal factors that are associated with productivity losses in cattle within the environments of the resource-poor farmer community on Rusinga Island. Once these factors have been identified, they are then used to develop models which could be used for predicting productivity losses that are attributed to ticks and tick-borne diseases. Lastly, if found feasible, a general productivity model based on the tick population dynamics and the other factors would be developed. In this study the productivity factors considered is liveweight gain (LWG) for calves.

Although the study area is Rusinga Island on Lake Victoria in Western Kenya, it is the belief of the researcher that these models if developed would be applicable as well in other areas falling under the same agro-ecological and climatic zones and where such cattle and tick species are found.

1.2 The study objectives

The specific objectives of this research study are:

(1) To identify those factors that are associated with cattle productivity losses.

(2) To determine the relationship between the identified

causal factors and the productivity changes.

(3) To develop predictive models for cattle productivity factors as functions of the causal factors with special reference to tick population dynamics.

(4) To develop a general stochastic model for predicting losses based on the causal factors with special reference to tick population dynamics, nutritional measures and climatic data.

(5) To illustrate the use of such predictive models in management decision-making process.

1.3 Scope of the study

Livestock Ticks Research Programme (LTRP) of ICIPE started its work on Rusinga Island in 1986. A baseline study was done to develop a sampling frame of all the livestock species (cattle, sheep and goats) and farmers on the Island. Enumeration exercise was conducted to solicit information on the livestock by farm, species, age and sex. Forty five such households were identified. These were households keeping all the three species simultaneously. For ease of identification and computer analysis, the farms were coded by numbering them from 1 to 45. However, since 1987, only ten of the farmers (households) remained in the study sample. These ten households were randomly selected adopting a stratified random sampling design in which the

Table 1.1: Cattle population on the target ten farms on the Island by December, 1987

Farm	Heifers	Steers	Cows	Bulls	Total	%Share
1	5	7	11	7	30	11.3
2	9	4	8	2	23	8.7
6	5	4	11	4	24	9.1
16	2	6	6	3	17	6.4
21	7	3	10	4	24	9.1
22	8	8	11	7	34	12.8
25	11	7	13	11	42	15.8
27	7	3	9	3	22	8.3
28	8	7	14	13	42	15.8
36	2	1	3	1	7	2.7
Total	64	50	96	55	265	-
%Share	24.1	18.9	36.2	20.8	-	100.0

Table 1.2: The study sample by farm and year

Farm	Calves			Dams	Total sample	%Share
	1986	1987	Total			
1	3	6	9	6	15	11.9
2	0	4	4	4	8	6.3
6	3	4	7	4	11	8.7
16	2	0	2	0	2	1.6
21	1	5	6	5	11	8.7
22	6	6	12	6	18	14.3
25	3	12	15	12	27	21.4
27	0	6	6	6	12	9.5
28	3	9	12	9	21	16.7
36	1	0	1	0	1	0.9
Total	22	52	74	52	126	-
% Share	17.4	41.3	58.7	41.3	-	100.0

stratification factor adopted was administrative Sublocation as used during Kenya's 1979 Population Census Survey.

In this study, the target population comprised of the same forty five households and the study sample consisted of the ten farmers that were involved in the LTRP Rusinga Project as described above. From the selected farms, all the calves born between 1986 and 1987 were included in the study for liveweight gain exercise. This integrated approach is very important since it enables all the scientists currently working on the Project to share and compare some of the information between themselves.

By December 1987, the ten farms had a cattle population of two hundred sixty five out of which two farms (Farm Nos 25 and 28) accounted for about 31.6% of the total. The details are shown in Table 1.1. Out of the two hundred sixty five cattle, one hundred twenty six were included in the study sample representing about 47.5% of the total (see Table 1.2 for details). This sample comprised of 22 and 52 calves born in 1986 and 1987, respectively. The study also included 52 dams as well. Farm No. 25 and 28 accounted for about 38.1% of the total sample size. In this respect, therefore, the two farms were very important in the study.

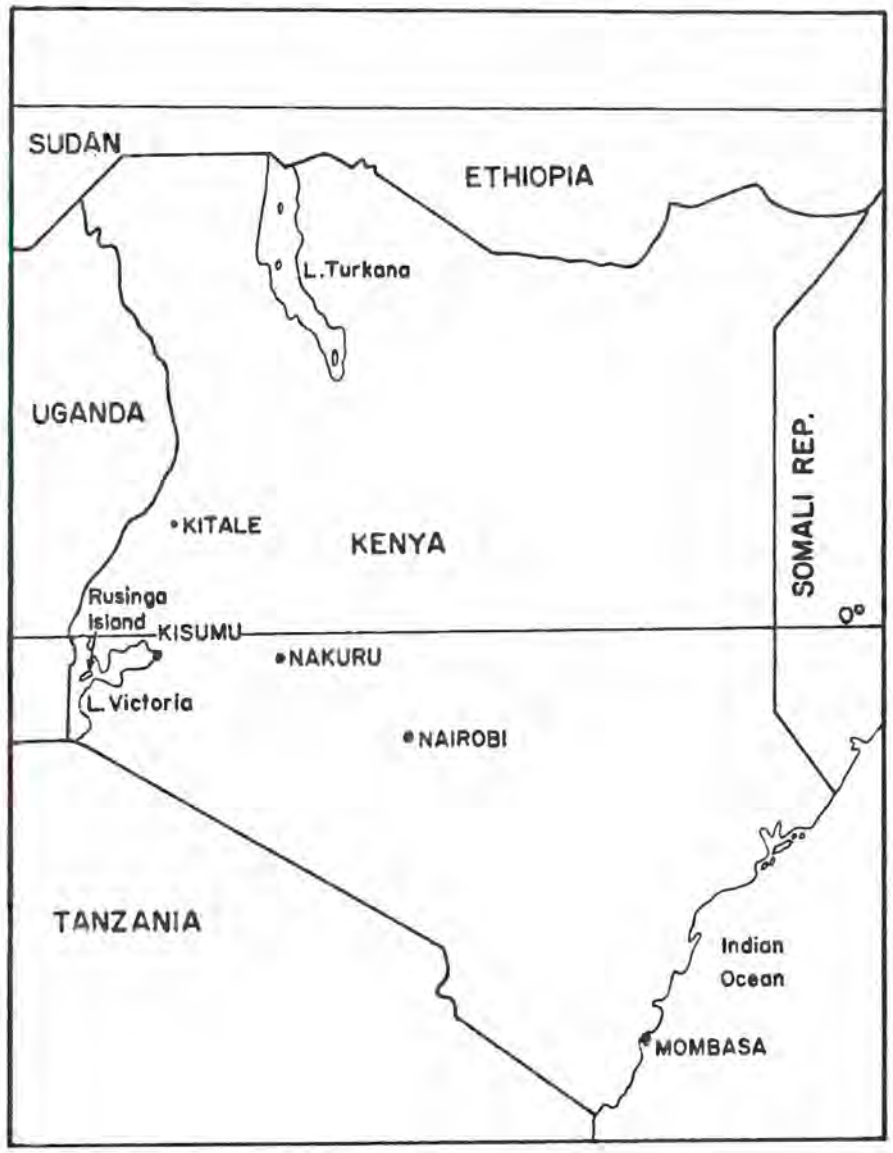
Rusinga Island is representative of many tropical regions in the Third World. The local farming communities on the Island are characteristic of the smallholder resource-poor peasantry found within many countries in Africa. On Rusinga Island, so far only four tick species have been

identified, namely, ***Amblyomma variegatum, Rhipicephalus appendiculatus, R. evertsi***, and ***Boophilus decoloratus***. These tick species are representative of the most important vectors of tick-borne diseases in Africa. The findings of this study are therefore expected to be applicable to those areas falling within similar agro-ecological and climatic zones, and where such cattle and tick species are found.

1.4 The study area

The study area was Rusinga Island on the eastern edge of Lake Victoria in Western Kenya. It is located between latitudes 0^{o} 10'S and 0^{o} 30'S, and longitudes 34^{o} E and 34^{o} 30'E. In 1981, a causeway of about 0.5 km was constructed to link it with the mainland. See Map Nos. 1 and 2 for more details.

The Island has an altitude of 1128 m and rises to a peak of 1433 m. It has an area of about 43 km^2 and an estimated population of about 13,500 by 1989. It is estimated that there are about 1500 households on the Island. It has loam soil with a gravel or stone surface and tends to be dry. The geology is basically Tertiary sediments. Most of the Island is hilly and rugged such that most of the crop cultivation and settlement is within one kilometre strip around the shoreline. It experiences a mean



MAP No. I. THE LOCATION OF RUSINGA ISLAND.

MAP NO. 2: MAP OF RUSINGA ISLAND

● Farms

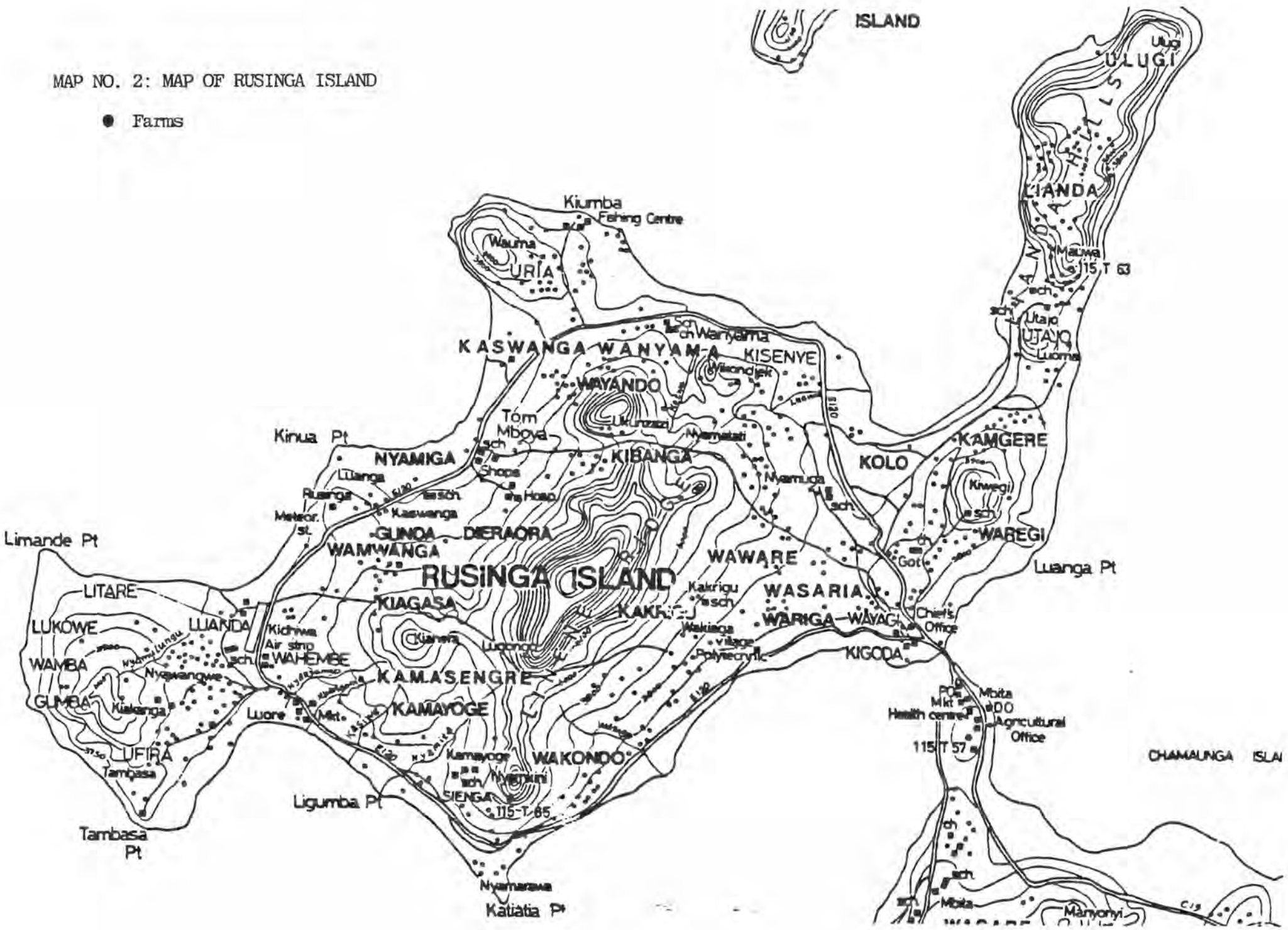


Plate No. 1: Perspective view of Rusinga Island

Plate No. 2: Landscape view of north-western part of Rusinga Island

annual rainfall of about 100-120 cm with two seasons; maximum in April-May, and least in December. The maximum annual temperature falls between 30-40^{o}C and a minimum of 14-18^{o}C.

The economy of the Island is based on fishing and subsistence farming. The crops grown are maize, sorghum, millet, cassava and cotton. Livestock population consists of cattle, goats and sheep, all of them being the indigenous unimproved stock. No acaricides have ever been tried on the Island. There are few wild animals found on the Island, namely rabbits, squirrels, monkeys, hippos and monitor lizards.

1.5 Justification of the research study objectives

Scientists all over the world are striving hard to develop several tick control measures. To date, such measures include the following techniques:

(1) Chemicals (Acaricides)

(2) Alternative methods:

* Pasture spelling

* Habitat modification

(3) Novel methods:

* Genetic control

* Pheromones

(4) Biological control:

* Anti-tick grasses

* Parasites and predators

* Tick-resistant cattle

It is now confirmed that no single control measure could be effective alone without supplementation by another. In this direction therefore scientists are now researching on the application of a combination of several of these simultaneously incorporating even the cultural, technological and the socio-economic background of the participating users (smallholder resource-poor farmers in the Third World). In the case of ICIPE, the views of the user (farmer) is now even incorporated during the initial design stages of the study so that the results so developed could be culturally and economically acceptable to the farmers. This approach is popularly referred to as Integrated Pest Management (IPM).

To date, even if a new control measure was developed several questions would still remain unanswered particularly with regard to cost-benefit merits and management decision-making. Both the government at the national level, and the farmer would have to be convinced of the socio-economic viability of the control measures being advocated.

In order to be able to answer the above questions, there is need to develop predictive models which could be used to provide estimates of changes in productivity

attributed to the proposed control measures. In this study, an attempt was made to develop such models that could provide estimates of losses due to different levels of tick infestations. This is normally referred to as *sensitivity analysis*. There is need to determine the economic injury level or threshold for tick burdens of the important tick species. Once the models are developed, the predicted productivity changes can then be converted into monetary terms and finally the cost-benefit analysis of such projects could be accomplished. The findings of this research study would therefore provide a basis for quantifying the damage done by ticks on their hosts, the indigenous Zebu cattle on the Island and the economy as a whole. The results would help planners and policy-makers in the understanding of the need for and appraisal of newly-developed tick control measures.

Indigenous zebu cattle are by far the most important domestic livestock in sub-Saharan Africa. This is true in respect of their numbers and the contribution they make to individual farmers and respective national economics. Latest estimates of the cattle population in sub-Saharan countries (excluding the Republic of South Africa and Namibia) stands at 152 million heads of cattle (FAO, 1984b). Of the total cattle population in the sub-Saharan region, probably about 90% are kept under traditional peasantry systems of management (de Leeuw *et al*, 1988); as is the case on Rusinga Island. Most studies on African cattle productivity have,


Farm
Communal grazing area
RUSINGA ISLAND
27
28
29
21
25
36
16
1
2
6
3900
4000
4100
3800

Plate No. 3: Type of zebu cattle on Rusinga Island

however, been undertaken on modern management systems, either on results obtained on research stations (Fall *et al*, 1982; ILCA/IER, 1978) or on data from commercial ranches (de Castro, 1986; Trail *et al*, 1985; Pullan, 1979). This study was aimed at generating data based on the natural field conditions on the farmers' animals and thus encompassing his traditional practices; and so the findings would be more widely applicable. Hence, although the study area was Rusinga Island, it is the belief of the researcher that such models if developed would be applicable as well in the developing countries falling within the same agro-ecological and climatic zones.

CHAPTER 2

LITERATURE REVIEW

2.1 Factors affecting cattle productivity

2.1.1 Ticks and tick-borne diseases

2.1.1.1 Ticks

2.1.1.1.1 The taxonomy of ticks in relation to cattle disease transmission.

Like scorpions, spiders, and mites, ticks also belong to the Order Acarina. There are two major well-defined families of ticks, namely the *Ixodidae* (or hard ticks) and the *Argasidae* (or soft ticks). The third family called *Nuttalliellidae* is not of any veterinary or economic importance. The *Ixodidae* and *Argasidae* families differ from each other markedly in appearance, habits and life histories. The family *Ixodidae* have hard dorsal shield which covers the entire upper surface of the male and a relatively small area just behind the head of a female, nymph or larvae. This dorsal shield or scutum bears a pattern which is characteristic for each species of the tick. Sometimes, the scutum is uniform in colour and pattern is only made up of the pit, grooves and minute punctuations on it, but in some ticks colour pattern is also present. Accurate identification of the species can only be achieved by using

a microscope or a hand lens with a magnification of 10x or more. See Figures 2.1 and 2.2 for the morphological details.

From the veterinary point of view, the hard ticks are by far the most important both socially and economically. Some ticks appear to be host specific. For example, hyraxes, ground squirrels and cane rats have their own particular species of ticks. Other ticks prefer animals belonging to a particular group such as cattle, sheep, goats, and herbivores in general, or even snakes, crocodiles and other reptiles. There are also some examples of ticks that attack almost any kind of animal they can come across.

Although different species of ticks and tick-borne diseases occur in different ecological regions, their impact on animal production is similar in nature and importance. The major effects of ticks are through tickworry, blood loss, damage to hides and udders, and the injection of toxins. Other sources of losses are through mortality or debility caused by the diseases transmitted.

Ticks and tick-borne diseases are widely distributed throughout the world, particularly in the tropical and subtropical regions. It is estimated that 80% of the world's cattle are infested with ticks (FAO, 1982). In Kenya, over 80% of the cattle are found within the distribution of *R. appendiculatus* (Dolan and Young, 1981). Productivity losses on cattle due to tick infestations could be as high as 50% of milk production from an infected cow (de Castro,

1896); in extreme cases, it can cause a total loss of productivity.

The effects of ticks and tick-borne diseases are multiple. The effects can be classified as either primary or secondary. The primary effects are those in which the ticks affect directly, such as growth or milk yield whereas the secondary effects are those which are the consequences of reduced growth or milk yield, such as reproduction and calf weaning weight. The primary effects tend to be less in areas or regions where indigenous cattle are kept under stable conditions while the diseases are a major significance when exotic animals susceptible to ticks and tick-borne diseases are introduced into the tick-infested areas.

There are several *Ixodidae* tick species in Kenya. Amongst these are *Amblyomma variegatum, A. gemma, Rhipicephalus appendiculatus, R. evertsi, R. pulchellus, Boophilus decoloratus, B. microplus , Hyalomma rufipes* and *Ixodes lewisi* to mention but a few. The tick *Rhipicephalus appendiculatus* is the main vector of *Theileria parva* (sporozoan that causes East Coast Fever) in Africa. This tick is widespread all over East, Central and Southern Africa. *Amblyomma variegatum* is the principal vector of the causal organism of heartwater in cattle and also transmits *Theileria mutans.* The *Amblyomma* spp are common and are serious livestock parasites from the Sahara to southern Africa. *Boophilus decoloratus* transmits *Babesia bigemina* and *Anaplasoma marginale.*

2.1.1.1.2 The morphology of ticks

Ticks also possess jointed legs as insects. The larva has six legs while both the nymph and adult have eight. The thorax and abdomen are strongly fused together to form a saclike leathery appearance. A distinct head is absent but the mouthparts together with the basis capituli in many species forms what is called the capitulum.

The adults and nymphs have a pair of spiracles, situated lateroventrally on the abdomen, one on each side. For the ixodid males, the scutum largely or wholly covers the dorsal side. In immature and females, the scutum covers only the anterior part of the scutum, behind the capitulum.

Although some ticks possess a pair of simple eyes (see Figures 2.1 and 2.2), many species of tick lack eyes. Both sexes possess festoons, though this is not evident in engorged females.

2.1.1.1.3 The predilection sites for ticks

Different ticks have preferrences for attachment to specific sites or predilection sites on the host body. The reasons for site specificity is still not quite understood by biologists and hence require further detailed studies to be done.

Boophilus decoloratus, the most common one-host tick in East Africa, prefers to attach itself to the face, neck,

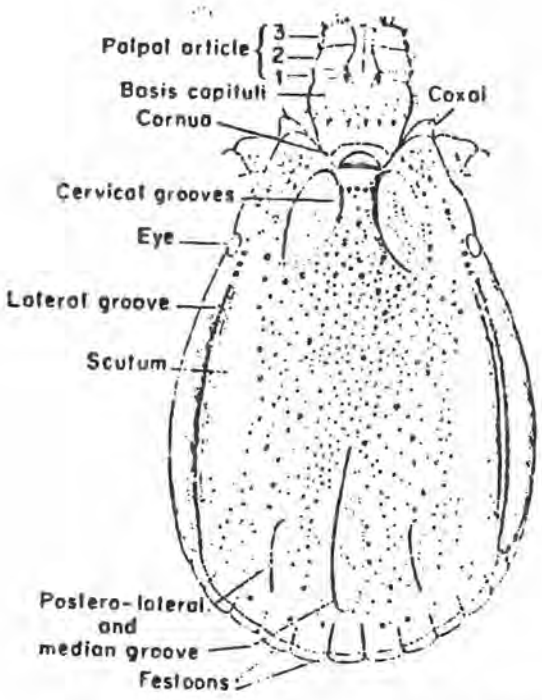


FIG. 2.1 DORSAL VIEW OF A MALE IXODID TICK

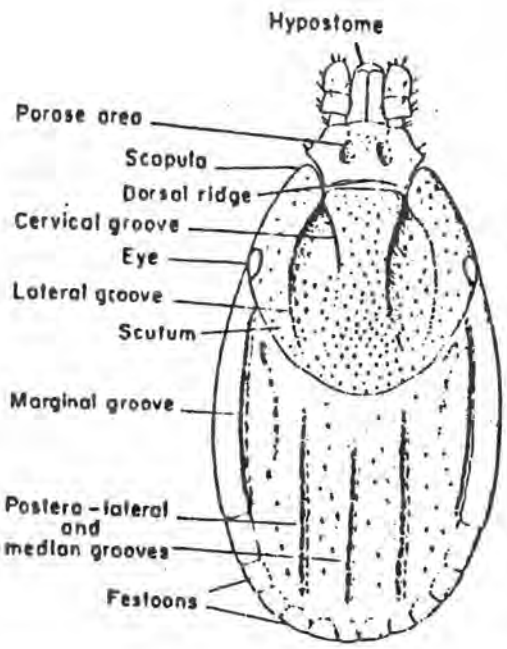


FIG. 2.2 DORSAL VIEW OF A FEMALE IXODID TICK

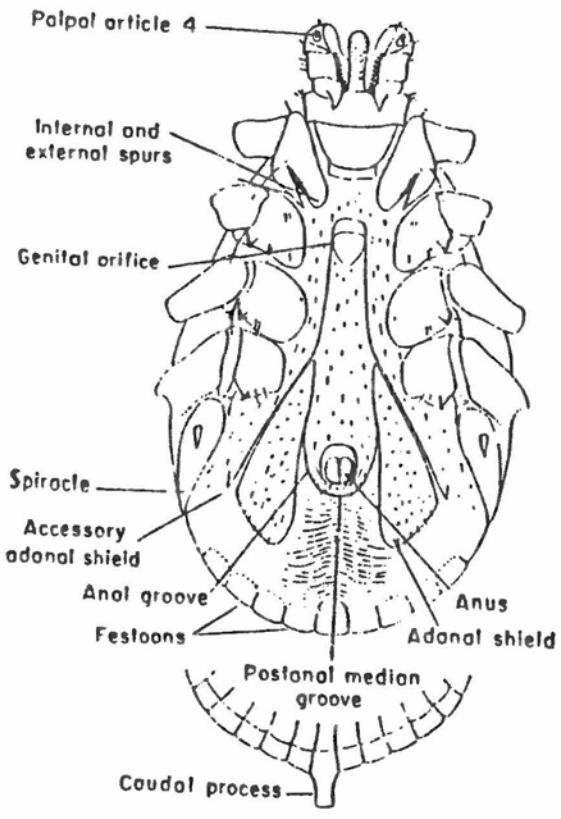


FIG. 2.3 VENTRAL VIEW OF A MALE IXODID TICK

dewlap and sides of the body. Once it is attached to the host as larva this tick does not move around the body much.

Rhipicephalus appendiculatus, commonly known as the *Brown Ear Tick*, feeds as larva and nymph mainly on the face and around the muzzle of cattle. The adult, brown in colour, on the other hand, prefers the ear of cattle and hence the name of *Brown Ear Tick*.

The bont species of ***Amblyomma*** attach on the head and ears as larvae. Nymphs and adults on the other hand feed on the groin, udder, scrotum, the axillae, perineal region, and the tail brush.

The red-legged tick, ***R. evertsi*** in their larval and nymphal stages are found deeply rooted in the grooves of the ears of cattle. On the other hand, their adults are usually found attached under the tail, around the anus and vulva of their host. The bont-legged ***Hyalomma*** spp, also a two-host tick like ***R. evertsi***, feed as larva or nymph on small mammals such as rabbits, but as adults feed on cattle or other large mammals and are found on the udder or scrotum, under the tail or in the tail brush, and on the feet.

A knowledge of the favourite predilection sites of each species is important when control measures are to be implemented. For example, in the case of ***R. appendiculatus***, if a dip is badly constructed such that cattle could manage to keep their heads off-dry, many of these ear-ticks will undoubtedly survive and hence defeat the whole purpose of ECF control.

2.1.1.1.4 The life systems of ticks

The life histories of ticks vary among many species. However, all species pass through the same stages as egg, larva, nymph and adult within a duration of about six weeks to three years. Although larva has six legs, nymphs possess eight. When all the life history stages take place on one host as is the case of *Boophilus microplus* and *B. decoloratus*, the tick is referred to as one-host tick. When two or three animals are involved then it is called a two- or a three-host tick, respectively. Examples are *R. evertsi* and *R. appendiculatus* as the two- and three-host ticks, respectively. For some argasids, for example, *O. hermsi*, more than three animals are involved and hence are referred to as many-host ticks.

Whereas the ixodid ticks go through only one nymphal stage, the argasids experience as many as five nymphal stages. Both male and female ticks suck blood. But whereas it is only the body of the ixodid female which is greatly distended, in *Argasidae* it is both sexes.

The life span system of ticks can be divided into three phases:

(i) Development phase

This is the phase when the tick is found in the vegetation. This includes the engorged female ticks and

their eggs, fed larvae and nymphs. During this phase, ticks are considered to be relatively immobile.

(ii) Host finding phase

This comprises of the distribution, dispersal, longevity, behaviour, and rate of host/tick contact of unfed larva, nymph and adults as appropriate to one-, two- or three-host tick.

(iii) Parasitic phase

This is the stage when the tick is feeding on the host. It is this phase which is the main reason for studying ticks because it is when the tick inflicts damage to domestic livestock and man himself. It is also the most complex phase and that in which the more important tick stabilising mechanisms are to be found.

The duration of parasitic phase varies from one genus to the other depending on whether it is one-, two-, or three-host tick. One-host ticks take about 17-25 days to complete engorgement on the European breeds of cattle and 18-30 days on zebu cattle (FAO, 1984a). Larvae and nymphs of most three-host ticks each complete engorgement in 4-6 days but most *Hyalomma* spp and *Amblyomma* spp take 1-2 days longer. Larvae of two-host ticks remain on the host where they moult to nymphs, feed to engorgement and then drop 2-3 weeks after first attachement of the larvae. Females of most two- and three-host ticks complete engorgement in 5-8 days with *Hyalomma* spp and *Amblyomma* spp taking 7-10 days. For *R. appendiculatus*, the time spent on the host is 5-22 days in

total (larvae 3-5 days, nymphs 5-7 days, females 7-10 days); the rest of the tick life cycle is spent on the ground and the total could be up to 500 days.

Scientists are striving hard to develop new tick control measures that are adaptable in tune with the existing farming systems, the economics of control, and the demands on management. In order to achieve these, research must be done which considers all the three phases. Otherwise, any exclusion may lead to the development of incompatible control methods and the creation of new problems.

2.1.1.2 The biology and transmission of tick-borne diseases

2.1.1.2.1 Theileriosis

Theileriosis is a complex of diseases caused by single-celled ***Theileria*** parasites. ***Theileria*** is a genus of tick-transmitted protozoan parasites infecting both wild and domestic animals in many parts of the world. The most important species of this genus in East and Central Africa is ***Theileria parva*** and which comprises of several subspecies. Theileriosis presents a major constraint to livestock production on the continent. ***Theileria parva*** causes a virulent form of theileriosis and threatens about 25 million cattle in Kenya, Tanzania, Uganda, southern

Sudan, Rwanda, Burundi, Zaire, Malawi, Zambia, Zimbambwe and Mozambique (ILRAD, 1988).

In East and Central Africa, the protozoan exists in three forms of subspecies, namely, ***T. parva parva***, ***T. parva lawrencei***, and ***T. parva bovis***. The subspecies ***T. parva parva*** causes the disease East Coast Fever (ECF) and is principally transmitted between cattle by the tick ***Rhipicephalus appendiculatus***. *Corridor* disease is caused by ***T. parva lawrencei***. ***Theileria parva lawrencei*** is also transmitted to cattle by ***R. appendiculatus*** but from buffaloes. The third subspecies ***T. parva bovis*** transmitted by the same tick is a milder form of *theileriosis*.

All these ***Theileria*** parasites possess a complex life cycle in the mammalian host and the tick. The parasites are transmitted most commonly when the tick feeds on infected animals as nymph and then on susceptible cattle as adults. Thus ECF can only be picked up by larvae and nymphs and could only be transmitted by the infected nymphs and adults (WEAL, 1980; FAO, 1984a). Hence if an adult tick picks up infection, it cannot later be transmitted. Furthermore, when ***Theileria***-infected ticks feed on hosts, they become cleansed of infection so that none is carried through to the next stage. Thus if they feed continually on an immune or naturally resistant animal hosts such as game animals or sheep or goats, which are not susceptible to ECF, the infection will be lost and there will be no disease or the infection rate in ticks will decline. This property is

useful in tick control and some peasant communities are applying it in the field by grazing cattle, sheep and goats together; a situation in which the small ruminants will be picking the ticks before cattle (WEAL, 1980). Amongst the wild animals that act as reservoirs of theileriosis are:

(i) Buffalo (ECF and Corridor Disease)

(ii) Bush buck (Ondiri Disease)

(iii) Wild ungulates (Anaplasmosis)

The bont tick genus of ***Amblyomma*** also transmit a milder *theileriosis* commonly known as *Benign theileriosis*. This infection is caused by ***Theileria mutans***. This disease is known to affect cattle.

The subspecies of ***Theileria*** parasites found in other parts of the world include ***T. annulata***, ***T. orientalis***, and ***T. hirci***. The subspecies ***T. annulata*** causes disease in cattle over a broad area extending from the Mediterranean to the Middle East, India, southern Russia and Asia. ***Theileria orientalis*** affects cattle in the far East. ***Theileria hirci*** causes disease in sheep and goats in the Middle East.

2.1.1.2.2 Babesiosis (Redwater)

Babesiosis is a tick-borne haemotrophic disease of a variety of wild and domestic animals. The disease is named redwater since it is characterised by the release of a dark red-coloured urine, the result of massive invasion and destruction of red blood cells. In endemic areas, animals

become infected very early in life and the immunity continues only as long as these parasites remain or are present in their body, despite reinfection (Akinboade, 1982). These animals, however, are carriers and are capable of infecting ticks thereby propagating the disease cycle.

Ticks are the only known vectors of *babesia*. Under natural conditions (Weinmann and Ristic, 1968; Soulsby, 1972; and Dipeolu, 1975) all piroplasms are transmitted from infected to healthy animals through the agency of ticks, mainly the ixodid ticks (***B. microplus***, ***B. annulata***, ***B. decoloratus***, and ***B. geigyi***). ***Boophilus microplus***, being the most widespread, is the most significant vector of *babesiosis*. The genus ***Rhipicephalus*** is the most important vector amongst the two-host ticks that transmit the disease.

Transmission of babesia is either transstadial or transovarial. Mechanical transmission whether by ticks or other haematophagous arthropods are not known. The transovarial transmission of ***B. bigemina*** by the one-host ticks, is a big headache when developing any tick control strategies since the tick once infected, remains infected thoroughout its lifetime.

2.1.1.2.3 Anaplasmosis (Gall-sickness)

Anaplasmosis is a Rickettsial parasite belonging to the genus ***Anaplasoma***. In Africa, the most significant species of veterinary importance is ***A. marginale***. *Anaplasmosis* has a

wider distribution than babesiosis, because it is transmitted by more vectors, including a wider range of tick species (***Argas***, ***Boophilus***, ***Dermacentor***, ***Hyalomma***, ***Ixodes***, ***Ornithodorus***, and ***Rhipicephalus***), haematophagous insects such as Tabanids and mosquitoes. It can even be transmitted by use of unsterilised hypodermic needles (WEAL, 1980). As in the case of Babesia, the mode of transmission is transovarial.

Anaplasmosis is a disease of the adult cattle and in general it does not occur until an animal is about 18 months of age (WEAL, 1980).

2.1.1.2.4 Heartwater

The disease known as *heartwater*, characterised at postmortem by large amounts of fluid around the heart, is caused by a Rickettsial parasite called ***Cowdria ruminantium.*** It is principally transmitted by the tick genus of ***Amblyomma.*** The mode of transmission is transstadial. Once cattle has been infected and has recovered from infection, they acquire immunity to the disease for ever. It has been noticed that in calves, there is considerable degree of innate age resistance to the disease.

2.1.2 Pasture and nutrition

2.1.2.1 Pasture

In the absence of major animal diseases, nutritional stress is the major constraint to increased livestock production (Chigaru, 1984). The main source of nutrients for ruminants is the natural grassland. The quantity and quality of the herbage available from the grassland is determined by many factors with rainfall and soil type being the major determinants. Both these factors will affect not only the nutritive values of the herbage but also the herbage species composition in any given area. For example, low soil phosphorus (P) levels result generally in low plant P status which is further aggravated by prolonged dry seasons. Generally P or N levels are low and the tendency for these nutrients to vary in parallel is worldwide (Hemingway, 1975). The low nutritional quality of the pastures during the dry season are also characterised by high fibre content and low digestibilty (Siebert, 1974). Thus, the multiplicity of low nutrients content and their low availability in pasture make it dificult to interpret the results of P supplementation or the diagnosis of a response situation of P.

The advantages of ruminants over monogastric livestock is that they do not compete with humans for the major part of their feed. Ruminants are able to utilise feeds high in fibre such as grasses and transform them into highly

nutritious food for humans such as meat and milk, and some by-products as butter and ghee. However, although cattle can maintain life on poorer types of grassland, they cannot produce milk or meat in economic quantities without such grasslands being improved to produce high quality fodder in ample supply. The nutrients derived from pastures are in most cases, far more cheaply produced than the ones derived from other cattle feeds such as concentrates. From some studies carried out in Madagascar (Granier *et al.* 1968 and de Reviers, 1970), it was found out that the annual liveweight gain for zebu cattle grazing on natural vegetation was around 40-70 kg. The growing period coincided with the rainy season. The liveweight gain attained a maximum of 50-120 kg/head, but during the dry season, losses amounted to about 20-60 kg/head putting the young cattle into a high risk of possible death (de Reviers, 1970).

The quantity and quality of forage on offer in any given production system and area varies considerably from season to season within a year, and from one year to the next. The quantity of herbage on offer and pasture yield are both only indirect measurements of the value of the pasture to the animal as neither gives an indication of what the animal is eating. The quality of pasture or its nutritive value is estimated by digestibility trials and is expressed in terms of *in vitro* dry matter digestibility (IVDMD) as percentage. The total dry matter intake (DMI) can be assumed to be 1.5% of the body weight. Forage consumed is considered

adequate if digestibility is above 45% and crude protein above 5% (Konandreas *et al* 1983).

The forage intake of extensively grazing cattle is influenced by the environment, age and physiological status of individual animals and the quality of forage on offer. For a given quality of forage on offer, *ad libitum* intake is a function of body liveweight and the physiological status of individual animals (Conrad *et al*, 1964; Cordova *et al*, 1978; Montgomery *et al*, 1965; Elliot *et al*, 1961; Hodgson, 1968) However, within a given functional form, the estimated parameters can vary considerably between breeds and climatic conditions.

Conrad *et al* (1964) suggested the following general voluntary intake relationship

$$I = a\ W^{0.73}/(1-d) \qquad (2.1)$$

where

I = DM intake in kg/d

W = body liveweight in kg

d = digestible fraction of the forage on offer

a = a breed and system-specific parameter whose value is a function of age and physiological status of individual animals.

At high digestibilty levels, intake for mature animals is reduced due to chemostatic or thermostatic mechanisms (Conrad *et al*, 1964; Montgomery *et al*, 1965; Baile *et al*, 1974), implying a constant energy intake for these higher digestibility levels. Konandreas *et al* (1983) in their model

assumed that for digestibility greater than 65%, feed intake is of the level such that the resultant metabolizable energy is equal to that obtained from the above relationship at the 65% digestibility level. This assumption implies a relationship (referred to as a physiological limit) of the form

$$I = K.W^{0.73}/d \qquad (2.2)$$

where

$$K = 1.86a \qquad (2.3)$$

Based on the above Equation (2.1), Cordova *et al*, 1978 showed that cows in the last 3 months of pregnancy and lactating cows have a 7% and 15% higher intake, respectively than dry, non-pregnant cows. The estimated coefficients for a are a = 0.042, a = 0.045 and a = 0.049 for dry, pregnant and lactating cows, respectively.

Not much work has been done on the voluntary intake for young calves. Hodgson (1968) experimented with calves from 3 to 6 months old and grazing on forage with digestibilty ranging from 65 to 80%. He observed that physiological limits are not constraining for young, fast-growing animals. And applying his figures on Equation (2.1) yields a coefficient value of a = 0.022, i.e. about 53% of the coefficient for dry cows obtained from Elliot *et al* (1961). Hence for modelling purposes, the intake coefficient for very young calves (3 to 6 months old) can be assumed to be 53% of the estimated coefficient for the reference animal, and is increased linearly until the level of the reference

animal is reached at 18 months of age. Similarly, the intake coefficients for pregnant and lactating cows can be taken as 107% and 115% of the estimated coefficient of the reference animal (Konandreas *et al*, 1983).

In addition to the above adjustments, Saunders and Cartwright (1979) have suggested that the following correction factors be applied when intake quality is low. For a crude protein level below 5% (equivalent to approximately 40% digestibility), it is suggested that intake be reduced by a factor $(d/0.4)^{0.6}$. For older cows (above 8 years), intake should be reduced by [1-0.03(age-8)]. It is, however, very difficult to be sure of the animal's feed intake unless fistulated animals are used. Fistulation cannot be used in this study since the farmer's own animals are involved.

2.1.2.2. Nutrition

2.1.2.2.1 General overview

A young growing calf requires :

i) Protein of sufficient quantity and quality.

ii) Enough digestible nutrients to permit fast and adequate growth.

iii) Sufficient minerals to allow normal skeletal growth, keeping pace with the rapid muscular development.

iv) Supply of essential vitamins. Young cattle requires

most of the B vitamins.

Because of the late development of functional reticulo-rumen, calves must be supplied with more liberal amounts of proteins. Further, the ration of the young calf should be less fibrous and more highly digestible until the reticulo-rumen is developed.

A cow's colostrum is highly digestible with a nutritive value 40% above ordinary milk (Brandt, 1979c). It is rich in protein, certain minerals and vitamins. Colostrum also acts as a laxative aiding to the expulsion of faetal dung (meconium). Lactose content in colostrum is depressed. However, fat and casein percentages are high but variable. Calcium, phosphorus, magnesium and chloride are high though potassium is low. Iron is 10-15 times that in ordinary milk, vitamin A 10 times and vitamin D 3 times. The albumin/globulin fraction may be 20-30 times that in the normal milk.

The gamma globulins (immune globulins) represent the disease protecting quality of colostrum. These globulins are concentrated in the udder prior to parturition and are passed on to the colostrum in large amounts. At birth, calves are born with traces of gamma globulins (antibodies) in their blood. This is because gamma globulins of the pregnant mother's blood serum are neither travelling through the placenta nor absorbed from the amnionic fluid in the uterus. The newborn calf must drink colostrum to obtain the antibodies. These gamma globulins provide the calf with

resistance against micro-organisms to which the dam has been exposed to at the place where she was kept. During the first 24-36 hours, these antibodies are passed to the intestines and absorbed unchanged into the blood stream. The high content of iron and vitamins also contribute to disease resistance.

A newborn calf lacks vitamin A in its system. This is virtually obtained from colostrum and milk. Good quality hay contains carotene which is convertible to vitamin A in the calf's body. The B-complex vitamins are secured from colostrum, milk or milk replacers. However, as the calf begins to feed on dry feed, the rumen micro-organisms begin to synthesize all of them in adequate amounts. Vitamin C is synthesized in the tissues of the calf and is not really required in the diet.

A newly-born calf has no vitamin D but secures it from colostrum. Exposure to sunshine causes body tissues to produce enough vitamin D to ensure good calcium and phosphorus metabolism with sound bone formation. Vitamin E is readily available in whole milk, cereal grains or good forage. Vitamin K is got from milk and colostrum and also synthesized by micro-organisms in the reticulo-rumen.

The major minerals are widely distributed throughout the animal's body and each element serves a variety of functions. In practical conditions, requirements for sodium and chlorine are readily met throughout the provision of a supplement of common salt, and with the possible exception

of all-concentrate diets, the dietary intake of potassium is invariably in excess of requirement (Brandt, 1979c). Many ruminant feeds require the supplementation with calcium and phosphorus but because of the extensive skeletal reserves, animals normally can adjust to temporary imbalances, providing they are in overall balance over longer periods. The important exceptions are females in late pregnancy and early lactation as metabolic changes associated with the onset of lactation can cause hypocalcaemia, irrespective of the dietary or nutritional status.

Specific mineral deficiencies have long been recognised as having a marked influence on the health of cattle. For example, calcium is required for milk production; phosphorus is required for growth, pregnancy and lactation (Brandt, 1979c; Hafez *et al*, 1969). Deficiency of phosphorus in ruminants is characterised by a low concentration of inorganic phosphate in blood, poor mineralisation and growth of the skeleton and anorexia or a depressed appetite, the latter leading to an intensification of any weight loss or depression in milk yield which can be attributed to phosphorus deficiency. Opinions differ on which of these signs is the most sensitive to phosphorus deficiency. Burroughs *et al* (1956) and Tillman *et al* (1975) have argued that requirements for maintenance of normal appetite and growth are greater than for bone growth or maintenance of normal plasma inorganic phosphorus concentrations. Field *et al* (1975) found that the appetite of growing lambs were

affected within 1 week of the introduction of the low phosphorus diet long before any effect on plasma concentration of the inorganic phosphate was apparent. On the other hand, Van Landingham *et al* (1935) considered that the fall of inorganic phosphorus in blood preceeds any physical signs such as loss of appetite or stiffness in front and rear quarters. In the face of these contradictions, a diet is deemed adequate if growth and concentrations of inorganic phosphorus in plasma or blood are not significantly different from those of the adequately fed group.

In addition to deficiencies, some mineral elements are known to interfere with the metabolism of other elements or minerals, e.g. calcium/phosphorus/magnesium, or iron/copper or molybdenum/copper. Mineral mixtures should not be used indiscriminately in cattle.

2.1.2.2.2 Phosphorus nutrition

Phosphorus (P) may be the first limiting factor to growth during the pasture growing period of the rains, since during the same period, protein and digestible energy content of the forage is plentiful (Little, 1970). Further, Underwood (1966) found that under severe P shortage, it is the yield rather than composition of milk which is affected. The depressed yield was attributed to increasing demand for P during lactation (NRC, 1970). Further, Duncan (1958) found

that negative P balance was common in early lactation or with high yields. To date, very few studies have been done on modelling the impact of additional P. McTaggart (1959) reported that P supplementation given to lame lactating cows apparently improved bone mineralisation without affecting milk yield.

Ellenberger *et al* (1950) found that 83% of the total body P in younger cattle and 87% in the mature cattle were in the bones. Expressed on a fat-free dry matter (DM) basis, they found that percentage of P in the skeleton increased from 6.3% in the foetus of 6 months gestation to 7.0% at birth and 9.0% in the calf of one year. In the adult cows, the percentage ranged between 9 to 12%.

Church *et al* (1972) quoted that P content of bone ash (46% of bone DM) for different species vary between 16-17%; or about 4-4.5% of wet bone tissues. Bone DM consists approximately of 46% mineral matter, 36% protein and 18% fat (McDonald *et al*, 1969). The skeletal and teeth account for 75-80% of the total body P. Of the remaining, the smooth and skeletal muscle account for 8% and 21%, respectively; brain tissue 24-44% and liver about 28%. P is found to be indispensable in many intermediary metabolic processes particularly the functioning of both cytoplasm and the nucleus of all living cells (Bartter, 1964).

Because the mineral phase and the organic phase of the bone are functionally inseparable, any consideration of P metabolism in the tissue must necessarily involve the

important constituents of both phases. In this regard, nitrogen (N) and hence protein, and calcium (Ca) are of major importance (Teleni, 1976).

Teleni (1976) has extensively reviewed the literature on the absorption and metabolism of P. It is particularly noted that the nutritive value of a feed is a function of intake and subsequentm absorption and utilisation of its P. Thus P must be absorbed into the blood stream and converted to the appropriate sites in the tissues and converted into its functional combinations.

Young *et al* (1966) investigated the nutritional interaction between Ca and P on monogastrics and found that the Ca:P ratio should be maintained within relatively narrow limits of 1:1 to 2.5:1. In contrast, the ruminant animals appear to be less sensitive to the dietary ratio of Ca:P (Leuker and Lofgreen, 1956; Haag *et al*, 1932; Lonmba *et al*, 1969). Other minerals such as zinc, molybdenum, copper, aluminium, manganese, berylium and iron are also known to adversely affect P metabolism (Dyer, 1969; Jacobson *et al*, 1972).

The dietary requirements of P depend on several factors. However, it is generally agreed that a level of 0.18% of P in DM of any pasture is adequate for all except lactating and young fast growing animals (ARC, 1965; NRC, 1970). Lactating cows 3-4 months post partum require levels of P of 0.23% while concentrations of up to 0.31% are

necessary to ensure an adequate P intake by rapidly growing steers (NRC, 1970; Teleni, 1976).

The clinical symptoms of P deficiency are often associated with depraved appetite, and animals ingest articles such as rocks, dirt, wood, bones and hair (Underwood, 1966). P-deficient cattle may also consume carcass debris, when available (Teleni, 1976). P-deficiency can be monitored either in the blood plasma (Underwood, 1966; Church *et al*,1972) or bone (Cohen, 1975).

2.1.3. Other diseases of cattle

2.1.3.1. Trypanosomiasis

2.1.3.1.1 General introduction

Trypanosomiasis is a disease complex caused by several species of blood- and tissue-dwelling protozoan parasites belonging to the *Trypanosoma* genus. The disease occurs throughout the tropical regions of Africa and in large areas of Asia and South America. It affects cattle, sheep, goats, pigs, horses, camels and man. Although wild animals can be infected by the parasites, generally they do not suffer from the disease but instead acts as the source or reservoir of the infection for domestic animals.

In Africa alone, *trypanosomiasis* is prevalent in 37 countries, extending from over 10 million km² or roughly one

third of the continent (ILRAD, 1988). The implication of this is that 30% of Africa's total cattle population (about 50 million cattle) are at risk of infection. The impact of trypanosomiasis in Africa is said to reduce the continent's animal protein per hectare to about 70 times less that of Europe (ILRAD, 1988).

2.1.3.1.2 The taxonomy of tsetse flies

Tsetse flies belong to the genus *Glossina*, family *Muscidae* and the Order Insecta. There are twenty two living species of *Glossina*. Four species of fossil *Glossina* have been described from the Oligocene shales of Colorado. These species can be divided into three major groups - the *fusca*, *palpalis*, and *morsitans*. The *fusca* group includes *G. fusca*, *G. fuscipleuris*, *G. brevipalpis*, and *G. longipennis*. The *palpalis* group (the riverine species) includes *G. palpalis*, and *G. fuscipes* while the *morsitans* group are *G. morsitans*, *G. swynnertoni*, *G. pallidipes*, and *G. austeni*.

2.1.3.1.3 The trypanosomes and their transmission

In Africa, the most important trypanosome species that affect domestic livestock are *Trypanosoma congolense*, *T. vivax* and *T. brucei brucei*. Pigs and camels are likewise attacked by *T. simiae* and *T. evansi*, respectively. Sleeping

sickness of humans is caused by *T. brucei gambiense* and *T. brucei rhodensiense*. Taxonomically, *T. rhodensiense*, *T. gambiense* and *T. brucei* are morphologically indistinguishable but biologically distinct species. Willett (1962) contends that *T. rhodensiense* is a virulent strain of *T. gambiense* that has been able to continue its spread by transmission through game animals and that has thus been able to survive under circumstances that would suppress all less virulent strains.

Trypanosomes can also be transmitted by other biting insects such as the Tabanids and *Stomoxys* (Hoare, 1947). For example, *T. evansi* and *T. equiperdum* are not tsetse-borne but are transmitted by the *Tabanidae. Trypanosoma vivax* can be transmitted by all the *Glossina* spp. However, Hoare (1970) states that in East, Central and Southern Africa, *G. morsitans, G. swynnertoni* and *G. pallidipes* are the definite vectors. *Trypanosoma congolense* is responsible for the most important form of African trypanosomiasis in domestic mammals. In Kenya, the most efficient carriers are *G. morsitans. G. austeni* and *G. pallidipes* (Hoare, 1970). According to Willett (1970), it was observed that around Lake Victoria in Kenya, cattle exposed to *G. fuscipes* had less risk of contracting *T. congolense* than when kept in contact with *G. pallidipes.* The cause of this differential infectivity is said to be due to their distint feeding hosts. *Glossina pallidipes* tends to feed on animals which are more likely to carry infection. On the other hand, *G.*

fuscipes feeds mainly on man and reptiles, both of which are insusceptible to *T. congolense*. Some scientists also suggest that it is possible that *G. fuscipes* could genuinely be less susceptible to infection by *T. congolense*.

Trypanosoma gambiense is normally transmitted by the waterside flies of the species *G. palpalis* and *G. tachinoides* in West Africa, and *G. fuscipes* in East Africa. Like *G. fuscipes*, the other two species also feed mainly on crocodiles. *Trypanosoma rhodensiense* is principally transmitted by *G. morsitans, G. swynnertoni* and *G. pallidipes* which inhabit savannah-like woodland abundant in wild animals. With regard to *T. brucei*, although the main vectors are *G. morsitans* and *G. pallidipes*, it had also been observed that *G. brevipalpis, G. tachinoides* and *G. palpalis* are also known to be good transmitters. Willett (1970) states that *T. brucei* has now rigidly adapted itself to transmission by the Tabanid flies and other biting arthropods.

Willett (1962) discussed the relative roles of vectors in trypanosomiasis transmission. He advanced a theory on this puzzle. He postulated that the riverine species (*G. palpalis* and *G. tachinoides*) are more dangerous when circumstances are such that survival becomes difficult. Under favourable conditions, the fly is more generally distributed over its habitat, but, when conditions are marginal for existence which in this case means low humidity, it will concentrate near temporary pools, which it

may be unable to leave. The search for water, washing and other activities would normally bring the host and the fly together. This theory explains such anomalies as the apparent greater ability of the fly to transmit the parasites in areas near the limits of the tsetse' geographical range.

The symptoms of infection are that the infected animals develop fever, lose weight and progressively become weak and unproductive; breeding animals may abort or become infertile. If not treated the animals die of anaemia, heart failure or intercurrent bacterial infection that take the advantage of the weakened resistance of the animal. In later stages of infection all three trypanosome species of livestock may invade the central nervous system.

2.1.3.2. Bovine coccidiosis

The Order Coccidia consists of a protozoan (sporozoan) parasite that causes a disease called *coccidiosis*; a disease which is of considerable importance in domestic animals, especially poultry, rabbits, cattle, sheep and goats. The sporozoa attack the epithelial cells of the intestines of the host animal. It is also important in wild animals but does not occur in man.

Coccidiosis is essentially a man-made disease, the result of abnormal crowding of single host species in a

limited area. It is only under these circumstances that animals become infected with enough oocysts to become ill.

Coccidiosis mostly affects calves between 3 weeks and 6 months of age (Marquart, 1973). But occassionally, clinical disease has been diagnosed in yearlings and even adults, especially when massive infection has occurred. Amongst the symptoms of coccidiosis is diarrhoea with visible blood and mucuous, soiling with manure, straining, arched back, rough haircoat, weakness and dehydration. In order to prevent coccidiosis, overstocking and crowding should be avoided.

For more literature on the taxonomy and life history of coccidia, Norman (1973) and Marquart (1973) have extensively covered these.

2.1.3.3 Salmonellosis

Salmonellosis is a cattle disease characterised by fever and diarrhoea which is watery initially but gradually changing to a smelly yellowish pasty consistency with mucuous. It is common in calves from the age of 10 to 14 days old and its typical symptoms are depression and dehydration.

2.1.3.4 Diarrhoea

Calf diarrhoea is caused by the failure of management to provide the calf with the balanced good feeds and

particularly due to inadequate vitamin A intake, lack of colostrum feeding, etc. The disease is stimulated by as well by parasites such as bacteria and viruses.

2.1.3.5 Tick toxicoses

The toxins injected by ticks are known to cause paralyses in animals and man. In East and Central Africa, those toxins injected by the *Hyalomma* spp cause the Sweating Sickness. Sweating Sickness affects mainly calves under the age of one year and could even be fatal. Occassionally, old cattle might be affected (WEAL, 1980).

2.1.3.6 Other minor diseases and infections

Bovine Petechial Fever also known as *Ondiri Disease* is caused by a *Rickettsial* parasite called *Erlichia ondiri* and its symptoms are numerous pin-point haemorrhages on the mucuous membranes. Although little is known about this disease, it is suspected that ticks are the vectors (WEAL, 1980).

The other diseases of cattle that have not been discussed above include tuberculosis, brucellosis and leptospirosis (both could cause abortions in cattle), diptheria, pneumonia, vibrosis, anthrax, vesicular diseases, foot-and-mouth disease, mastitis, and various skin diseases. These are, however, not of much veterinary or economic

importance to cattle productivity on the Island (ICIPE, 1986).

2.1.4. Endoparasitic helminths

The term *helminth* was derived from a Greek word *helmins* or *helminthos* meaning *worm*. Endoparasites or internal parasites are living organisms that internally inhabit hosts thereby establishing a harmful association, the parasite living at the expense of the host.

Helminths must not necessarily be harmful or pathogenic. There are some helminths that are neither pathogenic nor harmful; some are even beneficial. For example, the cilliates of the rumen of the ruminant are metabolically dependent on the host and yet are non-pathogenic and there is much to indicate that they are beneficial. There are helminths that produce parthological changes which may lead to severe ill-health or death of the host.

The parasitic helminths of domestic animals fall mainly in the classes Trematoda, Eucestoda and Nematoda. The species of Trematoda that are parasitic to domestic animals belong to the subclass Digenea. Some of the parasitic species of the subclass Digenea are *Fasciola hepatica and F. gigantica.*

The effects of endoparasites on their hosts are varied and in many cases represent a combination of several of the following:

* Compete with the host for food.
* Cause decreased food utilisation by the host.
* May cause reduction in appetite with concormitant reduction of food intake.
* Increased passage of food through the digestive tract.
* Decreased synthesis of protein in skeletal muscle.
* Changes in the absorptive surface of the intestine may result in marked alterations in the efflux and influx of water and sodium and chloride ions into the bowel.
* Changes in the morphology and biochemistry of the epithelial cells and their microvilli.
* The removal of the host's tissues and fluids e.g. blood, in some cases may cause death of the host.
* Destruction of the host tissues by means of mechanical action, pressure, or blockage of ducts.

Infestation of cattle, especially young stock, with endoparasites is a constant threat. Worms are picked up by cattle while grazing and in drinking water, and the worm-burden builds up when animals keep on swallowing infective stages of worms. Severe outbreaks of parasitism

with heavy losses do occur, but even light burdens are costly because they continue to take their toll of production, often unnoticed, mainly by lowering animal's performance through reduced appetite and inefficient feed conversion. Usually endoparasites do not cause much trouble under stall-feeding conditions or on pastures with very low stocking rates (Brandt, 1979c). The risk of parasitism is likely to increase as animal production increases, as with intensive grazing on dairy farms.

In veterinary parasitology, several methods have been developed for the identification of of the species of endoparasitic helminths in domestic livestock (Soulsby, 1982 and MOAFF, 1970). Since for live animals is difficult to do this on the adult worms, such clinical examinations have been based on the eggs of these helminths as manifested in the faeces or laboratory-cultured larvae from such faeces. Since culturing of most helminth eggs normally takes about 7 days under optimal conditions, methods based on the direct counts of eggs are usually more popular. Many helminths possess unique egg shapes which enables their identification in the laboratories using microscopes.

The most popular egg-counting techniques are McMaster's and Stoll's methods (Soulsby, 1982 and MOAFF, 1970). However, it should be noted that egg-counting methods are subject to certain sources of errors (MOAFF, 1970). These are:

(i) Because of uneven distribution of eggs in

faeces, egg counts have shown very large sampling errors between samples. But this is not considered to be very serious compared to the other sources.

(ii) There exists fairly very regular daily fluctuations in faecal egg counts. Definitely depending on the time of day the faeces is collected, egg counts made from the same host would vary hence affecting the accuracy of the data.

(iii) The number of eggs counted per unit weight of faeces is dependent on the amount of faeces passed by the animal.

In the light of these shortcomings, a more accurate approach for egg counting is to determine the total daily egg output by performing egg counts on random samples derived from all the faeces passed in a 24-hour period. In practice, under field conditions, this approach is almost infeasible.

Though the presence of large numbers of eggs or larvae in the faeces would tend to confirm a diagnosis, their absence or presence in small numbers does not necessarily mean that the animal is not sufferring from helminthiasis. This point is evident by the fact that:

(a) The presence of males or immature worms (non-egg producers) cannot be detected through eggs and yet a good number of species of these groups are

highly pathogenic.

(b) The resistance of the host is known to affect the biology of the helminths. It can depress or entirely suspend the ovulation of the worms. It can also lead to marked prolongation of the pre-patent period. Thus worm burdens can give rise to a disease but fail to be manifested in the faeces egg counts.

(c) For some species of nematodes, it is not possible to distinguish different species through their eggs and so egg counts can only be done for a mixture of species which possess heterogeneous pathogenicity and fecundity.

(d) It is true that there are many other biological factors that affect the relationship between the number of adult female worms and the number of eggs passed (e.g. possibly other diseases such as diarrhoea).

(e) Occassionally there are eggs that have abnormal shapes. Hence for such eggs, identification becomes difficult.

2.1.5 Climatic stress

Weather can be defined as a specific, temporary combination of certain metereological factors. These factors include air temperature, humidity, air movement (wind

speed), radiation (both visible and invisible), barometric pressure and precipitation (rain, snow). Weather is also characterised by the rate at which these factors vary from hour to hour, day to day, and even from one week to another. Living organisms respond to both the levels and rates of change of these factors. Climate is the long-term pattern of weather, usually the averages over the whole year and its rate of change from one year to another. The most important climatic factors are those which define the animal's thermal environment. These factors are air temperature, humidity, air movement, and infrared radiation. These factors in combination, create what is called a " physiologically-effective temperature".

The regional and seasonal variations of climate produce effects that are far-reaching. Climate affects the animal's growth both directly and indirectly. Climate acts on the regional geological structure of the land to give a particular soil. The soil interacting with the climate, supports particular forms of plant life to flourish. Certain animals, the ruminants, depend on this plant life for their food. Plants are the primary sources of food for the flora and fauna. This chain reaction in the evolution of a natural habitat, which connects climate successively with soils, plants, and animals has built a characteristic ecology.

By its control of the food supply, the climate of a region has a profound influence on the animals living there. Animal life is geared to the seasonal rhythm of plant growth

and decline. Most insects go into diapause or hibernation in response to the harsh climatic conditions ahead, particularly where there is likeliness of food shortage for the offspring in future. They go into such state until when they sense through hormonal action that the conditions are favourable. Thus, in addition to its effect on food supplies, climate affects living creatures directly through its control of their heat exchanges, and thence, through nervous, hormonal, and behavioural mediation, all productive processes.

2.1.6 Impact of social environment

The management of natural grassland by the farmers whose livestock use that grassland, is an additional important factor. Management includes such components as the grazing system utilized, the stocking rates applied, whether or not soil fertlization and other feed supplements are applied, e.t.c. The behaviour of the social environment of man directly influences survival, reproduction, growth, and productive capacity of the domesticated animals.

Under all husbandry systems, adequate living space has to be provided in relation to animal density. Floor space requirements for maximum growth rates and efficiency of feed utilization vary with species. Overcrowding causes conflicts which result in undue competition for feed, improper digestion of food, reduced feed conversion efficiency,

injurious aggressive encounters in the case of the presence of a dominant cow, as well as diseases such as coccidiosis.

Under the intensive systems, feeders and watering systems must be placed where the young or inexperienced animal can find them. In the case of extensive grazing, a herdsman must be around to direct the young animals to the water points (rivers, lakes, etc) to drink.

Through proper management, man can establish a suitable social environment conducive to optimal growth and hence productivity of his domestic animals.

2.2 Cattle disease surveys in Rusinga

2.2.1 Tick-borne diseases

The survey started in September, 1986, covering about 200 cattle on the ten farms (ICIPE, 1986). The broad objective of this study was to collect some baseline data on cattle productivity on the Island in relation to ticks and tick-borne diseases.

From thirty seven calves born that year, aged between 1 and 3 months, about 34% of them were found to harbour *Theileria* piroplasms. The following three months, that is, at the age of between 4 to 6 months, about 36% of these calves showed severe ECF reactions. By December, all the calves had been infected. However, none of the calves died.

The parasites *B. bigemina* and *A. marginale* were diagnosed on 6- to 8-months old calves in November and December and incidence was found to be synchronous with the peak of *B. decoloratus* in October. The survey results thus indicated that 9 out of 19 calves (50%) were positive for *B. bigemina*. *Anaplasma marginale* recorded a prevalence rate of 70% (9 out of 25 calves showed positive on examination). The parasitaemia for both diseases was found to be generally low causing no deaths. However, *T. velifera,* a non-pathogenic protozoa, was common but its epidemiology was not monitored.

Further, the results showed that 56-79% of the adult cattle had Theileria piroplasms of low parasitaemia each month. Serological tests also indicated that 65% of the cattle had positive antibody titres to T. parva schizont antigen.

Dolan (1980) and Young *et al* (1981 and 1986) have also carried out extensive epidemiology studies on the *Theileria* parasites on the Island. Their results are discussed later.

2.2.2 Helminthesiosis

Faecal examinations in the laboratory revealed that the most prevalent helminth was the *Trichostrongylus* spp. It was found that about 70% of the 1- to 3-months old calves were infested with this worm. Even after treatment, helminths

re-infection was achieved in a month's time after treatment. Total re-infestation amongst the calves was attained within two months after treatment with recording a worm burden of over 1000 eggs per gram of faeces.

Other endoparasites that were found on the Island included *Fasciola gigantica, Paramphistomum* spp, *Strongyloides* spp, and *Coccidia* spp.

2.2.3 Trypanosomiasis

Several studies on the epidemiology of trypanosomiasis have been carried out on the Island. In 1985, 200 cattle were sampled for haemoparasites but none was found infected. Then further, an ecological study was carried out in which 600 tsetse flies were trapped and identified. All the 600 flies were found to be *G. fuscipes* species (ICIPE, 1987).

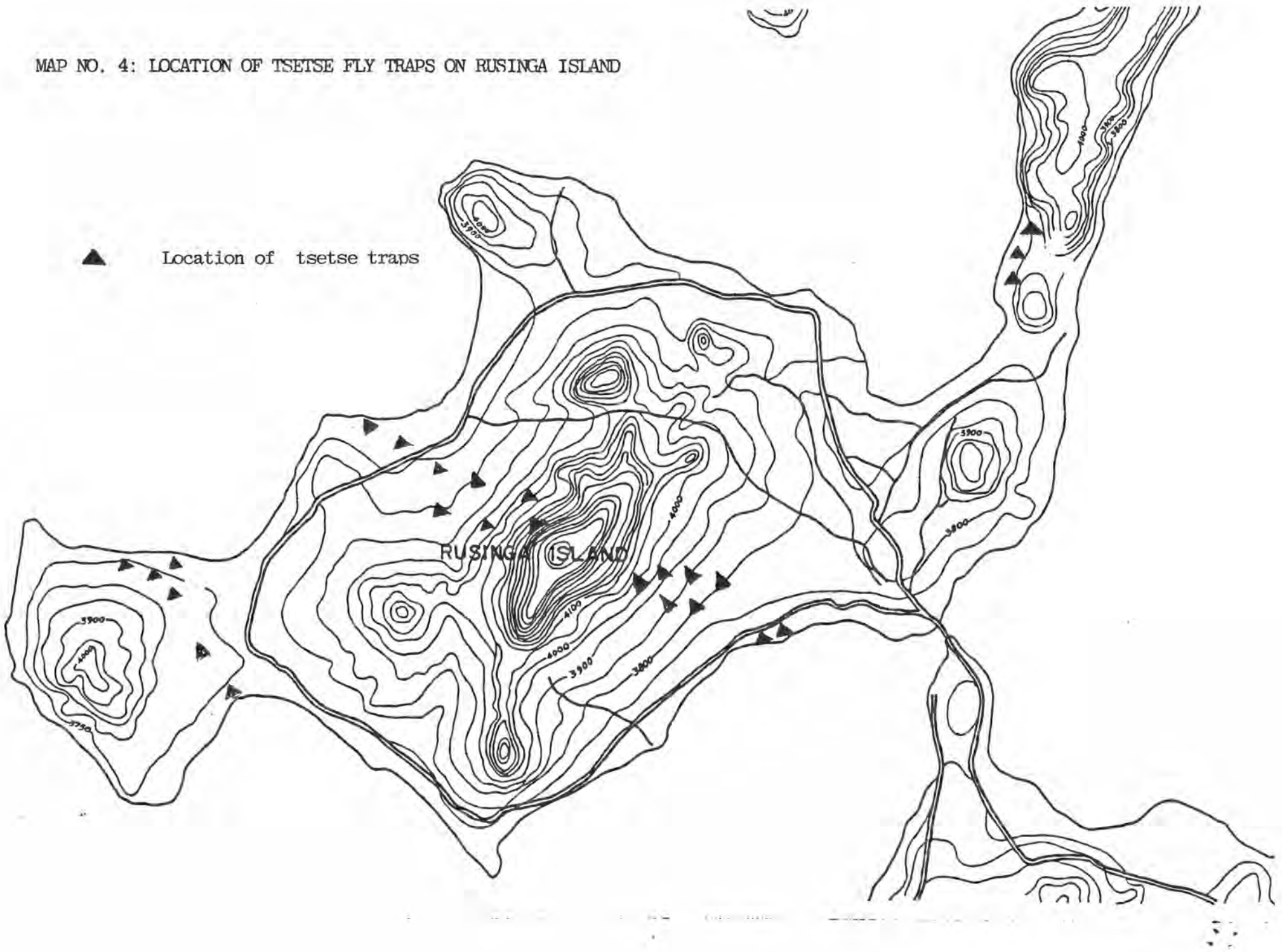
In 1987, another study was carried out on the Island in order to verify the species abundance and diversity of *Glossina* spp. In this study, 25 traps were set in four locations as shown on the Map No. 4. The trapping was done at monthly intervals. Traps were set and insects collected after 24 hours. After ten months of trapping, only Utajo and Kakrigu yielded flies; a total of 1344 flies, all of which were *G. fuscipes* species. The flies were then examined for parasites and only one was found having a parasite in the gut. The lone parasite was identified as a reptilian

Table 2.1: The distribution of tsetse traps

Location	No. of traps
Utajo	3
Kakrigu	8
Kamasengre	6
Kaswanga	8
Total	25

(Source: ICIPE, 1987)

MAP NO. 4: LOCATION OF TSETSE FLY TRAPS ON RUSINGA ISLAND



parasite. Majority of these flies were caught in the dry months between June and September.

Based on these past studies therefore, it is conclusive that the deadly trypanosomiasis is absent or is very rare on the Island.

2.3 Liveweight gain models

2.3.1 Review of models

In both plant and animal sciences, growth models have been developed and used for many years to provide a mathematical summary of a time series data on the growth of an organism or part of the organism. Most of the growth models have been applied in plant sciences (Richards, 1959 and 1969; Hunt, 1982; Causton and Venus, 1981). France *et al* (1984) has extensively discussed the various growth models so far developed. These include the simple exponential, monomolecular, logistic, Gompertz, Chanter, Richards, and exponential polynomial models.

It was shown that liveweight gain plotted against time is normally sigmoid in shape in both animals (Fowler, 1980) and birds (Wilson, 1980). The growth curve consists of two distinct phases (Brody, 1945):-

(i) The self-accelerating or autocatalytic phase, when growth is unrestricted by environment, and,

(ii) The self-inhibiting or nutrient-limited phase, when

growth is restricted by other factors.

According to Brody, growth in the first phase is a function of the growth already made and this phase can be described by a simple exponential function as

$$\frac{dW}{dt} = \mu W \qquad (2.4)$$

where W is the liveweight at time t and μ is the specific growth rate constant.

Integrating the Equation (2.4) gives

$$W = W_o e^{\mu t} \qquad (2.5)$$

where W_o is the value of W at time t = 0. But in the second phase, Brody assumed that the growth rate is a function of growth yet to be made to reach maturity, rather the growth already made. Brody used a monomolecular function

$$\frac{dW}{dt} = k(W_f - W) \qquad (2.6)$$

where W_f is the final or mature weight, and k is a constant describing the growth rate in relation to the growth yet to be made. Integrating Equation (2.6) gives the growth model as

$$W = (W_f - Be^{-kt}) \qquad (2.7)$$

where B is a constant. This model assumes that the growth rate k decreases continually and there is no limit of inflexion. Brody used the Equations (2.5) and (2.7) to compare different species and different breeds of the same species.

The use of Gompertz model brought a new impetus to animal growth modelling. Gompertz model assumes that the quantity of growth is proportional to the liveweight W , with a constant of proportionality μ as follows

$$\frac{dW}{dt} = \mu W$$

This model assumes that the effectiveness of the growth machinery decays with time according to the first- order kinetics. Thus

$$\frac{d\mu}{dt} = -D\mu$$

where D is the decay in the specific growth rate μ. When integrated it gives

$$\mu = \mu_o e^{-Dt}$$

where μ_o is the value of μ at time t=0.

And so

$$\frac{dW}{dt} = \mu_o [We^{-Dt}] \qquad (2.8)$$

Integrating equation (2.8) we get

$$W = W_o\{\exp[\mu_o(1-e^{-Dt})/D]\} \qquad (2.9)$$

In this model, the final weight at maturity W_f, is given by

$$W_f = \underset{t\to\infty}{\text{Limit}}\ W_t$$

$$= W_o[\exp(\mu_o/D)] \qquad (2.10)$$

The Gompertz Model has the same number of parameters as the Logistic Model except that for the latter the point of inflexion is half-way total period while for the former it is not.

Many researchers have used Gompertz model to simulate growth processes. The Gompertz function has been described as a growth function (Winsor, 1932) and in its modified form given by Equation (2.11), as one of the best non-linear models for volume-age description (Nokoe, 1974). The modified form, abstracted from the generalized and reparameterized non-linear model described by Grosenbaugh (1965) is of the form:

$$W_t = b\{\exp[-\exp(-a(t-g))]\} \qquad (2.11)$$

where W_t is the liveweight at age t, the constants a, b and g are parameters to be determined, and e is the exponentiation constant (e = 2.71828). We find that

$$\frac{dw}{dt} = b.\exp(s).\frac{ds}{dt}$$

where s = -exp(-a(t-g)).

$$\frac{ds}{dt} = a.\exp(-a(t-g))$$

And so

$$\frac{dw}{dt} = ab.\ \exp[\exp(-a(t-g))-a(t-g)]$$

$$= ab, \qquad \text{when } t = g$$

Setting

$$\frac{d^2W}{dt^2} = 0$$

and if

$$\frac{d^3W}{dt^3}$$

exists we find that

$$t = g, \quad \text{and } W_g = b/e$$

$$= \frac{b}{2.71828}$$

In the modified Gompertz model, the parameter g represents the age at which liveweight growth rate is maximum, and Yg is the coresponding liveweight at that age g (see Figure 2.3).

Nokoe (1978) demonstrated the flexibility of the modified form by successfully applying it to volume-age data of three forest tree species, namely, Western red cedar, Lodgepole pine and Douglas fir in British Columbia. Laird et al (1965) and Laird (1965) used this function to predict organ weights within a species from early embryonic life to

maturity with considerable accuracy. The Agricultural Research Council (1980) used it to describe pregnancy in cattle and sheep as

$$\frac{dE}{dt} = d[Ee^{-ht}] \qquad (2.12)$$

where t in days is time since conception, E is the energy stored (MJ) in the gravid uterus at time t, d = 0.0201 for cattle or d = 0.0737 for sheep, and h = 0.0000576 for cattle and h = 0.00643 for sheep. The above values of b and h relate to a calf birthweight of 40 kg and a lamb birthweight of 4 kg; the energy retentions are in proportion for other birthweights. Wilson (1980) showed that growth in birds for meat production is well described by a Gompertz model. One advantage of the Gompertz model (Equation (2.8)) is that one can attempt to separate out the effects of nutrition (this may be viewed as modifying μ_o), of the development rate D, and of the initial weight of the animal or tissue ($W = W_o$ at $t = 0$). Other more complex dynamic growth models have been described in the literature e.g. Baldwin and Black (1979).

Konandreas *et al* (1982) made the first attempt to comprehensively derive a theoretical simulation model for both milk and liveweight gain. According to them (Konandreas *et al*, 1982), the observed average liveweight, $\bar{W}_t$, say, of a given breed and sex, is a function of age of the animal, t. That is,

$$\bar{W}_t = \phi(t)$$

Further, they assumed that for the observed liveweight, W_t

$$W_t \sim \Phi(\mu_t, \sigma^2_t)$$

that is, liveweight W_t is distributed normally with mean μ_t and variance σ^2_t at age t. In this model, the variance, σ^2_t is also a function of age t. That is,

$$\sigma_t = f(t)$$
$$= k_t . \bar{W}_t$$
$$= k_t . \phi(t)$$

where k_t is the coefficient of variation.

The assumption that liveweights are distributed normally around their mean for a given sex and age category, with a coefficient of variation k_t implies that

$$W_{max,t} = \bar{W}_t(1+1.96k_t)$$

and

$$W_{min,t} = \bar{W}_t(1-1.96k_t)$$

where $W_{max,t}$ and $W_{min,t}$ are the upper and lower liveweight limits, respectively, at the 5% level of significance.

For an animal of a certain age and weight, a liveweight condition index can be defined depending on the relative position of its current liveweight vis-a-vis the corresponding upper and lower liveweight limits. This index denoted by c_t above is given by

$$c_t = \frac{(W_t - W_{min,t})}{(W_{max,t} - W_{min,t})}$$

This index varies between 1.0 (when $W_t = W_{max,t}$) and 0 (when $W_t = W_{min,t}$).

According to this simulated model (Konandreas *et al*, 1982), the maximum daily liveweight increase, DW^i_{max}, and decrease, DW^d_{max} are given by

$$DW^{i}_{max} = (W_{max,t+1} - W_t)/30 \qquad (2.13)$$

and

$$DW^{d}_{max} = (W_t - W_{min,t+1})/30 \qquad (2.14)$$

whose data is collected at monthly intervals. The above stochastic model was tested by studying cattle productivity of four pastoral production systems in Nigeria and Mali in 1982 with quite a success (de Leeuw and Konandreas, 1982). The model simulated data compared fairly well with the field data.

2.3.2 The OLS assumptions and their tests of significance

2.3.2.1 The assumptions

If the model parameters were estimated by the Ordinary Least Squares (OLS) method, the assumptions of the method must be satisfied. If the OLS assumptions are not fulfilled, then the estimates would not possess the desirable properties of linear, unbiased and smallest variance among the subgroup of linear unbiased estimators. Hence the violation of the assumptions would render the model invalid and useless (Johnston, 1972; and Koutsoyiannis, 1973).

Here only two assumptions, namely autocorrelation and multicollinearity are discussed. Assuming the general linear model:

$$W_k = \alpha_o + \alpha_1 u_k + \alpha_2 m_k + e_k$$

where α_i (i = 0, 1, 2) are parameters and e_k is the error term which is assumed normally distributed with mean zero and constant variance, σ (homoscedasticity). If variance of e_k is not constant, i.e

$$var(e_k) = \sigma_k \qquad k = 1, 2, 3,..$$

then there is autocorrelation and the series is said to be heteroscedastic. If a series is heteroscedastic and OLS is applied, although the parameter estimates would be unbiased, their variances would be very large both in small and large samples. Thus the estimates would be inefficient. Moreover, because of the high variances of coefficient estimates, prediction based on the model would also possess high variances. Heteroscedasticity is attributed to various factors:

i) Omission of important explanatory variables

ii) Mis-specification of the mathematical form of the model

iii) Mis-specification of the true random error term e_k

iv) Interpolations in the statistical observations

Linear dependence between the expanatory or predictor variables is quite common in macro-economics and applied life sciences. It is a crucial condition in OLS that the predictor variables are not perfectly linearly correlated. If they are, then the problem of multicollinearity would

arise. Multicollinearity may arise because of several reasons:

i) Tendency of several explanatory variables to move together over time.

ii) Use of lagged values of some of the explanatory variables as separate independent factors in the models.

The consequences of multicollinearity are that the estimates would be indeterminate and in some cases their standard errors might be infinitely large. Frisch (1934) showed that standard errors are not always large when multicollinearity is present. Therefore we may have inaccurate estimates of the parameters due to multicollinearity and yet their variances may not show it. The effects of multicollinearity on the estimates depend on the severity of interdependence as well as on the importance of the variables which happen to be collinear.

2.3.2.2 Tests for homoscedasticity

There are several methods of establishing homoscedasticity. Apart from the graphical methods (Koutsoyiannis, 1973) which are quick, there are other rigorous techniques available in the literature. Some of these are:

i) The Spearman's rank correlation test

ii) The Goldfield and Quandt test (Goldfield and

Quandt, 1965)

iii) The Glejser test (Glejser, 1969)

Method (i) is said to be superior to both (ii) and (iii) (Johnston, 1972). Method (i) is simple and applicable to both small and large samples.

Spearman's rank correlation test

a) Obtain the estimates of the residuals e_k's

b) Order the absolute values of e_k's and the explanatory variable values in ascending or descending order.

c) Compute the rank correlation coefficient

$$r_{e.x} = 1 - \frac{6\Sigma d^2}{n(n^2-1)},$$

In order to test

H_o: there is homoscedasticity

vs H_1: No homoscedasticity

compute the test statistic

$$t^* = r_{e.x}\frac{\sqrt{(n-2)}}{\sqrt{(1-r^2_{e.x})}},$$

and which is distributed as t with n-2 degrees of freedom.

Thus reject H_o at α-level of significance if

$$t^* > t_{\alpha(n-2)}$$

Otherwise accept H_o. The test then is that a high rank correlation coefficient suggests the presence of heteroscedasticity.

In the case of autocorrelation, if

$$corr(e_t, e_{t-k}) = c$$

where c is non-zero, then the serial correlation is termed as autocorrelation of order k.

There are two known methods of testing autocorrelation:

(a) The Von Neumann ratio (Von Neuman, 1941; and Fox, 1968)

(b) Durbin-Watson test (Durbin and Watson, 1951a and 1951b).

Durbin-Watson test is appropriate for small samples and only where the autocorrelation is of first order. In the case of first order autocorrelation

$$e_k = c.e_{k-1} + v_k$$

where $v_k \sim N(0, \sigma^2)$. In order to test

$$H_o : c = 0$$

vs $$H_1 : c = 0$$

compute the test statistic

$$d^* = \frac{\sum (e_k - e_{k-1})^2}{\sum e^2_k}$$

and compare this with the tabulated values of Durbin-Watson d-statistic, d_u and d_L. The test procedure is that if either

$$d^* \geq d_u \text{ (with n-k degrees of freedom)}$$

or

$$(4 - d^* \geq d_u$$

then there is no autocorrelation. But if $d^* \leq d_L$, then there is positive autocorrelation whereas if $(4 - d^*) \leq d_u$, there is negative autocorrelation. However, if either $d_L < d^* < d_u$ or $d_L < (4 - d^*) < d_u$ then the test becomes inconclusive. Durbin's two-step method developed later (Durbin, 1960) is however applicable to any order of autoregressive scheme.

2.3.2.3 Tests for multicollinearity

i) According to Klein (1963), multicollinearity is harmful only if

$$r^2_{xi.xj} \geq R^2_{y.x1.x2...xk} \qquad (4.10)$$

where $r^2_{xi.xj}$ is the simple correlation between any two explanatory variables x_i and x_j, and $R^2_{y.x1.x2....xk}$ is the multiple correlation of the relationship.

ii) Frisch's Confluence Analysis (Frisch, 1934).

iii) The Farrar-Glauber test (Farrar and Glauber, 1967). If we wish to test for the presence and severity of multicollinearity, then compute a statistic D defined as the determinant of matrix Q, where

$$Q = \begin{matrix} 1 & r_{x1.x2} \\ r_{x2.x1} & 1 \end{matrix}$$

Thus

$$D = |Q|$$
$$= 1 - r^2_{x1.x2}$$

Then to test the null hypothesis

H_o: X's are orthogonal

vs H_1: X's are not orthogonal

Farrar and Glauber found that the quantity

$$X^{2*} = -[n-1-1/6(2k+5).\log_e D]$$

is distributed as X^2 with degrees of freedom equal to $k(k-1)/2$, where k is the number of explanatory variables and n the sample size.

If it is found that multicollinearity exists and has serious effects on the estimates of parameters of important factors, then the following could be provide some corrective solutions:

a) Application of methods incorporating extraneous quantitative information
b) Increase the sample size
c) Substitute the lagged variables for other explanatory variables in distributed-lag models
d) Introduction of additional equations in the model
e) Application of the principal components.

2.3.3 Validation of models

2.3.3.1 The process of validation

Validation is the process of determining how well the model fits data. There is need to validate the developed model if its applicability is to be evaluated. A model could either be validated to evaluate reproducibilty of its parameter estimates or to confirm its functional form. A good model should be simple in addition to:

i) Should be compatible with the *a priori* postulates of the theory underlying the subject of study.

ii) Should be consistent with the data whose relationship it determines besides being able to explain the observations of the real world.

iii) The estimates of parameters should be accurate and possess the desirable properties of estimators such as unbiasedness, minimum variance, etc.

iv) The model should be able to produce satisfactory future values of the dependent variables.

Since the inception of the use of ecological simulation models to represent the seasonal dynamics of energy and material flow in large ecosystems around the beginning of this decade, the use of such models has increased (Steele, 1974; Innis, 1978; Kremer and Nixon, 1975; Steele and Frost, 1977; Bledsoe, 1976; DiToro *et al*, 1975; Coniferous Forest Biome Modelling Team, 1977; MacCormic *et al*, 1972; and Anderson and Ursin, 1977). The primary means of evaluation (validation) of these models has been comparison of the model output to field data, preferrably data independent from that used to develop the model. Recently, a number of criteria for model evaluation have been suggested in addition to model predictivity.

Several articles (Innis, 1976; and Woodmansee, 1978) have suggested that models should be evaluated on how well they meet their objectives. This opens the door for a wide range of alternative criteria for evaluation of which validation is only one. The question arises, however, whether ecological models are similar enough in their objectives that criteria for their evaluation can be discussed as a whole rather than separately for each model. Swartzman (1978a) reviewed objectives for a number of large-

scale ecological models and found them to be very similar. For this, he formulated several objectives common to most models reviewed. These include:

(i) To replicate system behaviour with fresh field data

(ii) To further understanding of ecosystem berhaviour

(iii) To organise information and data on processes

(iv) To pinpoint areas of future research

(v) To generalise the model beyond single site, i.e. spatial replicability

(vi) To investigate the effect of manipulation and pertubation of system behaviour

Validation of a model takes several forms. Two methods of model validation were adopted. A model could betested for the form of its functional relationship. Second, the estimates could be tested for their ability to simulate the corresponding parameters in the light of the '*a priori*' biological mechanisms behind the processes.

2.3.3.2 The functional form of the models

In the light of numerous relevant factors and their complex interactions, biological theory may or may not indicate the precise mathematical form of the relationships, or the number of equations to be included in the biological model. In most cases, biological theory does not explicitly state the mathematical form of the biological

relationships. One way out of this dilemna is to plot the actual data on two-dimensional scattergrams, taking two variables at a time (the dependent and each one of the explanatory variables) in turn. Most often when there are two or more explanatory variables, this method does not help much.

Sutherst *et al* (1986) asserted that a linear relationship between tick numbers and lost growth of animals as

$$D = d.N$$

where D is the total loss in liveweight gain, d is the loss attributed to each engorging tick, and N is the total number of ticks present. They also admitted that where there are some very damaging species, non-linear relationships are likely to be the case. Thus, it has become a common practice of biostatisticians attempt by trial and error to develop both linear and non-linear models and then choose from among the various results the ones that are judged as the most satisfactory on the basis of certain criteria, e.g. R^2, standard errors of estimates, e.t.c.

2.3.3.3 The biological 'a priori' criteria for model parameters

In this case a biostatistician would be confronted with a problem of deciding whether the estimates of the parameters, through their signs and sizes, are theoretically

meaningful and statistically satisfactory. These should be determined by the principles of biological theory. If the estimates have signs or sizes not conforming to the biological theory, they should be rejected unless there is good reason to believe that in that particularly instance, the principles of biological theory do not hold.

Effects of different tick species are considered to be independent. The observed loss of production of attributed to each female tick varies from one life system to another. For the 1-host ticks, the observed loss represents loss due due to that female as a larva, as a nymph and as an adult, plus its male counterpart at each stage and also a proportionate number of larvae, nymphs and adults which failed to complete engorgement.

In the case of 3-host ticks, the observed loss due to the feeding tick represents the true loss caused by the instar alone, plus a proportionate number of its siblings that failed to complete engorgement. Sutherst (1981) estimated that for different species of 3-host ticks, the adult female account for 60-80% of total amount of blood taken from the host. Further, Sutherst (1981) postulated that the amount of blood loss by a host is most likely correlated to the production loss by that host. The desire to make results on economic losses to be comparable, the idea of a 'standard tick' was adopted. The 'standard tick' concept has been used to estimate the number of adult

females of 1-host ticks that complete engorgement on the host.

2.3.3.4 Sensitivity analysis

Sensitivity analysis is necessary for evaluating how sensitive model output is to changes in parameter values. Sensitivity analysis involves changing parameter values, singly and in various combinations, by a constant percentage and observing changes in model behaviour. This would provide some idea of the relative sensitivity of model output to each of the parameters (Little *et al*, 1974).

2.4 Effect of ticks and tick-borne diseases on cattle productivity

Whereas very few studies have been done in Africa on the economic losses on cattle due to tick infestations, in the developed world a number of workers had observed the effects of heavy tick infestations on livestock productivity as early as the beginning this century. Hunter and Hooker (1907) reported that as many as 90.9 kg of blood may be withdrawn from a large host animal by ticks in a single season. Woodward and Turner (1915) also reported that under experimental conditions, cattle infested with *B. annulatus* produced only about 65.8% as much milk as the tick-free cows. They also found that while tick-infested cows gained

only 3.1% in body weight, the tick-free group gained about 6.1%. Jellison and Kohls (1938) also concluded in an experiment that female adults of *D. andersoni* withdrew about 1.7-2.0 g of blood and fluids during engorgement.

The first comprehensive study on the subject was carried out by Norman (1967) in the Northern Territory of Australia. He showed that acaricide-treated Shorthorn (*Bos taurus*) steers gained significantly more weight (about 40.9 kg per animal) than non-treated animals. After Norman's work, several workers in Australia carried out similar studies on the effects of *B. microplus* on both *Bos taurus* and *Bos indicus* cattle. Francis (1960) found that after 34-weeks field experimentation trials, sprayed Hereford (*B. taurus*) heifers were 9.5 kg heavier than similar non-sprayed animals. After reversing the treatment onto the two groups of animals, Francis found that the formerly tick-infested group gained 24.1 kg after a further 30 weeks. The observed tick loads were 109 and 73 engorged females per day during the first and second stages of the experiment.

Little (1963) found that after a 16-weeks period, an average daily infestation of 60.1 ticks depressed growth rate by 10.4 kg whilst in the second period of 29 weeks, 36.7 ticks retarded growth rate by 14.5 kg. In his (Little, 1963) calculations, each tick was responsible for an annual reduction of growth of 0.76 kg. Wilkinson (1964) also asserted that heavy burden of *B. microplus* greatly reduced weight gains of cattle when compared with those of similar

animals but with very light tick challenge. Harley and Wilkinson (1964) found that under conventional acaricide treatment and a combination of planned dipping and pasture spelling, Shorthorn cattle under the latter method gained weight faster and suffered only mild tick challenge permitting better utilisation of the pasture resources. Wharton *et al* (1969) concurred with the above findings but were unable to identify the most significant regime for tick control. Johnston *et al* (1981) while working on three groups of animals under strategic dipping , pasture spelling plus dipping , pasture spelling but no dipping, found that there was a significant difference of 12% in the final weight of animals under strategic dipping over the other two groups.

Johnston *et al* (1969 and 1971) conducted field experiments on the performance of Hereford and Shorthorn crosses with Droughtmaster (***Bos indicus X Bos taurus***) cattle. They found out that Hereford cattle carried significantly more ticks and had to be dipped repeatedly. They also found that recently weaned Droughtmaster calves showed better liveweight gains when compared to the Shorthorn and Hereford crosses. O'Kelly and Seifert (1969) simulated different conditions of tick challenge (***B. microplus***) encountered in the tropics by keeping Shorthorn and Hereford cattle under three different plains of nutrition. During the tick challenge, the two groups with good nutritional conditions not only gained significantly more weight but also carried significantly less ticks than

those on low plain of nutrition. O'Kelly and Seifert (1970) demonstrated a direct relationship between tick burden and weight gains, considering anorexia due to tick infestation, an important component in the observed differences. Seebeck, Springell and O'Kelly (1971) while working with tick infested cattle under carefully controlled nutritional conditions concluded that the loss of appetite of tick-infested cattle accounted for two-thirds of the difference in favour of the tick-free animals; the remaining one third was attributed to the toxic effects of the ticks.

Gee, Bainbridge and Haslam (1971) found that although the Brahman-cross steers performed significantly better than the Shorthorns, tick infestation had no effect by the time the experiment was terminated. This was probably due to compensatory liveweight gain when tick numbers decreased. They found out that at times both breeds realised lower weight gains which were directly related to tick numbers. In an early study, Johnson and Haydock (1969) had showed that under tick challenge, there was no difference between the performance of the treated Shorthorn and untreated Brahman-cross steers.

Seifert (1971b) studied the effects of parasitic nematode infections and of ticks, separately and in combination, in zebu (*B. indicus*) cross-breeds and British cattle. His findings were that at the levels of tick infestation recorded, the nematode parasites had little or no effect on liveweight gains while the animals were

thriving, though some effect became evident when pasture conditions deteriorated. In the latter stage, it was found that losses due to ticks were up to 1.0-1.3 kg per year per mean tick. Turner and Short (1972) conducting a similar experiment with more animals, concluded that there were clear differences in favour of dipped animals. These two scientists further concluded that when tick numbers were between 20-100 engorging females per side, the differences between breeds in response to the same infestation could be explained by the difference in the number of ticks which matured. The mean effect observed was equivalent to 0.28 kg per year per tick per animal.

O'Kelly and Spiers (1976) conducted an experiment on calves of Brahman and British breeds under equal tick challenge. The number of ticks which matured was found to be negatively correlated ($P < 0.05$) with body weight gain, total protein, as well as serum, albumin and cholesterol levels at 33 days of age.

Holroyd and Dunster (1978) studied the effect of *B. microplus* on weight gains and conception rates. They discovered that dipped heifers had significantly higher average daily weight gains. The group also conceived two weeks earlier though their pregnancy rates were similar to those in the undipped group. Significant negative correlations between weight gain and tick counts were reported between one and two years of age.

One of the most recent work on the effects of ticks on

cattle in Australia has been done by Sutherst, Maywald, Kerr and Stegeman (1983). While comparing three different infestations during three periods using *B. indicus X B. taurus* steers, they found that liveweight losses were 0.72, 0.47 and 1.52 g, respectively per " standard tick " (Wharton and Utech, 1970) during the three periods. The compensatory weight gain between infestations was of the order of 30-50%. This led the authors to conclude that losses of up to 6 kg do not affect dressed carcass quality, suggesting that it is unnecessary to keep tick populations at a very low level. The economic threshold for justifying tick control for the region was estimated at 79 ticks per side.

Very few studies to measure the effects of tick infestations on cattle productivity have been done outside Australia. This fact is evident from the above review. However, some workers have attempted to do so in some other parts of the world. Williams, Hair and Buckner (1977) carried out a study in U.S.A., to assess the effects of the Gulf Coast tick *Amblyomma maculatum* on drylot Hereford (*B. taurus*) steers. In a seven-weeks trial, high and low-infested animals were 24 and 14 kg lighter than tick-free cattle. And although the number of ticks feeding decreased as the experiment progressed, the tick-infested cattle did not show compensatory growth. Two similar trials in successive years, this time with the animals on native grass pasture, showed differences of 8.2 and 12.4 kg, respectively in favour of the tick-free cattle (Williams,

Hair and McNew, 1978). However, in two other trials, Williams (1976) could not detect any significant differences between the treated and untreated cattle.

Corrier, Vizcaino, Terry, Betancourt, Kurtler, Carson, Trevino and Ristic (1979) carried out some work in Columbia in South America on the effects of ticks and tick-borne diseases on tick-naive Normandy (*B. taurus*) calves. These experimental animals were divided into two groups which were placed in two separate pastures with heavy and light tick challenge, respectively. Both groups were treated with acaricide on days 21 and 27. The results were that by day 39 about 40% of heavily infested calves died . Even by day 21, a mean difference of 38 kg in favour of lightly infested calves was detected but by day 125, the difference was 24 kg.

In South Africa, Taylor and Plump (1981) conducted an experimental trial to compare cattle which were subjected to natural infestation with several tick species against animals treated weekly with acaricides. The undipped animals underwent a heavy mixed tick and tick-borne disease challenge and by the end of the trial, 50% of them had died; the remainder being on average 48 kg lighter than the dipped cattle. Their conclusion was that regular application of acaricides can effectively prevent economic losses due to tick infestation.

In Zambia, studies to investigate the impact of ticks on cattle productivity has been conducted since 1982 under

an FAO/DANIDA funding (FAO, 1982). This study comprised of two phases. The first phase (1982-84) consisted of field trials designed to assess the effects of naturally occurrying tick infestations on liveweight gain of calves through to maturity. The second phase (1985-88), the trials were extended and expanded, to assess the impact of ticks on milk production and overral herd productivity. Herd productivity factors were liveweight gain (LWG), age at first calving, calving interval, milk production (offtake and calf intake); all of which are interdependent.

In 1982-83, two experimental herds were established; the first in a low tick challenge area and the second in a high tick challenge area. In each herd, two groups were maintained as tick-free (by weekly spraying) and tick-infested. Tick counts (standard females and total) and LWG were recorded every two weeks. In 1984-85, the third group was established in the high challenge area to assess the effects of dry season supplementary feeding on tick loads and LWG. Also included in the study were herds owned by small-holder farmers in the Lutale area in Zambia. These were monitored and various tick control strategies or options investigated, namely

(i) Strategic spraying

(ii) Efficiency of Invermectin

(iii) Efficiency of ear-tags

(iv) Efficiency of pour-on formulations

(v) Strategic dipping

A herd of 150 heifers and 5 bulls was established. Pairs of heifers were allocated to treated and untreated groups, according to conception date, weight and previous tick burdens.

In the above trials, it was found that the mean LWG in the tick-free groups was 10.3 kg greater than in the tick-infested group. In the three separate observations, there were significant relationships between tick-loads and LWG in the infested animals (Pegram *et al*, 1983; Tyler, 1984). Control of ticks using Invermectin showed that treated animals gained significantly more weight than could be attributed to ticks or patent endoparasite infestations (Pegram and Lemche, 1985). The use of the other options were also confirmed to be effective.

These preliminary results from Zambia indicated that in years or areas with low tick challenge, there is little or no benefit in terms of LWG to be derived from regular chemical control. The results also demonstrated that, in calves and yearlings, at least one acaricide may depress LWG more than low tick numbers. This feature has also been confirmed by Sutherst and Kerr (1986). However, in seasons when tick infestations are moderate-high, especially of the larger more damaging species such as *Amblyomma* spp, there would be potential economic benefits in terms of increased LWG from strategic tick control.

Recently a study to investigate the effects of ticks on cattle productivity was conducted in Zimbambwe with the aim

of assessing the economics of dipping (Norval *et al*, 1986). Here separate experiments on the two most important ticks of cattle were conducted at sites in the highveld and lowveld areas. These two species are ***R. appendiculatus*** and ***A. hebraeum*** which occur in the highveld and lowveld, respectively. The experiments were laid in three phases. The first phase (1984-85), was concerned with the determination of the effects of larvae, nymphs and adults of the two species on LWG of cattle. The second phase (1985-86) was concerned with the determination of the effects of adults of the two species on milk production and calf growth in beef cattle. The third phase (1986-87) was concerned with the effects of adults of ***R. appendiculatus*** on milk production in pure and crossbred dairy cattle and the effects of ***A. hebraeum*** on LWG in different breeds of cattle.

The experimental design in the first phase of the Zimbambwean trials was similar to that used by Sutherst *et al*, (1983) to determine the effects of ***B. microplus*** on the LWG in cattle in Australia. These cattle were first immunised against tick-borne diseases and then given a 3-months exposure to adult ticks to allow them to become resistant. Thereafter, they were artificially infested with known number of ticks to determine individual resistance and were allocated to three groups which were balanced for resistance. Each group was later challenged with either high, moderate or low tick numbers. In the highveld experiment, each group contained eleven Sanga cattle and

the high and low groups contained an additional eight European breed cattle (*B. taurus*). In the lowveld experiment each group contained sixteen Sanga cattle.

At both sites, larvae, nymphs and adults were applied to the cattle at the times of the year when each stage occurs naturally in the field. The exposure period were of 2-3 months duration and were interspersed with rest periods of 1-2 months duration when no ticks were applied. The cattle were infested with nymphs and adults by confining them for a period each day in small "infesting paddocks" which were seeded with ticks. Larvae were applied directly to the hair on the backs of the cattle three times a week. The number of ticks used to infest the high , medium and low groups were in the ratio of 4:1:0.

When not in the infesting paddocks the cattle were always run together on the tick-free pastures to eliminate any possible pasture or management effects. The cattle were weighed once a week and counts of standard nymphs and adults were made three times per week (see Wharton and Utech (1970) for the definition of standard tick). It was not possible to count standard larvae. The second phase dealt with milk production from the Sanga and Sanga X Zebu cows using the weigh-suckle-weigh technique.

Phase three involved 40 Friesland X Sanga cows and 20 Jerseys of which half were tick-free and the other half tick-infested. In the lowveld areas, steers of different breeds (Zebu, Sanga, Sanga X European, European) were

equally exposed to adults of *A. hebraeum* tick numbers and LWG monitored.

The results of the Zimbambwean experimental trials showed that adult *R. appendiculatus* significantly reduced LWG in European breed cattle but not in the Sanga, which were very resistant. Larvae and nymphs of *R. appendiculatus* did not have a significant effect on either breed. Adults of *A. hebraeum* did not significantly affect LWG, but heavy infestations were very difficult to obtain because of the grooming and tick avoidance reactions of the cattle. Larvae and nymphs of *A. hebraeum* appeared to have no significant effects on LWG.

In Kenya, a study was done to assess the effect of tick infestations on cattle productivity. The research work was done by de Castro (1986). The objective of his work was to assess the effects of tick infestations on liveweight gain, blood parameters and development, and the assessment of host resistance to *R. appendiculatus*. His first experiment evaluated the possible effects of two different levels of infestation with disease-free *R. appendiculatus* adults on weight gains, blood parameters and development of tick resistance by cattle kept under controlled conditions. In this experiment, thirty cattle categorically enumerated as 17 Borans (*Bos indicus*), 3 Herefords (*Bos taurus*) and 10 Boran cross-bred by Hereford (*B. indicus X B. taurus*) were used. These cattle were of both sexes aged between five and fourteen months by April

1982. The animals were divided into three groupings according to weight: 12 of 90-130 kg,9 of 131-170 kg and 8 of 171-210 kg. They were then randomly allocated to three treatments groups, viz to 0, 40, and 400 adult *R. appendiculatus* feeding once a week for 24 weeks. They were housed in-doors in tick-proof accommodation in nine separate pens where they were fed hay and water ad libitum and 5 kg of concentrates/animal/day.

The second experiment on the subject was a field trial organised at Intona Ranch in Trans-Mara Division of Narok District where Boran *(B. indicus)* cattle, immunised against *theileriosis*, were used in order to assess the effects on weight gains of a natural field tick challenge. Here again thirty cattle were observed but for 30 weeks; divided into two groups of fifteen each.

In his work, de Castro (1986) came to the following conclusions. Low or moderate infestation with *R. appendiculatus*, as well as similar field tick challenge involving the other tick species had a transient effect on cattle. With pure *R. appendiculatus* infestations this was probably due to irritation and blood loss and hence reduced grazing. Secondly, host resistance development was found to be the main factor which neutralized the effects of ticks and enabled the animals to compensate in their liveweight gain and to normalize blood parameters when tick numbers were below an injury threshold. And finally when the field tick challenge went over the threshold , tick-susceptible

animals suffered considerable losses in productivity, or even died. Under similar tick challenge, exposed cattle showed loss of liveweight but did not die. Their lack of strong resistance is regarded as the main reason for the failure of the exposed cattle in controlling the natural three-host tick population present in an enclosure from which all other alternative tick hosts were excluded. Their ability to control *B. decoloratus* appeared linked to the greater time this one-host tick spends on the host.

De Castro's work represented a cornerstone for cattle tick studies on the impact of the parasites' infestation on the host productivity. The study did, however, include two controls which might affect the natural conditions in which there are multiple hosts and parasites interacting simultaneously. In his first experiment, de Castro only considered *R. appendiculatus* as the only tick species and were treated under laboratory conditions. In his second experiment, only a single host (cattle) was considered; all the other possible hosts (goats and sheep), even cattle from the neighbouring ranches were excluded. It is the aim of this Ph.D research to study the effects of tick infestations on bovine productivity under the natural field conditions of multiple host-parasite populations and then develop a model to describe the relationship between the tick populations and cattle productivity.

Secondly, in all the previous studies that were done in Australia, *Boophilus microplus* (the principal vector of

babesiosis), was the only tick species considered. This study on the other hand, would consider all the cattle ticks that are prevalent on Rusinga Island and the adjacent zones. These were ***R. appendiculatus, R. evertsi, A. variegatum*** and ***B. decoloratus.***

Rusinga Island was selected as the study area since it is a typical habitat for the tick species and hosts of concern in the dry regions of Africa; in particular, the Lake Basin Region of Western Kenya; many parts of East, Central and Southern Africa.

2.5 Role of nutrition on resistance of cattle to ticks

Resistance of the bovine host to ticks can be defined as the ability of the animal in inhibiting the feeding, survival and reproduction efficiency and capacity of the ticks that feed on it. There are several ways of measuring this resistance in cattle to ticks (ICIPE, 1986, 1987 and 1988). These include:

* size of engorging adult female ticks
* number of fully engorged female ticks
* quantity of egg batch laid by the female tick
* egg hatchability into larvae and survival to adults
* tick pick-up burdens or attachements
* skin thickness
* coat colour and response to interdermal injection of tick antigens

All the above methods have been used extensively in field experiments in Kenya on both the immatures and adult ticks (de Castro, 1986; ICIPE, 1986 and 1987). In this study, calves were assessed for tick resistance on the basis of adult tick attachments.

From studies in Australia, it was found that the resistance of cattle (***Bos taurus*** and ***Bos taurus*** X ***Bos indicus*** cross-breed) changed with season (Utech *et al*, 1978; Sutherst *et al*, 1979a; Doube and Wharton 1980). The experiment by Doube and Wharton (1980) provided evidence that photoperiod could be an important factor in the induction of the bovine resistance to ticks. O'Kelly and Seifert (1969) and Gladney *et al* (1973) showed that severe nutritional stress erodes the resistance of British breed of cattle to ticks. Further, nutritional stress was found to accentuate the loss of resistance and delays its recovery (Sutherst *et al*, 1983).

All the studies so far done have generally shown that nutritional quality of the feeds affect the host's resistance capacity. However, the specific nutritional qualities or factors that are responsible for such resistance characteristics have not been extensively diagnosed. Moreover, such factors have not been quantified in relation to the resistance of the bovine host to specific tick species that continue to indiscriminately plunder the world's animal resources.

In this study. an attempt was made to identify those feed nutrients that are responsible for the induction of the host resistance, and to explore the interrelationships between nutrient-factors and host's resistance characteristics to the major ixodid ticks that are found on Rusinga Island in Kenya. From studies so far carried on the Island, it was found that there are only four livestock ticks on the Island. These are *Rhipicephalus appendiculatus*, *Amblyomma variegatum, R. evertsi* and *Boophilus decoloratus* in a decreasing order of abundance. Furthermore, the study was designed to provide information on the quantitative interrelationships between the specific nutrients and host's resistance parameters with regard to all the prevailing livestock ticks on the Island.

2.6 Liveweight-dependent survivorship threshold model

Several workers have investigated both the concept and estimation techniques of the upper and lower bounds of growth of organisms (Konandreas *et al*, 1982 and 1984; Guttman, 1970; Proschan, 1953; Chew, 1966; Wallis, 1951; Working and Hotelling, 1929; and Jolicoeur *et al*, 1984 and 1986).

Calf growth, like most biological phenomena, is controlled by many factors as genetical, physiological, environmental (as diseases, nutrition, weather) and many others. Biological variation is often attributed to these

factors and in small part to random errors or inaccuracies. Thus, individual variation (as opposed to group variation) within the permissible limits for the biological population under study, is of crucial interest in itself. It would provide an indication of the systematic effects acting on the animal. In order to develop the threshold, therefore, it is the variation intervals that are to be determined. The meaning of this interval is that it is the region within which 95% of the new individual observations may be expected to fall if they were drawn from a population whose parameters are equal to the sample estimates.

Conceptually, a variation interval is different from confidence interval. Jolicoeur *et al*, (1986) has extensively dealt with the distinction between the two intervals. For confidence intervals also refer to Lindgren (1976).

The approach in this study was to develop the threshold models based on the two order statistics; the minima and maxima. Suppose W_1, W_2, W_3,.....,W_n is a random sample from a population with probability density function f(w). Then if the sample observations are arranged in an ascending order as

$$W_{(1)}, W_{(2)}, W_{(3)},.....,W_{(n)}$$

such that

$$W_{(1)} \leq W_{(2)} \leq W_{(3)} \leq.....,W_{(n)}$$

where

$W_{(1)}$ is the observed minimum liveweight

$W_{(n)}$ is the observed maximum liveweight

The joint probability density function of the $W_{(1)}$, $W_{(2)}$, $W_{(3)}$,.....,W(n) is given by

$$h[W(1), W_{(2)},.....,W_{(n)}] = n!f\{W_{(1)}\}*f\{W_{(2)}\}*f\{W(n)\} \qquad (2.15)$$

$$0 \leq W_{(i)} \leq \infty$$

for all $i = 1, 2, 3,....,n$

$= 0$, otherwise

The joint p.d.f. of the minimum and the maximum is given by

$$h_1[W_{(1)},W_{(n)}] = \int_0^{\infty}..\int_0^{\infty} h[W_{(1)},W_{(2)},..,W_{(n)}]dW_{(2)}..\ dW_{(n-1)}$$

$$= n(n-1)f\{W(1)\}f\{W_{(n)}\}[F\{W_{(n)}-F\{W_{(1)}\}]^{n-2}$$

$$0 \leq W_{(1)},\ W_{(n)} \leq \infty \qquad (2.16)$$

$= 0$, otherwise

where

$$F[W_{(s)}] = \int_0^{\infty} f\{W_{(s)}\}dW_{(s)}$$

$s = 1, 2, 3,.....,n$

The marginal density function of the minimum $W_{(1)}$, is given by

$$g_1[W_{(1)}] = \int_{W_{(1)}}^{\infty} h_1[W_{(1)},W_{(n)}]dW_{(n)}$$

$$= n\{1-F\{W_{(1)}\}^{n-1}f\{W_{(1)}\} \qquad (2.17)$$

$$0 \leq W_{(1)} \leq \infty$$

$= 0$, otherwise

Similarly, the density function of the maximum is given by

$$g_2[W_{(n)}] = \int_0^{W_{(n)}} h_1[W_{(1)}, W_{(n)}]dW_{(1)}$$

$$= n[F\{W_{(n)}\}]^{n-1} f\{W_{(n)}\} \qquad (2.18)$$

$$0 \leq W_{(n)} \leq \infty$$

$$= 0, \text{ otherwise}$$

Due to several diverse harsh factors (such as diseases, nutrition deficiencies, etc) after birth, particularly between the third and sixth months, growth of the Rusinga calves is usually greatly affected (ICIPE 1986 and 1987). As a result, the standard errors of the mean increase with the age of the animal. This causes heteroscedasticity effects. The probability distribution of the liveweights has been reckoned to be normal (Konandreas *et al*, 1982). Thus incorporating the heteroscedasticity effect, the liveweights are assumed to be distributed as

$$W_t \sim N(\mu_t, \sigma^2_t)$$

where W_t is the liveweight of a calf at age t, and μt and σ^2_t are the mean and variance at age t, respectively. That is

$$\Phi(W_t) = \exp[-(W_t-\mu_t)^2/2\sigma^2_t]/\sigma_t\sqrt{(2\pi)} \qquad (2.19)$$

Thus the probability of occurrence of any observation can be determined using Equation (2.19).

CHAPTER 3

MATERIALS AND METHODS

3.1 Types of data to be collected

The following are the variables that were considered in the study:

Household

a) Name and age of the head of household

b) Location of the household

c) Size of the household

d) Size and composition of livestock in the household, i.e. cattle, sheep and goats by sex.

This data was only collected once at the beginning of the study.

Calves

a) Sex

b) Date of birth

c) Weight at birth

d) Colour of the coat

e) Liveweight

Data on (e) was collected at monthly intervals. Monthly interval is the most recommended for such a productivity study (Konandreas et al, 1982).

Ticks

a) Identity of the host (animal number)

b) Number of the adult ticks by species and sex

on each animal. Data on number of ticks were collected at the same time as liveweight of the calf was collected.

Environment

a) Daily temperature (max, min and mean)

b) Rainfall (daily, monthly, and no. of rainy days)

c) Humidity (daily)

d) Pasture quality

3.2.Monitoring of growth of calves

Liveweight gain (LWG) data was secured by weighing the calves during the mornings of the ticks collection days. This was done in the mornings so as to avoid the errors that could be caused by the dry matter intake during grazing [1.5% of body weight (Hafez *et al*, 1969)]. The data was gathered once during the routine monthly visits to the farms. The weighing was done using an electronic balance (of beam type).

Specific days were allocated during the months for sampling. During the investigation periods, sampling was carried during the following dates.

Table 3.1: Specific dates for the sampling months

Sampling month	Dates
1	21st Dec, 1987 - 30th Dec, 1987
2	4th January, 1988 - 7th January, 1988
3	25th February, 1988 - 3rd January, 1988
4	2nd April, 1988 - 7th April, 1988
5	12th May, 1988 - 19th May, 1988
6	20th June, 1988 - 24th June, 1988
7	18th July, 1988 - 21st July, 1988
8	24th August, 1988 - 26th August, 1988
9	19th September, 1988 - 22nd September, 1988
10	24th October, 1988 - 27th September, 1988
11	21st November, 1988 - 24th November, 1988
12	31st December, 1988 - 4th January, 1989

Plate No. 4: Weighing a calf on the electronic beam balance

3.3 Identification of livestock ticks

Accurate identification of the ticks was done on a microscope with a magnification factor of 16x. One of the eye pieces of the microscope was a calibrated graticle. In this study, once the species of a tick was known, for the males, only the total number by species was recorded.

The most important factor for identifying tick species is by its appearance. However, the site of attachment on the cow and its geographical distribution is also helpful in the process of identification. Basically, taxonomic keys and the common descriptive names, where there existed one, such as the 'Red-legged tick' (*R. evertsi*) were used for species identification. The *Amblyomma* spp, like the *Hyalomma* spp, possess 'bont' or banded legs. *R. evertsi* possess distinctly red legs. One exception to the usage of such names is *B. decoloratus* which is commonly known as the *Blue Tick*. This tick is no bluer than any other fully engorged female tick. Below is given a list of some of the main features that were used for identification of the species.

In the field, ticks were kept in small bottles with 70% alcohol filled half-way full. In the laboratory, the ticks were removed from the bottles and then mounted on petri dishes. Since this study included only the adult ticks, all the larvae and nymphs that might have been errorneously collected were avoided. They were mounted in lines based on any crude species appearances using the naked eye. These

mounted ticks were then passed under the microscope one by one and their details (species and sex) recorded. Counting was done using a digital telly counter.

There are occassions when it becomes difficult to distinguish the sex of a tick especially the newly moulted adults of *R. appendiculatus*. In such a case, other morphological features are used. Particularly, male *R. appendiculatus* possess the adanal plates whereas these are lacking in females.

3.4 Evaluation of pastures and nutrition of the natural grassland.

Pasture samplings were conducted the same day when LWG was done. The first exercise was to identify the common grass pasture species found on the Island particularly the communal grazing grounds as shown on Map No.3. To do this, the field was transversed across "east-west" and "north-south". This involved pacing through the grazing ground and recording the grass species and the number of paces made along the transect. The total number of paces across the transect is divided by four so that at least four replicates of each species are picked. Suppose the total number of paces is n, then after every rth pace, the pasture species are picked up and recorded, where

$$r = n/4$$

It is important that the pacing should be equal so that no bias is introduced (Olang', 1984).

These sample species were then taken to the laboratory at Mbita and carefully pre-treated as laid down by the Kenya Herbarium of the Museums of Kenya. For the selected species, the whole grass plant from the leaves to the roots is uprooted. While still fresh, the grass is pressed using a press made up of weld-mesh material. In this press, the species were kept for about 3-5 days while drying. This presses the pasture species flat while being dried. Each replicate was kept between two sheets of a newspaper. Once ready, the pasture species were taken to the Kenya Herbarium for species identification. Kenya Herbarium has prepared keys for the identification of most grass species together with well illustrated diagrams (K.M. Ibrahim *et al* 1987).

For pasture collection, the animals were followed for about three hours in the morning while grazing in the field. During this period, the animals' pasture preference was observed and noted. Once this preference had been noted, then a sample of the grass pasture was cut at the soil level. In the laboratory, the grass pasture was dried in oven at 60°C for twelve hours, cut into small chippings and then ground at a mesh of size 1mm. The ground pasture was then packed in paperbags and later taken to the Kenya Agricultural Research Institute (KARI) at Muguga near Nairobi for quality analyses.

The assessnent of the availability of P in feeds presents difficulties that are non-existent with organic nutrients, as the faeces constitutes an important pathway for endogeneous P loss, thus invalidating the use of conventional balance methods for measuring P absorption. Various attempts such as the use of P-free fed animals (Nicolaysen, 1937; O'Donovan *et al*, 1965) and regression procedures based on absorption and endogeneous loss (Field and Shuttle, 1969) have been undertaken. A technique developed by Kleiber *et al* (1951) and subsequently improved by Lofgreen and Kleiber (1954) and Luick and Lofgreen (1957) using lambs seems to be efficient. The problems associated with the measurement of endogeneous faecal P arise due to the fact that it varies considerably depending on the amount of P in the diet, the nature of the P source and other factors (Kleiber *et al*, 1951; Lofgreen and Kleiber, 1953; Tillman *et al*, 1959).

Because of the numerous problems of measuring the endogeneous faecal P loss, the methods based on the conventional balancing are not satisfactory (Teleni, 1976). Research work has established alternatives. These are blood analysis (Theiler *et al*, 1927; Parker and Bowley, 1974; Teleni *et al*, 1976a), and bone analysis (Neal and Palmer, 1931; Kleiber *et al*, 1936; Wise *et al*, 1961; Little, 1972; Little and McMeniman, 1973; and McMeniman and Little, 1974). Cohen (1973a, 1973b, 1974) confirmed the sentivity of the

bone analysis in assessing P status in sheep and cattle compared to plasma Pi or hair P.

Teleni (1976) has given extensive literature on the merits of blood plasma analysis approach. There are several factors that affect blood P values. The factors are identified as those between animals variations (due to physiological status); within animal variations (due to feeding, excitement and site of sampling), and variations due to analytical techniques. Therefore the approach of blood analysis calls for the most practical and accurate method of procuring blood samples and to standardise analytical procedures for animals of different physiological status. Although in general, blood analysis is reckoned as a practical and useful aid in assessing the P status of cattle under extensive grazing conditions as on Rusinga Island, it is clear for the above discussions that it is technically too demanding and costly (both in time and money) It is also necessary to recognise its limitations and to ensure to incorporate other considerations such as herbage P analysis and animal health when making management decisions.

The bones analysis is a post-mortem method and is not socio-technically feasible under the conditions of this study in which the farmers' animals are used. Even then, the bone analysis has its own limitations since not all bones give the same figures (Benzie *et al*, 1959). Further, the biopsy technique must be standardised. Several workers have established concentration ranges for P in bones to about

140 mg P per cm^3 fresh bone (Little and McMeniman, 1973) and about 137 mg P per g of dry fat-free bone (Cohen, 1973b).

Although the aim of the nutrition studies was to establish the nutrition status of the animals, the available logistics and resources could not permit the use of the standard blood analysis as had been prior designed. Instead, only the pasture P analysis was conducted; as was the case with all the other minerals and organic nutrients considered in the the exercise.

As already discussed above, the parameters to be measured when considering the nutritional composition of the pastures can be obtained using direct or indirect methods. However, in this study, the organic nutrients were determined on the basis of the indirect method called Proximate Analysis. This method estimates the parameters by approximations and hence the name proximate composition (as % of dry matter). Laboratory procedures of Proximate Analysis are given in Appendices I to V.

3.5 Cattle diseases on the Island

Information on the diseases of cattle on the Island was secured from secondary sources from past and ongoing studies as well as discussion with scientists who were working in the same area.

With regards to to tick-borne diseases, coccidiosis, and helmithesiosis, ICIPE had compiled massive data on these

aspects (ICIPE, 1986 and 1987). The ecology of tsetse flies, the transmission and epidemiology of trypanosomes on the Island and the mainland areas of Gembe, Kaksingri and Lambwe Locations had already been studied by the Tsetse Research Program of ICIPE so that alot of data was available.

The relevant information on the diseases was therefore acquired from secondary sources, scrutinised, analysed and included into the models. The findings are reported in Chapter 4.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 The natural grassland pasture species and quality.

4.1.1 Pasture species

The botanical survey of pasture species carried out on Rusinga Island revealed the existence of the following major species:

a) *Cynodon nlemfuensis* Vanderyst.
b) *Heteropogon contortus* (L.) Roem & Schult.
c) *Enteropogon macrostachyus* (A. Rich.) Benth.
d) *Cenchrus ciliaris* L.
e) *Rhynchelitrum repens* (Willd) C.E.Hubbar
f) *Sporobolus ioclados* (Trin.) Nees.
g) *Enneapogon schimperanus* (A. Rich.) Renv.
h) *Bothriochloa radicans* (Lehm) A. camus.
i) *Diheteropogon amplectens* (Nees).
j) *Leptochloa obtusiflora* Hochst.
k) *Sporobolus pyramidalis* P. Beauv.
l) *Eleusine indica* (L.) Gaertn Subsp. africana.
m) *Eragrotis aspera* (Jacq.) Nees.

Within the common grazing lands for the ten selected farms on the Island, the most abundant grass species was

Cynodon nlemfuensis, locally known in Luo language as *"Modhno"*. This was followed by *B. radicans*, *H. contortus*, and *D. amplectens* in that order.

4.1.2 Pasture quality

4.1.2.1 General overview

The nutrient factors considered were crude protein, phosphorus, potassium, calcium and magnesium contents of the pastures. It was found that except for magnesium, crude protein in the pastures was highly correlated to all the other nutrients (P = 0.0001); positively to both phosphorus and potassium but negatively to calcium. Phosphorus was correlated only to magnesium (r = 0.179, P = 0.0001); potassium was positively correlated to calcium (r = 0.081, P = 0.037) and negatively to magnesium (r = -0.351). Calcium had a strong positive correlation (r = 0.272) to magnesium. The results therefore provided evidence that pastures with high crude protein also tended to have high phosphorus and potassium, but low calcium levels. For a good perfomance of cattle, protein , phosphorus and calcium have been reckoned to be directly necessary (Brandt 1979c; Hafez et al , 1969). Calcium is necessary for milk production while phosphorus for skeletal growth, pregnancy and lactation.

Table 4.1: Correlations between different nutrient factors

	P	K	CA	MG
CP	0.308	0.452	-0.307	-0.053
	(0.0001)	(0.0001)	(0.0001)	(0.1977)
P		-0.041	0.023	0.179
		(0.30)	(0.56)	(0.0001)
K			0.081	-0.351
			(0.037)	(0.0001)
CA				0.272
				(0.0001)

( ) = Level of significance

Table 4.2: Simple statistics on pasture quality on Rusinga Island

Nutrient	Minimum	Maximum	Mean	std	CV (%)
CP	3.32	12.25	6.97	(2.129)	30.54
P	0.00	0.94	0.25	(0.148)	61.20
K	0.10	2.30	0.77	(0.478)	62.34
CA	0.25	3.14	1.14	(0.548)	48.29
MG	0.09	1.53	0.59	(0.290)	49.31

( ) = std = standard deviation

Table 4.3: Mean pasture quality by season on Rusinga Island

Season	CP	P	K	CA	MG
Jan-Mar	5.26	0.17	0.722	1.24	0.50
	(0.964)	(0.048)	(0.472)	(0.662)	(0.25)
Apr-June	7.67	0.23	1.23	1.30	0.49
	(2.406)	(0.056)	(0.425)	(0.553)	(0.328)
Jul-Aug	7.47	0.25	0.53	0.87	0.65
	(2.436)	(0.176)	(0.205)	(0.345)	(0.187)
Sept-Dec	7.70	0.37	0.37	0.73	0.90
	(1.486)	(0.262)	(0.075)	(0.191)	(0.199)
All	6.97	0.24	0.77	1.11	0.59
	(2.129)	(0.148)	(0.478)	(0.548)	(0.290)

( ) = standard errors

Table 4.4: Mean nutrition quality of pastures by farm

Farm	CP	P	K	CA	MG
1	7.62	0.27	0.76	1.03	0.62
	(2.355)	(0.168)	(0.253)	(0.746)	(0.391)
2	7.40	0.27	0.74	1.00	0.59
	(2.365)	(0.170)	(0.246)	(0.720)	(0.379)
6	6.75	0.28	1.02	1.26	0.49
	(1.364)	(0.129)	(0.550)	(0.464)	(0.132)
16	7.09	0.28	0.58	1.11	0.68
	(1.341)	(0.099)	(0.383)	(0.437)	(0.232)
21	7.53	0.27	0.80	1.22	0.73
	(2.095)	(0.241)	(0.494)	(0.448)	(0.246)
22	6.84	0.24	0.75	1.08	0.51
	(2.022)	(0.113)	(0.534)	(0.252)	(0.194)
25	6.91	0.19	0.69	1.43	0.74
	(2.940)	(0.092)	(0.592)	(0.802)	(0.200)
27	6.06	0.20	0.80	0.81	0.36
	(1.643)	(0.111)	(0.480)	(0.181)	(0.290)
28	6.06	0.19	0.60	1.03	0.62
	(0.625)	(0.096)	(0.246)	(0.284)	(0.348)
36	6.96	0.29	0.65	1.40	0.79
	(1.298)	(0.178)	(0.413)	(0.577)	(0.305)

( ) = standard errors

Table 4.5: Mean nutrition quality of pastures by month of collection (season)

Month	CP	P	K	CA	MG
1	4.64	0.17	0.51	1.16	0.67
	(0.809)	(0.30)	(0.194)	(0.351)	(0.301)
2	5.67	0.16	0.82	1.36	0.41
	(1.047)	(0.033)	(0.640)	(0.881)	(0.122)
3	5.53	0.20	0.87	1.16	0.39
	(0.448)	(0.074)	(0.327)	(0.590)	(0.183)
4	5.51	0.26	0.98	1.72	1.72
	(1.309)	(0.074)	(0.260)	(0.770)	(0.498)
5	9.73	0.21	1.39	1.13	0.43
	(1.582)	(0.047)	(0.422)	(0.374)	(0.199)
6	7.50	0.21	1.28	1.13	0.39
	(2.150)	(0.034)	(0.443)	(0.268)	(0.141)
7	7.39	0.35	0.55	1.35	0.60
	(0.713)	(0.075)	(0.085)	(0.376)	(0.181)
8	8.68	0.28	0.62	0.57	0.59
	(3.279)	(0.230)	(0.256)	(0.280)	(0.184)
9	6.37	0.15	0.45	0.95	0.74
	(1.466)	(0.115)	(0.170)	(0.340)	(0.158)
10	7.97	0.28	0.41	0.88	0.83
	(1.642)	(0.174)	(0.079)	(0.442)	(0.169)
11	6.78	0.51	0.37	1.01	0.80
	(1.141)	(0.271)	(0.095)	(0.220)	(0.260)
12	6.92	0.20	0.33	0.96	0.92
	(0.457)	(0.163)	(0.029)	(0.331)	(0.166)

( ) = standard errors

Principal component analysis was used to identify those nutrient factors which contributed greatest variability in the multivariate data of the nutrient domain. A program called PRINCOMP in SAS was used for this analysis. The results are shown in Tables 4.6 and 4.7. The first two largest eigenvalues were 1.728 and 1.296. Their corresponding principal components accounted for about 34.6% and 25.9% of the total variance in the system, respectively; jointly they contributed 60.5% Of the total variance in the domain. The corresponding eigenvectors and which represent the coefficients of the principal components reveal that the first component is dominated by crude protein and potassium. This component represents the difference between those nutrient factors that are positively correlated to crude protein and those that are negatively correlated; that is, CP, P and K as one group and Ca and Mg as the other group. The second component consists of the sum of P, Mg and CP. Looking at the coefficients, it is deductive that crude protein (0.629) and potassium (0.533) are the two important nutrients that contribute most of the variability associated with the first component; P contribute the least. However, the second component is mainly dominated by P and Mg, respectively.

Since the original nutrient variables were highly correlated to one another, a technique due to Jolliffe (1970, 1972, and 1973) could be used to select a subset of the variables which would contain virtually most of the

Table 4.6: Principal component analysis of pasture quality

Component	Eigenvalue	% Contribution	Cumulative %
Y_1	1.728	34.57	34.57
Y_2	1.296	25.92	60.49
Y_3	1.121	22.42	82.91
Y_4	0.631	12.61	95.52
Y_5	0.224	4.45	100.00

Table 4.7: Principal components analysis of pasture quality

Nutrient	Eigenvectors				
	Y_1	Y_2	Y_3	Y_4	Y_5
CP	0.629	0.317	-0.008	0.422	-0.57
P	0.214	0.699	-0.032	-0.669	0.131
K	0.533	-0.148	0.598	0.100	0.571
CA	-0.353	0.091	0.798	-0.145	-0.457
MG	-0.386	0.617	0.065	0.586	0.350

information available in whole of the nutrient domain. Jolliffe's approach is that we associate one variable with each of the first m principal components, namely the variable not already chosen, with the highest coefficient, in absolute value, in each successive component. These m variables are retained and the remaining $m^* = p - m$ are deleted (where p = 5 is the number of the original variables). In this study, Jolliffe's method retained the following variables:

m	Retained variable(s)
1	CP
2	CP, P
3	CP, P, Ca
4	CP, P, Ca, Mg
5	CP, P, Ca, Mg, K

The first three components contributed about 82.9% of the total variance in the domain. And so taking m = 3, Jolliffe's method suggests that we could safely consider only CP, P, and Ca in our analysis and still be able to capture most of the variance in the multivariate data. Magnesium and potassium had the least variances in that descending order, respectively. As already been noted, K is in abundance in nature and that is probably why it was not an important nutrient constraint in discriminating between different farms. The three nutrient factors, CP, P, and Ca, are the most important limiting mineral deficiencies amongst the group as regards cattle productivity (Brandt 1979c;

Hafez *et al*, 1969). It is therefore important that these nutrients should be further analysed to determine whether there are any differences in them between the farms.

4.1.2.2 Crude protein

The results of nutrition analysis showed that on the average crude protein (%) of the pastures was about 7% with a standard error of 2.13% and CV = 30.54%. According to Konandreas *et al* (1983) the minimum critical amount of CP acceptable is 5%. Temporal analysis of CP (Table 4.5) showed that pastures experienced the lowest levels of CP during the driest months of the year, i.e. December - April with December/January having the least that year. Crude protein was highest around April - October.

Analysis of variance test revealed evidence that there were significant differences in CP between farms and also between sampling months (P = 0.0001). The results showed that the highest levels of CP are attainable during the long rains, that is, between April and August. In this case, April had significantly highest level of CP, recording an average of about 9.73% during the year (based Duncans' multiple range test). The lowest mean CP experienced was 4.6%.

Table 4.8: Analysis of variance table for crude protein (arcsine transformed data)

Source	df	SS	MS	F	Pr > F
Farms	9	0.01666	0.00185	8.23	0.0001
Sampling Months	11	0.14123	0.01284	57.10	0.0001
Error	643	0.14459			

Table 4.9: Temporal analysis of crude protein (%)

Sampling month	Minimum	Maximum	Mean	Std	CV (%)
1	4.14	6.56	4.638	0.809^{h}	17.4
2	3.85	7.40	5.665	1.047^{g}	18.5
3	4.95	6.23	5.530	0.448^{g}	8.1
4	3.32	7.68	5.517	1.309^{g}	23.7
5	5.96	10.84	9.73	1.582^{a}	16.3
6	5.10	10.60	7.502	2.150^{cd}	28.7
7	5.55	8.79	7.389	0.713^{cde}	9.6
8	4.40	12.25	8.682	3.279^{b}	37.8
9	4.08	9.40	6.368	1.466^{f}	23.0
10	4.74	9.92	7.966	1.642^{c}	20.6
11	5.61	7.85	6.781	1.141^{ef}	16.8
12	6.14	7.61	6.921	0.457^{def}	6.6
All	3.32	12.25	6.973	2.129	30.54.

Treatments having same letters are not significantly different from each other (Duncans' multiple range test)

Table 4.10: Crude protein contents (%) of pastures by seasons

Quarter	Mean*	CV (%)
Jan-March	5.260[b]	18.32
	(0.9635)	
April-June	7.667[a]	31.38
	(2.4061)	
July-Sept	7.471[a]	32.61
	(2.4360)	
Oct-December	7.697[a]	19.30
	(1.4856)	

( ) = standard error

*Means with the same letters are not significantly different (Duncans' multiple range test)

Table 4.11: Analysis of crude protein by farms (%)

Farm	Minimum	Maximum	Mean	Std	CV (%)
1	5.00	12.25	7.624[a]	2.355	30.9
2	5.00	12.25	7.624[a]	2.355	30.9
6	4.28	9.94	6.750[bc]	1.364	20.2
16	4.56	9.93	7.085[ab]	1.341	18.9
21	4.40	10.60	7.529[ab]	2.095	27.8
22	4.65	10.84	6.839[ab]	2.022	29.6
25	3.85	12.03	6.911[ab]	2.940	42.5
27	3.32	9.40	6.062[c]	1.643	27.1
28	5.29	7.41	6.060[c]	0.625	10.3
36	4.95	9.13	6.957[ab]	1.298	18.7

On the linear scale, the results could be summarised as follows (all underlined together are not significant from one another):

5 8 10 6 7 12 11 9 2 3 4 1

An attempt was made to analyse the CP at quarterly intervals. Although the monthly data showed very big differences between sampling months, the quarterly data was much stable in CP quality as expected. The results, however, still provided strong evidence that the mean CP between January - March was significantly lower than experienced during the other quarters. It was notable that the CP figure for January-March were less variable when compared to the other quarters; as revealed by the CV's. The implication of this was that the differences of CP between farms was low in the first and last quarters (which coincides with the driest months) and relatively high during the second and third quarters (the wettest or greenest months).

Duncan's multiple range test showed that the highest levels of CP were experienced on Farms 1 and 2 as distinctly from the other farms. At the bottom level, Farms 27 and 28 showed the poorest levels of CP. One clear point in the results was that farms on the eastern side of the Island, that is, Farms 27 and 28 seemed to have pastures with the lowest CP levels relative to those on the western/north-western sides (i.e. Farms 6, 16, 21, 22, and 25). However,

Farm 36 had pastures with relatively higher CP levels than either Farm 27 or 28.

1 2 16 21 22 25 36 6 27 28

(farms underlined together are not significantly different)

4.1.2.3 Phosphorus

There were significant differences in phosphorus levels between farms and between sampling months (P = 0.001); plentiful in pastures during the dry months of the year (i.e July - December) and lowest between January - May. The highest P level was experienced in November and the lowest in January. However, the P levels from August - December were quite variable as indicated by their CV's. On a linear comparison, it was during the months of July and November when pastures experienced the highest P levels that are distinct from the rest of the months. This other relationships are shown below:

11 7 10 8 4 5 6 12 3 1 2 9

The results showed that Farms 1, 2, 6, 16, 21, and 36 as a group showed no significant differences in P amongst themselves. Similarly, the second group comprising of Farms

Table 4.12: Analysis of variance of phosphorus

(arcsine transformed data)

Source	df	MSS	F	Pr > F
Farms	9	0.00000886	6.52	0.0001
Sampling months	11	0.00004553	33.50	0.0001
Error	636	0.00000136		

Table 4.13: Phosphorus content of pastures by sampling months (%)

Sampling month	Minimum	Maximum	Mean	Std	CV (%)
1	0.14	0.21	0.17^{ef}	0.030	17.7
2	0.12	0.23	0.16^{ef}	0.033	20.6
3	0.10	0.30	0.20^{cd}	0.074	37.0
4	0.14	0.38	0.26^{de}	0.074	28.5
5	0.17	0.30	0.21^{de}	0.047	22.4
6	0.15	0.25	0.21^{de}	0.34	16.2
7	0.11	0.44	0.35^{b}	0.075	21.4
8	0.11	0.70	0.28^{c}	0.228	81.4
9	0.00	0.55	0.15^{f}	0.115	76.7
10	0.03	0.55	0.28^{c}	0.174	62.1
11	0.14	0.94	0.51^{a}	0.271	53.1
12	0.05	0.56	0.20^{ef}	0.163	81.5

Table 4.14: Phosphorus content of pastures by farms (%)

Farm	Minimum	Maximum	Mean	Std	CV (%)
1	0.14	0.70a	0.27[a]	0.168	62.2
2	0.14	0.70a	0.27[a]	0.168	62.2
6	0.05	0.59	0.28[a]	0.129	46.1
16	0.19	0.44	0.28[a]	0.099	35.4
21	0.00	0.94	0.27[a]	0.241	89.3
22	0.11	0.42	0.24[a b]	0.113	47.1
25	0.05	0.39	0.19[b]	0.092	48.4
27	0.03	0.47	0.20[b]	0.111	55.5
28	0.08	0.44	0.19[b]	0.096	50.5
36	0.11	0.56	0.29[a]	0.178	61.4

Treatments with the same letters are not significantly different from each other.

25, 27, and 28 also were not significantly different from each other. The two groups were, however, significantly different from each other. Thus, linearly the above results could be expressed as follows:

36 16 6 21 1 2 22 27 25 28

4.1.2.4 Calcium

The results of a two-way analysis of variance showed that there were significant differences in calcium contents of pastures between farms as well as between sampling months ($P = 0.0001$). The highest levels of Ca were found in pastures during the dry months of December - March; and the lowest after August.

The fourth and eigth sampling months which were actually March and August, 1988 (see Chapter 3) were distinctly different from the rest of the sampling months; March had the highest while August the lowest. The details are shown in the linear presentation below.

4 2 7 1 3 5 6 11 12 9 10 8

The spatial analysis revealed that Farms 21 and 25 and hich are located on the north-western side of the Island had relatively high levels of Ca; the least mean Ca was

Table 4.15: Two-way analysis of variance of calcium contents of pastures (arcsine transformed data)

Source	df	MSS	F	Pr > F
Farms	9	0.0002	10.71	0.0001
Sampling months	11	0.0005	26.78	0.0001
Error	647	0.00002		

Table 4.16: Calcium contents of pastures by seasons (%)

Sampling	Minimum	Maximum	Mean	Std	CV (%)
1	0.65	1.98	1.16^{c}	0.351	30.3
2	0.78	3.14	1.36^{b}	0.881	64.8
3	0.59	1.94	1.16^{c}	0.590	50.9
4	0.80	3.01	1.72^{a}	0.770	44.8
5	0.84	2.40	1.13^{cd}	0.374	33.1
6	0.55	1.42	1.13^{cd}	0.268	23.7
7	0.88	1.91	1.35^{b}	0.376	27.9
8	0.25	1.09	0.57^{f}	0.280	49.1
9	0.44	1.44	0.95^{de}	0.340	35.8
10	0.56	1.75	0.88^{e}	0.442	50.2
11	0.56	1.34	1.01^{cde}	0.220	21.8
12	0.41	1.34	0.96^{de}	0.331	34.5

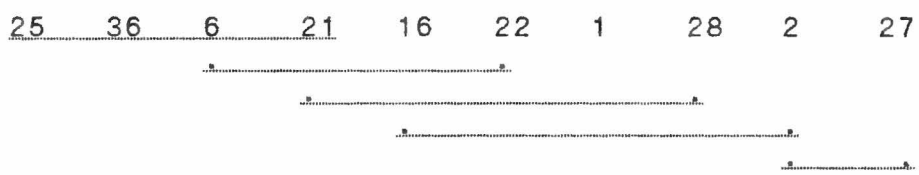
Treatments with the same letter are not significantly different (Duncan's multiple range test)

Table 4.17: Calcium contents of pastures by farms (%)

Farm	Minimum	Maximum	Mean	Std	CV(%).
1	0.53	3.01	1.03^{cd}	0.746	72.4
2	0.53	3.01	1.03^{cd}	0.746	72.4
6	0.41	1.94	1.26^{ab}	0.464	36.8
16	0.50	1.98	1.11^{bcd}	0.437	39.4
21	0.41	1.91	1.22^{abc}	0.448	36.7
22	0.56	1.49	1.08^{bcd}	0.252	23.3
25	0.25	3.14	1.43^{a}	0.802	56.1
27	0.41	1.03	0.81^{e}	0.181	22.3
28	0.65	1.44	1.03^{cd}	0.284	27.6
36	0.81	2.40	1.40^{a}	0.577	41.2 .

Treatments with the same letter are not significantly different from each other (Duncan's multiple range test)

experienced in Farms 1, 2, 28 and 27. On a linear scale, the farms could be grouped as follows:



4.1.3 Detection of multivariate outliers in the nutrition data

The method of principal component analysis was used to screen the nutrition data in order to identify and isolate any possible outliers. This technique involves scatter plots of the two least significant principal components. The outliers in the data would appear as isolated data points on the scattergram.

The last two principal components on the nutrition domain were:

$$Y_4 = 0.42CP - 0.67P + 0.10K - 0.14Ca + 0.59Mg$$

and

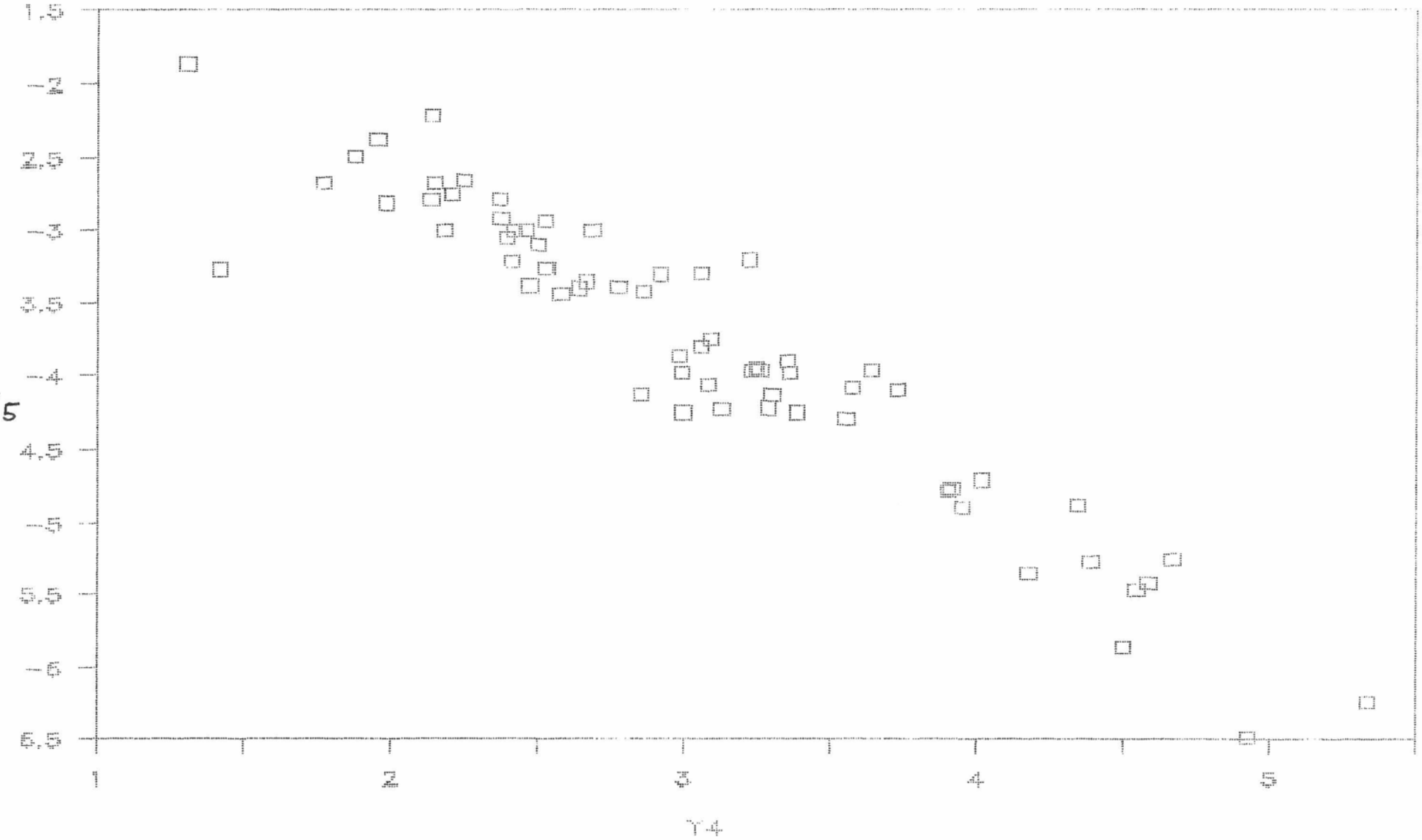
$$Y_5 = -0.57CP + 0.13P + 0.57K - 0.46Ca + 0.35Mg$$

with variances $\tau_4 = 0.631$ and $\tau_5 = 0.224$ and contributing about 12.6% and 4.5% of the total variance in the system, respectively.

The use of scatter plots of the last principal components in detecting multivariate outliers had been proposed by many workers (Gnandesikan, 1977; Gnandesikan *et al*, 1972; Hawkins, 1974, 1980; and Hawkins *et al*, 1984). A

FIG 4.1: DETECTION OF MULTIVARIATE

OUTLIERS FROM NUTRITION DATA



scatter plot of Y_4 against Y_5 revealed no serious outliers in the data except for some data points from farms 1 and 2 (August), 25 (February and August) and 27 (April). The details are shown in Figure 4.1. Looking at the distribution of data, these outliers could be accomodated.

4.1.4 Clustering of farms and sampling months by pasture quality

4.1.4.1 Consideration of all the nutrients

An attempt was made to identify any possible grouping of farms and seasons in terms of the nutritional quality of the pastures. The methods of principal component analysis and canonical correlations are usually applied (Rao 1964; Gnanadesikan 1977; Gnanadesikan *et al*, 1972; Hawkins 1974, 1980; and Hawkins *et al*, 1984). In both approaches, the first two important components or the most significant canonical variables are plotted against each other on a scattergram.

The first two principal components based on all the nutrient factors were:

$$Y_1 = 0.63CP + 0.21P + 0.53K - 0.35Ca - 0.39Mg$$

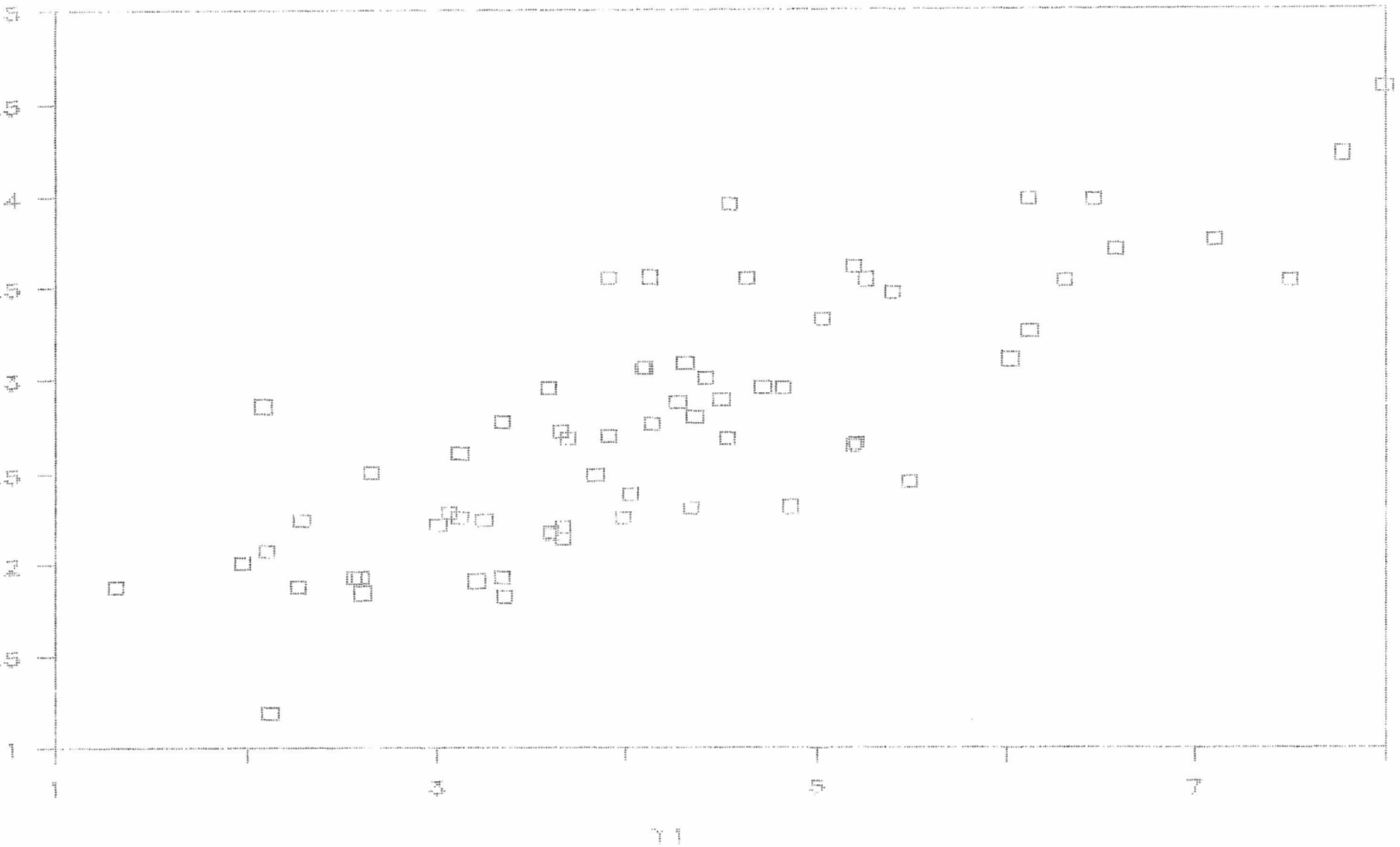
and

$$Y_2 = 0.32CP + 0.70P - 0.15K + 0.09Ca + 0.62Mg$$

The two components cumulatively accounted for about 60.5% of the total variance in the nutrition data. The scatter plots

FIG 4.2: CLUSTERING OF FARMS BY

PRINCIPAL COMPONENTS OF NUTRIENTS



of Y_1 and Y_2 (Fig 4.2) does not reveal any clustering effect.

4.1.4.2 Consideration of CP, P and Ca only

Jolliffe's approach (Jolliffe, 1970, 1972, and 1973) revealed that CP, P and Ca were most important nutrients in that order, in terms of variance contribution to the nutrition variability within the Rusinga pasture conditions at the time of the investigation. An attempt to determine any groupings of the farms in terms of all the nutrients was not very successful as shown in Figure 4.2 above. The first three principal components in which these three nutrients were important, were significant respectively, cumulatively accounted for about 82.9% of the total variance in the system.

Principal component analysis of the three nutrients on their own produced the following results:

Eigenvalue	% contribution	cumulative %
1.433	47.76	47.76
1.022	34.08	81.84
0.545	18.15	100.00

The first two components contribute 47.76% and 34.08%, respectively, cumulatively about 81.84% of the total variance in the system. The corresponding eigenvectors were:

$a_1' = (0.716 \quad 0.503 \quad -0.484)$

$a_2' = (-0.002 \quad 0.695 \quad 0.719)$

Table 4.18: Farms grouped by nutrients

Group	CP	P	Ca
1	1, 2		1, 16, 22, 28
2	6, 16, 21, 22, 25, 36	1, 2, 6, 16, 21, 22, 36	6, 21, 25, 36
3	6, 27, 28	22, 25, 27	6, 16, 21, 22
4			1, 16, 21, 22, 28
5		2, 27	

Table 4.19: Frequency of joint grouping of farms by CP, P and Ca

	Farm								
Farm	2	6	16	21	22	25	27	28	36
1	1	1	2	1	2	0	0	1	0
2		1	2	1	1	0	1	0	1
6			2	3	3	2	1	1	3
16				3	3	1	0	1	2
21					3	2	0	1	3
22						2	1	2	2
25							1	1	2
27								2	0
28									0

Table 4.20: Frequency of joint grouping by sampling months CP, P and Ca

	Sampling month										
Sampling month	2	3	4	5	6	7	8	9	10	11	12
1	1	2	0	2	2	0	0	0	0	0	1
2		2	1	1	1	1	0	0	0	0	1
3			2	2	2	0	0	0	0	1	1
4				1	1	0	0	0	1	0	0
5					2	0	0	0	0	1	1
6						1	0	0	1	1	1
7							0	0	1	2	1
8								0	1	0	0
9									1	1	2
10										1	2
11											2

a_3' = (0.698 -0.514 0.498)

The method of principal components as described above failed to clearly define the nutrient clusters comprehensively. An attempt was made to achieve the same using the analysis of variance results. Grouping by Duncan's multiple range test were utilised. With this approach, the farms and sampling months were grouped by means of differences in CP, P and Ca .

Table 4.19 shows the observed data in Table 4.18 transformed into frequencies of joint occurrences or similarity of farms out of a total of three since there were three criteria of groupings by CP, P and Ca. The higher the frequency the higher the probability of similarity or joint grouping.

There was significant statistical evidence that pasture quality were different between farms and between sampling months (P = 0.0001). In terms of crude protein, phosphorus, and calcium contents of pastures, there were three distinct clusters as follows:

Group I: Farms 1 and 2

Group II: Farms 6, 16, 21, 22, 25, and 36

Group III: Farms 27 and 28

By the similar methods as above, the sampling months could generally grouped into five clusters:

Group I: 1, 2, 3, 5, and 6

Group II: 4

Group III: 8

Group IV: 7, 9, 10, 11, 12

4.2 The population dynamics of ticks.

4.2.1 General considerations

Time series analysis of population dynamics of ticks is essential in order to understand the physio-ecological responses of the arthropods in relation to environmental changes over time. In order to study the temporal changes in population size and structure of ticks in the free-living stage, the data required is practically not easy to get. But in this study, data was available from the parasitic phase. Ticks were picked from the calves at monthly intervals. In the absence of any other external influential factors, and with the assumptions that the animals randomly and evenly picked up ticks, the information from the parasitic phase could validly be used to predict the trend in population changes of adult ticks during their host-finding stage. That is,

$$n_t(p) = \alpha n_t(h)$$

where $n_t(p)$ and $n_t(h)$ are the numbers of ticks during parasitic and free-living stages, respectively at time t, and α is a parameter measuring foraging efficiency of ticks at free-living stage.

It is known that the ability of an animal to pick up ticks is dependent on several factors such as the vegetation

Table 4.21a: Selected calves for tempo-spatial analysis of tick population dynamics in Rusinga Island

Farm	Sample size	Calves selected
6	4	226, 227, 391, 392
21	6	319, 351, 354, 355, 356, 386
22	9	236, 237, 239, 240, 377, 380, 381, 385, 394
27	3	339, 344, 366

cover and microclimate of the habitat, and resistance offered by the host to ticks. In this study, the measure used was the mean number of ticks per calf. All the calves born in 1986 and 1987 were considered. In order to eliminate the effect of host resistance to ticks from the results, only those calves that were present in the study by December, 1988 were considered. Cattle in Rusinga graze in particular well-defined grounds whose vegetation and microclimate remain the same except during the crop season when the effective grazing area is reduced due to planted space limitation (Map no. 3). Hence data was analysed by farms. In order to adequately describe the picture all over the Island, four farms were selected. The selected farms were:

1) Farm 22 (North)
2) Farm 6 (South)
3) Farm 27 (East)
4) Farm 21 (West)

It was important that the farms covered had adequate data covering the whole spectrum of study period. The calves considered are listed in Table 4.21a.

Based on simple correlations, there was strong evidence to suggest the existence linear relationship of pupulation sizes between male and female ticks on the Island. Pearson's correlation coefficient based on the mean number of ticks per calf, all the calves included, was 0.934 (P = 0.0001), thus suggesting a strong positive relationship between the

Table 4.21b: Pearson's correlation coefficient between the sexes

Farm	Sample size	Coefficient(r)	P > r .
6	12	0.926	0.0001
21	11	0.959	0.0001
22	10	0.951	0.0001
27	10	0.865	0.0012
All	43	0.934	0.0001

Table 4.21c: Pearson's correlation coefficient between nutrients and female tick burdens per calf

Nutrient	Coefficient (r)	P > r
CP	-0.558	0.0001
P	-0.598	0.0001
CA	-0.607	0.0001

two sexes. The details are given below. Except for Farm 27, the other three farms recorded a coefficient greater than 0.92 (P = 0.0001).

Given the strong positive correlations between female and male ticks, it is therefore valid to use data on one sex to study the overall temporal patterns of the tick populations. Here, data on female ticks was used primarily because of the importance of the gender in respect of productivity losses through blood-sucking and disease transmission.

4.2.2 Association between tick burdens and pasture nutrients

An attempt was made to analyse the association between tick burdens (mean number of ticks per calf) and the three nutrient factors, namely crude protein, phosphorus and calcium. The analysis based on Pearson's correlation coefficient revealed the existence of a strong negative correlation between the two subsets of data. All the three nutrients recorded highly significant negative correlations with the tick burdens; with crude protein recording -0.558 (P = 0.0001), phosphorus -0.598 (P = 0.0001) and calcium -0.607 (P = 0.0001). The details are given in Table 4.21c.

The results of the above analysis provided a strong evidence of possible influence of nutrition on the induction of host resistance to the major ixodid livestock ticks in Africa. The trend in the results show that a calf exposed to

good nutrition especially higher levels of crude protein, phosphorus and calcium would tend to develop greater resistance to ticks attachments on them. It is true that there exists some optimal nutrition regime or plane for which induction of maximal resistance would be possible. This study was not concerned with that kind of work. However, the results of this study were based on data falling within the ranges shown below.

The ranges of data on nutrient factors

Nutrient	Minimum	Maximum	Mean	Std
CP	6.06	7.53	6.81	0.519
P	0.20	0.28	0.25	0.031
CA	0.81	1.26	1.10	0.177

4.2.3 Distribution of ticks on the Island

4.2.3.1 Distribution by single species

The spatial distribution of ticks on the Island is important in explaining specific farm differences in relation to certain productivity and morbidity factors. Here again data on the mean number of female ticks per calf was used. Initially, only data from the four selected farms were

analysed. The four farms are representative of the four geographical loci of the Island.

The results from the four farms revealed that during the whole year, Farm 27 recorded the highest mean number of female ticks per calf, followed by Farms 22, 6, and 21, respectively. The recorded data further indicated that relatively, tick pick-up rates in Farm 27 was about double that in Farm 22, three times that of Farm 6, and four times of Farm 21. The details are shown below.

Tick pick-up rates by farm

(mean number of female ticks per calf)

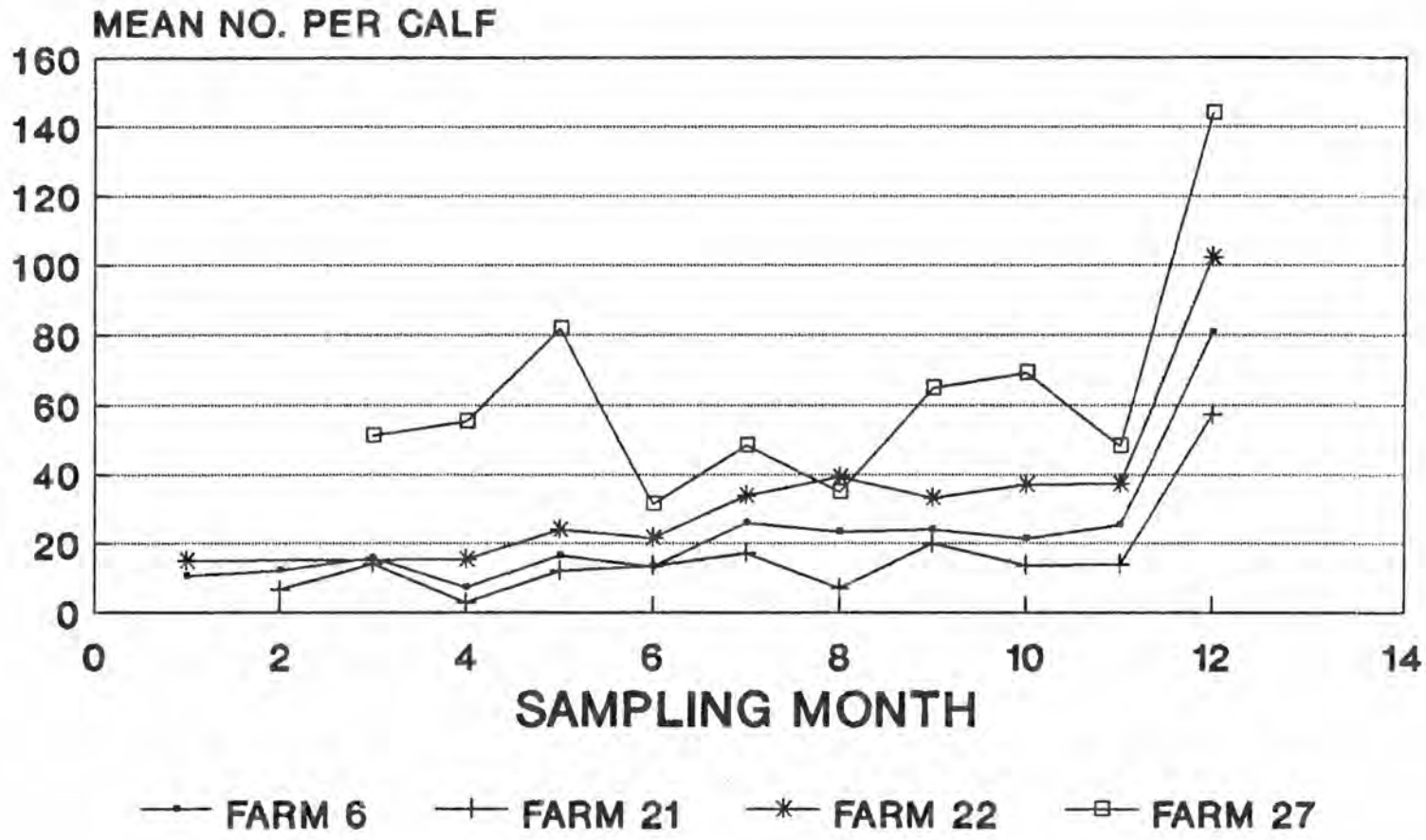
Farm	Tick pick-up rates
27	63.0
22	35.9
6	23.0
21	16.2

Temporal analysis showed that *R. appendiculatus* was the dominant species on the Island followed by *A. variegatum*, *R. evertsi* and *B. decoloratus* in that order. Generally, the data in 1988 showed that tick pick-up rates on the Island was highest around February/March. Then the activities steadily declined to the lowest level around August-October. The sudden steep increase in the activities was mainly attributed *R. appendiculatus*.

Table 4.21d: Grouping of farms by tick pick-up rates

Period	Transformed data	Raw data
1. Quarter:		
Second	(27) (22, 6, 21)	(27) (22, 6, 21)
Third	(27, 22) (6, 21)	(27, 22) (6, 21)
Fourth	((27) (22) (6) (21)	(27) (22, 6) (21)
2. Half-year:		
First	(27) (22, 6) (21)	(27) (22, 6, 21)
Second	(27) (22) (6) (21)	(27) (22) (6, 21)
3. Whole year	(27) (22) (6) (21)	(27) (22) (6, 21)

FIG 4.3: ALL FEMALE TICKS
BY FARMS



Assuming the absence of farm x sampling interaction, an attempt was made to test the null hypothesis:

Ho: No differences in tick pick-up rates between farms

against

H_1: At least one farm is different from the rest in tick pick-up rates

The two-way anova on the raw data provided strong evidence of the existence of farm differences in tick pick-up rates ($P = 0.0001$).

In order to differentiate between the four farms, Duncan's Multiple Range Test (DMRT) was carried out. The two-way anova test in conjunction with DMRT performed on different subsets of the data. The details are shown below.

It was clearly evident from all the data sets above that Farm 27 was significantly different from the rest of the farms. Consistently, Farm 21 experienced the least tick pick-up rates. Calves in Farm 6 experienced slightly higher tick infestation rates than Farm 21 but less compared to Farm 22. Generally the above results showed the existence of a definite trend in the spatial distribution of tick pick-up rates across the Island; least to the northern and western sides and steadily increasing towards the eastern.

Below are discussed differences in tick pick-up rates between all the ten farms in terms of various tick species.

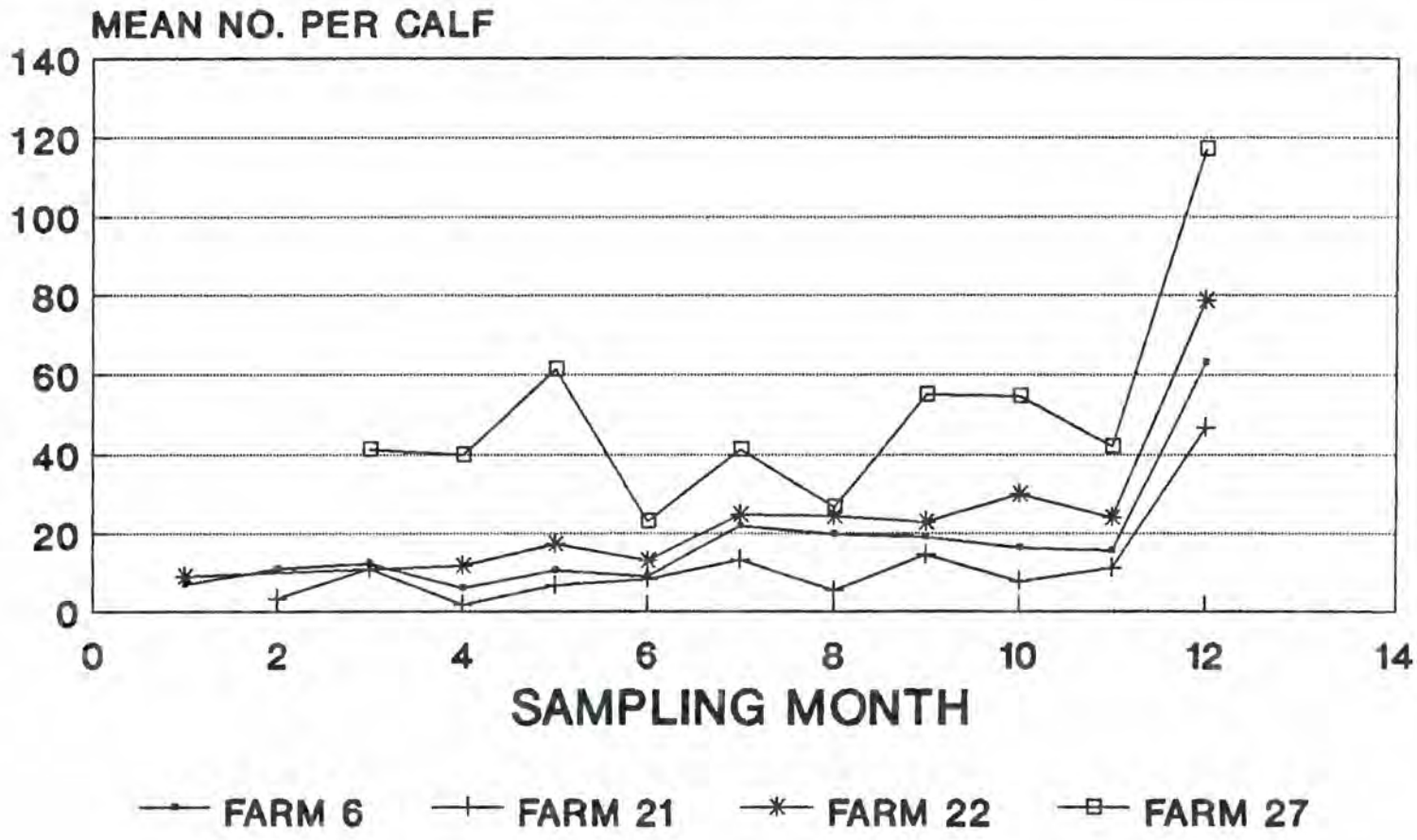
Table 4.21e: Two-way analysis of variance for female *R. appendiculatus*

Source	df	SS	MS	F	P > r
Farms	9	67830.83	7536.76	26.33	0.0001
Sampling	11	45200.56	4109.14	14.36	0.0001
Error	710	203226.13	286.24		

Grouping by DMRT test

Farm	n	Mean	Grouping
27	52	50.96	a
28	62	30.73	b
36	10	26.10	bc
22	137	25.08	bcd
1	93	24.79	bcd
2	43	22.33	cde
6	106	17.14	def
25	106	15.65	ef
21	94	13.86	f
16	28	9.18	f

FIG 4.4: R. APPENDICULATUS
FEMALES



(a) Female *R. appendiculatus*

The analysis revealed that there were significant farm differences in pick-up rates for female *R. appendiculatus* ($P = 0.0001$). The DMRT test clearly showed that Farms 27, 28 and 36 experienced slightly higher rates than the rest of the farms. On the other hand, Farm 21 and 16 distinctly experienced relatively lowest rates. Farms 1, 2, 6 and 22 had median rates. It was definite that farms to the eastern side (Farms 27, 28 and 36) experienced higher pick-up rates than those to the western and north-western sides (Farms 16, 21 and 25).

In 1988, *R. appendiculatus* activities was steadily maintained. For Farm 27, which attained the highest levels, maintained a median of 40 female ticks per calf, fluctuating between a mean of 20 and 60. Two modal peaks were, however, observed around May and September/October. One striking feature noted was a sharp increase around December; the tick numbers more than doubled when compared to the highest figures for the previous months.

Data collected the previous years on adult cattle showed that peak activity of *R. appendiculatus* was around March in 1986 dropping to a low level in June and remaining relatively low for the rest of the year. In 1987, the peak activity was experienced in February. In relation to infestation levels on calves, it was evident that *R. appendiculatus* activity generally started increasing

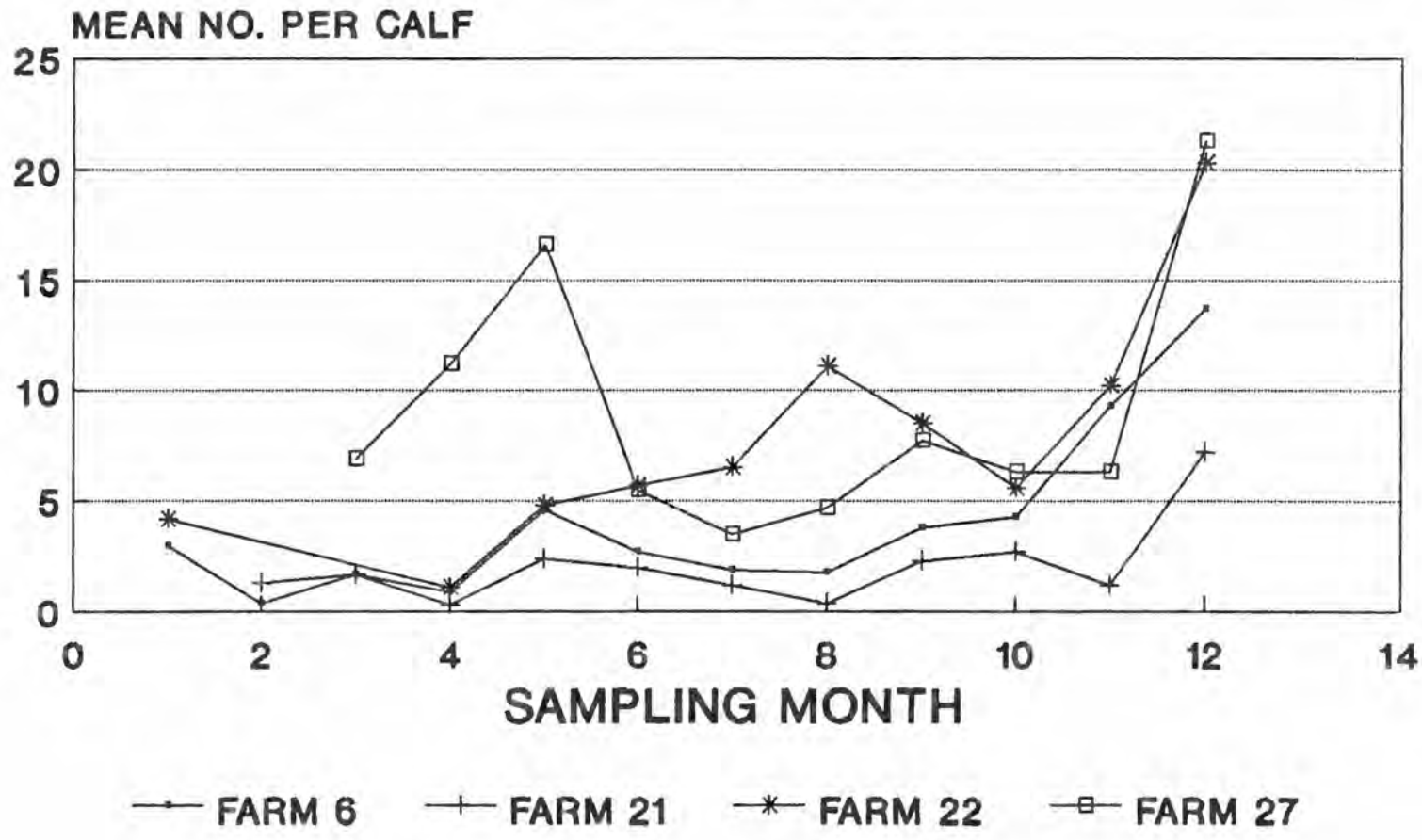
Table 4.21f: Two-way analysis of variance of female *A. variegatum*

Source	df	SS	MS	F	P > r
Farms	9	2799.95	311.12	9.17	0.0001
Sampling	11	2835.05	257.73	7.60	0.0001
Error	710	24074.95	33.91		

DMRT Grouping

Farm	n	Mean	Grouping
27	52	9.44	a
22	137	7.95	ab
16	28	6.39	bc
1	93	5.29	bcd
25	106	4.89	cd
36	10	4.80	cd
6	106	4.44	cd
2	43	3.88	cd
21	94	3.54	cd
28	62	2.63	d

FIG 4.5: A. VARIEGATUM
FEMALES



steadily from around September and attained highest peak between February and May; the lowest being around June-August.

(b) Female *A. variegatum*

There were significant differences in pick-up rates of female *A. variegatum* between farms (P = 0.0001). The details are given in Table 4.21f.

While Farm 27 showed consistently highest pick-up rates of female *A. variegatum* (9.4 ticks per calf), Farm 28 experienced the lowest (2.6 ticks per calf). Farm 28 refused to participate in the study during the months of March-June. Hence the information gathered is not realistic. Data on Farm 2 was very scanty. The spatial distribution of *A. variegatum* appeared to be evenly similar between Farms 2, 6, 21, 25, and 36. A thorough scrutiny of the groupings reveal the following clusters:

I : 22 and 27

II : 1 and 16

III : 2, 6, 21, 25 and 36

The activity peak of *A. variegatum* in calves occurred in May, 1988. The second smaller peak was experienced around August/September. Unlike *R. appendiculatus*, with the exception of Farm 22, most of the farms experienced similar trend with regard to *A. variegatum*. Farm 22 experienced its peak in between January and June.

Table 4.21g: Two-way analysis of variance of female *R. evertsi*

Source	df	SS	MS	F	P > r
Farms	9	631.97	70.22	8.04	0.0001
Sampling	11	331.64	30.15	3.54	0.0001
Error	709	2066.31	2.91		

DMRT grouping

Farm	Mean	Grouping
21	2.02	a
25	1.87	b
22	1.72	abc
36	1.60	abc
16	1.11	bcd
6	1.00	cd
28	0.73	d
2	0.70	d
1	0.65	d
27	0.58	d

FIG 4.6: R. EVERTSI FEMALES

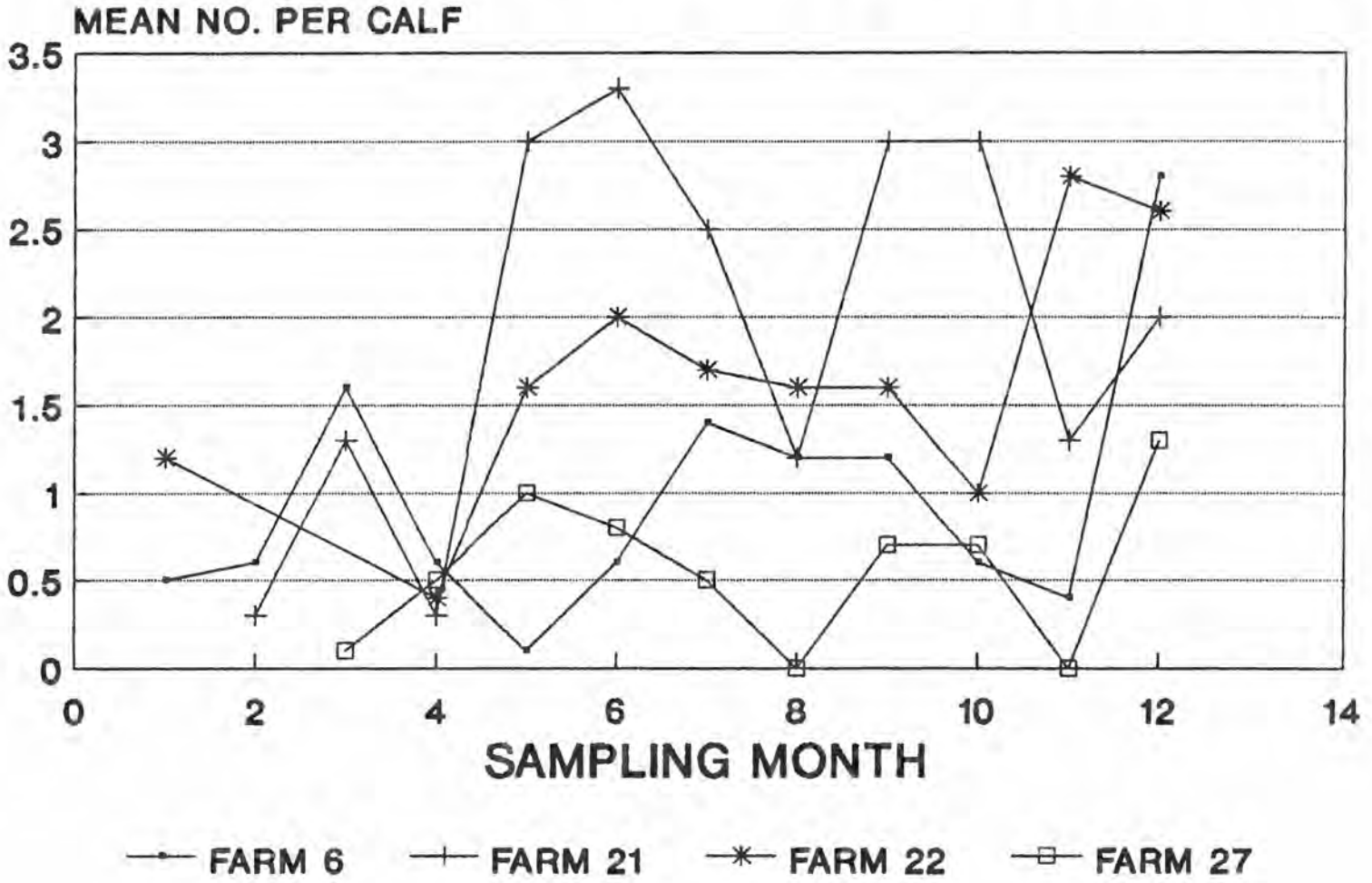


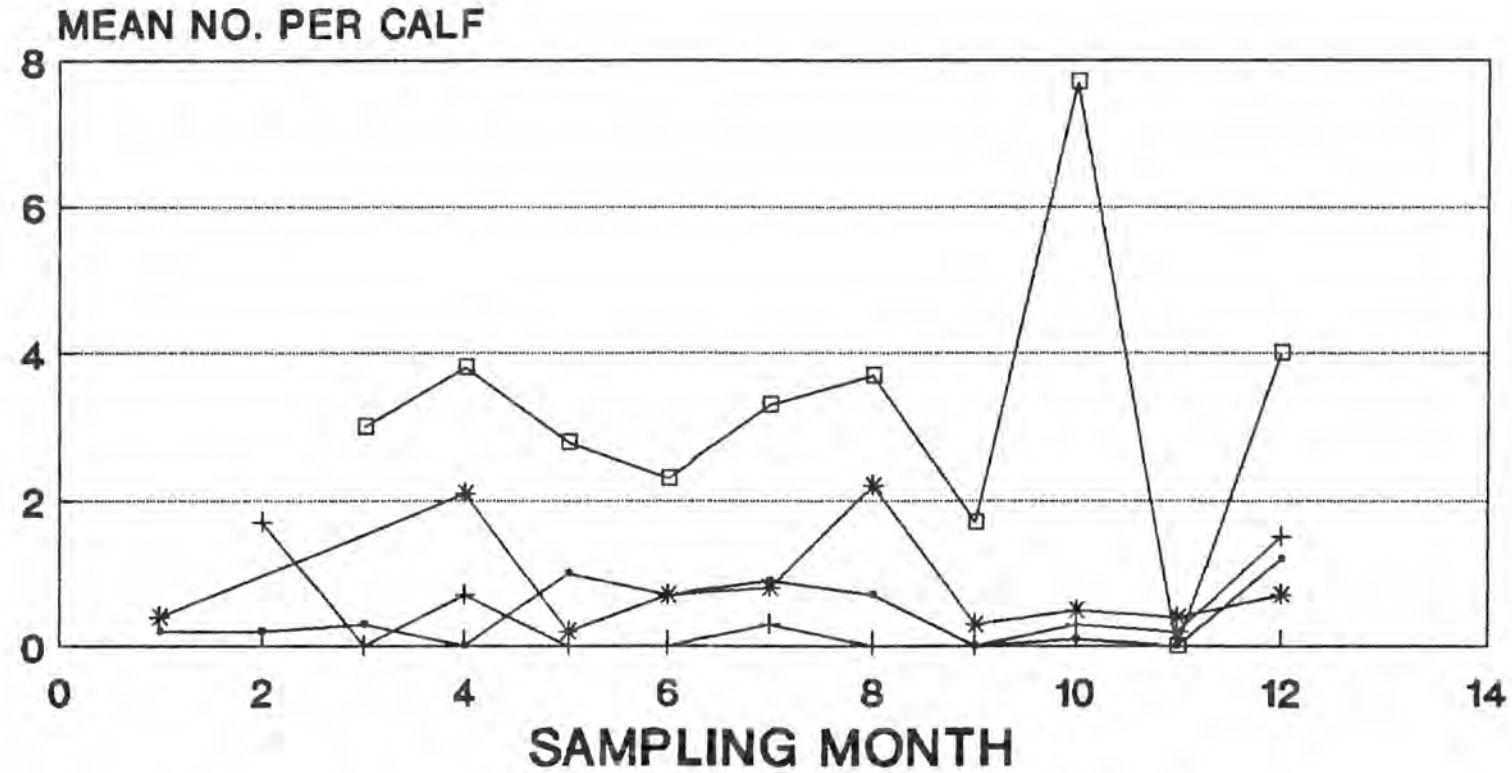
Table 4.21h: Two-way analysis of variance for female *B. decoloratus*

Source	df	SS	MS	F	P > r
Farms	9	435.65	48.41	12.53	0.0001
Sampling	11	83.97	7.63	1.98	0.0001
Error	709	2739.53	3.86		

DMRT groupings

Farm	Mean	Grouping
27	3.48	a
22	1.48	b
36	0.90	bc
25	0.82	bc
28	0.74	bc
6	0.63	bc
2	0.56	bc
21	0.43	c
1	0.42	c
16	0.25	c

FIG 4.7: B. DECOLORATUS
FEMALES



c) Female *R. evertsi*

The results showed that the distribution of female *R. evertsi* was more concentrated to the northern and north-western sides than the eastern. Farms 21, 22 and 25 experienced relatively higher pick-up rates than Farms 27 and 28. Farm 21 recorded the highest rate of 2 ticks per calf followed by Farms 25 and 22 which experienced rates of 1.9 and 1.7, respectively.

The adult infestation of *R. evertsi* on calves was generally uniform within farms throughout the year. However, a visible peak occurred in May/June and which suddenly dropped to a low level in August. A sharp increase occurred around November.

d) Female *B. decoloratus*

There was significantly greater pick-up rates of female *B. decoloratus* in Farms 27 and 22 compared to the rest of the farms (P = 0.0001). The least rates were experienced by Farms 1, 2, 6, 16 and 21. The details are given below. From the above groupings, four clusters could be identified as:

I : 27

II : 22

III : 2, 6, 25, 28 and 36

IV : 1, 16 and 21

Generally the activities of *B. decoloratus* was very steady in 1988 except for two small peaks in April and August. In October, 1988, the tick numbers almost doubled and then suddenly dropped to zero level.

Table 4.21i: Principal component analysis of female ticks

Component	Eigenvalue	% proportion	% cumulative
1	1.789	44.73	44.73
2	0.972	24.29	69.02
3	0.741	18.52	87.54
4	0.499	12.46	100.00

4.2.3.2 Distribution by multiple species

4.2.3.2.1 Selection of important tick species

Principal component analysis of female ticks revealed that the first and second components cumulatively accounted for about 69% of the total variance within the system. The eigenvalues were as follows (details in Table 4.21i):

δ' = (1.789, 0.972, 0.741, 0.499)

The eigenvectors for the first two components were:

a_1'= (0.57, 0.620, 0.256, 0.478)

a_2'= (-0.057. -0.024, 0.918, -0.392)

where the entries correspond to coefficients for *A. variegatum*, *R. appendiculatus*, *R. evertsi* and *B. decoloratus*, respectively. From the magnitudes of coefficients of the first component, it was evident that *R. appendiculatus* dominated it followed by *A. variegatum*, *B. decoloratus* and *R. evertsi* in that order, respectively.Thus on the basis of the first component, and which accounted for 44.7% of the total variance of the system, *R. appendiculatus* and *A. variegatum* were the first two most important species (in terms of variance) in that order, respectively.

On the basis of Jolliffe's approach (Jolliffe 1970, 1972, and 1973) and applied to the female ticks, the most important species are female *R. appendiculatus*, *A. variegatum*, *B. decoloratus*, and *R. evertsi* in that order. Hence Jolliffe's method corroborated the findings of the

Table 4.21j: Frequencies of joint occurrences of farms using females of *R. appendiculatus* and *A. variegatum* ticks

	Farm								
Farm	2	6	16	21	22	25	27	28	36
1	2	2	1	1	2	1	0	2	2
2		2	1	1	1	2	0	1	2
6			2	2	1	2	0	1	1
16				2	1	2	0	1	1
21					0	2	0	1	1
22						0	1	1	1
25							0	1	1
27								0	0
28									2

principal components analysis above. The above results therefore provided strong evidence that we could as well use data on the females of ***R. appendiculatus*** and ***A. variegatum*** jointly in order to group the farms in terms of the pick-up rates.

4.2.3.2.2 Distribution of farms using multiple factors

On the basis of the respective DMRT grouping of farms by female ***R. appendiculatus*** and ***A. variegatum***, the following frequencies of joint occurrences were established. From the Table 4.21j, three distinct clusters of farms could be clearly defined. These are:

I : 1

II : 6, 16, 21, 22, and 25

III : 27, 28 and 36

4.2.4 Canonical analysis of the role of nutrition on the resistance of calves to the ixodid ticks.

Host resistance to ticks was measured by the number of female adult ticks picked up by each calf. From each calf, tick data collected were on the numbers of:

A. variegatum males (X_1)

A. variegatum females (X_2)

R. appendiculatus males (X_3)

R. appendiculatus females (X_4)

R. evertsi males (X_5)

R. evertsi females (X_6)

B. decoloratus females (X_7)

The nutrition data consisted of:

Y_1 - Crude protein (%)

Y_2 - Phosphorus (%)

Y_3 - Potassium (%)

Y_4 - Calcium (%)

Y_5 - Magnesium (%)

Let $X' = (X_1, X_2, ..., X_7)$ and $Y' = (Y_1, Y_2, ..., Y_5)$

The method of canonical correlations, a multivariate technique attributed to Hotelling (1936), was used to analyse the data. The method enables one to concisely describe the interrelationships of different characteristics between two or more subsets of data of the whole multivariate system. The method develops linear combinations of each subset of data, say

$$V_i = \alpha_i'X \quad \text{and} \quad W_i = \beta_i'Y$$

$$i = 1, 2, 3, 4, 5$$

where

$$\alpha_i' = (\alpha_{i1}, \alpha_{i2}, \alpha_{i3}, ..., \alpha_{ip})$$

$$\beta_i' = (\beta_{i1}, \beta_{i2}, \beta_{i3}, ..., \beta_{iq})$$

are standardized canonical coefficients. The new pair, V_i, and W_i, called the ith canonical variables, are determined such that

$$corr(V_i, V_j) = corr(W_i, W_j) = 0 \quad \text{for } i = j = 1, 2, 3, 4, 5$$

and the parameter δ_i, defined as

$$\delta_i = \text{corr}(V_i, W_i)$$

$$i = 1, 2, 3, 4, 5$$

and called the ith canonical correlation is maximized such that $\delta_1 \geq \delta_2 \geq \delta_3 \geq \delta_4 \geq \delta_5$.

The determination of $\delta' = (\delta_1, \delta_2, \delta_3, \delta_4, \delta_5)$, α and β is based on the eigenstructure analysis of the matrix product H, such that

$$H = \Sigma_{11}^{-1}\Sigma_{12}\Sigma_{22}^{-1}\Sigma_{21}$$

where $\Sigma_{11} = \text{cov}(X)$, $\Sigma_{22} = \text{cov}(Y)$ and $\Sigma_{12} = \Sigma_{21} = \text{cov}(X, Y)$ Further,

$$\delta_i = I\sqrt{\mu_i}I$$

where μ_i is the ith largest eigenvalue of H and so δ_i is the absolute square root of μ_i. The unknown weight α_i can be obtained from the relation

$$(H - \mu_i I_n)\alpha_i = 0$$

and

$$\beta_i = (\Sigma_{22}^{-1}\Sigma_{21}\alpha_i)/\mu_i$$

The sign and magnitude of the correlation between the original variables and canonical variate are useful in showing (a) which variables contribute most heavily to a canonical variate and the direction of their effects, (b) the existence of the affinities or contrasts among variables in their relationship with a canonical variate. The correlations thus contribute towards establishing the nature of relationships which may be present between

domains. The correlations are more stable than either the raw or standardised canonical weights under the addition or deletion of variables and in replicate samples drawn from the same population. Moreover, correlations are more readily translated into meaningful terms than are weights such as canonical or regression weights (Dempster, 1969). Thus the square of a variable/canonical variate correlation express the proportion of the variance of a variable which is directly associated with a particular canonical variate.

There are two kinds of variable/canonical variate correlations of interest in this study:

(i) **Intraset correlations.** These are correlations between canonical variates and observed variables of the same dormain.

(ii) **Interset correlations.** These are correlations between canonical variates of one dormain and the observed variables of the other. The square of an interset correlation coefficient specifies the proportion of the variance of a variable which is predictable by a canonical variate of the other dormain.

Data analysis was accomplished using CANCORR available in the SAS Package (SAS, 1986). For more extensive literature on canonical correlations analysis, the references cited would be a compulsory reading (Anderson, 1958; Morrison, 1976; and Cooley and Lohnes, 1971).

Table 4.22a: F-tests of the joint nullity of the smallest 5-k canonical correlations

k	Roots	Value	df1	df2	Pr > F
0	1, 2, 3, 4, 5	2.4261	35	2371	0.0001
1	2, 3, 4, 5	1.5846	24	1969	0.0357
2	3, 4, 5	0.8140	15	1560	0.6628
3	4, 5	0.6196	8	1132	0.7619
4	5	0.3716	3	567	0.7735

Table 4.22b: Contribution of individual canonical correlations in the total system

k	Contribution %	Cumulative %
1	55.50	55.50
2	30.32	85.82
3	8.43	94.26
4	4.46	98.71
5	1.29	100.00

Table 4.23: Correlations between individual variables and the first two pairs of canonical variates

Variable	V_1	V_2	W_1	W_2
Host resistance:				
X_1	0.237	0.033	0.066	0.007
X_2	0.003	0.266	0.001	0.056
X_3	-0.592	-0.069	-0.165	-0.014
X_4	-0.620	0.430	-0.173	0.090
X_5	0.295	-0.031	0.083	-0.007
X_6	0.232	0.188	0.065	0.040
X_7	-0.717	-0.188	-0.200	-0.040
Variance extracted:	0.206	0.048	0.016	0.002
Redundancy:	0.016	0.002	0.016	0.002
Nutrients:				
Y_1	0.208	0.082	0.743	0.39_2
Y_2	0.066	0.036	0.236	0.17_3
Y_3	0.132	-0.098	0.471	-0.467
Y_4	0.098	-0.153	0.349	-0.728
Y_5	0.087	0.080	0.310	0.379
Variance extracted:	0.016	0.010	0.210	0.215
Redundancy:	0.210	0.215	0.210	0.215

Table 4.24: Tests of significance of interset correlations between host resistance factors and W_1

n = 575

Variable	r	r^2	ltl
X_1	0.066	0.0044	1.5882
X_2	0.001	0.0000	0.0191
X_3	-0.165	0.0273	4.0120**
X_4	-0.173	0.0300	4.2120**
X_5	0.083	0.0068	1.9816
X_6	0.065	0.0042	1.5544
X_7	-0.200	0.0401	4.8913**

**Highly significant at P = 0.001

The canonical correlation coefficients $\delta' = (\delta_1, \delta_2, \delta_3, \delta_4, \delta_5)$ and associated standard errors of estimate (in brackets) were:

δ' = [0.279, 0.210, 0.113, 0.082, 0.044]

(0.0385) (0.0399) (0.0412) (0.0415) (0.0417)

The canonical weights, α and β are estimated from the sample data by **a** and **b** where

$a' = (a_1, a_2, a_3, a_4, a_5)$

where

a_1'= (0.458, -0.015, -0.221, -0.383, 0.181, 0.168, -0.602)

a_2'= (-0.300, 0.526, -1.488, 1.593, -0.080, 0.215, -0.211)

a_3'= (1.196, -0.765, 0.391, 0.161, -0.679, 0.277, -0.260)

a_4'= (0.206, 0.317, 0.213, 0.091, 0.553, -0.710, -0.188)

a_5'= (-0.024, 0.501, -0.020, -0.320, 0.138, 0.573, 0.530)

and

$b' = (b_1, b_2, b_3, b_4, b_5)$

where

b_1' = (0.994, -0.108, 0.007, 0.618, 0.217)

b_2' = (0.404, -0.050, -0.414, -0.668, 0.451)

b_3' = (-0.472, -0.520, 1.090, -0.720, 0.684)

b_4' = (0.134, 0.388, 0.263, -0.336, -0.637)

b_5' = (0.806, -0.869, -0.739, 0.392, -0.592)

The results showed that both the first and second canonical correlations were significantly different from the rest of the correlations.

The nutrition data was grouped into quarters by sampling months and analysed by a two-way analysis of

variance test. The assumption here was that the effect of nutrition on resistance could be realised only three months after being consumed. For crude protein, only the first quarter was different from the other quarters (P = 0.0001). Moreover, by the methods due to Jolliffe (1970, 1972, and 1973), it was found that crude protein was the most important nutrient contributing to the variance in the data, followed by phosphorus and calcium. On that basis, the study ignored the problem of lag effect of nutrition on the bovine resistance to the ixodid ticks.

The canonical correlations obtained from the sample were 0.279, 0.210, 0.113, 0.082, and 0.044. The first two pairs of canonical variables contributed about 55.5% and 30.32% of the total correlation between the two sets of data, repectively (Table 4.22b). Based on F-ratio test statistic, a test of the null hypothesis:

$$Ho: \Sigma_{12} = 0 ,$$

i.e the absence of overall correlations between the two subsets of data is given in Table 4.22a. The results in Table 4.22a led to the rejection of the overall hypothesis of no association, hence the two subsets of data on host resistance and nutrition can be considered to be linearly related. Furthermore, tests on the joint nullity of the canonical correlations groups (δ_1, δ_2, δ_3, δ_4, δ_5) and (δ_2, δ_3, δ_4, δ_5) showed strong evidence to reject the null hypotheses (P = 0.0001), respectively. Thus only the first and second canonical correlation coefficients were of

statistical significance with P = 0.0001 and P = 0.0357, respectively. It may therefore be inferred that the nutrient-factors and the host resistance as measured by tick burdens are linealy related and that the relationship can be fully accounted for by the first and second pairs of canonical variates, (V_1, W_1) and (V_2, W_2). These two canonical pairs cumulatively accounted for about 85.8% of the total correlation in the multivariate system. Hence if we concentrate only on these first two pairs of canonical variables, then we shall foresake only about 14% of the information on correlation in the original multivariate system.

On the host resistance domain, *R. appendiculatus* (both males and females) and females *B. decoloratus* contributed to V_1 in the same direction, while the rest of the tick species, in the opposite direction. The variate V_1 was characterised particularly by *R. appendiculatus* and *B. decoloratus* females. This was reflected by their intraset correlations with V_1 and which were 0.592, -0.620 and -0.717 for *R. appendiculatus* males and females, and *B. decoloratus* females, respectively. The intraset correlations showed that both sexes of *R. appendiculatus* dominated the variate V_1. The variate V_1 extracted about 20.6% of the variance in the host resistance domain. Correlations with V_2 were noticeably weaker than with V_1, except for females of *R. appendiculatus* and *A. variegatum* which registered 0.430 and 0.266, respectively (Table 4.23).

All the nutrient factors contributed to W_1 in the same direction, the strongest being crude protein with intraset correlation of 0.743, followed by potassium with 0.471, calcium 0.349, magnesium 0.310, and phosphorus 0.236. Thus the variate W_1 is characterised particularly by crude protein and potassium, and it extracts about 20.96% of the total variance in the nutrition domain. The second variate W_2 is the difference between the total contribution of crude protein and magnesium as one group, and that of potassium and calcium as the other group. As in W_1, the effect of phosphorus is negligible in W_2. The results therefore showed that the direct role of phosphorus on host is minimal. The variate W_2 extracted about 21.5% of the total variance in the nutrition domain. Thus jointly, W_1 and W_2 extracted about 42.5% of total variance in the nutrition domain, the remaining being attributed to W_3, W_4, and W_5.

4.2.5 The epidemiology of tick-borne diseases (TBD)

The only tick species found on the Island were *R. appendiculatus*, *A. variegatum*, *R. evertsi*, and *B. decoloratus*. The major disease organisms amongst the host population were *T. parva*, *B. bigemina*, *A. marginale*, *T. mutans* and *Cowdria ruminantium* (ICIPE, 1986). The morbidity study based on 200 cattle provided a comprehensive baseline picture of the tick-borne diseases on the Island (ICIPE, 1986 and 1987). Generally, it was found that TBD and

helminths were the major clinical problems of cattle on the Island.

From the monthly clinical and parasitological examinations of 37 calves born on the ten farms, about 43% of one to three months old calves showed positive *Theileria* piroplasms implying a prevalence rate of 430 per 1000 calves. The incidence of severe ECF was noticed on calves aged between four to six months; prevalence of which was noted as 36%. The report also confirmed that by the age of about six months, all the calves had already been infected by *Theileria* parasites. It was also found that despite the high parasitaemia of both *Theileria* macroschizonts and piroplasms, calves were quite tolerant resulting in no deaths at all.

Babesia bigemina and *Anaplasoma marginale* were also clinically examined in the investigation. It was found that *B. bigemina* was present in 50% of the farms and *A. marginale* in 70% of them. These were calves aged between six to eight months. Infections of *B. bigemina* was greatest in October coinciding with the peak of *B. decoloratus*, its principal vector. The parasitaemia for both diseases was found to be low and no deaths were attributed to either. A non-parthogeinc protozoa called *Theileria velifera* was diagnosed and found to be common also. Its incidence was, however, not recorded.

The adult cattle were also clinically examined. The direct examination revealed that 56 - 70% of the animals

showed *Theileria* piroplasm of low parasitaemia each month. A serological study showed that 65% of the cattle had positive antibody titres to *T. parva* schizont antigen. During the same study, one two-year old bull died of acute cerebral ECF infection, one of turning sickness and three of blindness (due to lens opacity); all cases attributed to chronic ECF.

From September, 1987, the disease survey was continued on by introducing the Friesian cattle in order to assess the natural tick-parasite challenge to these tick-naive cattle (ICIPE, 1987). Six Friesian steers were released onto three of the farms, namely Farms No. 6, 16, and 28 for a period of six days and then monitored closely clinically and parasitologically. It was found that Farm 6 had the highest ECF challenge resulting in one of the Friesians dying from acute ECF infection. During the period of this study, all the calf deaths on this farm were also confirmed to be due to acute ECF. Despite the highest tick challenge on Farm 28, only one Friesian reacted severely but then recovered. On the other hand, Farm 16 had the lowest tick/ECF challenge and only one animal showed a mild reaction. On both farms 16 and 28, no treatment with Clexon was required. *Anaplosoma marginale* of low parasitaemia and *B. bigemina* of high parasitaemia were both detected in the second and third weeks, respectively, of exposure of the susceptible Friesians.

Earlier in March/April 1987, four Friesians were used to monitor the TBD disease prevalence on the Island. One

animal died of acute heartwater infection and massive numbers of *Cowdria ruminantium* were demonstrated in the brain smear thus confirming the presence of the disease on the Island.

The past disease surveys had revealed the prevalence of all the major tick-borne diseases on the Island. With the prevalence rate 36% for one to three months old calves and over 56% for adult cattle, the Island is an ECF endemic area. All the tick-borne diseases are common amongst the cattle population there.

4.3 The epidemiology of other cattle diseases

4.3.1 Helminthesiosis

From laboratory examinations of faecal samples obtained from calves, it was found that calves were infested with several internal parasites, namely helminths of the *Trichostrongylus* spp, *Fasciola gigantica* spp, *Paramphistomum* spp, *Strongloides* spp, and *Coccidia* spp (ICIPE, 1986, 1987 and 1988). It was not possible to measure incidence rates of the different endoparasites. The survey carried out in 1986 on the Island revealed that about 70% of the calves aged between one to three months were infested with the *Trychostrongylus* spp. In this study, the least prevalence rate for helminths could be assumed as 70%.

Oral treatment with anthelminths such as Nilzan and Nilverm reduced the infestation to 11%. However, it was realised that reinfestation was quite fast. For the above study, reinfestation increased the worm burden level to 100% within one month's time. At the age of five months, all the calves were already infested with *Trychostrongylus* spp in which over 70% showed faecal egg burden of over 1000 eggs per gram of faeces. These results therefore showed that the prevalence rate of helminths is very high amongst the calves particularly in the absence strategic antihelminths treatment as it is on the Island.

Due to the fact that farmers on the Island do not drench their animals with antihelminths, it was believed that prevalence rates of the helminths amongst the calves aged over five months was very high well above the economic injury levels. Because of the homogeneous spatial distribution of the intermediary hosts of the helminths, the snails, around the Island, it was valid to assume equal infestation amongst the farms. Thus, the effect of helminths was considered to be immense but equal between the ten farms.

4.3.2 Trypanosomiasis

In 1985, a general investigation in which 204 buffy coats from cattle were examined and no trypanosomes were seen (ICIPE, 1986 and 1987). Further, a trapping study was

undertaken using four traps set up along the Lake for four days around the areas most likely to be infested with tsetse flies. About 604 flies were caught and all belonged to *Glossina fuscipes* species.

In 1987, twenty five traps were put in four locations on the Island. Three traps were located around Utajo on the eastern side of the Island. Eight traps were put around Kakrigu (on the southern side) with a transect stretching from the Lake shore (1230 m) towards the Lugogo Ridge (1500 m). The third site covered the area from the lowland on the western side of the Island from the Lake shore in the south to the Lake shore in the north and accomodated six traps. The fourth and the largest transect stretched from the northern Lake shore through settlement areas and thickets towards the Lugogo Ridge, comprising of eight traps. Trapping was done at monthly intervals. Traps were left positioned for 24 hours before the captured flies were collected. The exercise continued for ten months. Details are given in Map No. 4.

Flies were caught only at Kakrigu and Utajo sites. A total of 1344 flies caught all belonging to the *Glossina fuscipes* species. After laboratory examinations for parasites, all the flies were parasite-free except for one fly which had parasites of the reptilian species in the gut. There was no trace of the most virulent Trypanosomes such as *T. congolense, T. vivax, T. rhodensiense*, or *T. brucei*. Though the efficient vectors of the virulent parasites , the

morsitan group of the tsetse flies (*G. morsitans* and *G. pallidipes*) are found on the mainland, they are absent on the Island. Temporal analysis of the data revealed that the flies were most abundant during the dry months of June to December.

Due to the absence of the parasite reservoirs as well as suitable vectors on the Island, *nagana* is absent on the Island. *Glossina fuscipes*, the only tsetse fly species on the Island prefer the reptilian host, the monitor lizard and aligators that are plentiful around the Lake shores particularly around Kakrigu and Utajo. *Glossina fuscipes*, however, is an efficient vector of human trypanosomes, *T. rhodensiense*, and *T. brucei* which are also rare amongst the islanders. This fact has minimised the chances of transmission of both human and animal trypanosomiasis on the Island (Willet, 1970).

4.3.3. Other miscellaneous cattle diseases

One of the bovine diseases of calves on the Island is coccidiosis mainly caused by the genus *Elmeira*. The prevalence of coccidiosis is expected to be uniform between farms. No comprehensive clinical study had been carried out on coccidiosis on the Island. However, because of uniform stocking rates and similar housing conditions across the Island, this study assumed that the impact of *coccidiosis* is equally distributed between the farms. Moreover, coccidia

mostly affect calves between the age of three weeks to six months (Marquart, 1973); an age group which included only a few of the calves under investigation. During the monthly visits, there were few clinical symptoms of *coccidiosis* amongst the study animals.

Salmonellosis is not of significance in this study since it affects only calves aged between ten to fourteen days old. However, diarrhoea is common particularly during the wet months when pastures are lush.

No clinical studies have been carried out on tuberculosis, brucellosis, leptospirosis, diptheria, and pneumonia on the Island. Foot-and-mouth disease is, however, common in the area, almost occurrying every year. Although no data is available, the *sweating disease* is assumed absent due to the absence of its principal vector, ticks of the genus *Hyalomma* (WEAL, 1980).

4.4 Climate

Because of its small size, the differential impact of climate on calf growth was considered similar across the Island. Thus the direct effect of climate was not different between the farms and particularly rainfall which is the main driving factor on the population dynamics of ticks (ICIPE, 1986) and pasture nutrition. So although it is recognised that climate affects cattle productivity, it requires a large area with varied agroclimatological span

for a study to be able to determine its impact on calf growth.

4.5 Management

Except for Farm 2, all the calves were in general, well managed with regard to grazing. In all of them, there was someone responsible for herding them. On Farm 2, there was nobody allocated the responsibilty of looking after the calves. Thus the calves in Farm 2 could not graze sufficiently and so most of them were too malnourished to be able to face the harsh conditions within the environment. Virulent ECF incidence in the presence of poor nutrition and management caused heavy fatal losses on Farm 2. In fact, all the calves died at an early age before attaining even six months. Thus no valid comparisons would be possible with Farm 2.

Farm 28 was the best managed. Here the farmer himself, always ensured that at least one of his four wives grazed the animals each day. He also enclosed particular paddocks and which were used for grazing selectively. On many occassions, he was personally involved in grazing the animals especially during the cropping as well as dry months of the year when the vegetation is scarse and patchy.

In Farms 6, 21, 22, and 25 a herdsboy was employed to look after the animals. In Farms 1, 27, and 36, most often one of the young nonschool-going family members was engaged

in grazing the animals. However, these were four- to eight-year old boys and who could not understand and appreciate the reasons behind their missions. On most occassions, they lost the tract of the animals while playing. Moreover, they could not easily know either where the greener pastures were or the right time to take the calves to drinking water points.

In terms of social environment of the animal, management practices on the ten farms could be classified into three broad groups, namely

I: Farm 28

II: Farms 6, 21, 22, and 25

III: Farms 1, 16, 27, and 36

4.6 Structure and characteristics of the zebu cattle

4.6.1 Herd structure

4.6.1.1 Sex ratios

Calf sex ratio in terms of heifers per bullock for the study sample was about 0.36 for 1986 as compared to 0.47 for 1987. This showed that on the average, more bullocks are born compared to heifers in the target population. However, on every farm, there were more bulls as compared to cows as revealed by the average ratio of cows per bull which was about 0.62. This figure was slightly higher than the average

Table 4.25: Sex ratios of the study cattle population in 1986 and 1987

Farm No.	Calf sex ratio 1986	Calf sex ratio 1987	Cows/bull ratio
1	0.33	0.33	0.61
2	0.00	0.50	0.78
6	0.33	0.75	0.73
16	0.00	0.00	0.67
21	1.00	0.60	0.67
22	0.33	0.33	0.61
25	0.33	0.42	0.56
27	0.00	0.67	0.64
28	0.67	0.44	0.46
36	0.00	0.00	0.75
Total	0.36	0.47	0.62

Table 4.26: Age distribution of the 1987 dams by the number of calves born

Farm	No. of calves born									
	1	2	3	4	5	6	7	8	9	Total
1	1	0	0	1	3	0	0	0	0	5
2	0	1	2	1	1	1	0	0	0	6
6	2	2	0	0	0	0	0	0	0	4
21	3	1	0	1	0	0	0	0	0	5
22	3	0	2	0	1	1	0	0	0	6
25	2	0	5	2	1	0	0	0	0	10
27	1	0	1	3	0	0	0	0	0	5
28	2	1	1	1	0	1	0	1	1	8
Total	14	5	11	9	5	3	0	1	1	49
%Share	28.6	10.2	22.4	18.4	10.2	6.2	0	2.0	2.0	100

calf sex ratios indicating that there was gradual relative build-up of cows over the years. This relative decline in the sex ratios could be attributed to the preference of bullocks as transactions for as dowries. The details are shown in the Table 4.25.

4.6.1.2 Age distribution of the dams

Table 4.26 represents the distribution of the dams of 1987 calves in terms of age. An attempt to solicit data on age of the dams from the farmers was not feasible. The farmers could not remember the exact dates when the dams were born. Moreover, some of the dams were brought from outside the household and that their dates of birth were unknown to the farmers. Nonetheless, ages of the dams were determined from the mean age at first calving, the number of calves given birth to so far, and mean calving interval.

The average age at first calving for the Rusinga dams was estimated by the ICIPE Social Science Research Unit to be about 5.2 years (ICIPE, 1987). The ICIPE Livestock Ticks Research Programme estimated the mean calving interval for the dams to be about 1.5 years. Therefore, in terms of age in years the following conversion would be necessary.

From the results, it was apparent that most of the 1987 dams were young animals. About 61.2% of the dams had delivered between one and three calves, that is, between the age of 5 and 8.5 years. It was only in Farm No. 28 where

Table 4.27: Calving season during 1986 and 1987

Month	1986		1987		Both years	
	No.	%	No.	%	No.	%
January	0	0	1	1.8	1	1.1
February	0	0	0	0	0	0
March	1	2.9	1	1.8	2	2.2
April	5	14.3	3	5.4	8	8.9
May	5	14.3	1	1.8	6	6.7
June	8	22.8	12	21.8	20	22.2
July	15	42.8	14	25.5	29	32.2
August	1	2.9	4	7.3	5	5.6
September	0	0	3	5.4	3	3.3
October	0	0	10	18.2	10	11.1
November	0	0	6	11.0	6	6.7
December	0	0	0	0	0	0

Table 4.28: Distribution of dams in terms of the number of working udders

	No of udders				
Farm	No. of working udders				Total
	1	2	3	4	
1	0	1	1	2	4
2	0	2	2	2	6
6	0	1	0	3	4
16	0	0	1	0	1
21	1	0	0	4	5
22	2	0	0	4	6
25	0	3	4	5	12
27	1	0	0	5	6
28	0	0	0	8	8
Total	4	7	8	33	52
% Total	7.7	13.5	15.4	63.4	100.0

there were dams with more than seven calves (that is, over 14 years of age).

Conversion of age of dams in years

No. of calves	Age (years)
1	5.2
2	6.7
3	8.2
4	9.7
5	11.2
6	12.7
7	14.2
8	15.7
9	17.2

4.6.2 Calving season

From the data on birth dates for those calves born in 1986 and 1987, the peak calving months were June and July. In 1987, about 47.3% of all the calves were born in June and July as compared to 65.6% in 1986. The details are shown in Table 4.27.

4.6.3 Udders

Mastitis is not a common disease on the Island (ICIPE, 1987). The majority of the known cases of lost working

udders were mainly due to damages done by the large tick species *Amblyomma variegatum*; the second most prevalent tick species on the Island following *R. appendiculatus*. Table 4.28 shows that about 63.4 % of those dams that gave birth in 1987 had all the four udders working; and only about 7.7 % had one udder working. About 79.8% had at least three udders working.

4.6.4 Weight at birth

For the calves born in 1987 birth weights varied between 11 kg and 23 kg. Farm No. 2 experienced the highest average birth weight of 18.5 kg per calf followed by Farm Nos. 1 and 16 with 17.60 kg and 16.79 kg, respectively. The details are shown in Table 4.29.

Mean calf birth weights were 16.48 kg and 15.17 kg for males and females, respectively. Based on a three-factor factorial design with the factors being farm, sex, month of birth, and the assumption that the only important interaction is the two-factor interaction between sex and month of birth, the analysis of variance is given by the model:

$$w_{ijk} = \alpha_i + \beta_j + \tau_k + \eta_{jk} + e_{ijk} \qquad (4.1)$$

for $i = 1, 2, 3, 4, \ldots, 10$

$j = 1, 2$

$k = 1, 2, 3, 4, \ldots\ldots, 12$

Table 4.29: Weight at birth for the calves born in 1987

Farm No.							
1	2	6	21	22	25	27	28
19.0	17.0	14.0	14.0	18.0	16.0	14.0	14.0
19.0	23.0	16.5	19.0	15.0	14.0	15.0	15.5
15.0	15.5	14.0	14.0	14.5	15.0	16.0	16.0
15.0			12.5	14.5	16.0	11.0	17.0
17.5				16.0	14.0	17.5	18.0
					15.5		20.0
					15.0		17.0
					14.0		
					16.0		
					19.0		
					14.5		
					12.0		
Mean 17.60	18.50	14.83	14.88	15.60	15.08	14.70	16.79
Std* 1.64	3.97	1.44	2.84	1.47	1.69	2.44	1.91

*Std = Sample standard deviation

where w_{ijk} = birth weight in kg for a calf in the ith farm, jth sex and kth month of birth

α_i = the effect of the ith farm which is a random effect

β_j = the effect of the kth sex which is a fixed effect

τ_k = the effect of the kth month of birth which a fixed effect

n_{jk} = the interaction between the jth sex and kth month of birth

e_{ijk} = the error term

$e_{ijk} \sim N(0, \sigma^2)$

Although the relatively heavier calves were born on farms 1, 2, and 28, the results of analysis of variance showed that there was no statistically significant differences in calf birth weights between farms (P = 0.2863). Further, although mean birth weights for males were about 6.7% heavier than females, the results also showed no significant differences between the sexes (P = 0.1776).

A pregnant dam requires sufficient amount of good quality feeds in order to give birth to a healthy normal calf. The quantity and quality of feeds on offer is dependent on climate which in turn varies between months (and hence seasons). High quality pastures are usually available on the Island shortly after the beginning of the long rains around May/June every year. In the case of

Table 4.30: Parameter estimates of birth weights for calves born in 1987

Estimate	Males	Females
1. Sample size (N)	23	21
2. Minimum weight (kg)	14.00	14.00
3. Maximum weight (kg)	23.00	19.00
4. Mean weight (kg)	16.48	15.17
5. Standard deviation	2.40	1.92
6. Coefficient of variation	14.56	12.66

Table 4.31: Analysis of variance of birth weights for calves born in 1987

Source	df	Mean squares	F	Pr > F
Farm	7	5.9267	1.32	0.2863
Sex	1	8.6919	1.94	0.1776
Month of birth	8	1.4994	0.33	0.9431
Sex*Month of birth	4	1.6910	0.38	0.8223
Residual	22	4.4806		

Note: the birth weight for calf no. 328 (=23 kg) which is an outlier, is ommited.

Table 4.32: Calf birth weight by month of birth

Month of birth	Sample size (N)	Weight (kg) Minimum	Maximum	Mean	Std*
Jan	1	17.00	17.00	17.00	..
March	1	23.00	23.00	23.00	..
April	3	15.50	19.00	17.83	2.021
May	1	16.00	16.00	16.00	..
June	10	14.00	19.00	15.00	1.563
July	13	11.00	19.00	15.46	2.222
August	1	14.00	14.00	14.00	..
September	2	14.00	18.00	16.00	2.828
October	5	12.50	20.00	16.38	2.326
November	4	14.00	16.00	15.00	0.913

*Std = sample standard deviation

Rusinga, the analysis of variance test on month of birth did not show any evidence to reject the null hypothesis that birth weights between months of birth were equal (P = 0.9481). Finally, there was no statistical significance in the interaction between sex and month of birth (P = 0.8223). Table 4.30 contains some parameter estimates of calf birth weights by month of birth.

4.7 Calf Growth

4.7.1 The Growth Model

4.7.1.1 Identification of the Model

A useful model should be simple and tractable and be ideal on validation. In this case, the conceptual model to be developed must be able to describe the growth pattern of the calves of the breed under investigation. The model should be able to answer questions pertaining to the fundamental growth characteristics of the breed and in this context, there was need to answer the following questions:

(i) Are there any differences in growth rates between calves within farms and between farms?

(ii) At what age are the calves expected to attain the highest growth rates?. And what is this average liveweight at which growth rate is maximum?

(iii) At the prevailing growth rates, what is the

maximum expected growth potential of the calves within the underlying production system?

There are several ways of identifying the functional form of an unknown model. For growth models on living organisms, many workers are convinced that the sigmoid models are the most appropriate (Brody 1945; Wilson, 1980; Fowler, 1980; France *et al*, 1984; Winsor, 1932; Grosenbaugh, 1965; and Nokoe, 1978). Thus literature provide sufficient evidence to support the application of the sigmoid models to the growth data in Rusinga. Secondly, it is the modified Gompertz Model whose parameters could effectively answer the above questions.

4.7.1.2 Estimation of the Model parameters

The Modified Gompertz Model is given by the following equation:

$$W_t = b.\exp(-\exp(-a(t-g))) \qquad (4.2)$$

where W_t is the liveweight at age t (lbs), b is the maximum breed growth potential (lbs), a is a constant inversely related to the growth rate, and g is the age (weeks after birth) at which growth rate is maximum.

The Modified Gompertz Model is so complex such that linearization by applying the conventional logarithmic transformation in order to perfom the ordinary least squares

Table 4.33: Parameter estimates for growth calves
(b in lbs and g as weeks after birth)

Farm	Calf	Sex	M/Birth	Estimates		
				a	b	g
1	330	M	4	0.0236	196.97	19.78
	331	F	4	0.0387	137.80	5.53
	346	F	6	0.0425	105.99	4.24
	363	M	7	0.0378	150.60	8.69
	406	M	7	0.0299	186.35	27.78
	274	F	4	..	..	..
	275	M	4	0.0285	294.83	49.80
	277	M	7	..	..	..
2	328	M	3	..	..	..
	329	F	4	..	..	..
	373	F	7	0.0540	112.85	1.97
	393	M	11	0.0092	198.14	-42.00
	278	F	6	0.0899	100.00	60.00
	280	F	7	0.9280	168.18	73.04
6	375	F	8	0.0268	243.39	23.91
	390	F	10	0.0488	103.72	1.82
	391	M	11	0.0335	215.66	10.98
	392	F	11	0.0840	112.28	-1.04
	226	F	6	0.0070	664.50	97.20
	227	M	7	..	..	..
	314	M	7	0.1425	150.00	40.00

Table 4.33 cont.

6	316	M	7	0.0240	315.50	37.12
16	388	M	..	1.4417	102.89	18.91
	242	M	..	..	..	..
	243	M	..	..	..	..
21	343	F	6	0.0222	232.99	27.13
	351	F	6	0.0212	264.05	31.71
	386	F	10	0.0124	366.87	60.71
	348	M	6	0.0326	221.01	16.41
	376	M	8	0.0677	124.81	10.60
	319	F	5	..	..	..
22	377	F	8	0.0722	162.38	6.47
	396	F	11	0.0878	103.74	2.07
	380	M	9	0.0324	204.62	11.67
	381	M	10	0.0471	166.95	4.62
	385	M	10	0.0491	171.97	6.90
	394	M	11	0.1115	92.50	0.19
	235	M	4	0.1012	152.91	58.23
	236	F	4	0.0272	322.54	64.93
	237	M	4	0.0174	300.15	45.74
	238	M	5	0.0797	247.90	68.62
	239	F	6	0.0738	255.30	59.02
	240	M	7	..	..	..

Table 4.34: Fitting Modified Gompertz Model to calf growth data

Farm	Sample size	No. of fitted models	ni/Ni
1	8	6	0.750
2	6	4	0.667
6	8	7	0.875
16	3	1	0.333
21	6	5	0.833
22	12	11	0.917
25	15	10	0.667
27	5	4	0.800
28	11	5	0.455
36	2	2	1.000
Total	76	55	0.724

estimation process (Gauss, 1809; Sadler, 1975) is not possible. Hence, an iterative computer programme called NLIN in the SAS (Statistical Analysis System) package was used. NLIN is a nonlinear least squares iterative computer program (SAS, 1985). Table 4.33 contains the estimates for the growth parameters for the calves. The results revealed that Farms 1 and 21 experienced the highest growth rate while Farm 27 had the lowest. Farm 27 was noted for its lowest CP content in the pastures.

In testing the adequacy of the Model in describing growth, data on the seventy two calves was used. The estimates of the parameters converged on 55 calves thus representing about 72% of all the calves that were examined. The quantity

$$p_{[N]} = \frac{n}{N} \qquad (4.3)$$

is a measure of the appropriateness of model in explaining growth patterns of the calves. Of course

$$\lim_{N \to \infty} E[p_{(N)}] = \text{probability of success of the model in growth simulation}$$

For the divergent iterations, it was observed that data was scanty and scattered so that the growth trend was linear. Except for Farm 16, the growth of calves in the rest of the farms could satisfactorily be described by the Modified Gompertz Model. The details are shown in Tables 4.33-4.36.

Estimates of the growth parameters were also determined by month of birth. The results are given in Table 4.37.

Table 4.35: Estimates of growth parameters for all calves by farm

Farm	Sample size	Mean estimates		
	n	a	b	g
1	6	0.03233	178.76	19.30
		(0.00841)	(65.77)	(17.50)
2	4	0.27028	144.79	23.25
		(0.43972)	(46.26)	(53.35)
6	6	0.05993	190.09	18.79
		(0.04606)	(82.88)	(17.63)
16	1	1.44170	102.89	18.91
		(.)	(.)	(.)
21	5	0.03302	241.95	29.31
		(0.01997)	(87.08)	(19.45)
22	11	0.06358	198.27	29.86
		(0.03106)	(75.31)	(28.87)
25	9	0.06281	172.60	17.01
		(0.04177)	(68.47)	(22.30)
27	4	0.07060	211.37	10.79
		(0.03917)	(117.08)	(13.26)
28	5	0.09556	160.56	6.15
		(0.06386)	(79.73)	(8.25)
36	2	0.04090	228.26	55.75
		(0.02800)	(181.38)	(8.13)

4.7.2 The spatial (farm) differences on calf growth

Each farmer has his own ways of management of livestock. In some farms, herdsmen (whether family member or employees) go round with cattle directing them to better pastures and clean drinking water points when the tides are low. In other farms, particularly during the off-growing season, the animals are let loose in the morning and they go round the grazing fields on their own. Researchers have noted that social environment of the animal, particularly the young calves could as well seriously affect their productivity.

Correlation analysis of the parameter estimates of the Modified Gompertz Model revealed the existence of a strong positive correlation between the maximum breed potential liveweight, b, and the age at which a calf experiences the maximum growth rate given by g. Thus,

Corr (b, g) = 0.5483

and which shows that the correlation between the two estimates was significantly different from zero (P = 0.0001). Except for farms 2 and 6, all the other farms registered individual significant positive correlations between the two parameter estimates. The implication here was that a calf that experiences its highest growth rate at an early age tends to attain a lower liveweight at maturity; and vice versa.

Except for Farm 22, there is no significant correlation

coefficient between either the growth rate measure, a, and the maximum potential liveweight at maturity, b; or between a and g. Farm 22 registered a statistically significant negative correlation (P = 0.0152) between the estimates of a and b implying that as a increases (and hence actual growth rate decreases) the maximum potential liveweight at maturity decreased, and vice versa.

Based on multivariate analysis of variance (MANOVA), the differential spatial impact of farms and hence the social environment on calves was investigated. Table 4.35 was the estimates of the parameters by farms, i.e. the three parameter estimates, a, b, and g. Suppose we let B_i denote the the vector of the estimates from the ith farm as

$$Bi' = (a_1, b_1, g_1)$$

We wish to test the multivariate null hypothesis

$$H_o : B_1 = B_2 = B_3 = B_4 = \ldots\ldots = B_{10}$$

against

$$H_1 : \text{At least two vectors are not equal.}$$

To test the above hypothesis Wilks' Lambda and Hotelling-Lawley Trace statistics were used.

The two multivariate tests require two input matrices, namely the error sum of squares and cross-products, E say, and the sum of squares and cross-products when the null hypothesis is true, H say. These two matrices are symmetric. When data for all the calves (both 1986- and 1987-born) were analysed, it was found that

$$H = \begin{matrix} 2.0132 & -164.2771 & -7.6631 \\ & 42276.2584 & 7546.5183 \\ & & 5326.4770 \end{matrix}$$

and

$$E = \begin{matrix} 0.6379 & -44.0510 & 47.8663 \\ & 286397.5183 & 48368.3269 \\ & & 26318.8553 \end{matrix}$$

The characteristic roots of $E^{-1}H$ were:

Eigenvalue	% Contribution
$\delta_1 = 4.1093$	92.84
$\delta_2 = 0.2195$	4.96
$\delta_3 = 0.0975$	2.20

The corresponding characteristic vectors are:

for $\delta_1 = 4.1093$,

$\alpha_1 = (1.4610, 0.0007, -0.0043)$

for $\delta_2 = 0.2195$,

$\alpha_2 = (-0.0119, -0.0010, 0.0074)$

and finally for $\delta_3 = 0.0975$,

$\alpha_3 = (0.1639, 0.0021, -0.0014)$

The MANOVA results were as follows:

Statistic	Value	F	df_1	df_2	Pr > F
1. Wilks' Lambda	0.1462	4.1531	27	120.3835	0.0001
2. Hotelling-Lawley Trace	4.4263	6.5028	27	119	0.0001

df_1 = degrees of freedom for the numerator

df_2 = degrees of freedom for the denominator

These results showed that there was evidence of significant

differences between farms (P = 0.0001). There were statistically significant differences in growth of calves between the farms and so the null hypothesis was not accepted.

Further, it was found that the growth rate measure, a, was responsible for the differences between farms. The means of the estimates of a for different farms are given below. The higher the parameter a, the lower the actual growth rate; and vice versa. From the ANOVA results there was no statistically significant difference between Farms 2, 28, 27, 22, 25, and 6 as the first group. As a second group Farms 36, 21, and 1 also showed no within-group differences. However, because of scanty data, no comparison should be made with Farm 2. Thus

2 28 27 22 25 6 36 21 1

Means of the estimates of a

Farm	Mean
2	0.2703
28	0.0956
27	0.0706
22	0.0636
25	0.0628
6	0.0599
36	0.0409
21	0.0330
1	0.0323

From Table 4.35, Farms 2 and 16 had very odd data on the estimates of g and a, respectively. By omitting these two data, MANOVA tests were carried out on the data on the calves born in 1987 yielded the following:

$$H = \begin{matrix} 0.015065 & -6.866381 & -3.599597 \\ & 36856.137163 & 7269.272106 \\ & & 2018.471111 \end{matrix}$$

$$E = \begin{matrix} 0.032830 & -50.527029 & -6.648578 \\ & 148176.792540 & 20710.828875 \\ & & 3608.389300 \end{matrix}$$

and

Statistic	Value	F	df1	df2	Pr > F
Wilks' Lambda	0.22201	3.1099	18	80	0.0003
H-L Trace	2.35367	3.4869	18	80	0.0001

The test statistics above indicated that there was strong evidence from the data which supported the rejection of the null hypothesis. The results still showed that there was statistically significant farm differences in relation to the growth patterns of the calves born in 1987 (P = 0.0003). The differences could be attributed to multiple of several factors such as nutrition and tick burdens, and their interactions.

4.7.3 The influence of sex and calving season on calf growth

Several workers have investigated factors and herd productivity characteristics (particularly sex and calving season) that influence growth of calves (Trail *et al*, 1985 and Saeed *et al*, 1987). In this study, an attempt was made to determine whether sex and calving season of the calves on Rusinga Island had any influence on calf growth. Calving season was determined by the month of birth of the calf.

The multivariate model assumed was

$$Y_i = \mu + a_i + e_i \qquad (4.4)$$

$$i = 1, 2, 3, \ldots\ldots, p$$

where Y_i is nx1 observation vector, μ is a kx1 mean vector and a_i is the kx1 column vector of the parameters of the ith factor, e_i is the nx1 vector of unknown errors and p is the number of factors investigated.

4.7.3.1 Influence of sex

In order to test for the effect of sex on calf growth, the null hypothesis is

$$H_o : \pi_m = \pi_f$$

against

$$H_1 : \pi_m = \pi_f$$

where π_m and π_f are effects of male and female calves, respectively. The vectors of mean estimates are

π_m = 0.1065 and π_f = 0.0946

194.1864 180.2740

19.1254 24.7410

The sex model sum of squares and cross-products

H = 0.0019 2.1875 -0.8829

2556.2486 -1031.8027

416.4762

and the error sum of squares and cross-products

E = 2.6493 -210.5156 41.0861

326117.5281 56946.6478

31228.8561

The eigenstructure analysis results showed that the first root δ_1 = 0.063 accounted for total variance. The other two roots were zero, each. The corresponding vector was

a_1' = (-0.3269 -0.0020 0.0067)

The results of MANOVA tests were as follows:

Statistic	Value	F	df1	df2	Pr> F
Wilks' Lambda	0.9407	1.0289	3	49	0.3880
Hotelling-Lawley Trace	0.0630	1.0289	3	49	0.3880

The MANOVA test showed that there was no statistically significant differences in growth between sexes (P = 0.3880). All the univariate ANOVA tests on the data also confirmed the conclusion of MANOVA.

Data was also analysed separately for those calves born in 1986 and 1987. For the 1987 calves,

Table 4.36: Parameter estimates of the Modified Gompertz Model for different sexes

Estimate	Sample size	Mean	Standard error
Females:			
a	25	0.09462	0.17677
b	25	180.27440	78.03485
g	25	24.74080	26.17340
Males:			
a	28	0.1065	0.2652
b	28	194.1864	81.6431
g	28	19.1254	23.4029

Table 4.37: Estimates of growth parameters of all the calves by month of birth

Month	Sample size	Mean estimates		
	n	a	b	g
April	6	0.03943	234.20	40.67
		(0.03105)	(81.38)	(23.14)
May	2	0.11905	270.28	70.94
		(0.05564)	(31.64)	(3.28)
June	10	0.04935	217.43	25.50
		(0.03200)	(87.62)	(19.90)
July	16	0.10794	182.27	23.95
		(0.22099)	(71.83)	(22.29)
August	3	0.05557	176.86	13.66
		(0.02501)	(60.60)	(9.11)
September	2	0.05055	142.89	5.87
		(0.02567)	(87.31)	(8.21)
October	7	0.07614	164.21	10.60
		(0.06029)	(94.90)	(22.28)
November	6	0.06842	139.84	-4.30
		(0.03862)	(52.89)	(18.95)

H = 0.000207 -0.028164 -0.119212
3.840192 16.254793
68.803405
E = 0.047689 -57.365246 -10.128963
185029.089520 27963.846188
5558.0570058

and for the MANOVA tests

Statistic	Value	F	df1	df2	Pr > F
Wilks' Lambda	0.95334	0.5384	3	33	0.6593
H-L Trace	0.04894	0.5384	3	33	0.6593

Thus there was no strong evidence from the data to reject the null hypothesis (P = 0.6593). Hence there were nostatistically significant differences in growth between sexes as regards the the calves born in 1987. Similar MANOVA test carried out on data on the calves born in 1986 also confirmed the acceptance of the null hypothesis (P = 0.2143).

4.7.3.2 Influence of month of birth

For the month of birth, the detailed data is given in Table 4.36 With regard to the mean estimates of the parameter, g, the results showed that those calves born in May experienced their maximum growth rate latest (about 71 weeks after birth) while those born in November had theirs earliest (about 5 weeks before birth). Data on month of

birth had very high variability as was reflected in the coefficient of variation (CV = 94.46%). The findings revealed that calves born between April and July experienced their highest growth rate between the second and fifth month after birth. Although, the results showed that calves born in November experienced their highest growth rate before birth, because of the high variability in the data this revelation should be validated using more field data.

The month of birth model

$$H = \begin{matrix} 0.0380 & -8.6182 & 2.4247 \\ & 57771.3359 & 25615.7151 \\ & & 12930.6175 \end{matrix}$$

and

$$E = \begin{matrix} 0.7808 & -83.9143 & 41.6926 \\ & 263584.4899 & 30051.7715 \\ & & 18706.3537 \end{matrix}$$

The eigenvalues roots and vectors were:

Eigenvalue	% Share	Vector		
		a	b	g
0.78	92.27	-0.4183	-0.00004	0.0079
0.05	6.42	0.8826	-0.0008	0.0016
0.01	1.31	0.8740	0.0022	-0.0045

When data relating to the calves born in 1987 were analysed separately, the results were as follows:

H = 0.009215 -12.432564 -1.956856
36043.349115 5165.360014
790.345143

and

E = 0.038680 -44.960847 -8.291319
148989.580590 22814.740967
4836.515268

The MANOVA tests were Wilks' Lambda = 0.646446 (P = 0.762) and Hotelling-Lawley Trace = 0.481395 (P = 0.7881). Since there were no significant differences between months of birth, the results provided no strong evidence of rejecting the null hypothesis with regard to the calves born in 1987.

4.7.4 Liveweight-dependent survivorship threshold model

4.7.4.1 Identification

Model identification is one the problems modellers have to face in their work. In this study, the method of 'slope characteristics' was used in an attempt to identify the functional form of the model (Gregg *et al*, 1964, Levenbauch et al , 1976; Sandland *et al*, 1979 and Holmes, 1983). The analysis of the slope characteristics did not support the

the choice of a sigmoid curve.

4.7.4.2 Development of the models

Figure 4.8 depicts a scattergram of the liveweights of calves plotted against their respective ages. It revealed the existence of heteroscedasticity in the data. Thus variances of the residuals at age t, denoted by σ^2_t, are age-dependent. In such a situation, the estimates of the regression coefficients α and β based on the ordinary least squares method, although unbiased, would possess very large variances (Koutsoyiannis, 1973; Gilchrist, 1976 and 1984; Johnston, 1972; and Hu, 1982). Thus assuming any model form

$$W_t = \phi(\alpha, \beta, t, e_t), \qquad (4.5)$$

say, any attempt to predict liveweight W_t at age t based on t as the explanatory variable would yield inefficient predictions.

Although the raw data was heteroscedastic, the logarithmic transformed data became homoscedastic and suggested that either a linear

$$Y_t = \alpha + \beta t$$

or quadratic

$$Y_t = \alpha + \beta t + \tau t2$$

models of the log data were suitable candidates.

The distribution of the minimum and maximum liveweights were also heteroscedastic, while the transformed data were not (Figs 4.9a and 4.9b). Suppose we denote the minimum

FIG 4.8: SCATTERPLOTS OF CALF WEIGHTS

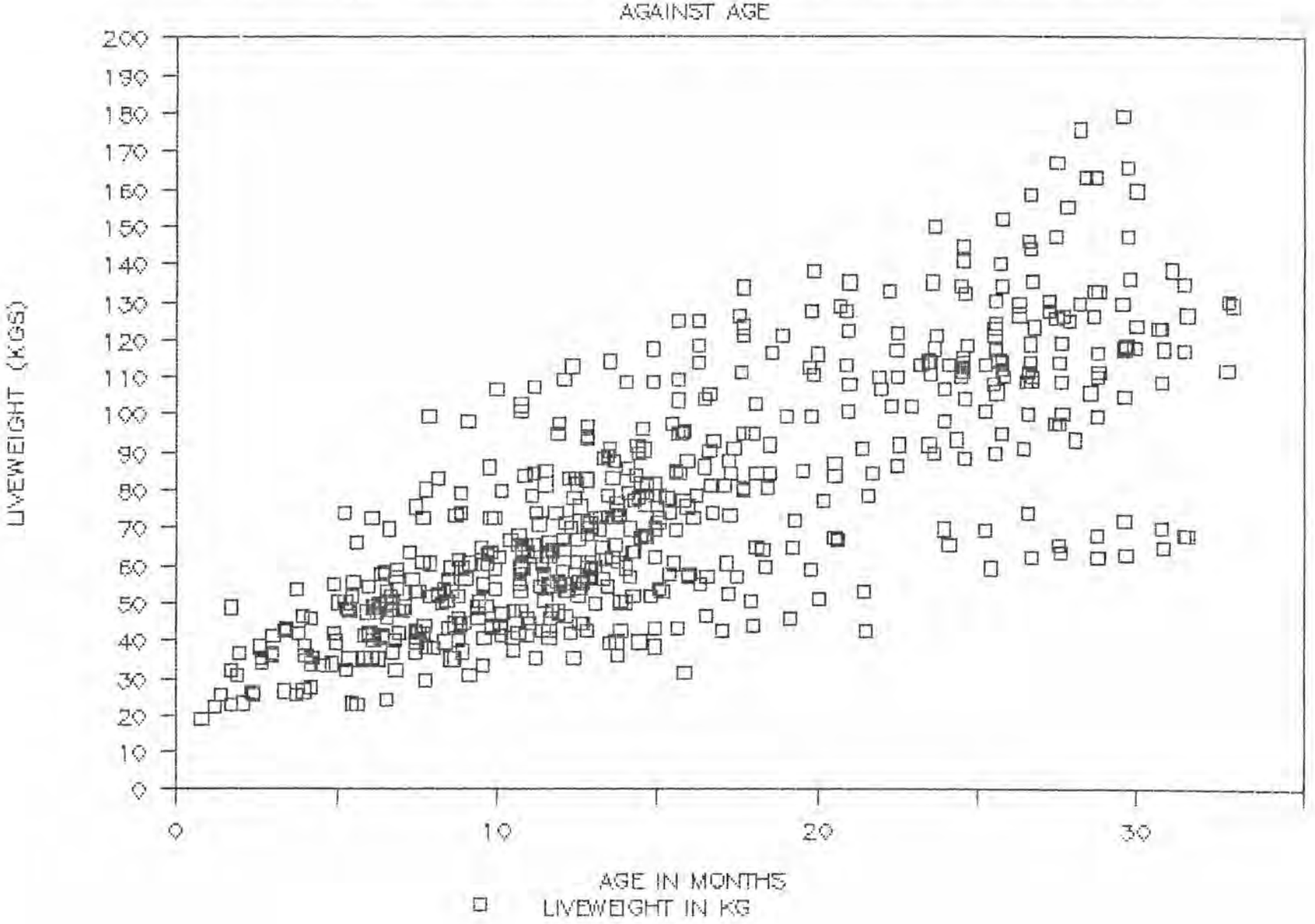


FIG 4.9A: SCATTERPLOTS OF CALF WEIGHTS

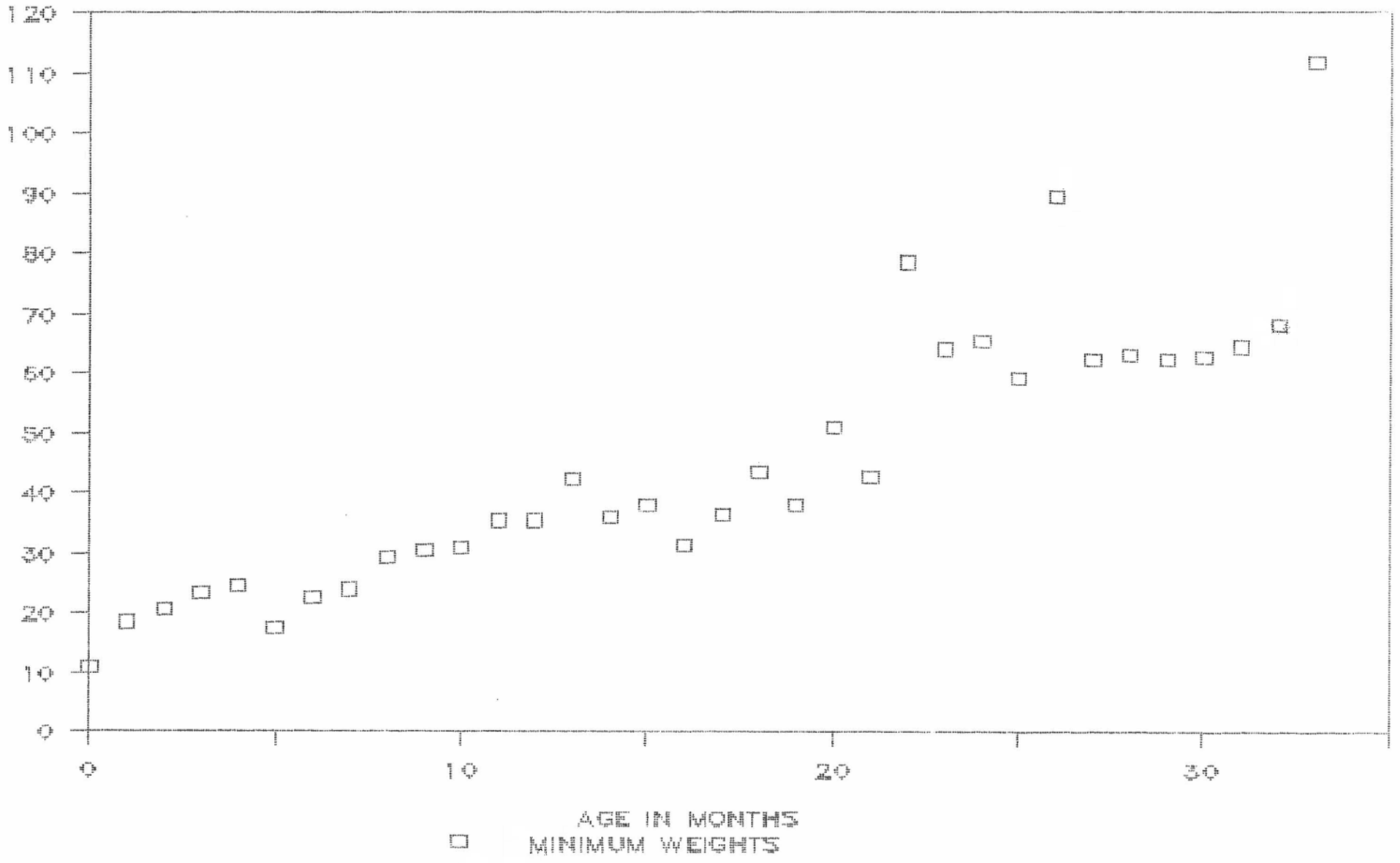
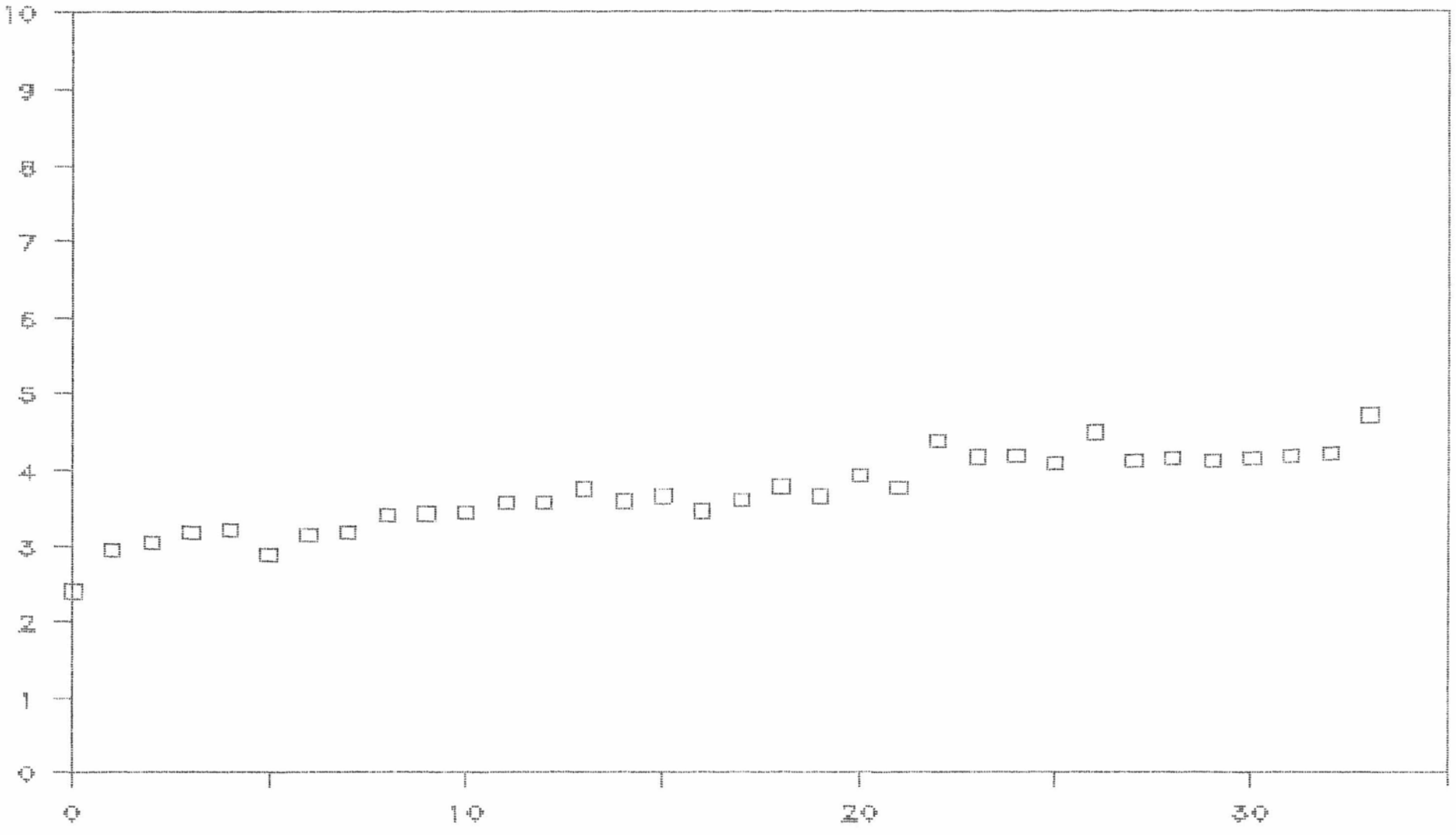


FIG 4.9B: SCATTERPLOTS OF CALF WEIGHTS



liveweights at age t by $W_{min,t}$. Further, let

$$Y_1(t) = \log(W_{min,t})$$

$$Var(Y_1(t)) = \sigma^2_1(t)$$

In developing the threshold model, it is the model of the data on minimum liveweights which is important in determining the survival of the animal. Hence, $Y_1(t)$ would define the threshold model for the calves under the Rusinga production system.

Based on analysis of variance, the log-linear model was found to be the best fit to $Y_1(t)$ ($P = 0.0001$). For the log-parabolic model, the third parameter, τ, was found not to be significantly different from zero at 5% level. The best model was

$$Y_1(t) = 2.8799 + 0.0488t \qquad (4.6)$$
$$(0.0631) \quad (0.0033)$$

with $R^2 = 0.8696$, CV = 5.0999 and the estimated sample variance was

$$s^2_1(t) = 0.03534$$

In terms of the original measurements

$$W_{min,t} = 17.81 \exp(0.0488t) \qquad (4.7)$$

The probability density function of $W_{min,t}$, the observed minimum liveweights, is given by Equation (2.17). However, where $W_{min,t}$ and σ^2_t are unknown, the predicted minimum weight, $W_{min,t}$, and $s^2_{min,t}$ are substituted, respectively. The sample variance for Wmin,t is estimated by

$$s^2_{min,t} = \Sigma(W_{min,t} - W_{min,t})^2/(n-1)$$

$$= \exp(s^2_1(t))$$

$$= 1.0360$$

4.7.4.3 Forecasting power and validation of the models

In order to evaluate the forecasting power of the models, we test the null hypothesis

$H_o: W_F = WA$

against

$H_1: W_F = W_A$

where

W_A is the actual observed weight in the study

W_F is the weight estimated by the model

The test statistic is based on students' t-distribution and is given by

$$t^* = \frac{W_A - W_F}{\sqrt{[\sigma^2_u\{1 + 1/n + (t_f - t)/\Sigma(t_f - t)\}]}}$$

where σ^2_u is the error variance, t_f is the age assumed in the the period of forecasting. The sample error variance s^2_u can be taken as estimate of σ^2_u. The test statistic t^* is distributed as students' t-distribution with n-2 degrees of freedom. Therefore, at α level of significance, reject H_o if

$$t* > t\alpha/2(n-2)$$

Otherwise accept.

Figure 4.10 depicts the survivorship threshold model, $Y_1(t)$, with data scanned on the same graph. It was clear

Table 4.38: The model predictions of observed minimum liveweights of calves in Rusinga Island

Age	Observed	Predicted	Log-transformed		Residual
(k)	minimum	minimum	Observed	Predicted	e_k
0	11.00	17.81	2.40	2.88	-0.48
1	18.64	18.70	2.93	2.93	0.00
2	20.91	19.64	3.04	2.98	0.06
3	23.64	20.62	3.16	3.03	0.14
4	24.55	21.65	3.20	3.08	0.13
5	17.73	22.73	2.88	3.12	-0.25
6	22.73	23.87	3.12	3.17	-0.05
7	24.09	25.07	3.18	3.22	-0.04
8	29.55	26.32	3.39	3.27	0.12
9	30.45	27.64	3.42	3.32	0.10
10	30.91	29.02	3.43	3.37	0.06
11	35.45	30.47	3.57	3.42	0.15
12	35.45	31.99	3.57	3.47	0.10
13	42.27	33.59	3.74	3.51	0.23
14	35.91	35.27	3.58	3.56	0.02
15	38.18	37.04	3.64	3.61	0.03
16	31.36	38.89	3.45	3.66	-0.22
17	36.36	40.83	3.59	3.71	-0.12
18	43.64	42.88	3.78	3.76	0.02
19	38.18	45.02	3.64	3.81	-0.16
20	50.91	47.27	3.93	3.86	0.07
21	42.73	49.64	3.75	3.90	-0.15
22	78.64	52.12	4.36	3.95	0.41
23	64.09	54.72	4.16	4.00	0.16
24	65.45	57.46	4.18	4.05	0.13
25	59.09	60.33	4.08	4.10	-0.02
26	89.55	63.35	4.49	4.15	0.35
27	62.27	66.52	4.13	4.20	-0.07
28	63.18	69.85	4.15	4.25	-0.10
29	62.27	73.34	4.13	4.30	-0.16
30	62.73	77.01	4.14	4.34	-0.21
31	64.55	80.86	4.17	4.39	-0.23
32	68.18	84.90	4.22	4.44	-0.22
33	111.82	89.15	4.72	4.49	0.23

Table 4.39: Correlations between estimates from low tick density farms

	p_k	m_k	m^*_k	r_k	z_k
u_k	0.08010	0.89570	0.92076	-0.04509	-0.16050
	(0.6796)	(0.0001)	(0.0001)	(0.8163)	(0.4335)
p_k		-0.06618	0.00208	0.08059	-0.20856
		(0.7330)	(0.9915)	(0.6777)	(0.3066)
m_k			0.98416	-0.22903	-0.28015
			(0.0001)	(0.2320)	(0.1657)

FIG 4.10: SCATTERPLOTS OF CALF WEIGHTS

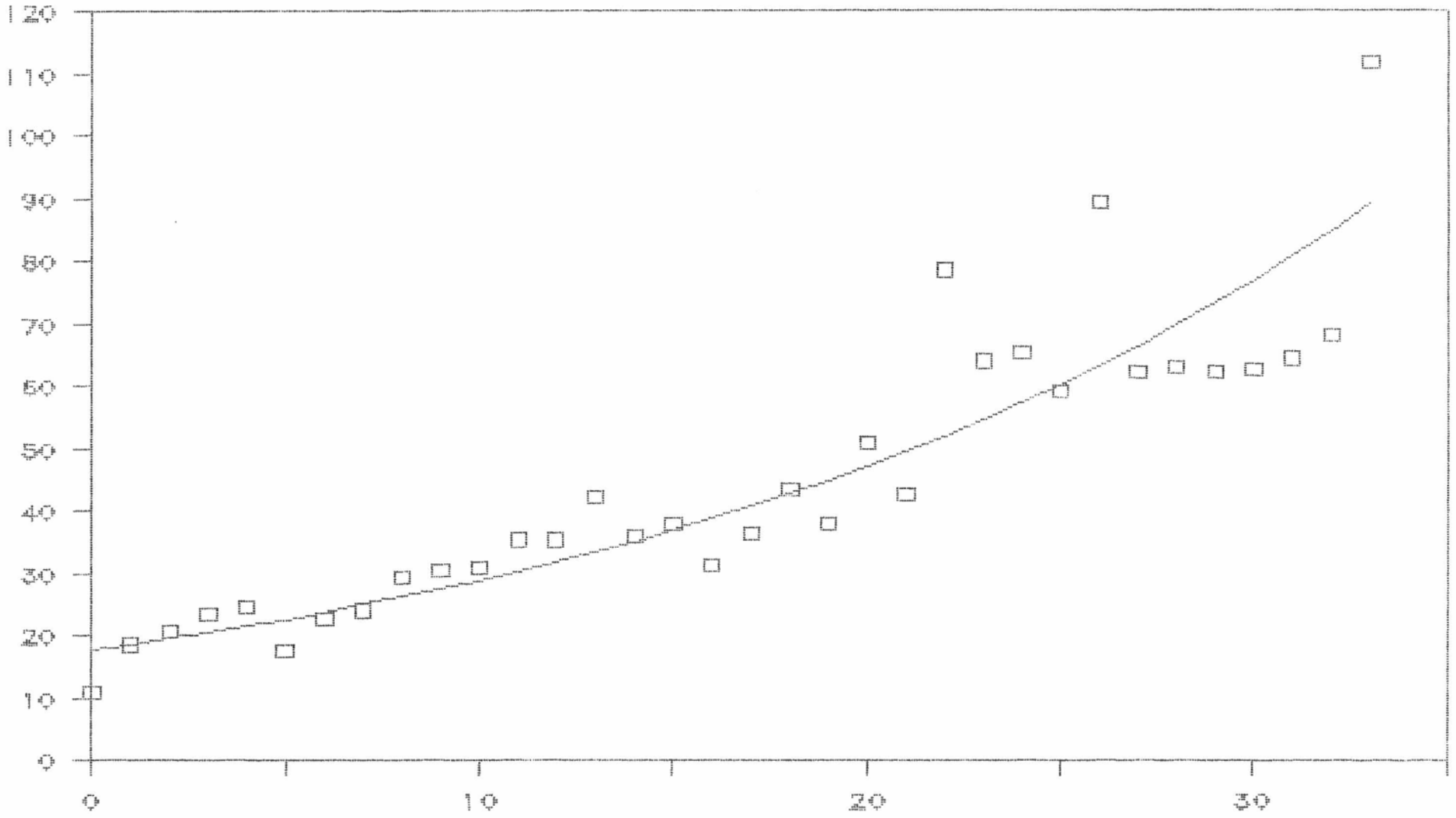


FIG 4.11: SCATTERPLOTS OF RESIDUALS

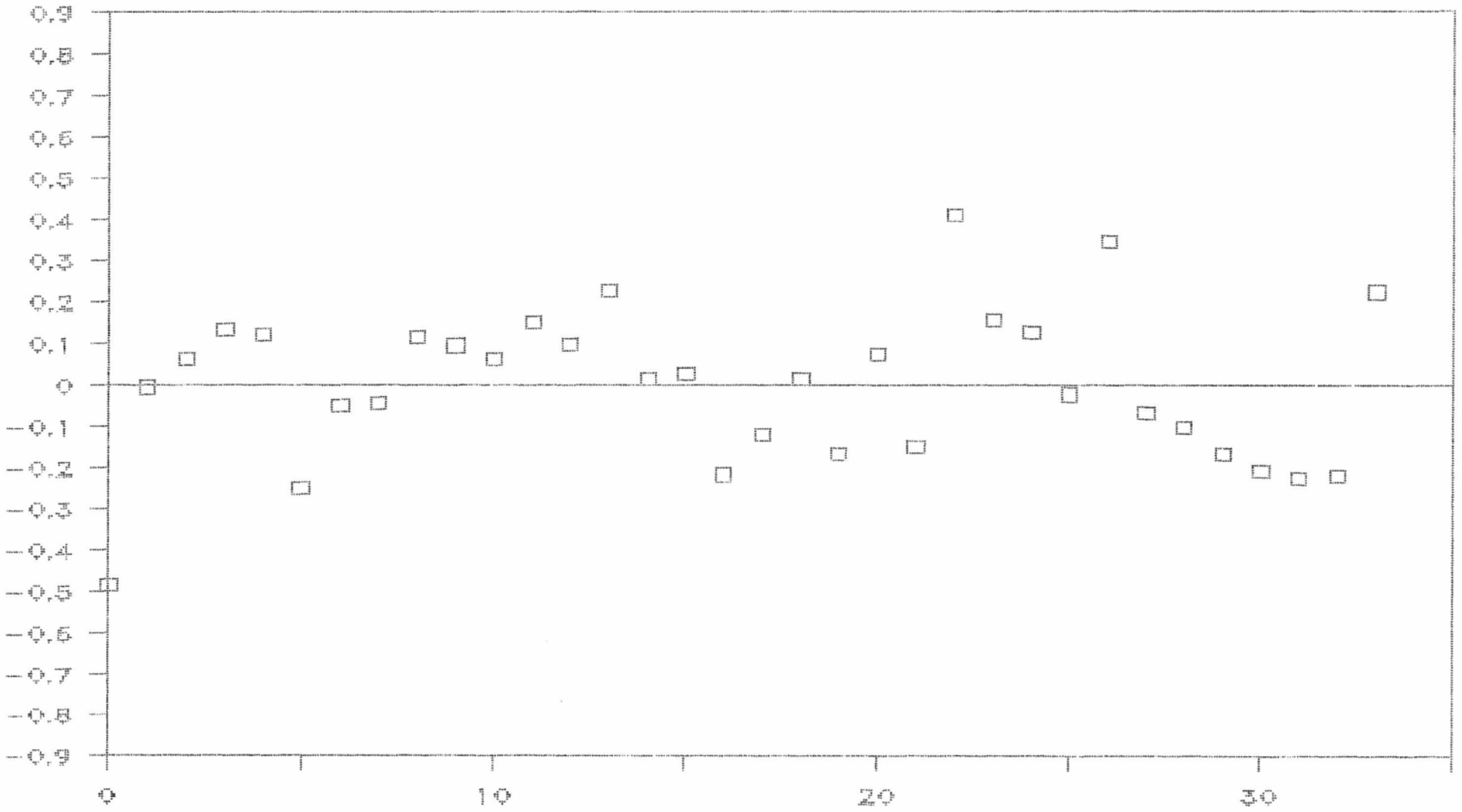


FIG 4.12: SCATTERPLOTS OF RESIDUALS

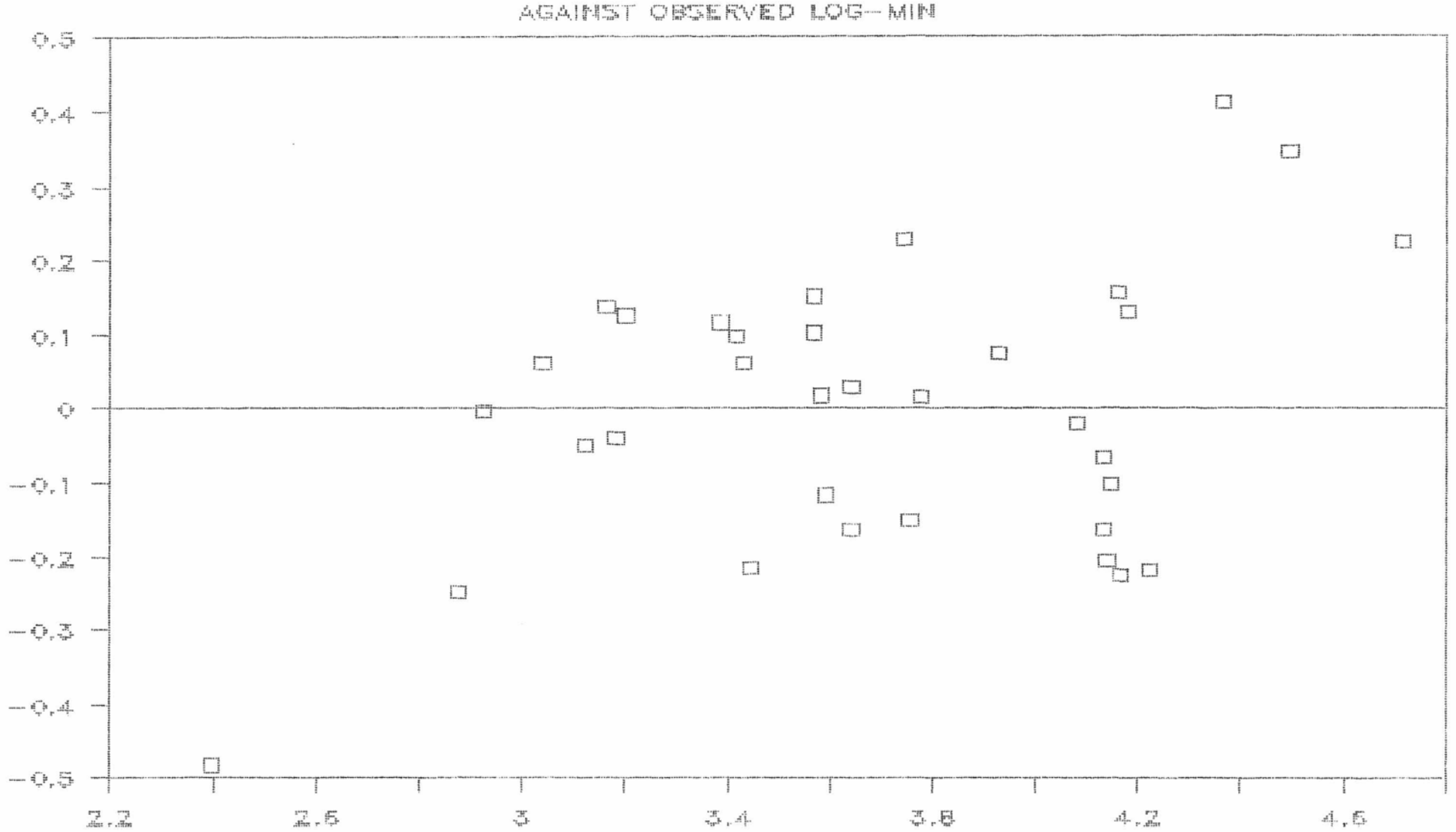
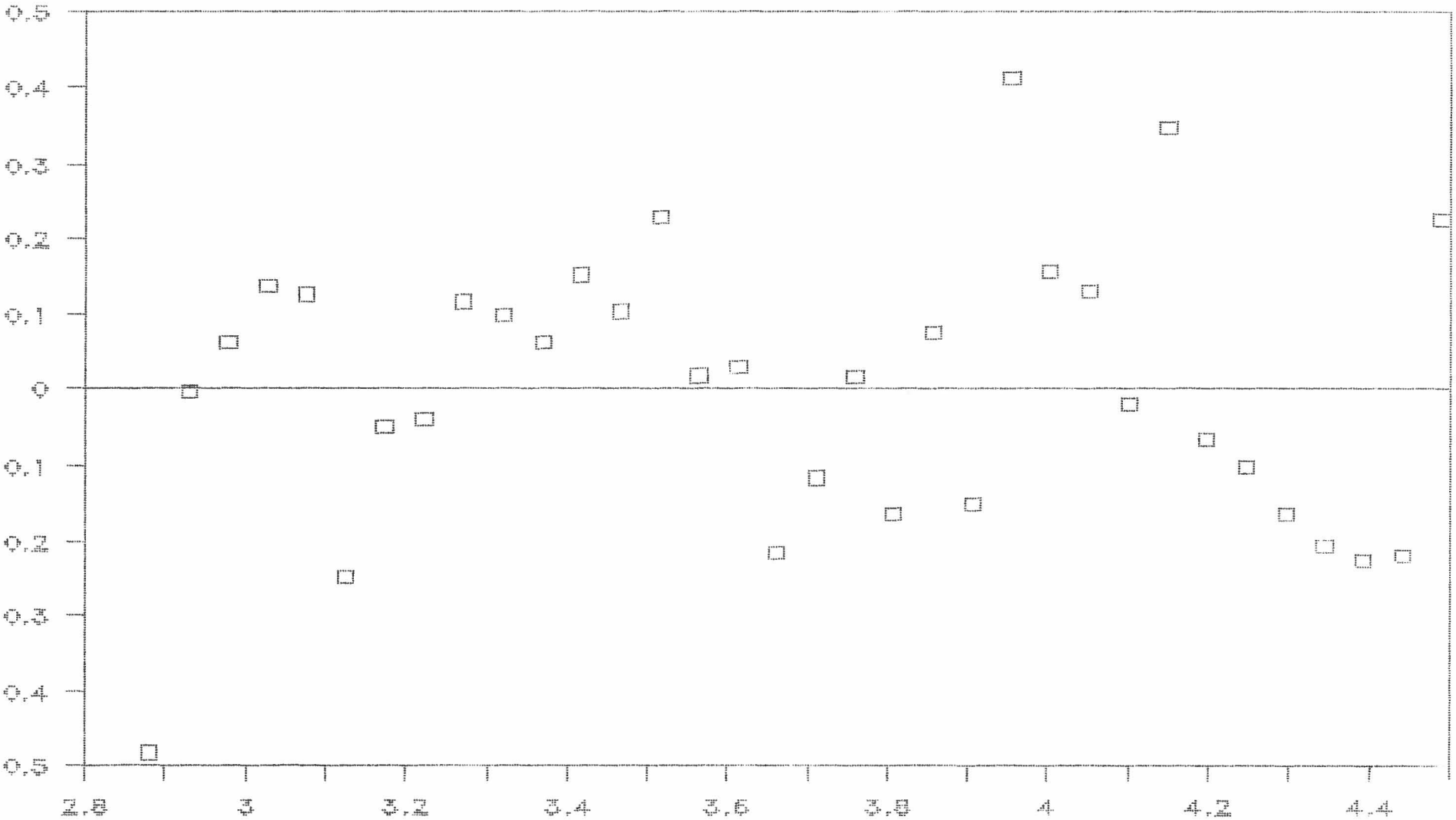


FIG 4.13: SCATTERPLOTS OF RESIDUALS

AGAINST PREDICTED LOG-MIN



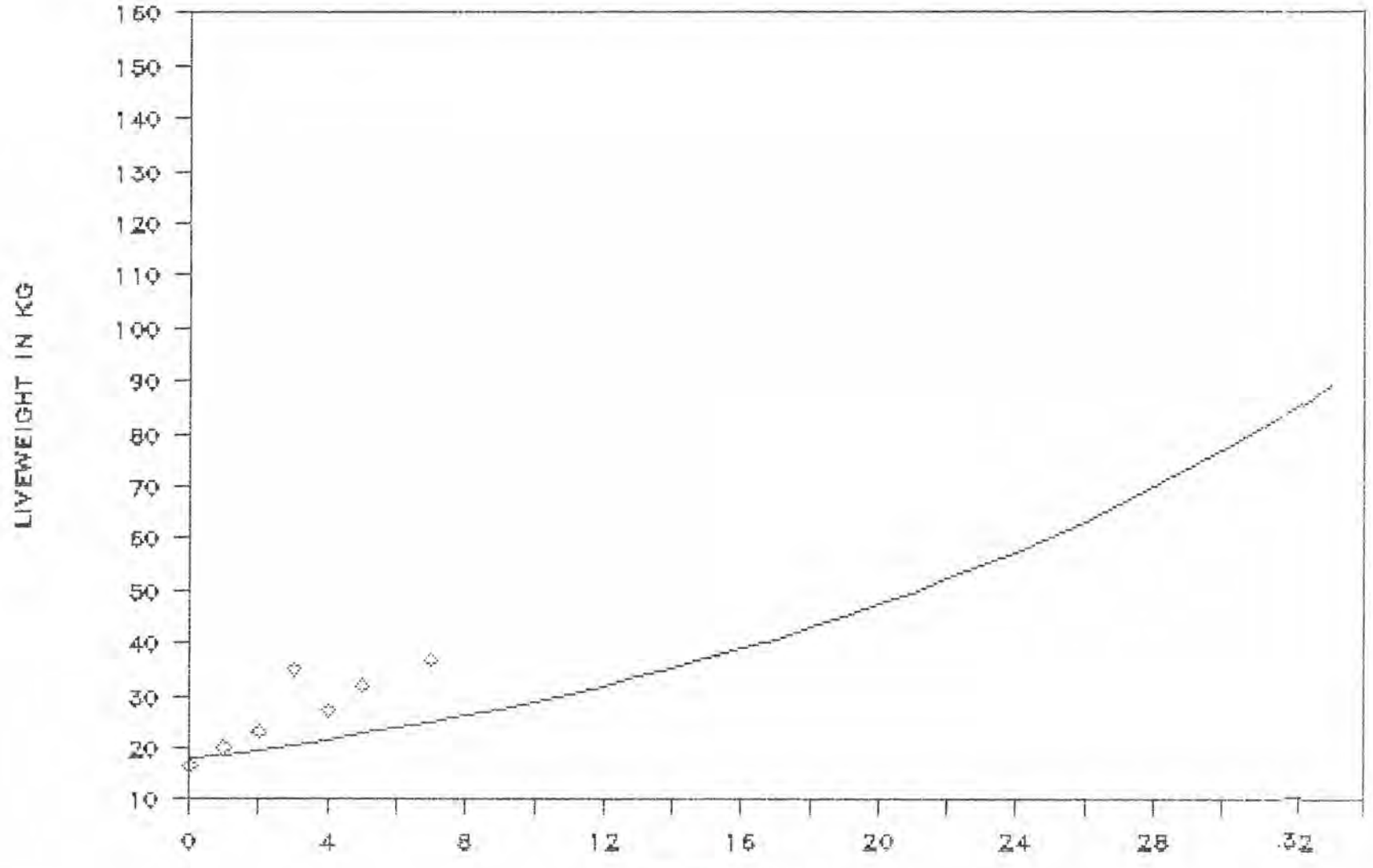
PREDICTED LOG-MIN

from the graph that the model $Y_1(t)$ was inefficient at age ($t = 0$). For example, $W_{min,0} = 17.81$ whereas the actual data are 11.00. This error was attributed to lack of sufficient data to be able to monitor the homogeneous growth being experienced by calves at this period of growth. In order to be able to develop an efficient predictive model for this growth interval, data should be collected at shorter intervals; possibly weekly.

Further, predictions of the models are reasonably close to the actual observations. This is illustrated in detail in Table 4.38. Due to lack of sufficient new field data, the Jack-knife validation method was used instead of traditional approaches (Gilchrist 1984). Figures 4.11 - 4.13 provided additional support of the forecasting power of the models since the plotted scattergram of the recursive residuals against age in months, indicated the absence of either heteroscedasticity or first-order autocorrelation. Figure 4.14 depicts a temporal distribution of one calf in relation to the threshold model.

When developing the threshold models, it is important that there should be at least one disease-free calf in the sample. It is on this basis that a reliable and accurate estimate of the maximum liveweight could be determined. It is only such an estimate that would be representative of the growth potential of the breed within the production system under study.

FIG 4.4: SURVIVORSHIP SCATTER OF CALF F6C390



In 1986 and 1987, ICIPE carried out an extensive epidemiological study on Rusinga Island, comprising of 200 cattle from the ten farms on the Island (ICIPE 1986 and 1987). The results of the study showed that 36% of the calves aged between 4 and 6 months had showed positive for *Theileria parva parva* culminating with a severe East Coast Fever (ECF) attack, though none of them died at the end of the first year. The same study showed that 9 out of 19 four- to six-months old calves showed positive for *B. bigemina* piroplasms representingabout 50% infection rate. About 70% of the calves carried *A. marginale* piroplasms. Similarly, about 70% of the calves carried *Trichostrongylus* spp of helminths.

Suppose we let X represent the number of disease-free calves and N , the total number of calves in an age category. Then

$$\Pr(X \geq x \,/\, N = n) = \sum_{x}^{n} p^{x}(1-p)^{n-x} \qquad (4.8)$$

$$\text{for } x = 0, 1, 2, 3, \ldots\ldots, n$$

$$= 0, \text{ otherwise}$$

The diseases caused by the above four parasites are the most prevalent on the Island (ICIPE 1986 and 1987). Here, a disease-free calf was defined as one that is tolerant or has none of all the four disease-causing organisms.

Based on the above studies, an attempt was made to determine the associated prevalence probabilities as follows. Let

A = the event that a calf is serologically positive to *T. parva parva* piroplasms

B = the event that a calf is serologically positive to ***B. bigemina*** piroplasms

C = a calf is serologically positive to ***A. marginale***

D = a calf is infested with an helminth

$Pr(A) = 0.36$

$Pr(B) = 0.50$

$Pr(C) = 0.70$

$Pr(D) = 0.70$

$Pr(AUBUC) = 0.904$ and $Pr(AUBUCUD) = 0.9712$. Hence, the probability that a calf was healthy was given by

$$Pr(\text{a calf is disease-free}) = Pr(AUBUCUD)^c$$
$$= 1 - 0.9712$$
$$= 0.0288$$

$$Pr(X \geq 1 / N = n) = (1 - 0.9712^n)$$

$$Pr(X \geq 2 / N = n) = Pr(X \geq 1/ N = n) - Pr(X = 1/ N = n)$$
$$= 1-0.9712^n-n(0.0028)(0.09712)^{n-1}$$

The results revealed that for the Rusinga situation, except for calves aged 32 and 33 months,

$$Pr(X \geq 1/ N = n) > 0.25$$

and which provided additional evidence in respect of the reliability of the survivorship threshold model, $Y_1(t)$.

4.8 Productivity Loss models

4.8.1 Decomposition of the growth rate components

The growth rate r_K is made up of the natural maximum growth potential of breed r_{NA} and the contribution of the causal factors. The causal factors are discussed in Chapter 1 as nutrition, ticks and tick-borne diseases, trypanosomiasis, helminths, climate, other diseases (e.g. salmonellosis, coccidia, cough, anthrax, etc), and management. Thus

$$r_K = r_{NA} - (r_N + r_{TT} + r_{TP} + r_H + r_C + r_{OD} + r_M)$$

where r_{NA} = optimal natural growth rate

r_N = growth rate retardation due to nutrition

r_{TT} = growth retardation due to ticks and tick-borne diseases

r_{TP} = growth retardation due to tsetse and trypanosomiasis

r_H = growth retardation due to helminths

r_C = growth retardation due to climate

r_{OD} = growth retardation due to other diseases

r_M = growth retardation due to management

Alternatively

$$r_K = (1 - \alpha_N - \alpha_{TT} - \alpha_{TP} - \alpha_H - \alpha_C - \alpha_{OD} - \alpha_M) r_{NA}$$

where α's are unkown weights measuring the impact of the corresponding factors on the natural growth rate potential of the animal, r_{NA}. All these weights are unknown and to

determine their estimates would require a lot of data. Since there were seven unkowns to be estimated, there should be seven equations as well for the estimates to be unique. It is also true that joint contributions from both vectors and diseases e.g. α_{TT} and α_{TP} could be split up to explain their relative contributions as

$$\alpha_{TT} = \alpha_{TK} + \alpha_{TBD}$$

where α_{TK} = effect of ticks alone

α_{TBD} = effect of tick-borne diseases and so on.

In the Rusinga situation, it was found that the only *Glossina* species, ***G. fuscipes fuscipes***, did not affect cattle productivity (ICIPE, 1986 , 1987). In tropical Africa, the relative impact of climate, management and other diseases are negligible compared to nutrition, ticks and tick-borne diseases, and helminths (Gavora, 1982; and Chigaru, 1984). Hence $\alpha_M << 0$, $\alpha_C << 0$, and $\alpha_{OD} << 0$. The impact of climate is usually felt indirectly as reflected in the animal nutrition.

Accordingly, ***A. marginale*** is said to be a disease of the adult cattle and generally occurs when an animal is at least 18 months old (WEAL, 1980). Majority of the calves in this study were below 18 months old. It was also noticed that calves found in endemic areas, the hosts do develop considerable resistance and immunity to both redwater and heartwater diseases (Akinboade, 1982; WEAL, 1980). Thus the most devastating tick-borne disease on the Island was ECF, and its corresponding vector ***R. appendiculatus*** was also the

most dominant tick. It was revealed by the Divisional Livestock Officer in Mbita that the major diseases of cattle in the area were the tick-borne diseases.

In the light of the above discussions, the growth rate composition on the Island reduces to:

$$r_K = r_{NA} - (r_N + r_{TT} + r_H) \qquad (4.9)$$

The ten farms were grouped according to their nutrition regime, helminths and tick burdens. Helminth infestation was assumed equal between the ten farms. In order to determine the impact of ticks and tick-borne diseases, two farms in the same nutrition group could be used, since the only possible deviation in growth rate would be attributed to differences in the tick loads. This fact could be explained by the following argument. From Equation (4.9), suppose the growth rates for two farms i and j for calves aged k months from the same nutrition group are given by $r_K(i)$ and $r_K(j)$, respectively. Then

$$dr_K(i,j) = \{r_K(i) - r_K(j)\}$$
$$= \{\alpha_{TT}(i) - \alpha_{TT}(j)\}r_{NA}$$

where $\alpha_{TT}(i)$ and $\alpha_{TT}(j)$ are the effects of $t_{Ki.}$ and $t_{K.j}$, respectively, on r_K. The effect of each tick on growth would be

$$E_i = \frac{dr_K(i,j)}{[t_{Ki.} - t_{K.j}]} \qquad (4.10)$$

In this study, for every age-group, the following parameter estimates were computed from the sample data:

u_k = mean age of calves aged k months on average.

$$= [\sum_{i}^{n_i} \sum_{j}^{n_j} u_k(i,j)]/n_i n_j$$

where

$u_k(i,j)$ = age of ith calf in the jth farm for calves aged k months on average.

m_k = mean tick pick-up burdens for calves aged k months.

$$= [\{\sum_{i} \sum_{j} t_{k+1}(i,j)\}/(n_i n_j) + \{\sum_{i'} \sum_{j'} t_k(i',j')\}/(ni'nj')]/2$$

where n_i = no. of calves at age k+1 months

n_j = no. of farms with calves at age k+1 months

n_i · = no. of calves at age k months.

n_j · = no. of farms with calves at age k months.

$m^*_k = \sqrt{m_k}$

r_k = growth rate of liveweight per day for calves aged k months (lbs per day).

$$= \frac{1}{n_j} \cdot \sum_{j}^{n_j} \sum_{i}^{n_i} \frac{1}{n_i} \cdot \frac{[w_{k+1}(i,j) - w_k(i,j)]}{[u_{k+1}(i,j) - u_k(i,j)]}$$

$z_k = \log_e(r_k + 0.78)$ for low tick density farms

$= \log_e(r_k + 2.35)$ for high tick density farms

$t_k(i,j)$ = tick pick-up burden for ith calf in jth farm for calves aged k months.

$w_k(i,j)$ = liveweight of ith calf in jth farm for age k months.

p_k = tick population dynamics index for calves at age k months.

$$= t_{k+1}../t_k..$$

where $t_k.. = (\sum_i^{n_i} \sum_j^{n_j} t_k(i,j))/n_i n_j$

$$t_{ki}. = \sum_j^{nj} t_k(i,j)/n_j$$

$$t_{k.j} = \sum_i^{ni} t_k(i,j)/n_i$$

4.8.2 Selection of model variables

4.8.2.1 Low tick density farms

The low tick density farms selected were Farms 21, 22, and 25. For a model to be useful and widely applicable, it should be based on parameters that could easily be computed from the sample data and are comprehensive. The estimates should be robust and the model should be a good fit to the data to enable accurate and precise predictions.

From practical point of view, the parameter estimates, u_k, p_k, m_k and r_k could be easily computed from the data. The parameters are simple and can be understood without difficulty even amongst the non-mathematically oriented scientists and managers. In the modelling exercise, u_k, p_k and m_k were the possible independent or predictor variables while the functions of the growth rate, r_k, were the

dependent or predicted variables.

Correlation analysis showed very significant positive correlations (P = 0.0001) between the pair, u_k and m_k. There were no significant correlations between p_k or z_{k+j} (j = 1, 2, 3) and any of the other variables. The growth rates r_k, r_{k+1}, r_{k+2}, r_{k+3} were also not sigificantly correlated with the other variables. The highest correlations between predictor variables and the dependent variables, z_{k+j} (j = 1, 2, 3) was

$$\text{corr}\ (m_k, z_k) = -0.28015$$

$$(P = 0.1657)$$

Based on the correlations analysis, although the correlations were not significant at 5% level of significance, it was evident that by z_k could each be justifiably used as a dependent variable. The growth rates r_{k+j} (j = 1, 2, 3) could not be used since they were not correlated to any of the predictor variables. The predictor variable m_k was significantly correlated to u_k (r = 0.89570 with P = 0.0001) but neither was correlated to p_k. The estimator of p_k could not therefore be used as a predictor variable since it was not correlated to any of the predicted variables. In order to eliminate multicollinearity the predictors should be orthogonalised (Anderson, 1958; and Morrison, 1967).

Table 4.40: Correlation coefficients between parameter estimates from high tick density farms

	m_k	m^*_k	r_k	r_{k+1}	r_{k+2}	r_{k+3}
u_k	0.93158	0.96147	0.46960	0.06399	-0.45069	-0.55015
	(0.0001)	(0.0001)	(0.0493)	(0.7947)	(0.0528)	(0.0147)
m_k		0.98759	0.38172	-0.46951	-0.62186	-0.75875
		(0.0001)	90.1180)	(0.0493)	(0.0059)	(0.0003)
m^*_k			0.46841	-0.39286	-0.54448	-0.68594
			(0.0499)	(0.1068)	(0.0195)	(0.0017)

Table 4.41: Correlation coefficients between parameter estimates from high tick density farms

	Z_k	Z_{k+1}	Z_{k+2}	Z_{k+3}
u_k	0.24492	0.02971	-0.49835	-0.59720
	(0.3434)	(0.9039)	(0.0299)	(0.0069)
m_k	0.18056	-0.55150	-0.66727	-0.78950
	(0.4880)	(0.0177)	(0.0025)	(0.0001)
m^*_k	0.21153	-0.46784	-0.59266	-0.71921
	(0.4151)	(0.0502)	(0.0095)	(0.0008)

Given the above correlation structure, it would only be possible to develop growth models based on z_k as the predicted variable, and u_k and m_k as predictors. We wish to determine the models

$$z_k = \alpha_o + \beta_o u_k + \tau_o m_k$$

where μ_o, α_o, and β_o are unknown parameters to be estimated from the sample.

4.8.2.2 High tick density farms

The high tick density farms used were Farms 27 and 28. It was found that the average age of the calves , u_k, was significantly correlated to m_k (hence m^*_k), r_k, r_{k+2}, r_{k+3} and z_{k+3}. The average tick burden m_k was strongly correlated to r_{k+1}, r_{k+2}, and r_{k+3} (hence z_{k+1}, z_{k+2}, and z_{k+3} as well). It was found that

$$\text{Corr}\,(u_k, r_{k+j}) < \text{Corr}\,(u_k, z_{k+j}) \qquad j = 1, 2, 3$$

and also

$$\text{Corr}\,(m_k, r_{k+j}) < \text{Corr}\,(m_k, z_{k+j}) \qquad j = 1, 2, 3$$

The above relationships therefore implied that a linear model developed by the OLS and based on z_{k+j} instead of r_{k+j} as the predicted variable would be more efficient. Finally,

$$\text{Corr}\ (u_k,\ z_{k+i}) < \text{Corr}\ (u_k,\ z_{k+j})$$

$$k = 1,\ 2,\ 3$$

$$\text{and}\quad i < j = 1,\ 2,\ 3$$

Thus a model with z_{k+j} would on the average perform better than one with z_{k+i} ($i < j = 1, 2, 3$). The correlations also provided indication of the presence of lags of two and three months between growth rates of calves in relation to tick burdens. Thus, tick burdens this month would manifest its influence two or three months to come, i.e.

$$r_{k+t} = \phi(u_k,\ m_k)$$

$$t = 2,\ 3$$

There was strong positive correlation between average age of calves and average tick pick-up, i.e. u_k and m_k ($P = 0.0001$), suggesting presence of multicollinearity and calls for orthogonalization before applying the OLS method in determining model parameter estimates.

4.8.3 Development of the models

4.8.3.1 Low tick density farms

4.8.3.1.1 Multicollinearity

In Table 4.39, correlation between the explanatory variables u_k and m^*_k was found to be very high and statistically significant ($r = 0.92076$, with $P = 0.0001$).

This was a clear manifestation of the presence of multicollinearity. R^2 was found to be 0.2380 and 0.3636, respectively. Thus according to Klein (1963), for both models,

$$r^2_{uk.m*k} > R^2_{zk.uk.m*k}$$

confirming the presence of multicollinearity.

Applying student's t-test, the correlations were found to be statistically significant (Table 4.39). Thus there was strong evidence of multicollinearity.

4.8.3.1.2 The Models

In order to eliminate the multicolliearty problem, the dependent variable z_k was regressed on the principal components of the regressors (Johnston, 1972; Koutsoyiannis, 1973). For mathematical convenience in order to enable logarithmic analysis, a constant h = 0.78 was added to all the observed growth rates, r_k (k = 1, 2, 3,.....).

After several trials with z_k, u_k and m_k or their functions, it was found that using $m*_k$ ($m*_k = \sqrt{m_k}$) instead of m_k provided a better fit. When m_k was used R^2 was 0.1592 (P = 0.1049) while with $m*_k$, R^2 was 0.2380 (P = 0.0111) indicating a substantial improvement in its forecasting power. The eigenstructure analysis produced the values in Table 4.42. The corresponding principal components were:

$$Y_1 = 0.7071u_k + 0.7071m*_k$$

$$Y_2 = -0.7071u_k + 0.7071m*_k$$

Table 4.42: Eigenvalues of principal components of u_k and m^*_k

Component	Eigenvalue	%contribution	%cumumlative
Y_1	1.92076	96.04	96.04
Y_2	0.07924	3.96	100.00

Table 4.43: Analysis of variance for goodness-of-fit of model $z_k = \pi_o + \pi_1 y_1 + \pi_2 y_2$

Source	df	SS	MSS	F	Pr > F
Model	2	1.40358	0.70179	5.373	0.0111
Error	26	3.39625	0.13063		

$R^2 = 0.2380$

Table 4.44: Parameter estimates and their standard errors

model $z_k = \pi_o + \pi_1 y_1 + \pi_2 y_2$

Parameter	df	Estimate	sd	Pr > |T|
π_o	1	0.783515	0.36105	0.0393
π_1	1	-0.123193	0.03805	0.0033
π_2	1	-0.195193	0.06446	0.0055

sd = standard error of estimate

Table 4.45: Parameter estimates and their standard errors

model $z^*_k = \pi_o + \pi_1 y_1 + \pi_2 y_2$

Parameter	df	Estimate	sd	Pr > |T|
π_o	1	2.11210	0.50327	0.0003
π_1	1	-0.20929	0.05320	0.0006
π_2	1	-0.31520	0.09004	0.0018

Table 4.46: The forecasting power of the model

$$z_k = 0.78352 + 0.05091u_k - 0.22513m^*_k$$

Age (k)	m*k	z_k(o)	z_k(p)	e_k	e^2_k	r_k(o)	r_k(p)
4	6.1	-0.19031	-0.37856	0.18824	0.03544	0.3267	0.18489
5	5.3	-0.12783	-0.15108	0.02325	0.00054	0.3800	0.35978
6	4.3	-0.20053	0.11024	-0.31077	0.09658	0.3183	0.61655
7	5.7	-0.23851	-0.14158	-0.09693	0.00940	0.2878	0.36799
8	7.0	-0.34249	-0.38029	0.03780	0.00143	0.2100	0.18367
9	7.7	-0.84863	-0.48315	-0.36548	0.13358	-0.0720	0.11684
10	9.5	-0.51919	-0.83722	0.31803	0.10114	0.0950	-0.06708
11	8.1	-0.26788	-0.48197	0.21409	0.04584	0.2650	0.11757
12	7.8	-0.52340	-0.36820	-0.15520	0.02409	0.0925	0.19198
13	7.9	-0.47000	-0.32303	-0.14697	0.02160	0.1250	0.22395
14	8.1	-0.30585	-0.32924	0.02339	0.00055	0.2365	0.21947
15	7.9	-0.26919	-0.24045	-0.02874	0.00083	0.2640	0.28627
16	8.4	-0.10270	-0.28684	0.18414	0.03391	0.4024	0.25063
17	8.7	-0.28995	-0.32073	0.03078	0.00095	0.2483	0.22561
18	9.4	-0.19845	-0.42695	0.2285	0.05221	0.3200	0.15249
19	7.8	-0.23572	-0.00028	-0.23544	0.05543	0.2900	0.49971
20	10.2	-1.51413	-0.50242	-1.0117	1.02354	-0.2800	0.10506
21	10.2	-0.15665	-0.43828	0.28162	0.07931	0.3550	0.14514
22	9.5	0.83725	-0.24405	1.0813	1.16921	1.8100	0.28344
23	10.3	-0.26136	-0.37049	0.10913	0.01191	0.2700	0.19039
24	10.4	-0.35954	-0.32991	-0.02962	0.00088	0.1980	0.21898
25	11.3	-0.67609	-0.48330	-0.19279	0.03717	0.0086	0.11674
26	12.9	-0.36528	-0.78991	0.42463	0.18031	0.1940	-0.04612
27	11.3	-0.64112	-0.37499	-0.26614	0.07083	0.0267	0.18729
28	11.4	-0.35667	-0.36476	0.00809	0.00007	0.2000	0.19435
29	11.5	-0.32021	-0.33738	0.01717	0.00029	0.2260	0.21363
30	11.5	-0.28236	-0.28646	0.0041	0.00002	0.2540	0.25090
31	11.5	-0.11811	-0.22774	0.10963	0.01202	0.3886	0.29632
33	15.4	-1.44817	-1.00410	-0.44407	0.19720	-0.2650	-0.13363

(o) = observed (p) = predicted by the model

Table 4.47: The forecasting power and test of first order autocorrelations of the model

$z^*_k = 2.11210 + 0.07489u_k - 0.37087m^*_k$

Age (k)	$r_k(o)$	$r_k(p)$	$z^*_k(o)$	$z^*_k(p)$	e_k	e^2_k
4	0.3267	0.22302	0.26979	0.16185	0.10794	0.01165
5	0.3800	0.71514	0.31639	0.52759	-0.21120	0.04461
6	0.3183	2.45477	0.26196	0.94911	-0.68715	0.47218
7	0.2878	0.71042	0.23229	0.52530	-0.29300	0.08585
8	0.2100	0.19142	0.14627	0.12308	0.02319	0.00054
9	-0.0720	0.07474	-0.42868	-0.05535	-0.37333	0.13937
10	0.0950	-0.12345	-0.01938	-0.64760	0.62822	0.39466
11	0.2650	0.06616	0.20874	-0.07137	0.28010	0.07846
12	0.0925	0.17911	-0.02368	0.10707	-0.13075	0.01710
13	0.1250	0.23219	0.02956	0.17250	-0.14295	0.02043
14	0.2365	0.21583	0.17744	0.15330	0.02414	0.00058
15	0.2640	0.34978	0.20767	0.29058	-0.08291	0.00687
16	0.4024	0.26168	0.33454	0.20519	0.12935	0.01673
17	0.2483	0.20519	0.19066	0.14037	0.05029	0.00253
18	0.3200	0.08121	0.26356	-0.04358	0.30714	0.09433
19	0.2900	1.01611	0.23450	0.65031	-0.41581	0.17290
20	-0.2800	0.01191	.	-0.18587	.	.
21	0.3550	0.05694	0.29516	-0.08918	0.38434	0.14772
22	1.8100	0.27750	0.84897	0.22179	0.62718	0.39335
23	0.2700	0.10930	0.21401	0.00453	0.20948	0.04388
24	0.1980	0.14688	0.13144	0.06240	0.06904	0.00477
25	0.0086	0.00628	-0.19370	-0.19927	0.00557	0.00003
26	0.1940	-0.13578	0.12638	-0.71334	0.83972	0.70513
27	0.0267	0.08390	-0.15213	-0.03879	-0.11334	0.01285
28	0.2000	0.08834	0.13394	-0.03093	0.16487	0.02718
29	0.2260	0.10971	0.16534	0.00521	0.16013	0.02564
30	0.2540	0.15929	0.19691	0.08010	0.11682	0.01365
31	0.3886	0.22818	0.32345	0.16786	0.15559	0.02421
33	-0.2650	-0.19169	-2.95978	-1.12903	-1.83075	3.35165

The components Y_1, and Y_2 are orthogonal to each other (Anderson, 1958; Morrison, 1979).

The fitted model

$$z_k = \pi_o + \pi_1 y_1 + \pi_2 y_2$$

had its parameter estimates as given in Table 4.44. Hence the linear model significantly explained the variation in the sums of squares due to regression ($P = 0.0111$). All the parameter estimates were significantly different from zero ($P << 0.05$).

Hence the model is:

$$z_k = 0.78352 - 0.123193y_1 - 0.195193y_2 \qquad (4.11)$$

$$-\infty < y_1, y_2 < \infty$$

If reformulated in terms of the original regressor variables, the model becomes,

$$z_k = 0.78352 + 0.05091u_k - 0.22513m^*_k \qquad (4.12)$$

$$0 < u_k, m^*_k < \infty$$

$$= 0, \text{ otherwise}$$

Thus

$$r_k = -0.78 + \exp(z_k) \qquad (4.13)$$

$$= -0.78 + \exp(0.78352 + 0.05091u_k - 0.22513m^*_k)$$

Applying a further logarithmic transformation on z_k, that is,

$$z^*_k = \log_e(z_k)$$

$$= \log_e[\log_e(r_k + 0.78) + 1.5] \qquad (4.14)$$

and using z^*_k instead of z_k as a predictor variable produced a better fit since $R^2 = 0.3636$, with $P = 0.0013$.

The final model becomes

$$z^*_k = 2.11210 - 0.20929*y_1 - 0.31520*y_2 \qquad (4.15)$$

$$= 2.11210 + 0.07489*u_k - 0.37087*m^*_k$$

and

$$r_k = -0.78 + \exp(\exp(2.11210 + 0.074898*u_k - 0.37087*m^*_k)+1.5)$$

4.8.3.1.3 Test of autocorrelations

For Model (4.12), Durbin-Watson test statistic d^* was found to be 1.79212. For n = 29 and k = 2, the 95% confidence limits are d_L = 1.27 and d_U = 1.56. Since

$$d^* > d_U$$

according to Durbin-Watson test, there was no significant first order autocorrelation.

For Model (4.15), d^* = 1.8946. Therefore at 5% level of significance, there was no evidence of the presence of first order autocorrelation.

4.8.3.2 High tick density farms

4.8.3.2.1 Multicollinearity

Multicollinearity was present in the data (r = 0.96147, with P = 0.0001). For the models (4.18) and (4.21), R^2 were found to be 0.3380 and 0.5452, respectively. Thus

$$r^2_{uk.m^*k} = 0.9244 > R^2_{zk+j.uk.m^*k}$$

for all j = 2, 3, revealing the gravity of multicollinearity in the data. With student's t-test, the correlation

Table 4.48: Parameter estimates and their standard errors model $z_{k+2} = \alpha_2 + \beta_2 y_1 + \tau_2 y_2$

Parameter	Estimate	sd	Pr > T
α_2	2.34397	0.56486	0.0009
β_2	-0.11282	0.04009	0.0131
τ_2	0.24303	1.13549	0.0930

Table 4.49: Parameter estimates and their standard errors model $z_{k+3} = \alpha_3 + \beta_3 y_1 + \tau_3 y_2$

Parameter	Estimate	sd	Pr > T
α_3	2.88904	0.55465	0.0001
β_3	-0.15770	0.03936	0.0011
τ_3	0.33087	0.13304	0.0251

Table 4.50: Forecasting power and test of first order autocorrelation of the model

$$z_{k+2} = 2.34397 + 0.09208u_k - 0.25163m^*_k$$

Age	m^*_k	$r_{k+2}(o)$	$r_{k+2}(p)$	$z_{k+2}(o)$	$z_{k+2}(p)$	e_k
2	5.07	1.97	2.99	0.90	1.25	-0.35
3	6.26	2.16	2.35	0.98	1.05	-0.07
4	7.19	1.85	1.97	0.85	0.90	-0.05
5	8.92	1.98	1.25	0.91	0.56	0.35
6	6.92	1.98	2.67	0.91	1.15	-0.25
7	8.22	1.96	2.01	0.90	0.92	-0.02
8	7.85	2.02	2.52	0.92	1.11	-0.18
9	8.78	1.99	2.12	0.91	0.96	-0.05
10	9.80	2.09	1.72	0.95	0.80	0.15
11	10.55	1.84	1.52	0.85	0.70	0.15
12	10.04	2.20	2.01	0.99	0.92	0.07
13	11.79	2.16	1.28	0.98	0.58	0.40
14	11.28	2.08	1.71	0.95	0.80	0.15
15	11.42	2.31	1.84	1.03	0.85	0.18
16	13.08	2.54	1.19	1.11	0.53	0.59
17	14.50	1.84	0.80	0.85	0.26	0.59
18	14.38	0.00	0.97	-0.69	0.38	-1.08
19	16.69	0.00	0.40	-0.69	-0.11	-0.59

Table 4.51: Forecasting power and test of first order autocorrelation of the model $z_{k+3} = 2.88904 + 0.12245u_k - 0.34547m^*_k$

Age (k)	m^*_k	r_{k+3}(o)	r_{k+3}(p)	z_{k+3}(o)	z_{k+3}(p)	e_k
2	5.1	2.16	3.48	0.978	1.381	-0.403
3	6.3	1.85	2.49	0.854	1.095	-0.240
4	7.2	1.98	1.95	0.908	0.896	0.012
5	8.9	1.98	1.02	0.908	0.421	0.487
6	6.9	1.96	2.93	0.900	1.233	-0.333
7	8.2	2.02	1.97	0.924	0.906	0.019
8	7.8	1.99	2.68	0.912	1.158	-0.246
9	8.8	2.09	2.11	0.952	0.960	-0.008
10	9.8	1.84	1.57	0.850	0.727	0.123
11	10.6	2.20	1.30	0.993	0.591	0.403
12	10.0	2.16	1.93	0.978	0.889	0.089
13	11.8	2.08	1.01	0.948	0.409	0.538
14	11.3	2.31	1.53	1.033	0.707	0.326
15	11.4	2.54	1.68	1.112	0.781	0.331
16	13.1	1.83	0.89	0.846	0.331	0.515
17	14.5	0.00	0.46	-0.693	-0.040	-0.653
18	14.4	0.00	0.63	-0.693	0.126	-0.819
19	16.7	0.00	0.08	-0.693	-0.550	-0.143

(o) observed (p) predicted

coefficient, $r_{uk,m*k}$, between the explanatory variables was highly significantly different from zero. Therefore multicollinearity was considered harmful.

4.8.3.2.2 The Models

Principal components yielded eigenvalues $\delta_1 = 1.96147$ and $\delta_2 = 0.03853$. These two values contributed about 98.07% and 1.93%, respectively of the total variance in the data. The two components were:

$$y_1 = 0.7071u_k + 0.7071m^*_k$$

$$y_2 = 0.7071u_k - 0.7071m^*_k$$

We wish to determine the models

$$z_{k+j} = \alpha_j + \beta_j y_1 + \tau_j y_2$$

$$= \alpha_j + \beta^*_j u_k + \tau^*_j m^*_k \qquad (4.16)$$

$$j = 2, 3$$

Thus for j = 2, the estimates of model parameters are given in Table 4.48. Hence the model becomes

$$z_{k+2} = 2.34397 - 0.11282y_1 + 0.24303y_2 \qquad (4.17)$$

$$(R^2 = 0.3380 \text{ and } P = 0.0177)$$

i.e.

$$z_{k+2} = 2.34397 + 0.09208u_k - 0.25163m^*_k \qquad (4.18)$$

The second model was

$$z_{k+3} = \alpha_3 + \beta_3 y_1 + \tau_3 y_2 \qquad (4.19)$$

The OLS fitted model was

$$z_{k+3} = 2.88904 - 0.15770y_1 + 0.33087y_2 \qquad (4.20)$$

$$(R^2 = 0.5452, \quad P = 0.0011)$$

i.e

$$z_{k+3} = 2.88904 + 0.12245u_k - 0.34547m^*_k \qquad (4.21)$$

Tests of significance of the estimates are given in Table 4.49.

4.8.3.2.3 Tests of autocorrelation

For Model (4.18),

$d^* = 1.4769$

Here n = 18 and k = 2, the limits are $d_L = 1.05$ and $d_U = 1.53$. Since $d_L < d^* < d_U$, the test was inconclusive. However, since $(4-d^*) > d_U$ holds, the sample data did not provided no evidence to reject the null hypothesis and so there was no first order autocorrelation.

For Model (4.21), $d^* = 1.3172$. In this case, since $d_L < d^* < d_U$, the test was inconclusive. However, on the basis of the inequality $(4-d^*) > d_U$ there was no evidence from the sample to show the presence of first order autocorrelation.

4.8.3.3 Impact of ticks on calf growth

From the data in Table 4.46, an attempt was made to analyse the probability distribution of the observed growth rates, $r_k(o)$. Looking at the data, it was obvious that the negative values of $r_k(o)$ were inconsistent with the rest of the data. Further, the growth rate of calves aged 22 months

was disproportionately large in the light of its immediate preceding and following age-groups. It portrayed the characteristics of a typical outlier.

Ignoring the four data, development of a probability distribution was attempted. The grouped frequency table for the data was compiled as shown below.

Growth rate class (lbs/day)	Age (months)	mean tick burden	Frequency	Relative frequency
< 0.009	25	128	1	0.04
0.009 - 0.059	27	128	1	0.04
0.059 - 0.109	9	76	2	0.08
0.109 - 0.159	13	62	1	0.04
0.159 - 0.209	26	135	3	0.12
0.209 - 0.259	20	91	5	0.20
0.259 - 0.309	15	65	5	0.20
0.309 - 0.359	12	62	4	0.16
0.359 - 0.409	17	77	3	0.12
Total			25	1.00

The modal class fell in the growth rate range from 0.209 - 0.309 lbs per day, and which was experienced by calves aged between 15 - 20 months old. The modal class represented about 40% of the observations. And about 68% of the observations fell between 0.159 and 0.359 lbs per day. In the modal class, calves experienced average tick burdens of about 65 - 91 ticks per calf. The more general pattern was that the youngest calves and which also had the lowest

tick loads experienced the highest growth rates. H ence given that the sample of calves were representative, the probability of getting calves within growth rates between 0.159 - 0.359 lbs per day (i.e. 0.072 - 0.163 kgs per day) would be 0.68 and would tend to be mainly the younger calves.

The above results were comparable and consistent with those found in previous studies. For example, Francis (1960) had shown that *B. taurus* heifers with tick loads of 73 and 109 ticks, gained weight at about 0.252 and 0.088 lbs per day, respectively. On the other hand, Little (1963) in his experiments showed that with tick burdens of 36.7 and 60 ticks, weight gains were 0.158 and 0.196 lbs per day, respectively. The slightly lower weight gains experienced in these two experiments could be attributed to the low resistance of the Hereford breed (*B. taurus*) relative to the zebu (*B. indicus*). Moreover, in the two experiments, a different tick species *B. microplus* was applied. Since the two experiments were conducted on cattle alone as opposed to the Rusinga situation where cattle, goats and sheep were reared together in the farmers setting, it was possible that the Hereford calves had greater tick challenges continuously than their Rusinga counterparts.

Based on the observed growth rates experienced by the majority i.e. was between 0.159 - 0.359 lbs per day, the mean

Table 4.52: Validation of parameter estimates of the models

Model	α	β	τ
1. Low tick density:			
$z_k = \alpha_k + \beta_k u_k + \tau_k m^*_k$	0.78352	0.05091	-0.22513
$z^*_k = \alpha_k + \beta_k u_k + \tau_k m^*_k$	2.11210	0.07489	-0.37087
2. High tick density:			
$z_{k+2} = \alpha_{k+2} + \beta_{k+2} u_k + \tau_{k+2} m^*_k$	2.34397	0.09208	-0.25163
$z_{k+3} = \alpha_{k+3} + \beta_{k+3} u_k + \tau_{k+3} m^*_k$	2.88904	0.12245	-0.34547

annual weight for the calves would be between 26 - 60 kgs. An experiment conducted with zebu cattle grazing on natural vegetation in Madagascar showed that the annual liveweight gain was around 40 - 70 kgs which mainly occurred during the rainy season (Granier *et al*, 1968; and de Reviers, 1970). Hence the two sources of information were comparable. The real differences between the two situations could be attributed to feed nutrients in relation to the growing season of the calves.

4.8.4 Model validation

4.8.4.1 The process of validation

Validation of a model takes several forms. In this study, two methods of model validation were adopted. First, the models were tested for the form of their functional relationships. Second, the estimates were tested for their ability to simulate the coresponding parameters in the light of the '*a priori*' biological mechanisms behind the processes.

4.8.4.2 The functional form of the models

The biological theory on the effect of ticks on cattle productivity does not explicitly state whether a single-equation or multi-equation model was most

appropriate. As was shown in Fig 1.1, many factors claim their toll on calf growth simultaneously or sequentially. The Models (4.12), (4.18) and (4.21) were developed from data originating from farms in which each group had same nutrition regime. The idea behind this selective procedure was to ensure that the models were not mis-specified and so minimising the possible errors of model specification. Since all the important direct causal factors in the two groups of farms were kept homogeneous within groups, it was justifiable to use simple single-equation models within such groups. Hence the process of differential grouping enabled improved knowledge of the factors which were operative in the production system of Rusinga, and which would otherwise be reflected by the complexity of the models.

It was evident from the Models (4.12), (4.18) and (4.21) that the relationship between calf growth rates as dependent variable, and tick burden were exponentially related. In all the cases, the functional relationship was:

$$r_{k+j} = \exp(\alpha_j + \beta_j u_k + \tau_j m^*_k) \qquad (4.22)$$

$$j = 1, 2, 3$$

$$k = 1, 2, 3, 4, \ldots\ldots, K$$

where α_j, β_j and τ_j are parameters. The estimates of the parameters were tested and all were found to be statistically significant from zero with $P < 0.001$ thus confirming their reliability.

The absence of autocorrelation in the data as revealed by the Durbin-Watson test was also a confirmation of the

adequacy of the functional form of the models (Hu, 1973; and Koutsoyiannis, 1973).

4.8.4.3 The biological 'a priori' criteria for model parameters

The developed growth model in section 4.7.1, revealed that calf growth was best simulated by the modified Gompertz Model given by Equation (4.2). Therefore after age g, growth rate declined asymptotically towards zero. Intuitively such a growth characteristic was expected. Ecologically, ticks like other parasites reduce cattle productivity and so the estimates for their contribution to growth should be negatively correlated to the growth parameters. It was expected that the parameter estimates for the mean number of adult tick burdens should have opposite signs in relation to growth rate of the calves.

In Table 4.52 are the parameter estimates measuring the contribution of each of the explanatory variables in the models. These estimates were tested for their statistical significance as shown in Tables 4.44, 4.45, 4.48 and 4.49. Thus the models were uniquely defined and adequately fitted the given data. The values of α and which measures the intercept, were expected to increase in step with increasing age. The results confirmed that this was true since

$$\alpha_i < \alpha_j ,$$

for all the models z_{k+i} and z_{k+j}, where $i < j = 1, 2, 3$. All

of the β_i estimates (i = 0, 1, 2, 3) were expected to be positive, a fact which was confirmed by the results in Table 4.52. The parameter τ which defined the contribution of adult tick burdens in calf growth was negative in all the models. This implied that growth rate declined as the levels of adult tick burdens increased. The estimates of τ_i (i = 0, 1, 2, 3) were all valid since they possessed the expected signs of the appropriate parameters. It was also clearly identified in the results that there was a strong linear relationship between the estimates of τ_k's and j's, the lags, such that the higher the lag period, the greater the parameter. The implication of this statement was that the impact of adult ticks on calf growth was more pronounced with time lag. In this case, the lowest value was τ_1 = -0.22513 and the highest was τ_3 = -0.34547. Thus for Models (4.12), (4.18) and (4.21), on the average, given the mean age of calves, the impact of one tick on the growth was given by Equation (4.10).

Further, the absence of autocorrelations in the models also confirmed that the models included all the important variables (Hu, 1973; Johnston, 1972; and Koutsoyiannis, 1973). It is true that nutrition and helminths, like all the other causal factors act in the same direction on growth rate. The implication of these findings were that within a group of farms, nutrition and helminths, and other causal factors were unifrom for each in influencing growth rates of the calves.

4.8.4.4 Sensitivity analysis

Let us take Model (4.12). Suppose we wish to know to what extent would changes in mean tick burdens in steps of 10, 20, 40, 80, 160, and 320, say, affect growth rate of calves within a production system like that on the Island? Or given mean age of calves, how much change would those changes in tick burdens inflict on growth rate of the calves?

Adult tick burdens varied mainly between 10 and 200 ticks per calf. Here, sensitivity analysis was done for m_K, the average tick pick-up burdens within the range. Table 4.53 contains the details. From the results, when tick burdens doubled from 50 to 100 (100%) the growth rates changed by about 58.8% and 56.6% for the ten- and fifteen-month old calves, respectively. Two important features could be identified from the results. As was expected, the analysis revealed high fluctuations in the level of growth rates for the younger calves and which steadily declined as age and adult tick burdens the calves

Table 4.53: Growth rate fluctuations in response to adult tick burdens on calves based on model (4.18)

Age	Tick burden levels (m_k)					
(k)	0	10	20	50	100	200
1	10.9	4.7	3.2	1.4	0.4	-0.17
2	12.0	5.2	3.6	1.6	0.5	-0.14
3	13.2	5.7	4.0	1.8	0.6	-0.11
4	14.6	6.3	4.4	2.0	0.7	-0.07
5	16.0	7.0	4.9	2.3	0.8	-0.03
6	17.6	7.7	5.4	2.6	1.0	0.02
7	19.4	8.5	5.9	2.9	1.1	0.07
8	21.3	9.3	6.6	3.1	1.3	0.12
9	23.4	10.3	7.2	3.5	1.4	0.18
10	25.7	11.3	8.0	3.9	1.6	0.25
11	28.2	12.5	8.8	4.3	1.8	0.32
12	31.0	13.7	9.7	4.8	2.0	0.40
13	34.0	15.1	10.7	5.3	2.3	0.48
14	37.3	16.6	11.8	5.9	2.6	0.56
15	41.0	18.2	13.0	6.5	2.8	0.68
16	45.0	20.0	14.3	7.2	3.2	0.80
17	49.4	22.0	15.7	7.9	3.5	0.92
18	54.2	24.2	17.2	8.7	3.9	1.06
19	59.4	26.6	19.0	9.6	4.3	1.21

Table 4.54: Sensitivity analysis for model (4.18)

Age	Tick burden levels (m_k)	
(k)	50	100
1	0.5548	0.7040
2	0.5473	0.6829
3	0.5406	0.6648
4	0.5347	0.6491
5	0.5294	0.6354
6	0.5247	0.6235
7	0.5204	0.6129
8	0.5166	0.6036
9	0.5131	0.5953
10	0.5100	0.5880
11	0.5073	0.5815
12	0.5047	0.5757
13	0.5025	0.5704
14	0.5004	0.5658
15	0.4985	0.5616
16	0.4969	0.5578
17	0.4953	0.5544
18	0.4939	0.5513
19	0.4927	0.5486

increased. For example, increasing tick burdens from 20 to 50, reduced the growth rate by 51% for the ten-month old calves whereas for an increase from 50 to 100 ticks per calf, the change was 58.8%. At a tick load of 100 ticks per calf, there was a steady decline in the growth rate fluctuations varying between 70.4% and 54.9% for the one- and nineteen-month old calves, respectively. Therefore, the results revealed that the younger calves were more vulnerable to tick infestations than the relatively older ones.

4.9 Application of the models in management decision-making process.

4.9.1 An overview

Within the past decade many economists have become interested in natural resource models which simultaneously consider economic flows (such as cost and revenue) and the vector/pest population dynamics. Resource management is often cast as a problem in dynamic optimization where management objective may be to maximize the present value of net benefits subject to the stock adjustments which result from growth, natural mortality, and man's harvesting activities. When the resource in question is a plant or animal, capable of regeneration, these resource models are called *bioeconomic models*.

The basic bioeconomic model assumes that the renewable resource in question can be adequately described by a single (state) variable measuring biomass; for example, pounds or metric tons of beef. While such models have advantages of simplicity and mathematical tractability, according to Conrad (Conrad, 1986), they cannot take into account age or sex related attributes, nor multispecies interactions. However, in this study, the data analyses had been organised in such a way that age of the calves had been incorporated into the model. Moreover, sex and species of the ticks could also be taken into account in the models.

In the past, the logistic model had been extensively used in bioeconomic models. There are many alternative forms of the models. The logistic function belongs to a family of functions that is said to be 'purely compensatory' and which generates a smooth and continuous yield response when species is subject to exploitation by man. In this study, we have seen that the exponential models have fitted very well to the data, and it is not man but causal factors such as nutrition, helminths and ticks which harvest the resource. Several studies have been done in the past on bioeconomic models (Clark, 1973 and 1976; Gordon, 1954; Gould, 1972; Moloney *et al*, 1979; Schaefer, 1957; and Willen, 1979).

4.9.2 Microeconomic analysis

Quite often decisions are needed on problems related to microeconomic aspects of pests and vectors control programmes. Some of the questions with reference to tick control programmes could be:

i) What is the lower or upper economic threshold level of tick infestations on the Island?

ii) At what point of the control programme should the eradication be stopped due decreasing marginal returns to the farmer?

iii) To what level should tick burdens be reduced in order to experience a lower biological injury threshold level?

iv) Given mean age of calves in a herd by monthly age categories, what would be the level of tick infestation capable of totally stagnating the overall growth performance of the calves?

In this study, I have addressed myself to problem (i). The lower economic threshold (LET) is the lower level of tick infestations below which any tick control strategy would not be economic. Thus there would be no need for intervention when

$$t_{k..} < LET(k)$$

where LET(k) is the lower economic threshold level for calves aged k months. On the other hand, the upper economic threshold (UET) is the greatest tick infestation level

beyond which the animal would be totally stagnated in growth, i.e. the upper economic threshold level for calves aged k months, UET(k), is that tick infestation or burden where

$$r_{k+j} \leq 0,$$

$$k = 1, 2, 3,...$$

$$j = 0, 1, 2, 3,...$$

Suppose b_k and c_k (k = 1, 2, 3,...., K) are the benefits derived from a new tick control strategy and costs attributed to tick infestations on calves aged k months, respectively. The biological effectiveness of a tick control strategy would be measured by its ability to eradicate ticks during their parasitic phase on the host. A measure of this effectiveness is the LD_{50} or ED_{50} level of the strategy, be it an acaricide application, a biological control, or a combination of both. The unit cost of eradicating a tick basically depends on the LD_{50} or ED_{50} of the control strategy. Each tick exerts a certain amount of loss on the productivity on an animal individually (Sutherst *et al*, 1983). It has not been established yet whether the impact of each tick would be dependent on within and between species competition or not. However, if productivity losses , $L(u_k, m_k)$, under certain tick infestation levels were known, then the impact of each tick could be determined whether the loss function is linear or non-linear.

The implementation of a new strategy could reduce tick infestation level from t_k.. to t_k'... Given $c_k(j)$, the unit

cost of eradicating one tick of the jth species amongst calves aged k months, then

$$c_k = \sum_{j=1}^{v} n_k * \{c_k(j) * t_{k..}(j)\} \qquad (4.23)$$

where n_k, $t_{k..}(j)$ and v are the number of calves aged k months, mean tick burdens of the jth species, and number of species in the region, respectively. The benefits to be derived are given by

$$b_k = \sum_{j=1}^{v} n_k * \{b_k(j) * p(k)\} \qquad (4.24)$$

where $b_k(j)$ is the total amount of benefits from eradicating one tick of the jth species (e.g. kgs of beef, metres of grade 1 hides, etc), and p(k) is the market value or shadow price per unit of the benefit. Further, let us define

$$B = \sum_{k=1}^{K} b_k$$

$$C = \sum_{k=1}^{K} c_k$$

where K is the maximum age present in the herd. Then the lower economic threshold level for calves aged k months, would be that tick level $t_c(k)$ where

$$\sum_{k=1}^{K} \{[db_k/dt_{k..} - dc_k/dt_{k..}]_{t_{k..} = t_c(k)}\} = 0 \qquad (4.25)$$

With this approach of analysis, both b_k and c_k must be

known.

Sutherst *et al* (1983) while experimenting with *B. indicus X B. taurus* steers in Australia found that losses of up to 6 kgs did not affect the dressed carcass quality, suggesting a lower economic threshold for justifying tick control in the Region to be 79 ticks per side or 158 ticks per animal (both sides). Sutherst *et al* (1983) also determined liveweight loss to be 0.72 g, 0.47 g, and 1.52 g per standard tick for the three experimental groups of infestations studied.

In this study, the loss attributed to each tick could be determined from the equation

$$Lu(w_k, r_k, t_{k..}) = \{w_k*(r_k - r_{k+1})/t_{k..}\} \qquad (4.26)$$

Mathematically, the upper economic threshold level UET(k) is the m_k for which $r_k = 0$, i.e.

$$r_k = C_f + \exp(zk) \qquad (4.27)$$
$$= 0$$

where C_f is the correction factor introduced to enable mathematical manipulations (C_f was taken to be 0.78 and 2.35 for low tick density farms and high tick density farms, respectively). Then the UET(k) for a model can be determined from the formulae

$$UET(k) = \{(\log_e(C_f) - \alpha_k - \beta_k u_k)/\tau_k\}^2 \qquad (4.28)$$
$$k = 1, 2, 3, \ldots\ldots\ldots, K$$

Table 4.55 contains the UET(k) values computed from the formulae. The results indicated that for the Rusinga

Table 4.55: Determination of upper economic threshold (UET) levels using the formulae

Mean age (u_k)	Models 4.12	4.18	4.21
1	23.1	39.5	39.0
2	25.4	44.2	43.5
3	27.7	49.2	48.3
4	30.1	54.5	53.4
5	32.7	60.1	58.7
6	35.3	65.9	64.3
7	38.0	71.9	70.1
8	40.9	78.3	76.1
9	43.8	84.9	82.4
10	46.9	91.8	89.0
11	50.0	98.9	95.8
12	53.3	106.3	102.9
13	56.6	114.0	110.2
14	60.1	121.9	117.8
15	63.6	130.2	125.6
16	67.3	138.6	133.6
17	71.0	147.4	142.0
18	74.9	156.4	150.5
19	78.9	165.7	159.4
20	82.9	175.3	168.4
21	87.1	185.1	177.8
22	91.4	195.2	187.3
23	95.7	205.5	197.2
24	100.2	216.2	207.2
25	104.8	227.0	217.6
26	109.5	238.2	228.2
27	114.3	249.6	239.0
28	119.2	261.3	250.1
29	124.1	273.3	261.4
30	129.2	285.5	273.0
31	134.4	298.0	284.8
33	145.1	323.8	309.3

production system, the UET(10), UET(20) and UET(30) were 92, 175 and 286 ticks per calf, respectively. For the study sample comprising of calves with a maximum age of 33 months, the greatest upper economic threshold level of tick burden in one month was about 145 ticks per calf.

One important feature revealed in Table 4.55 and which was consistent with the physio-ecological principles underlying growth process was that the UET(k) levels were dependent on the duration of the tick burden on the host animal. It was found that for the lag of two months between infestation and effect, the tick burden that a calf could withstand was higher. For example, for calves aged ten months, if their impact on growth manifests itself the following month as in the case of Model (4.12), then the animals could only take a load of about 47 ticks per calf. If the lag period was 2 months, then the UET(10) was 92. Suppose we let $UET_j(k)$ represent the economic threshold level for calves aged k months and with the lag effect of j months (j = 0, 1, 2, 3). Then in general,

$$UET_0(k) < UET_2(k) > UET_3(k)$$

4.9.3 Cost-benefit analysis

The process of cost-benefit analysis involves measuring costs and income flows of anticipated benefits accrueing from project /or programme activities. Then based on either shadow or market prices, these costs and benefits are then

compared together in order to evaluate the project's or programme's financial and economic feasibility (Little *et al*, 1974; Squire, 1975; and Unido, 1972 and 1980). Naturally, a farmer will not accept and adopt a control programme or intervention which would not reap benefits in excess of the costs. Once the levels of biological costs (hence reduction in productivity) are known, then the series could be transformed into economic or financial costs. The latter costs would then be necessary in computing the benefits of the control programme. In this study, the Models (4.12), (4.18) and (4.21) developed could be used for estimating such losses and hence the costs, which in turn, would help in estimating the net benefits that would accrue due to the new tick control strategy adopted.

As an example, let us take Model (4.12). On the basis of this model, for mean age of calves, prediction of expected growth rate series could be generated. Given the model, a series of growth rates, $r_k(A)$ $(k = 1, 2, 3, \ldots\ldots)$ have been generated in a general situation where the calves are not exposed to any control or intervention program which we denote as strategy A. Suppose a new control strategy B involving dipping calves in acaricides is introduced and is said to be able to reduce tick infestations to some lower level. Then given the Model (4.12), say, a new series of growth rates, $r_{k'}(B)$ $(k' = 1, 2, 3, \ldots\ldots)$ can be generated. The difference,

$$dr_k = \left| r_k(A) - r_{k'}(B) \right| \qquad (4.29)$$

the absolute difference, is a measure of the effectiveness or benefits which would be derived from the new strategy B. Thus

$$dw_k = \left|\{r_k(A) - rk'(B)\}\right| w_k \qquad (4.30)$$
$$= dr_k * w_k$$

where w_k is the mean liveweight for calves aged k months in the given production system. The quantity dw_k represents the magnitude of the average liveweight gain for calves aged k months and which is attributed to the new control strategy B.

Suppose p(k), the unit price of beef for calves aged k months is known. Then the economic benefits realised on calves aged k months from strategy B would be

$$b_k = dw_k * p(k)$$

The total benefits in the whole herd would be

$$B = \sum_{k=1}^{K} b_k$$
$$= \sum_{k=1}^{K} dw_k * p(k)$$

Further, suppose c_k is the corresponding unit cost per tick of applying control strategy B to calves aged k months. The cost of dipping an animal is directly dependent on the liveweight of the animal. It was found in this study that tick burdens were directly proportional to liveweight. Hence

$$C \approx \sum n_k * w_k$$

and

$$t_k.. \approx w_k$$

Therefore

$$C = \sum_{k=1}^{K} (n_k * t_k..) * c_k$$

where n_k and $t_k..$ is the number of calves and mean number of tick burden levels for calves aged k months, respectively. The total of net benefits in the whole herd and which is attributed to the new tick control strategy B would be

$$BF = \{\sum_{k=1}^{K} dw_k * p(k) - \sum_{k=1}^{K} (n_k * t_k..) * c_k\}$$

$$= \sum_{k=1}^{K} \{dw_k * p(k) - (n_k * t_k..) * c_k\}$$

Suppose the strategy B was to be implemented for s years. Then a series of net benefits BF_1, BF_2, BF_3,...., BF_s shall be generated.

The next step would then be to evaluate the economic viability of the new tick control strategy B. There are several methods of carrying out economic evaluations of projects (Squire *et al*, 1975; and UNIDO, 1980). A rural peasant would hardly accept a technological intervention which does not produce immediate benefits. He tends to be reluctant to take risks. Two ways of convincing the peasant would be the payback period and net present value characteristics of the new control strategy.

The payback period is the total number of years during

which the application of the intervention will accumulate sufficient net cash earnings or benefits to cover the amount of its total investment costs. In this case, let k_p be the payback period. Then

$$I = \sum_{j=1}^{k_p} BF_j \qquad (4.31)$$

where I is the total investment costs during the period of implementation of the control strategy. A control strategy having the shortest payback period would be accepted when choosing amongst several alternatives. The shorter the payback period, the smaller the risk to which a peasant would be exposed to in adopting the new control strategy.

The second approach would be to compute the net present value (NPV). NPV of a project is the difference between present values of its future net benefits. Based on a predetermined discount factor, the net benefits are discounted to zero point in time. The discounting process determines the present value of future cash flows. Then

$$NPV = \sum_{j=1}^{s} a_j * BF_j \qquad (4.32)$$

where a_j is the discount factor at year j. The decision criteria would be to choose a control strategy for which NPV is greater than or equal to zero. A strategy would be commercially viable only if

$$NPV \geq 0$$

i.e.

$$\sum_{j=1}^{s} BF_j \geq 0 \qquad (4.33)$$

Thus when selecting a control strategy among alternatives, the best choice would be one with the largest NPV.

The above discussions have shown that in order to evaluate any tick control strategy, it is essential that net benefits must be determined. To do that, estimates of cash outflows and inflows resulting from implementation of the strategy would be needed. Cash flows could only be determined after knowing the average level of tick infestations in a herd with the help of the models (4.12), (4.15), (4.18), and (4.21). It is therefore evident that the models would be indispensable in the policy and management decision-making processes of livestock production systems involving tick control strategies. The data input and analytical requirements of the models are not many and hence the approach be suitable to most developing countries.

CHAPTER 5

CONCLUSIONS

5.1 Factors affecting calf growth

5.1.1 Climate

Climate is known to affect calf growth both directly and indirectly. In this study it was not possible to determine the direct impact of climatic factors since the whole Island experiences similar climatic patterns.

5.1.2 Helminths

Helminths inflict very heavy toll on calf growth. This has been documented by many scientists (Brandt, 1979c; Soulsby, 1982; and MOAFF, 1970). On Rusinga Island, the high prevalence rate on calves at the age of five months hints on the likely damage attributed to helminths given that no antihelminth treatment was practised. It was therefore assumed that prevalence of helminths is high and equal accross the Island.

Clinical studies conducted on the Island so far revealed that the *Trichostrongylus* spp have very high morbidity rates on the Island. With an incidence of total reinfection within one month, any strategic control measure

would be too expensive and involving for an ordinary peasant to cope up with, especially on Rusinga where extensive livestock rearing is the practice. Not so much has been revealed on the other Nematoda and Eustoda species of helminths such as the *Paramphistomum* and *Strongloides* spp. Some parasitic species of the Digenea subclass, namely *Fasciola hepatica* and *Fasciola gigantica* were also clinically diagnosed. Over 70% of the calves aged up to three months could be infected by any one of the parasitic helminths.

5.1.3 Management

On the basis of management practices by the selected households, the ten farms could be broadly classified into three groups. These were:

Group I: Farms 1, 16, 27, and 36

Group II: Farms 6, 21, 22, and 25

Group III: Farm 28

Because of the design and scale of this study, it was not possible to soundly determine the nature and extent of the influence of management on calf productivity. The lone example of Farm 2 could not be generalised to the rest of the Island.

5.1.4 Nutrition

Nutrition was studied intensively and extensively. Naturally, nutrition directly affects an animal's productivity through growth and development. Crude protein is necessary for the formation of muscles and blood while phosphorus is essential for skeletal formation and milk production. Lack of P causes loss of appetite implying less feeding and so results in poor growth.

The indirect role of nutrition on productivity is through avenues such as increased induced host resistance to ticks. It was found that good nutrition (CP and P) increased the animals resistance to ticks and hence reduced losses. This implied that a calf with better nutrition regime (higher levels of CP and P) would tend to experience faster growth than one without. The type of relationship between nutrition and resistance to ticks is described in section 5.2 below.

On the basis of crude protein, phosphorus and calcium contents of pastures, the ten farms could be divided into three broad categories as

Group I: Farms 1 and 2

Group II: Farms 6, 16, 21, 22, 25, and 36

Group III: Farms 27 and 28

Because the ten farms represented the four loci of the Island, it could be intuitively deduced that pastures on the whole Island can be described by the three categories of

nutrition regimes. Group I consisting of those farms with highest protein, medium phosphorus and lowest calcium. Group II are farms with median crude protein and phosphorus, but highest calcium levels. Group III are those farms which experienced lowest levels in all the three nutrients. In terms of spatial distribution, Group I represents farms to the south, and Group II farms to the northern and western parts of the Island. Group III generally are those farms to the eastern and north-eastern region. Although Farm 36 was in Group II, it experienced relatively lower CP levels but had one of the highest levels of both phosphorus and calcium. Group II can be considered as the '*Balanced-diet group*'.

Jolliffe's approach (Jolliffe, 1970, 1972, and 1973) showed that the most important nutrients for discriminating between farms were crude protein followed by phosphorus and calcium in that order of importance. The poor performance of potassium (K) was due to the fact that normally it is easily available from many natural sources of feeds. And so it was equally very well distributed between the farms.

Generally, the quality of the pastures during the study period was reasonable. The levels of the nutrients investigated were quite sufficient. This could be attributed to the good climate, particularly rainfall, which was experienced during the year.

5.1.5 Tick and Tick-borne diseases

The dominant tick on the Island was *R. appendiculatus*, followed by *A. variegatum*, *R. evertsi* and *B. decoloratus* in that order of magnitude (Fig 4.3). Tick pick-up rates were the highest around February-March and lowest around August-October. Farms located to the eastern and north-eastern sides of the Island (Farm 27 and 28) experienced the highest tick burdens while those to the western and north-western (Farm 16, 21, and 25) had the lowest. The spatial distribution was found to follow the pattern of crude protein levels in the pastures.

One question which was asked is whether the spatial distribution of ticks was real and true at the development and host-finding stages as well. The studies on the association of nutrients to host resistance to ticks revealed the strong association between crude protein and the host resistance to specific tick species. I do not think that the farms are that different in terms of the possible factors that reflect on the population dynamics of ticks, e.g. host breed, tick control, climate, vegetation, e.t.c. Hence the most probable cause of the difference in spatial distribution of tick burdens is the host resistance as natural resistance and induced by good nutrition of the pastures. Farms where the hosts had greatest resistance had the least number of ticks, especially *R. appendiculatus*.

Rusinga is an ECF endemic area. Because of the high

incidence of *Theileria* parasites, calves on the Island were infected as early as the age of four to six months. Morbidity of *B. bigemina* and *A. marginale* are also high although mortality attributed to these two are low. During the period of the study, there were no serious outbreaks of *B. bigemina* and *A. marginale* on the Island. The probability of the finding at least one animal uninfected with TBD is greater than 0.25. There were few cases of deaths due to acute ECF attacks in Farms 2, 6 and 28. Because of low nutrition status of the calves in Farm 2, all the calves on that farm were wiped out by acute ECF. Moreover, it was apparent especially from Farm 6 and 28 that zebu cattle exert a substantial amount of tolerance to the tick-borne diseases compared to the European breed *Bos taurus*. The studies with the hybrid cattle on the Island confirmed this (ICIPE, 1986 and 1987). Heartwater is also present on the Island.

5.1.6 Other factors

Although they were not seriously investigated, there were other diseases that attacked calves on the Island. Cases of coccidia, coughs and diarrrhoea were noticed. No clinical studies have been conducted to determine their epidemiology. These factors are not very important in relation to nutrition and tick-borne diseases.

5.2 Nutrition-host resistance relationships

Crude protein, potassium and calcium were the most important nutrients that played significant role in the induction of host resistance of the indigenous zebu calves (*Bos indicus*) to livestock ticks (Acarina: *Ixodidae*) on the Island. Increased levels of CP, K and Ca were associated with increased resistance of calves to both sexes of *R. appendiculatus* and *B. decoloratus* females. On the other hand, these three nutrients appeared to be associated with reduced resistance to the male *A. variegatum* and both sexes of *R. evertsi*.

Phosphorus seemed to play a negligible role in the host resistance-nutrition relationship. The following could be a possible explanation. Most of the phosphorus are used for bone formation and so are not accessible to the ticks (Ellenberger *et al*, 1950). It could be possible that this was the cause of very poor correlation between phosphorus and the ticks. The female *A. variegatum* seemed to be poorly associated with all the five nutrients. It might be responsive to other nutrients that were not included in the investigation.

It should be noted that this investigation was a preliminary exploratory study. It is therefore important that acarologists, particularly tick physiologists, should henceforth set-up efficient experimental designs to test for the validity of the above findings in relation to tick

physiology. The experiments should also be designed to determine the optimal levels of the nutrients which would be capable of exerting the desirable resistance pressure without harming the host.

The results of this study, if validated by other experiments would form a useful base for the application of feed nutrients as agents of biological control of livestock ticks (Acarina: *Ixodidae*) in an integrated tick management package.

5.3 Calf growth

There were no significant differences in calf birth weights between farms and sexes, respectively. Birth weights varied between 11 kg to 23 kg. The highest mean birth weight was 18.5 kg and was experinced in Farm 2 followed by Farm 1 and 16 with 17.6 kg and 16.79 kg, respectively. It was found that calf birth weights were associated with pasture nutrition, particularly crude protein. Mean birth weights by sex were 16.48 kg and 15.17 kg for males and females, respectively.

There were significant differences in calf growth between farms. Farms 1, 21, and 36 as one group and Farms 6, 22, 25, 27, and 28 as the second group were different in terms of calf growth. The first group experienced a significantly greater growth rate compared to the second. Relatively, calves in Farms 1 and 21 experienced the highest

growth rate while 27 and 28 had the lowest. The underlying pattern of growth rate was compatible and consistent with calf birth weight, quality of pastures available as well as tick burdens on the calves. Generally, farms with calves having high birth weights experienced highest growth rates and vice versa. As already been shown above, Farms 27 and 28 had the poorest nutrition in CP, P and Ca. It was also confirmed that the farms situated to the eastern and north-eastern sides (Farms 27, 28, and 36) had the highest burdens of *R. appendiculatus* compared to the rest of the Island. It was therefore apparent that farms 27, 28 and 36 were exposed to the most hostile conditions, i.e. the poorest pastures and highest tick burdens. It was evident that the poor growth was attributed to the interplay of the two causal factors. However, conclusion on Farm 36 should be reserved since only one calf was sampled from that farm. In contrast, Farm 21, in addition to its good quality pastures, had the lowest tick burdens and which enabled the calves to experience highest growth efficiency. No significant differences were detected in calf growth between the sexes and also between months of birth.

The observed growth rates of the majority of calves (68%) varied between 0.0159 - 0.359 lbs per day. This growth potential represented a mean annual growth of between 26 - 60 kg and which were comparable to those found in Madagascar (Granier *et al*, 1968; de Reviers, 1970). It was found that the lowest growth rate was 0.009 lbs per day

while the highest was 0.409 lbs per day. These calves experienced a mean tick burden of between 65 - 91 ticks per calf. Fluctuations in productivity as measured by decreases in growth rate was found to be higher for older animals than the younger ones. It was also found that the higher the tick burden, the greater the proportionate influence on the growth rate though sensitivity analysis. The details are given in Tables 4.53 and 4.54.

The upper economic threshold level of tick burden in a month for calves aged 33 months was about 145 ticks per calf. Also it was found that the older the calf, the greater the upper economic threshold level. Sutherst *et al* (1983) had suggested an upper economic threshold of 158 ticks per animals for their experiments in Australia involving the tick-naive *B. indicus X B. taurs* steers. Data from Rusinga was not sufficient for the determination of the lower economic threshold levels. The two findings were therefore comparable. The discrepancy in the two figures could be attributed to differences in nutrition and management between the two production systems. Details are found in Table 4.55.

5.4 Modelling

5.4.1 The calf growth model

Based on the results obtained from the Rusinga data, the modified Gompertz model defined by

$W_t = b*exp(-exp-a(t-g)))$

where W_t is liveweight at age t, b is the maximum growth potential of the breed under given production system, a is the a growth rate factor and g is the age at which growth rate is maximum adequately described the growth behaviour of the calves on the Island. The model is quite flexible and comprehensive in explaining the major growth features such as growth rate, age at which maximum growth rate is attained, and maximum potential growth of the breed under the given production system.

Except for Farms 2 and 6, it was found that calves which experienced their highest growth rate earlier did attain a lower liveweight at maturity. It would therefore be important for management purposes to find out the causes of such retardations so as to take care of them. Basically, the implication is that calves should better reach a stage where their energy demands are high as they grow older to be able to access the necessary nutritional stress.

The major differentiating morphological factors in growth between farms was growth rate, through the parameter a ($P = 0.0001$). The results confirmed that growth rate was mainly influenced by the availability of crude protein. Farms with greatest CP experienced the lowest rates of a, and hence highest growth rates.

There were no differences in growth between sexes, and also between months of birth.

5.4.2 Liveweight-dependent survivorship threshold model

The exponential model provided the best fit to the data on the minimum liveweights of the calves under the Rusinga management option. The maximum growth potential of the calves of the breed under the same management can also be determined from the maxima data. These two limits form the variation belt of the survivorship threshold for the calves under consideration. And so a calf whose liveweight approached the lower limit given by Equation 4.6 was under the risk of dying due to starvation, a hazard which seemed to be facing many calves on the Island. It was found that over 50% of the minimum liveweights were close to the threshold implying that majority of the calves were exposed to a high risk of dying as a result of starvation. This was a revelation of an interplay of many causal factors simultaneously influencing calf growth. The results of this study form a benchmark in future studies.

The approach taken here in developing the threshold model is new and would go a long way to supplement the existing methods so far developed for simulating growth curves (Jolicoeur *et al*, 1986; and Wallis 1951).Its calculation is based on actual observed extreme data rather than computations as advanced by the other methods.

The parameter values are expected to vary with different production systems. The Rusinga situation is representative of most agroecological zones of Africa. The form of the threshold model was, however, supposed to be invariant. However, more field data from other agroecological zones should be used to validate the form of the models. The models are flexible and hence have greater chances of having wider scope and spatial reference in application.

5.5 Productivity Loss Models

The study has confirmed that loss in calf weight in relation to tick burdens follows an exponential model given by Equation (4.22)

$$r_{k+j} = \exp(\alpha_j + \beta_j u_k + \tau_j m_k)$$

$$k = 0, 1, 2, 3, \ldots, K$$

$$j = 0, 1, 2, \ldots\ldots$$

where α_k, β_k and τ_k are parameters of the model, and u_k and m_k mean age and tick burdens of the calves at age k, respectively; K is the maximmum age of the study animals. The developed models (4.12), (4.15), (4.18) and (4.21) tested and validated and were found to be satisfactory.

Because of the significantly increasing correlations between tick burdens, m_k, and productivity loss parameters, z_k (Table 4.41), i.e.

$$\text{corr}\ (z_{k+1}, m_k) < \text{corr}\ (z_{k+j}, m_k)$$

$$i < j = 1, 2, 3$$

$$k = 0, 1, 2, 3, \ldots\ldots, K$$

it could be concluded that the loss models were more efficient with increasing lag effects. Thus z_{k+3} would be a better model than z_{k+2}. This was confirmed by the tests of hypothesis of the parameters of the two models in Tables 4.48 and 4.49, respectively. Moreover, model 4.12 was not very efficient because corr (m_k, z_k) = -0.28 (P = 0.1657). It was therefore conclusive that the relationship between calf growth was getting stronger as the time lag increased. Hence the effect of tick burden was more pronounced with time lag on the animals. In other words, relationship between tick load and its long-term effect on calf growth was stronger than those of the immediate past. It was particularly found that the relationship was strongest when the lag was two months.

APPENDIX I

DRY MATTER OR MOISTURE DETERMINATION

1.1 The amount of moisture or moisture free matter may be determined by loss of moisture (indirectly) in oven drying of chemically stable materials or vacuum oven drying of heat sensitive materials (A.O.A.C. 22.003, 1975).

Water content may be determined directly by distillation of the material with toluene (A.O.A.C. 22.004) and measuring the volume of water distilled (Bidwell and Sterling 1925; Anal. Chem. 1960; 32.1054).

1.2 Reagents

1.2.1 Dessicant: phosphorus pentoxide, anhydrous.

1.3 Apparatus

1.3.1 Drying oven, controlled circulating air.

1.3.2 Dessicator

1.4 Procedure

1.4.1 Weigh (to the nearest 0.1 mg) 2 to 5 grams of material to be tested into a crucible or drying dish.

1.4.2 Place the sample in the oven controlled at 105°C and dry for two hours. Cool in the dessicator to room

temperature and weigh.

1.5 Calculations

Calculate the percentage of dry matter or moisture as follows:

$$\% \text{ DM} = \frac{\text{dry sample weight}}{\text{wet sample weight}} \times 100$$

$$\% \text{ moisture} = \frac{\text{moist sample weight} - \text{dry sample weight}}{\text{moist sample weight}} \times 100$$

APPENDIX II

ASH DETERMINATION AND LOSS ON IGNITION

2.1 The organic matter of a sample is oxidized in a furnace and the residue weighed as ash (A.O.A.C. 22.010)

2.2 Apparatus

2.2.1 Crucibles, porcelain

2.2.2 Dessicator with phosphorus pentoxide or potassium perchloride dessicant.

2.2.3 Muffle furnace.

2.2.4 Analytical balance.

2.3 Procedure

2.3.1 Weigh to the nearest 0.1 mg a 2-gram sample into a tared porcelain crucible.

2.3.2 Place the sample in the muffle furnace preheated to 600°C. Maintain the sample at this temperature for 2 hours.

2.3.3 Remove the crucible from the furnace, cool until red glow is no longer visible, and place in the dessicator.

2.3.4 Cool and weigh immediately. Weigh as rapidly as possible to reduce error from hygroscopic moisture.

2.4 Calculations

Calculate the percentage of ash as follows:

$$\% \text{ Ash} = \frac{\text{Residue weight}}{\text{Sample weight}} \times 100$$

APPENDIX III

CRUDE FAT OR ETHER EXTRACT

3.1 That portion of the sample which is soluble in ether is extracted by a continuous dripping of the solvent. The extract is collected on a beaker, dried and weighed (A.O.A.C. 22.032).

3.2 Reagents

Ethyl ether, anhydrous.

3.3 Apparatus

3.3.1 Extraction apparatus.

3.3.2 Solvent beakers.

3.3.3 Extraction shells (or thimbles) alundum.

3.4 Procedure

3.4.1 Weigh to the nearest 0.1 mg a 2-gram sample into a previously extracted alundum extraction shell. The alundum extraction shell must be free from ether soluble materials before use. If the extraction shell was just used in the determination removing the residue by tapping and brushing is satisfactory. The thimbles may be ashed to remove all organic matter.

3.4.2 Dry the sample in the 105°C oven overnight. The previously dried sample from the dry matter determination

may be quantitatively transferred to an extraction shell and used after 2 hours of additional drying in the 105°C oven.

3.4.3 Wash and dry the solvent beakers in 105°C oven.

3.4.4 Cool the solvent beakers in a dessicator, weigh to the nearest 0.1 mg and record the tare weight.

3.4.5 Place the extraction shells in position on the extraction apparatus. Add 40 ml of ethyl ether to the tared solvent beaker and fix the beaker in position on the extraction apparatus.

3.4.6 Turn on the condenser water and position the heaters under the beakers with a low heat setting. Continue the extraction for 16 hours or overnight at the low setting with condensation rate of 2-3 drops/sec.

3.4.7 Extraction may be carried out in 4 to 5 hours at the high heat setting if the porosity of the thimble will permit the more rapid passage of ether (5-6 drops/sec.).

3.4.8 After the extraction is completed, lower the heaters, and allow the thimbles to drain empty. Remove the solvent beakers. Remove the sample thimbles. The residue in the extraction shells may be transferred to a beaker and used for the crude fibre determination. Place the solvent collection vials in position and replace the solvent beakers.

3.4.9 Raise the heaters and distill the ether into the vials. Lower the heaters just before the beakers evaporate to dryness or the extract might be burned.

3.4.10 Remove the solvent beakers and complete drying the

ether in open air. Complete drying of the extract in the oven at 100°C for 30 min., cool and weigh.

3.5 Calculation

Calculate the percentage of ether extract as follows:

$$\% \text{ E.E.} = \frac{\text{weight of ether extract}}{\text{weight of sample}} \times 100$$

APPENDIX IV

NITROGEN OR CRUDE PROTEIN DETERMINATION

4.1 Nitrogen or protein and other organic compounds is transformed into ammonium sulphate by acid through digestion with boiling sulphuric acid and a catalyst. The acid digest is coolled, diluted with water, and made strongly basic with sodium hydroxide. The ammonia is relased and distilled into a boric acid solution. The boric acid solution is titrated with standardised hydrochloric acid (A.O.A.C. 2.034)

4.2 Reagents

4.2.1 Sulphuric acid, 93-98%, N-free.

4.2.2 Potassium sulphate (or anhydrous sodium sulphate). Reagent grade, N-free.

4.2.3 Copper sulphate, fine crystalline or ground. Reagent grade, N-free.

4.2.4 Potassium sulphate - cupric sulphate catalyst (7% $CuSO_4$ in K_2SO_4).

4.2.5 Mercuric oxide or metallic mercury, reagent grade, N-free.

4.2.6 Sodium hydroxide solution, N-free (Dissolve 450 g NaOH in water and dilute to 1 litre).

4.2.7 Boric acid solution, 4%.

4.2.8 Indicator solution (0.1 methyl red and 0.2% bromcresol green in alcohol in the ratio of 1:5).

4.3 Apparatus

4.3.1 Kjeldahl nitrogen digestion-distillation apparatus.

4.3.2 Kjeldahl flasks, 800ml or 650 ml.

4.3.3 Erlenmeyer conical flasks, 500 ml.

4.4 Procedure

4.4.1 Weigh the sample of the material to be analysed large enough to contain about 30 mg of nitrogen or 200 mg of protein (about 2 g of dry feed) into a Kjeldahl flask.

4.4.2 Add 10 g of catalyst. The catalyst consisted was made of 80 g of K_2SO_4, 20 g $CuSO_4$, 3.2 g of HgCl and 0.34 g of SeO_2).

4.4.3 Pour 25 ml of concentrated sulphuric acid into the flask in such a way that any sample adhering to the neck is washed down. (Increase the amount of sulphuric acid used by 10 ml for each gram of organic matter above 2 g.).

4.4.4 Place the flask on the digestion heaters of the Kjeldahl apparatus and turn on heat and exhaust fan. Watch the digestion process until frothing ceases. If the froth of a sample starts up the beck of the flask remove it from the heat to allow froth to subside and return to heater.

4.4.5 Continue the digestion, turning flasks occasionally for 30 minutes after the solution clears.

4.4.6 Turn off the heat and allow the flasks to cool on the heaters until fuming ceases, then remove the flasks and continue cooling on a rack.

4.4.7 Before the digest solidifies, carefully add 250 ml of water while cooling the flask under running cold water. If the digest cooled to a solid state dissolve the solids by swirling before continuing the procedure.

4.4.8 Add 50 ml of boric acid solution to the 500 ml Erlenmeyer flasks and set them under the condensers with the tips beneath the surface of the solution.

4.4.9 Carefully add 80 ml of NaOH with the flask tilted so the reagent runs down the side to the bottom to the solution. (If additional H_2SO_4 was used add 40 ml of NaOH for each 10 ml of H_2SO_4).

4.4.10 Continue the distillation until about two thirds of the liquid in the flask has distilled over or about 200 ml of liquid are contained in the receiving flash.

4.4.11 Lower the receiving flasks and allow the condensers to drain for five minutes while the Kjeldahl flasks are cooling on the distillation heaters.

4.4.12 Titrate the ammonia with standardized HCl (0.1 or 0.07143 Normal) using the methyl red-bromcresol green indicator.

4.4.13 Run a reagent blank through all the steps of the procedure and substract the blank titration from the sample titrations.

4.4.14 When the Kjeldahl flasks have cooled, rinse out with tap water and invert in a rack to dry. If the titration was stopped at exact end point, the Erlenmeyer flasks need only be emptied and inverted to drain.

4.5 Calculation

4.5.1 Calculate the percentage of nitrogen as follows:

$$\% N = \frac{\text{ml. HCl x normality HCl x 1.4 x 100}}{\text{sample weight in grams}}$$

If 1/14N HCl was used,

$$\% N = \frac{\text{ml. HCl x 0.1 x 100}}{\text{sample weight in grams}}$$

4.5.2 Calculate the percentage of crude protein by multiplying the percentage of nitrogen by 6.25 or the approximate factor for the type of protein of the sample if known. That is,

$$\% CP = \frac{\text{ml. HCl x normality HCl x 1.4 x 6.25 x 100}}{\text{sample weight in grams}}$$

APPENDIX V

CRUDE FIBRE DETERMINATION

5.1 A sample is first boiled with a dilute sulphuric acid followed by boiling with dilute NaOH. The residue is determined indirectly by loss on ignition (A.O.A.C. 22.038).

5.2 Reagents

5.2.1 Sulphuric acid solution, 0.255 N 1.25 g H_2SO_4/100 ml.

5.2.2 Sodium hydroxide solution 0.313 N 1.25 g NaOH/100 ml.

5.2.3 Filtering cloth, Butcher's linen or dress linen with about 45 threads/inch.

5.3 Apparatus

5.3.1 Crude fibre extraction rack.

5.3.2 Digestion beaker, 600 ml tall form.

5.3.3 Filtering cloth.

5.3.4 Porcelain crucibles.

5.3.5 Vacuum pump

5.3.6 Muffle furnace.

5.4 Procedure

5.4.1 Extract 2 g of dry sample, or use the residue from the ether extract determination.

5.4.2 Add 200 ml of the boiling H_2SO_4 solution. Immediately place the beaker on preheated extraction heater and connect the condenser (the contents of the flask must come to

boiling in 1 minute and the boiling must continue briskly exactly 30 minutes).

5.4.3 Rotate the beaker frequently until the sample is thoroughly wetted. Take care to keep material from remaining on the sides of the beaker out of contact with the solution.

5.4.4 After 30 minutes, remove the beaker, immediately filter through the linen in fluted funnel, wash with boiling water until washings are no longer acidic.

5.4.5 Wash the residue back into the beaker with 200 ml of boiling NaOH solution. Place the beaker on the extraction heater, connect the condenser and boil exactly 30 minutes. Time the addition of NaOH so that the contents of different beakers reach the boiling point about 3 minutes apart, which permits enough time for filtration.

5.4.6 After 30 minutes, remove the beaker from heater and immediately filter through the linen filters. Thoroughly wash with boiling water.

5.4.7 Transfer the residue to porcelain crucible. After thorough washing with water, keep in an oven overnight at 105°C.

5.4.8 Ignite the contents of crucible in electric muffle furnace for 2 hours at 600°C, cool in dessicator and weigh.

5.5 Calculation

Calculate the percentage of crude fibre as follows:

$$\% \text{ CF} = \frac{\text{Loss by ignition}}{\text{DM}(\%)} \times 0.9284 \times 100$$

APPENDIX VI

DETERMINATION OF PHOSPHORUS CONTENT IN PLANT MATERIAL

6.1 Principle of the method

6.1.1 The organic material in a sample is destroyed by digestion with H_2SO_4/H_2O_2 (wet ashing). This releases the organically bound phosphorus as phosphate. The digestion with acid also hydrolyses polyphosphates to orthophosphate. This orthophosphate is then reacted with ammonium molybdate to form heteropoly molybdophosphate acid. This may be reduced with stannous chloride in an aqueous H_2SO_4 medium to form molybdenum blue. The molybdenum blue colour may be measured in a colorimeter at 660 mμ wavelength.

6.1.2 Alternatively, addition of ammonium molybdate and ammonium vanadate to the digest containing the orthophosphate produces a yellow phosphovanadomolybdate solution. The yellow colour may be measured in a colorimeter at 400 mμ wavelength (EAAFRO technique). The colorimeter procedure given does not deviate much from the present EAAFRO technique.

6.2 Procedure

6.2.1 Wet ashing of the plant material

6.2.1.1 Reagents

6.2.1.1.1 Sulphuric acid, conc. (about 36N) A.R.

6.2.1.1.2 Hydrogen peroxide, 30% w/v (or 100 vols)

6.2.1.2 Method

6.2.1.2.1 Place sufficient of the ground (20-40 mesh) plant sample in a glass dish and dry overnight in an oven at 100°C, and cool in a dessicator.

6.2.1.2.2 Weigh accurately 400 mg (0.4 g) of the cooled sample into a 125 ml (or 100 ml) conical flask (pyrex). Add 4 ml of conc. H_2SO_4 (A.R.).

6.2.1.2.3 Heat in a fume cupboard until all plant tissue material is charred (use "medium" heating setting on either an electric hot plate setting 2 or on a sand bath electrically heated).

6.2.1.2.4 Remove flask, cool, add 10 drops of 30% w/v H_2O_2, adding 3-4 drops at a time to avoid vigorous reaction.

6.2.1.2.5 Swirl contents of flask (keep contents at bottom of flask) and reheat - do not allow spattering of the contents to occur.

6.2.1.2.6 Cool, add 6 drops of 30% H_2O_2 and reheat.

6.2.1.2.7 Continue step 6.2.1.2.6 until there is a slight change of colour, i.e. from black to dark brown.

6.2.1.2.8 Now turn the heater on to "high" on the hot plate (or sand bath) and continue 6.2.1.2.6.

6.2.1.2.9 When the solution stays colourless on cooling, add H_2O_2 and leave for last time on "high" burner for 10-15

minutes (nearly all H_2O_2 is driven off at this stage).

6.2.1.2.10 Wash quantitatively into a 100 ml volumetric flask.

6.2.1.2.11 This is the solution (A) in which you will determine N (as NH_4+), P, K, Ca, Mg as well as other micronutrients.

6.2.1.2.12 Never allow solution to get so hot, it spatters (ESPECIALLY IMPORTANT IN "MEDIUM" BURNER STAGE).

6.2.1.2.13 Be certain the flasks are well cooled before addition of H_2O_2 at any stage.

6.2.1.2.14 Prepare a blank solution of the same amounts of reagents starting from H_2SO_4/H_2O_2 to the colour development for colorimetric measurement.

Note:

1) In case of insufficient plant sample is available, use reduced amounts of reagents and sample, e.g. if 0.2 g sample is taken, add 2 ml of conc. H_2SO_4, digest with (together with H_2O_2) and dilute to 50 ml.

2) Step 6.2.1.2.9 (above) must be strictly adhered to, as it ensures complete digestion or ashing of the plant tissue and the removal of H_2O_2. Incomplete removal of H_2O_2 may show up in the colorimetric determination of P using ammonium vanadate/molybdate method. A brownish coloration appear instead of the usual yellow colour when ammonium vanadate/molybdate mixture is added to the digest containing traces of H_2O_2.

However, heating of the brownish-coloured solution

on a water bath normally leads to the required yellow coloured solution.

6.2.2 Colorimetric determination of phosphorus (Vanadomlybdate method)

6.2.2.1 Reagents

6.2.2.1.1 Ammonium molybdate/ammonium vanadate mixed reagent. For each litre, use 140 ml of conc. HNO_3 (A.R., 16N), 1 g of A.R. ammonium vanadate and 20 g of ammonium molybdate. Dissolve the ammonium molybdate in 400 ml of distilled water at about 50°C and cool. Dissolve the ammonium vanadate in about 300 ml boiling distilled water, cool, add slowly the HNO_3. Then add gradually with stirring, the ammonium molybdate solution and dilute the mixture to 1 litre.

6.2.2.1.2 P-nitrophenol, 0.5% w/v. Weigh out accurately and dissolve in distilled water 0.5 g of P-nitrophenol. Make to 100 ml with distilled water.

6.2.2.1.3 6N aqueous NH_3. Dilute 420 ml of conc. NH_3 (A.R. 14.3N) to 1 litre with distilled water.

6.2.2.1.4 1N HNO_3. Dilute 63 ml of conc. HNO_3 (A.R. 14.16N) to 1 litre with distilled water.

6.2.2.1.5 Standard phosphorus solution, 1000 ppm P. Weigh out accurately 1.0967 g of oven dry (100°C) (A.R.) KH_2PO_4. Dissolve in distilled water and make to 250 ml with distilled water (1 ml = 1 mg P).

6.2.2.1.6 10 ppm phosphorus solution. Dilute 10 ml of the above solution (1000 ppm P solution) to 1 litre with distilled water.

6.2.2.2 Method

6.2.2.2.1 Pipette 10 ml of the wet ashed digest solution (A) into a 50 ml volumetric flask (or a 50 ml stoppered calibrated tube).

6.2.2.2.2 Add 0.2 ml of 0.5% P-nitrophenol solution (indicator).

6.2.2.2.3 Make just alkaline (yellow with aqueous NH_3 (6N) added dropwise with shaking, followed by dilute HNO_3 (IN), added dropwise with shaking until just colourless (pH ranges from 2.50 to 3.86).

6.2.2.2.4 Add 5 ml of ammonium molybdate/ammonium vanadate mixed reagent.

6.2.2.2.5 Make to 50 ml with distilled water, stopper and mix well.

6.2.2.2.6 Keep flask for about 30 min and measure the absorption of the solution using either a Hilger Spekker (2 cm cell, Filter 1) or the Eel Spectra Instrument at 400 mμ wavelength.

6.2.2.2.7 Read off the amount of phosphorus present in the solution from a calibration curve prepared as follows:

Add 0, 5, 10, 15, 20 and 25 ml of the standard 10 ppm P solution to 50 ml volumetric flask (or 50 ml calibrated tubes), representing 0, 1, 2, 3, 4, and 5 ppm P, respectively. Then add 0.2 ml of P-nitrophenol, 0.5% w/v

solution. Add dropwise, with shaking 6N aqueous NH_3 until yellow then dropwise with mixing iN HNO_3 until colourless. Add 5 ml of ammonium molybdate/ammonium vanadate mixed reagent.

Make to 50 ml and mix. Allow to stand for 30 min at a room temperature and measure the absorption of the solution as above.

* In the presence of a high salt concentration, full development of colour is delayed (Bould *et al* 1960).

6.2.2.2.8 The instrument is set to read zero optical density on the 0 ppm standard P, which is itself a yellow colour due to the ammonium vanadate reagent. This "reagent flask" must be freshly prepared with each bath of samples measured and used to set the instrument at zero optic density. Plot the optical density values versus the P concentration of the standards.

N.B: 1) Aqueous NH_3 (or NH_4OH) additions should be made in a laboratory where nitrogen determinations are not carried out. The uses of a fume cupboard is recommended.

2) Wet ashing procedure is faster than dry ashing procedure. A beginner does 30 samples in two days.

6.2.3 Calculations

0.4 g of plant sample is digested with H_2SO_4/H_2O_2 and diluted to 100 ml (solution in 6.2.1).

i.e. 100 ml soln contains 0.4 g sample.

If 20 ml digest solution is taken, then

0.4/100 x 20 = 0.08 g sample is taken.

If 0.08 g sample is diluted finally to 50 ml in the colour measurement, then 1 g sample is diluted finally to 50/0.08 x 1 ml = 625 ml or,

ppm P obtained in 1 g sample = ppm P in 50 ml soln X dilution factor (df)

But 10,000 ppm P = 1% P

i.e 1% of 10,000 = $\frac{1}{100}$ x 10,000

$$\% \text{ P in a plant sample} = \frac{\text{ppm P found in 50 ml soln}}{10,000} \times \text{df}$$

$$= \text{ppm P found in soln} \times 0.0625$$

If 0.04 g sample is diluted to 50 ml in P measurements (as ppm), then 1 g sample is diluted to 50/0.04 X 1 = 125 ml, or, ppm P obtained in 1 g

$$= \frac{\text{ppm P in 50 ml soln} \times 1250}{10,000}$$

$$= \text{ppm P in 50 ml soln} \times 0.125$$

By similar reasoning as above, when 5 ml of digest solution is taken, then

$$\% \text{ P in plant sample} = \frac{\text{ppm P in 50 ml soln} \times 2500}{10,000}$$

$$= \text{ppm P in 50 ml soln} \times 0.25$$

APPENDIX VII

DETERMINATIONS OF POTASSIUM, CALCIUM AND MAGNESIUM MEASUREMENTS FROM THE WET ASHED SOLUTIONS

7.1 Potassium

Either pipette 1 ml of the wet ashed digest solution of plant material into a 50 ml clean volumetric flask or 2 ml of the digest into a 100 ml volumetric flask. Dilute to mark with distilled water. Stoppered and shake contents very well. Take a portion of the solution into a little clean container (e.g. plastic container), properly rinsed with the diluted solution. Spray this portion directly into the Eel flame photometer flame. For calibration purposes, use all wet ashing K standards. The potassium standards for the calibration curve are:

0 ppm, 1 ppm, 2 ppm, 3 ppm, 4 ppm, 6 ppm, 10 ppm, 15 ppm

The K dilutions vary with the plant material. For example, 1 ml into 50 ml is sufficient when maize or sorghum plant is young. But at maturity, grain in particular, contains little K, so a dilution of 5 ml to 50 ml is often made. Pipetting 1 ml digest needs a lot of care!!.

7.2 Calcium

Pipette 10 ml of the wet ashed solution into a 50 ml volumetric flask. Add 10 ml of 0.15% lenthanium chloride solution. Add 1 ml of dilute ammonia chloride solution. Fill to mark with distilled water. Take a portion of this

solution for the Ca determination by spraying into the Atomic Absorption Spectrophotometer (SP90) using the Ca lamp or by flamephotometry.

The calcium standards for the calibration curve are: 0 ppm, 5 ppm, 10 ppm, 15 ppm, 20 ppm, 30 ppm, 40 ppm, 50 ppm, and 60 ppm.

Note:

1) **0.15% lenthanium chloride, $LaCl_3.7H_2O$**
   Dissolve 1.5 g of lenthanium chloride in distilled water and dilute to 1 litre. Shake well.
2) **Dilute ammonium solution**
   Dilute 3 ml of 0.91 s.g ammonia (A.R.) with distilled water to 1 litre.

7.3 Magnesium

Pipette 5 ml of the digest solution into a 50 ml volumetric flask. Dilute with distilled water to 50 ml. Stopper and shake contents very well. Take portion of the solution into a clean properly rinsed container for direct spraying into the AAS flame (SP90) for the Mg determinations, using the Mg lamp. Use the Mg wet ashing standards for the calibration curve. The magensium standards are:

0 ppm, 0.25 ppm, 0.5 ppm, 1.0 ppm, 1.5 ppm, 2.0 ppm, and 2.5 ppm.

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