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ESTIMATES OF REALISED AND POTENTIAL IMPACTS OF THREE* ACIAR PROJECTS ON THE ECOLOGY, EPIDEMIOLOGY AND CONTROL OF TICKS AND TICK-BORNE DISEASES IN SUB-SAHARAN AFRICA†

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* The three projects are:
PN8303: Ecology, and epidemiology of ticks and tick-borne diseases in sub-Saharan Africa.
PN9047: Genetic variation, resistance to acaricides and immunological cross-reactivity in ticks that infect cattle in Zimbabwe and Australia.
PN9118: Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia.

† Comments by Dr Jeff Davis (Program Manager, Rural Industries Research and Development Corporation, Canberra) and Dr Bob Sutherst (Chief Research Scientist, Cooperative Research Centre for Tropical Pest Management) are gratefully acknowledged. Special thanks go to the following scientists in Africa who spared their time to talk to Dr Godfrey Lubulwa in August and September 1994 about this project: Dr D.P. Kariuki (Director of National Veterinary Research Centre, Muguga, Kenya) and Dr S.K. Mbogo (Kenya Agricultural Research Institute, National Veterinary Research Centre, Muguga, Kenya), Dr B.D. Perry, Head, Epidemiology and Socioeconomics Programme, ILRAD and Dr A.W. Mukhebi, Economist, ILRAD, Nairobi. In October 1995, an earlier version of the paper was presented at a Staff Seminar at the Department of Veterinary Services, Ministry of Lands, Agriculture and Rural Settlement, Harare, Zimbabwe. Comments made by scientists al the seminar are acknowledged.

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CONTENTS

ABBREVIATIONS

ACIAR	Australian Centre for International Agricultural Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DANIDA	Danish International Development Agency
FAO	Food and Agriculture Organization of the United Nations
ICIPE	International Centre of Insect Physiology and Ecology
ILCA	International Livestock Centre for Africa
ILRAD	International Laboratory for Research on Animal Diseases
ILRI	International Livestock Research Institute
OVI	Onderstepoort Veterinary Institute
QDPI	Queensland Department of Primary Industries
UNDP	United Nations Development Program
WARRC	World Acaricide Resistance Reference Centre

1. INTRODUCTION

This paper describes a completed project assessment of the following three ACIAR-funded projects:

(1) Ecology, epidemiology and control of ticks and tick-borne diseases (PN8303)[1] which involved formal collaborative research work between:

- CSIRO Division of Entomology, Brisbane, Australia;
- Ministry of Agriculture and Livestock, Bujumbura, Burundi;
- Kenya Agricultural Research Institute, Muguga, Kenya;
- Banda Agricultural College of the University of Malawi, Malawi;
- Veterinary Research Laboratory, Balmoral, Zambia;
- Veterinary Research Laboratory, Harare, Zimbabwe;
- Food and Agriculture Organisation of the United Nations[2]–DANIDA[3] project in Burundi, Ethiopia, Kenya, Mozambique, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe;
- International Laboratory for Research on Animal Diseases (ILRAD)[4], Kenya; and
- International Centre of Insect Physiology and Ecology (ICIPE)

(2) Develop better methods to manage tick resistance to acaricides in Zimbabwe and Australia (PN9047)

(3) Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia (PN9118).

The project on acaricide resistance (PN9047) involved collaboration between the Department of Parasitology of the University of Queensland and the Veterinary Research Laboratory in the Department of Veterinary Services, Harare, Zimbabwe. The project on Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia (PN9118) involved collaboration between the Queensland Department of Primary Industries (Tick Fever Research Centre and Animal Research Institute, Brisbane) and the Veterinary Research Laboratory in the Department of Veterinary Services, Harare, Zimbabwe.

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1 This assessment has been undertaken nine years after project PN8303 was terminated as a result of a cut in ACIAR’s budget. The assessment focuses on the project's contribution to the policy shift from the costly strategy of intensive weekly dipping, to strategic dipping combined with host resistance in the control of ticks and tick-borne diseases in sub-Saharan Africa. This evaluation does not include the impact of a user-friendly 3-host tick model for use in assessing the costs and benefits of other control strategies. This model is near completion and is evaluated elsewhere (see Lubulwa and McMeniman 1997).

2 Linkages with FAO in Ethiopia, Sudan, Kenya, Mozambique, Tanzania, and Uganda were marginal and occurred mainly through the project leaders (Dr R. Sutherst) involvement with FAO coordination meetings.

3 Danish International Development Agency.

4 Linkages with ILRAD were marginal and occurred mainly through the project leaders (Dr R. Sutherst) involvement with FAO coordination meetings.

1.1 The projects and their objectives

1.1.1 PN8303: Ecology, epidemiology and control of ticks and tick-borne diseases

The first project (PN8303), funded from 1983 to 1986, was externally reviewed in 1986 and the review committee (Elder et al. 1986) concluded that:

> The ACIAR project has had an importance and effectiveness out of all proportion to its size and cost. It has been remarkably influential in ensuring that field research groups operating in Central and East Africa undertake investigations in such a way as to ensure that the data collected is reliable, capable of analysis and interpretation.
>
> The modelling of data obtained has resulted in the development of novel, integrated tick control methods which are now being tested by national authorities in Zimbabwe, Burundi and Zambia.
>
> The project has exceeded all reasonable expectations in the modification and development of existing Australian computer models to accept and interpret African ecological and epidemiological data.

The evaluation takes into account only the benefits already realised as a result of countries participating in project PN8303 changing their tick control strategies. The assessment focuses on the project's contribution to the policy shift from the costly strategy of intensive weekly dipping to strategic dipping combined with host resistance in the control of ticks and tick-borne diseases in sub-Saharan Africa.

A user-friendly 3-host tick model for use in assessing the cost and benefits of other control strategies is near completion. The potential impacts that would accrue to sub-Saharan Africa on adoption of the model and results from the analyses based on the model are not included in this assessment.

The general objectives of the ACIAR project PN8303 (see ACIAR 1983) were:

- to devise and integrate biological control methods of tick control with chemical controls in sub-Saharan Africa;
- to analyse African data from collaborative projects in progress at the time, with a view to improve and monitor control methods;
- to adapt the Australian tick models for African ticks and tick-borne diseases; and to use the research results with the Australian tick models adapted to African conditions in the determination of economic thresholds and the design of optimal acaricide treatment schedules;
- to determine the economic losses due to ticks and tick-borne diseases in the absence of control and establish a knowledge base on these losses;
- to understand the population ecology of ticks in different geographical regions and the epidemiology of tick-borne diseases, with special emphasis on theileriosis and babesiosis;
- to determine the cost of control measures in various regions in sub-Saharan Africa; and
- to provide specific guidelines for experimental studies and trials to implement biological strategies for tick control.

The methodology used in the project was outlined in Sutherst (1981) and consisted of a combination of:

- measurement of biological processes of tick and tick-borne diseases;

- monitoring of field populations and incidence of diseases in the absence of control measures;
- measurement of damage caused by ticks and associated disease;
- modelling the processes to simulate field populations; and
- modelling the damage and control relationships to design optimal and robust management systems.

ACIAR project PN8303 was aimed at sub-Saharan Africa, with emphasis on Commonwealth countries, and had close links with the concurrent FAO–DANIDA regional program on the control of tick and tick-borne diseases (Sutherst 1987a). The program was initiated by FAO and the national governments in the region to undertake a holistic, detailed ecological and economic study with the aim of designing control programs which were economically optimal, but at the same time did not disturb the endemic stability of tick-borne diseases.

ACIAR (1983) notes and lists the following pre-project linkages between Dr Sutherst, the project leader of PN8303 and the FAO projects.

Uganda

The ACIAR tick project (PN8303) had its roots in Uganda in 1978 (Sutherst 1987a). There was pre-project collaboration between Dr Sutherst and Dr M.N. Kaiser (FAO–UNDP) with local counterpart staff, O'Dello Oneng in Uganda. Data on tick populations on Zebu cattle in Uganda were analysed to compare African tick–host relationships with that of the cattle tick in Australia. The results were encouraging for the application of Australian research in Africa.

Burundi

Pre-project collaboration took place between Dr Sutherst and Dr M.N. Kaiser (FAO–UNDP) with local counterpart staff, Dr Musiru in Burundi. A country-wide research program was designed to define the effect of environment in four contrasting environments on the survival and seasonal dynamics of all important species of ticks.

Zimbabwe

There was pre-project collaboration between Dr Sutherst and scientists in Zimbabwe on two types of projects: (a) measurement of economic damage caused by ticks (*Amblyoma hebraem*) in the lowveld area and in the highveld area (*Rhipicephalus appendiculatus*). These two ticks are the most serious in Africa, transmitting Heartwater and East Coast fever; and (b) ecological research, aimed at understanding the economically important African ticks in more detail, was conducted following experimental designs provided by Dr Sutherst. Dr Sutherst guided the observations and analysis of the results. This work was completed under ACIAR PN8303.

Zambia

There was pre-project collaboration between Dr Sutherst and scientists in Zambia undertaking ecological studies, field monitoring and an experiment to measure economic damage of ticks. This work was completed under ACIAR PN8303

Kenya

Pre-project collaboration between Dr Sutherst and scientists in Kenya involved work on host resistance and acaricide application schedules in relation to the control of *Rhipicephalus appendiculatus.* These studies required the Australian tick models to integrate the information generated with other ecological information from other sources.

The link between the ACIAR project and the FAO project has been formally acknowledged by FAO. For example, at the time of the review of ACIAR project PN8303, an FAO officer commented as follows (McCosker 1986):

> I emphasise that I am not responding on behalf of a specific country, but rather from my position as an officer in FAO with technical responsibility for ticks and tick-borne disease control projects in a number of FAO member countries. The research objectives (of PN8303) have certainly been very relevant to the work that had been established in certain projects before the initiation of the ACIAR project (PN8303) and also those that have developed in the context of this collaboration.
>
> Significant progress has been made towards the achievement of the objectives in the collaborative work associated with FAO executed projects in Uganda, Burundi, Zambia and Zimbabwe and to a lesser extent Mozambique, Kenya and Ethiopia. The collaboration between the ACIAR project and the FAO executed projects has assisted in the formulation of projects and investigations, analysis of results, predictions of economic losses and development of control strategies. Without this collaboration the FAO projects would have taken a lot longer to plan and execute.
>
> In addition the ACIAR project and project staff have collaborated in the training of a number of individuals in various aspects of modern computer analysis of ecological results, etc. The project has also supplied consultant advice to individual projects in Uganda, Burundi, Zambia, Zimbabwe, Ethiopia, and also to the regional FAO/DANIDA program for ticks and tick-borne disease control in east and Central Africa.

Despite these strong linkages between the FAO project on the control of ticks and tick-borne disease in sub-Saharan Africa and the ACIAR project it is important to note the following major differences between the two projects. First, the two projects started at different times. The FAO project started in sub-Saharan Africa in the late 1970s while the ACIAR project started in 1983. The FAO project continued into the 1990s whereas the ACIAR project was terminated in 1986 as a result of a large cut in ACIAR's budget. Thus, the two projects had different time horizons. Second, the FAO project had a budget of $US5 million up to 1986 and, at the time of the review of PN8303, FAO–DANIDA proposed to spend $US1 million annually for the 5-year period to 1991 (Elder et al. 1986). On the other hand ACIAR project PN8303 had a small budget of just over $A0.2 million in total for the 3 years, 1983 to 1986. The FAO project was completed about 1991 whereas research activity under ACIAR PN8303 stalled in 1986, then restarted in 1994 on a smaller scale to make it possible for a user friendly, 3-host tick model currently under development to be completed.

1.1.2 PN9407: Develop better methods to manage tick resistance to acaricides

Acaricides and other pesticides are used to control ticks, but ticks can develop genetic resistance to these chemicals, resulting in instances where ticks have survived in concentrated dip solutions. This problem is costing the Australian cattle industry conservatively $AU150 millions annually.[5]

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[5] Dr Joan Opdebeeck, The University of Queensland News, 14 July 1993.

This project aimed to:

- identify genetic markers for resistance to acaricides in ticks;
- determine precisely the type and level of resistance to select acaricides in ticks in Zimbabwe; and to determine the distribution of species and strains of ticks;
- complete a preliminary study on the immunological cross-reactivity of ticks in Zimbabwe and Australia; and
- develop a molecular probe for more rapid identification of resistance of ticks to pesticides.

Estimates of benefits from this project are based on the following comments by the reviewers of the project, Spithill and Chandiwana (1996):

> The impact and relevance of this project will be significant. This project is making important contributions to the development of the tools to allow rational management of tick resistance. Knowledge of tick populations, the molecular basis of acaricide resistance and the rate of appearance of resistance under different management protocols will contribute to our data base on tick behaviour at the population and genetic level. This new knowledge should assist future managers in both the public and commercial sector to control tick resistance and potentially develop new acaricides.
>
> The return from the project would seem to be more than reasonable from the point of view of both the science and the training. Project 9047 is developing new reagents and generating new knowledge in an important field and the application of this knowledge in the future is likely to bring economic, social and environmental benefits to both Australia and Zimbabwe.

This paper makes some assumptions in order to estimate the potential benefits from the project.

1.1.3 PN9118: Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia

This project had the following objectives:

- assist Zimbabwe in developing protocols for the production and distribution of effective, living vaccines against bovine babesiosis and anaplasmosis;
- collaborate in the design and implementation of field and laboratory studies required to establish the efficacy and purity of the vaccines produced in Zimbabwe;
- provide the expertise required to culture *Babesia* in vitro;
- develop better methods for differentiating species and strains of *Babesia* and apply these methods in problem-solving research in Australia and East Africa;
- develop a better alternative than the present card agglutination test for *Anaplasma marginale.*

Project PN9118 achieved the prime objectives of producing and testing, in the laboratory and field, new vaccines of high quality against *Babesia bigemina* and *Anaplasma marginale* in Zimbabwe and for their production and quality control (Krishna et al. 1995; Dr R.J. Dalgliesh, QDPI, pers. comm., February 1996). The availability of a vaccine against these tick-borne diseases led to the following benefits:

- reduction in the use of acaricides to control ticks. This benefit is of greater significance because there are now strong arguments against the practice of the frequent use of acaricides on economic, safety and environmental grounds;

- extension of the time acaricides can be used without inducing tick resistance to the chemicals; and
- improvement in host immunity to ticks and tick-borne diseases.

The research component in Australia has provided the following benefits (Dr R.J. Dalgliesh, QDPI, pers. comm., February 1996):

- new tools (molecular markers) that allow Australian scientists to distinguish between strains (within species) of *Babesia*;
- new diagnostic tests for epidemiological studies in Australia and for screening of export animals in accordance with requirements of Australia's trading partners.

1.2 The scope of the paper

The paper is structured as follows. Section 2 discusses the factors that influenced the impacts of this research project. Section 3 deals with the quantification of the direct welfare impacts of the project. In section 4 the results on the rate of return analyses are presented. Section 5 discusses the impact of the project on knowledge. Section 6 discusses the impact of the project on capacity building. Section 7 makes some concluding remarks.

2. FACTORS THAT INFLUENCED THE IMPACT OF RESEARCH

2.1 The size and structure of the beef and milk industries in collaborating countries

2.2.1 Production and consumption levels for beef and cows milk

Factors playing a major role in the determination of the impacts of a research project are the levels of production and consumption of the commodity arising from the industry targeted by the project. The ACIAR projects aimed at producing strategies to control tick and tick-borne diseases in cattle in sub-Saharan Africa. These strategies in turn impacted on the productivity of the beef and milk sectors and on the costs of producing beef and milk. Table 1 shows the output of beef and milk in Australia and Africa. Beef and milk are traded commodities, and a change in the cost of producing beef and milk in one region is thus likely to impact on the price of beef and milk in other parts of the world.

The collaborating countries in project PN8303 are defined to include those countries that were directly involved in the ACIAR project, namely Burundi, Kenya, Malawi, Zambia, and Zimbabwe; and those that were only indirectly involved in the project through their participation in the FAO/DANIDA project on the control of ticks and tick-borne diseases in sub-Saharan Africa, namely Ethiopia, Mozambique, Sudan, Tanzania and Uganda.

In the case of the other two projects—to develop better methods to manage tick resistance to acaricides (PN9407) and to investigate improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia (PN9118), the analysis covers benefits to Zimbabwe and Australia only.

Table 1. Production and consumption of beef and milk in Australia and Africa ('000 t, 1990).

	Collaborating countries	Beef production	Beef consumption	Trade status	Milk production	Milk consumption	Trade status
1	Australia	1,677	796	Exporter	6,435	4,579	Exporter
2	Ethiopia	245	245	Non-trader	971	1,024	Importer
3	Kenya	329	327	Exporter	2,473	2,463	Exporter
4	Malawi	20	20	Importer	47	63	Importer
5	Mozambique	41	41	Importer	78	103	Importer
6	Tanzania	195	195	Non-trader	541	555	Importer
7	Uganda	77	78	Non-trader	430	442	Importer
8	Zambia	37	37	Non-trader	79	83	Importer
9	Zimbabwe	78	65	Exporter	262	259	Exporter
10	Africa-5 (Rwanda and Burundi)	21	21	Non-trader	138	158	Importer
11	Zaire	27	38	Importer	7	45	Importer
12	Ivory Coast	42	65	Importer	20	174	Importer
13	Ghana	20	28	Importer	22	53	Importer
14	Nigeria	256	256	Non-trader	354	515	Importer
15	Cameroon	78	86	Importer	173	227	Importer
16	Angola	56	76	Importer	148	366	Importer
17	Madagascar	142	142	Non-trader	473	482	Importer
18	Sudan	210	210	Non-trader	2,935	3,052	Importer
19	Africa-2	303	308	Importer	3,796	4,220	Importer
20	Africa-3	46	54	Importer	109	172	Importer
21	Africa-4	47	62	Importer	40	97	Importer
22	Africa-6	122	71	Exporter	244	290	Importer
23	Africa-7	5	19	Importer	37	202	Importer
24	Egypt	505	638	Importer	2,293	2,459	Importer
25	Africa-1	259	290	Importer	2,659	4,968	Importer
26	WA/NA Other	428	641	Importer	6057	8014	Importer
	Total (1–26)	5267	4810		30,822	35,066	
	World total	45,828	52,806		529,868	533,023	

The countries in the project area are major producers of beef and milk in sub-Saharan Africa. Anteneh (1984) indicated that East Africa produced 43% and 64% of the sub-Saharan output of beef and cows milk, respectively.

The trade status columns in Table 1 indicate whether a country is a net importer, a net exporter or a non-trader. A net importer is a country or region that consumes more of a product than it produces. A net exporter is a country or region that consumes less of a product than it produces and exports the excess output. A non-trader is a country or region where the quantity of a commodity consumed is approximately equal to the quantity produced.

2.1.2 The traditional versus the commercial subsector

A useful distinction in sub-Saharan Africa is between the traditional and commercial sub-sectors of the livestock sector. Table 2 shows the percentage of the national cattle herd in the traditional and commercial sub-sectors in the countries that collaborated directly or indirectly in ACIAR projects.

Table 2. The percentage of the national cattle herd in the traditional and commercial sub-sectors in selected sub-Saharan countries.

Collaborating country	**Percent of the national cattle herd in the traditional sector**	**Cattle breed common in the traditional sub-sector**	**Percent of the national cattle herd in the commercial sector**	**Cattle breed common in the commercial sub-sector**
Australia	0		100	
Burundi[a]	90	*Bos indicus*, a half-Zebu breed known as Ankole	10	Friesian, Jersey, Sahiwal and cross breeds
Ethiopia[b]	90	East African Zebu	10	Exotic cross breeds
Kenya[c]	76	East African Zebu	24	Sahiwal and cross breeds
Malawi[d]	85	Sanga	15	Exotic cross breeds
Mozambique[e]	90	Indigenous breeds	10	Exotic cross breeds
Sudan[f]	80	Kenana and Butana	20	Exotic cross breeds
Tanzania[g]	95	Short horn Zebu	5	*Bos taurus* Friesian and jersey and Jersey × Zebu crossbreds
Uganda[h]	90	Indigenous breeds for beef	10	Grade cattle mainly for milk
Zambia[i]	80	Angoni, Barotse and Tonga	20	Exotic cross breeds
Zimbabwe[j]	65	Sanga, Mushona, Tuli and Nkore	35	Exotic cross breeds

[a] Niyonzema and Kiltz (1987) state that the production is mainly traditional

[b] It is assumed that the share of the traditional sector in the cattle herd in Ethiopia is the same as that for Burundi.

[c] Kariuki et al. (1994)

[d] Mkandiwire (1987)

[e] It is assumed that the share of the traditional sector in the cattle herd in Mozambique is the same as that for Burundi.

[f] Latif (1987)

[g] Chiomba (1987) and Glass (1987)

[h] Laker (1993)

[i] Chizyuka and Mangani (1987). The information on indigenous breeds in the traditional sector is from FAO (1990)

[j] Perry et al. (1990) The information on indigenous breeds in the traditional sector is from FAO (1990)

In Africa, milk production is more important in the traditional system and beef production in the commercial system (Elder et al. 1986). In the commercial sector, cattle are kept purely to generate income. However, in the traditional sector, income generation is very much secondary to meeting nutritional needs, storage of wealth, providing security and utility from the use of cattle in social and cultural functions (Mwenya 1993). The research findings of the project are aimed to apply equally to traditional and commercial farming systems (Sutherst 1987a). This analysis[6] recognises that the traditional sector is increasingly becoming profit-orientated and there is now an increasing number of higher yielding cross-bred animals which are less resistant to tick-borne disease than the traditional breeds.

6 An earlier version of this paper had assumed that the breeds of cattle in the traditional sector are more resistant to ticks than those in the commercial sector and so may not benefit much from some of the ACIAR research. However, after discussions with scientists at the Department of Veterinary Services, Ministry of Lands, Agriculture and Water Development, 7 Street, 1 Borrowdale Road, Harare in October 1995, this assumption was changed to reflect the increasing importance of more susceptible animals in the traditional sector.

Table 2 also shows the cattle breeds most common in the two sectors. The breed of cattle is important because about 4 years before the start of the ACIAR projects, research results from Uganda revealed the ability of tick-resistant zebu cattle to control African species of ticks. It was also shown that progressive dilution of zebu genes by cross breeding with *Bos taurus* (European breed) animals decreased exponentially the resistance of cattle to ticks and tick-borne diseases (Sutherst 1984).

2.1.3 Tick species and tick-borne diseases in the collaborating countries

Table 3 shows the most common ticks in the collaborating countries and the most common tick-borne diseases that they spread. Ticks are a major constraint on the production of beef and milk in sub-Saharan Africa. The following are the main impacts.

(a) They lead to increased livestock mortality rates due to tick-borne diseases. Moll (1987) reported a 2.6% mortality rate in cattle in Kenya due to theileriosis.

(b) Ticks reduce live weight gain in cattle and reduce milk yield. The effect depends on the breed of cattle and the tick species involved. For example, *Rhipicephalus appendiculatus* causes significant losses in European breed cattle whereas it does not affect Sanga cattle, an indigenous breed in Zimbabwe. On the other hand, *Amblyoma hebraem* was observed to cause significant live-weight gain losses in the Sanga cattle[7] (Elder et al. 1986). Castro (1987) provides estimates of cattle weight loss due to tick infestation in Kenya, while Pegram and Chizyuka (1987) provide estimates of cattle weight loss due to tick infestation in Zambia.

(c) It has been estimated that engorging adults of *Rhipicephalus appendiculatus* and *Amblyoma hebraem* species cause blood losses of 4 grams and 5 grams per tick, respectively, compared with 0.5 to 1 gram for *Boophilus microplus*, the tick common in Australia. Ticks can cause significant damage when their numbers are high. Each female *Rhipicephalus appendiculatus* tick engorgement depresses weight gain by approximately 4 grams and each female *Amblyoma hebraem* by approximately 10 grams. However, effects vary with the nutritional status of the cattle.

(d) There are many other secondary effects of tick infestation, including reduced reproduction, reduced calving rate, acaricide toxicity-related reduction in the growth rates of Zebu cattle (Sutherst and Kerr 1987), hide disfigurement and increased susceptibility to screw-worm attack.

(e) The current system of intensive dipping results in environmental damage and any other regime involving some dipping will not reduce those impacts significantly. For example, Zimbabwe will need the same number of dips with strategic dipping as it does under an intensive dipping regime. The number of dips was determined on the basis of travelling distance that cattle can bear (no more than 20 kilometres from the farm to the dip). That biological constraint will remain with or without intensive dipping.

(f) There are human health impacts of acaricide use those on children and women in the traditional sector who usually look after cattle and may be exposed to high level of acari-

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7 Unfortunately the experiment was carried out only on Sanga cattle, Elder et al. (1986).

cides. Dr Unesu Ushewokunze-Obatolu (Assistant Director-Research, Department of Veterinary Services, Harare) has made a study on residues of Bacdip and Quntiofos in milk following spraying. However, these impacts have not been included in this analysis.

Table 3. The prevalence of different tick species in selected sub-Saharan countries.

Country	Number of tick species	Tick species and tick-borne disease they transmit				
		Rhipicephalus appendiculatus (large 3-host brown ear tick)	*Ambylomma variegatum* (large 3 host tick)	*Boopholis decoloratus* (a 1-host blue tick)	*Boophilus microplus* (an Asian tick)	*Hyalomma truncatum*
		East Coast Fever (*Theileria parva bovis*)	Heartwater (*Cowdria ruminantum*)	Red water fever (*Babesia bigemina*) and gall sickness (*Anaplasma marginale*)	*Babesia bovis, Babesia bigemina* and *Anaplasma marginale*	Anaplasmosis and Babesiosis
Australia				Present	Present	
Burundi[a]	13	Common	Common	Common	Common	
Ethiopia[b]				Common	Common	
Kenya[c]				Present	Present	
Malawi[d]		Common	Common	Common	Common	Found in lowlands
Mozambique[e]				Present	Present	
Sudan[f]	62	Common	Common	Common	Present	
Tanzania[g]		Common	Present in Lake zone		Present in southern highlands	
Uganda[h]	62	Abundant in central province, but rare in other provinces	Abundant	Abundant	Present	Abundant
Zambia[i]		Common (1st in order of importance)	Common (4th in order of importance)	Common (3rd in order of importance)	Common (2nd in order of importance)	Common in the lowlands
Zimbabwe[j]		Common in highveld	Common in lowveld	Present	Present	

[a] Niyonzema and Kiltz (1987) state that the production is mainly traditional
[b] It is assumed that the share of the traditional sector in the cattle herd in Ethiopia is the same as that for Burundi.
[c] Kariuki et al. (1994)
[d] Mkandiwire (1987)
[e] It is assumed that the share of the traditional sector in the cattle herd in Mozambique is the same as that for Burundi.
[f] Latif (1987)
[g] Chiomba (1987) and Glass (1987)
[h] Laker (1993)
[i] Chizyuka and Mangani (1987)
[j] Perry et al. (1990)

There is a regional dimension to the incidence and impact of ticks and tick-borne diseases. Table 4 gives estimates of the incidence of the four major tick-borne diseases in Zimbabwe in the eight provinces of Zimbabwe. The information is obtained from the Veterinary Department field data base on incidence of the four major diseases in Zimbabwe. The table gives the number of outbreaks of disease (by province), and estimated mortality and morbidity rates. The information in Table 4 is given to show possible regional differences in the benefits from research.

However, these estimates need to be interpreted with caution because (a) the estimates refer to the beginning of an outbreak and so understate the morbidity and mortality rates, and (b) the quality of information is variable because in some cases the reports of diseases are made by non-veterinarians and the necessary confirmatory checks by a veterinarian which are planned for future improvements of the database have not yet been built into the reporting system. For these reasons a regional analysis of the benefits has not been undertaken.

2.2 The strategies used to control ticks and tick-borne diseases before and after research

Table 5 indicates the set of strategies that ACIAR projects considered in the control of ticks and tick-borne diseases in sub-Saharan Africa. The costs and benefits associated with most of the strategies have not been fully determined. The determination of these costs and benefits for all possible strategies and for each of the collaborating countries will be possible on completion of the two small projects, namely ‘Completion of computer modelling study of ticks in Africa’; and ‘The provision of a user-friendly 3-host tick model’.

Thus, the set of possible strategies available after the completion of the 3-host tick model is larger than is considered in this paper. The model will enable each country and possibly each farmer to optimise the choice of the tick and tick-borne control strategy to minimise the control costs, where control cost is measured as the sum of the cost of dipping, the cost of vaccination, where applicable, and the monetary value of live weight and milk yield lost.

The before-research strategy most commonly used to control ticks and tick-borne diseases in sub-Saharan Africa was intensive, weekly dipping. Intensive dipping was probably unnecessary in the traditional sector because of the higher level of genetically based resistance of the traditional breeds to ticks. However, there were inefficiencies in the way so-called intensive dipping regimes were implemented before this research in sub-Saharan Africa. Examples of inefficiencies in the before-research implementation of intensive dipping in the traditional sector in sub-Saharan Africa abound.

In Burundi in the 1980s, there were 159 dipping tanks of which only 80% were operational and cattle were dipped at irregular intervals (Niyonzema and Kiltz (1987);

- In the 1980s, Tanzania had about 1800 dips but 700 of them were not working due to lack of water or to vandalism. In addition dipping was not compulsory Chiomba (1987).
- In Malawi, all cattle within a 5 mile radius of a dip tank were required by law to be dipped, but this regulation was not enforced. Dip tank operational costs, especially cost of acaricides, were prohibitively high (Mkandiwire 1987).
- In Sudan, control measures such as regular dipping have never been practised (Latif 1987);
- Data from Kenya (Table 6) indicate that even where dips were operational there were dip quality factors which compromised the efficiency of an intensive dipping strategy in the country. In most cases, even where dips were operating, the acaricide concentration was either too high or too low. In the majority of cases the acaricide concentration was under-strength, in which case dipping was unlikely to kill the ticks on cattle.

Table 4. Estimates of the number of bovine tick-borne disease outbreaks, mortality rates and morbidity rates in eight Provinces of Zimbabwe based on returns from the field in 1995 (January to October 1995).

Province	Heartwater			East Coast Fever			Anaplasmosis			Babesiosis			Total reports
	Outbreaks	Average sick	Average dead	Outbreaks	Average sick	Average dead	Outbreaks	Average sick	Average dead	Outbreaks	Average sick	Average dead	
1. Manicaland	9	1	0.56	14	1.29	0.5	16	1.25	0.5	6	1	0.33	121
2. Mashonaland central	0	0	0	3	10.67	6.33	7	1.43	1.14	2	2	1.5	115
3. Mashonaland east	2	1	0	3	10.33	5.33	10	2.2	1.2	10	2	0.7	125
4. Mashonaland west	1	7	3	8	3.75	1.38	10	2.1	1.2	5	15.8	1.8	94
5. Matebeland north	20	1.1	1.5	11	2.27	2.55	13	1.31	0.31	1	1	1	111
6. Matebeland south	9	2.2	2.67	1	10	10	4	1.0	0.75	1	2	0	79
7. Midlands	5	0.8	1.4	1	0	0	1	1.0	0	0	0	0	35
8. Masvingo	13	1.54	1.38	1	2	2	10	1.1	0.2	3	2.33	2	95

Note: The result of average number of animals sick of 15.8 for babesiosis in Mashonaland West is based on one farm (Mazoe).
Source: Data was provided by Dr Peter Gamble, Department of Veterinary Services, Ministry of Lands, Agriculture and Water Development, 7 Street, 1 Borrowdale Road, Harare.

Table 5. Some tick control strategies explored under PN8303, PN9407 and PN9118.

No	Tick control strategies explored under ACIAR projects	Description
A	**Chemical-based strategies**	
A1	Prophylactic dipping	This is a dipping strategy designed to reduce the contamination of pastures so that future tick challenge to livestock is reduced
A2	Threshold dipping	Involves use of economic thresholds as a trigger to start or to abandon a series of planned dippings (Sutherst 1987b)
A3	Opportunistic dipping	This involves treatment of cattle for ticks when the animals are being handled for other purposes (Sutherst 1987b)
A4	Intensive dipping	
A5	Strategic dipping	This involves shifting from a rigid dipping schedule (e.g. dip twice a week) and changing dipping frequency and duration depending on tick challenge and other economic variables
A6	Strategic spraying	
A7	Pour-on formulations	
A8	Hand dressing using Gamatox	
B	**Vaccine based-strategies**	
B1	The preventative use of vaccines	
B2	Immunisation by chemoprophylaxis	
B3	Chemotherapy	
C	**Management practice-based strategies to interrupt the tick–host interaction**	
C1	Pasture spelling	This is a strategy which involves paddock rotation in order to interrupt the tick–host interactions. For example in some parts of Africa the use of low-lying swampy areas at one time of the year and the higher country or crop waste at another is a pasture spelling practice (Floyd et al. 1987)
C2	Night confinement	
C3	Herd migration	
C4	Pasture burning	
C5	Use stover and cut-and-carry fodder	
D	**Strategies to reduce chances of acaricide resistance**	
D1	Impregnated ear tags	
D2	Foot baths	
D3	Udder washes	
D4	Strategic dipping	This involves shifting from a rigid dipping schedule (e.g. dip twice a week) and changing dipping frequency and duration depending on tick challenge and other economic variables
E	**Biological control**	
E1	**Host resistance-based strategy**	This strategy involves exploitation of the host resistance of some breeds of cattle to ticks
E2	Use of sticky vegetation	This strategy involves use of sticky vegetation (e.g. certain cultivars of *Stylosanthes*) to trap and kill ticks
E3	Insect-eating birds	This involves encouraging insect-eating birds (e.g. the ox-pecker) to feed ticks infesting cattle
F	**Integrated pest management strategy**	Use acaricides as part of an integrated pest management in conjunction with host resistance, cattle movement or vaccination

Table 6. Data on the number of dips available, number of dips operating and the quality of dips in national tick control areas in Kenya.

District	Total dips available	Number of dips operating	Number of dippings in a year	Number sampled for dip quality test	Percent of dips under strength	Percent of dips satisfactory	Percent of dips over strength
Siaya	81	17	11 801	nt	nt	nt	nt
Nandi	357	274	12 913 444	2 714	45%	51%	4%
Kericho	340	286	1 472 262	1 327	40%	55%	5%
Baringo	172	152	1 555 810	466	26%	54%	20%
Laikipia	240	44	1 103 919	291	41%	29%	30%
Samburu	22	14	54 780	466	26%	54%	20%
Nakuru	411	156	82 307	1468	50%	39%	11%
Narok	145	31	58 794	274	65%	27%	8%
Kajiado	220	180	na	nt	nt	nt	nt
Transnzoia	406	84	33 783	138	75%	11%	14%
Marakwet	153	132	2 960 857	nt	nt	nt	nt
Kiambu	264	185	16 579 432	nt	nt	nt	nt
Muranga	294	285	2 408 632	2 114	78%	14%	8%
Nyeri	250	248	2 841	600	66%	16%	18%
Nyandarua	239	212	120 884	481	63%	23%	14%
Kirinyaga	110	109	725 929	1079	40%	48%	12%
Meru	229	160	604 115	nt	nt	nt	nt
Embu	108	103	310 714	nt	nt	nt	nt
Machakos	242	226	1 118 933	nt	nt	nt	nt
Kitui	80	10	42 747	nt	nt	nt	nt
Kwale	21	na	75 892	nt	nt	nt	nt
Tana River region	12	3	8 764	nt	nt	nt	nt
Nyamira	70	44	87 210	25	80%	4%	16%
Kakamega	192	151	540 286	186	57%	39%	4%
Bungoma	176	163	554 731	nt	nt	nt	nt
Kisumu	63	na	76 385	nt	nt	nt	nt
Kisii	84	68	307 735	nt	nt	nt	nt
Mombasa	26	2	5 826	nt	nt	nt	nt
Kilifi	66	39	382 736	nt	nt	nt	nt
Taveta	63	44	365	693	nt	nt	nt
Lamu	10	7	77 922	nt	nt	nt	nt
West Pokot	64	38	na	nt	nt	nt	nt

na: not available
nt: not tested
Source: Dr D.P. Kariuki and Dr S.K. Mbogo (Kenya Agricultural Research Institute, National Veterinary Research Centre, Mugugu, Kenya, pers. comm., September 1994).

This paper estimates the benefits that are likely accrue to these countries as a result of:

(a) shifting from a regime of intensive dipping to one of strategic dipping (PN8303). The main strategy adopted to date after research is strategic dipping. However, the adoption of strategic dipping did not influence herd sizes in either the traditional or commercial livestock sectors (R. Sutherst, pers. comm., April 1995).

(b) the future translation of the results from PN9047 into tools for rational management of tick resistance to acaricides.

(c) the availability in the future of new vaccines of high quality against *Babesia bigemina* and *Anaplasma marginale* in Zimbabwe; new tools (molecular markers) that allow Australian scientists to distinguish between strains (within species) of *Babesia;* and new diagnostic tests for epidemiological studies in Australia and for screening of export animals in accordance with requirements of Australia's trading partners (PN9118).

2.3 The herd structure and dynamics in the livestock sectors in sub-Saharan Africa—before and after research

In order to simulate the herd dynamics over a 10-year period, use is made of ILCA's Bio-Economic Herd Model for Microcomputer (IBIEHM) which has been documented in von Kaufmann et al. (1990). The ILCA model is a dynamic bio-economic simulation model used to compute herd structures and herd outputs (beef and cows milk) annually over 10 years. The model was validated in 1990 (see von Kaufmann et al. 1990), and has been used in a number of economic studies of the livestock sector in Africa (see, for example, Itty (1988), von Kaufmann and Mohamed-Saleem (1989) and McIntire (1988)). The parameters that largely determine the herd dynamics in this paper are summarised in Table 7.

Table 7. Key parameters about the livestock sector in sub-Saharan Africa before and after research.

Parameter	Units	Before research	After research PN8303 Shift from intensive to strategic dipping	After research PN9047 Better methods for the management of acaricide resistance	After research PN9118 High quality vaccine against babesiosis and anaplasmosis
Herd structure					
Female 0–1year	Number	2	2	2	2
Female 2 years	Number	2	2	2	2
Female 3 years	Number	1	1	1	1
Female 4 years	Number	1	1	1	1
Female 5 years	Number	1	1	1	1
Female > 5 years	Number	1	1	1	1
Male 0–1year	Number	1	1	1	1
Male 2 years	Number	1	1	1	1
Male 3 years	Number	1	1	1	1
Male 4 years	Number	2	2	2	2
Male 5 years	Number	2	2	2	2
Male > 5 years	Number	1	1	1	1
Total		16.0	16.0	16.0	16.0
Base female reproduction					
Age at 1st calving	Months	44	44	44	44
Calving rate	Percent	65%	65%	65%	70%
Base mortality rates					
Cattle 0–1 year	Percent	5.5%	5.5%	4.7%	2.2%
Cattle 1–2 yrs	Percent	6.5%	6.6%	5.6%	2.6%
Cattle >2 yrs	Percent	0.0%	0.0%	0.0%	0.0%
Milk production					

Table 7. (cont'd) Key parameters about the livestock sector in sub-Saharan Africa before and after research.

Parameter	Units	Before research	After research PN8303 Shift from intensive to strategic dipping	After research PN9047 Better methods for the management of acaricide resistance	After research PN9118 High quality vaccine against babesiosis and anaplasmosis
Lactation off-take	kg/cow/ day	3.64	3.64	3.64	4.17
Lactation length	Days	267	267	299	300
Beef production					
Live weights					
Female 0–1year	Kilograms	51	56	61	61
Female 2 years	Kilograms	100	110	120	120
Female 3 years	Kilograms	130	143	156	156
Female 4 years	Kilograms	212	233	254	254
Female 5 years	Kilograms	260	286	312	312
Female > 5 years	Kilograms	260	286	312	312
Male 0–1year	Kilograms	51	56	67	67
Male 2 years	Kilograms	100	110	132	132
Male 3 years	Kilograms	130	143	172	172
Male 4 years	Kilograms	212	233	280	280
Male 5 years	Kilograms	240	264	343	343
Male > 5 years	Kilograms	260	286	343	343
Off-take rates					
Young females	Percent	3%	3%	3%	3%
Adult females	Percent	5%	6%	8%	8%
Young males	Percent	3%	3%	3%	3%
Adult males	Percent	75%	75%	75%	75%

Sources: Sources of the different parameters are discussed in the text.

Herd structure

The cattle age classes used in the analysis are from von Kaufmann et al. (1990). The livestock sector in sub-Saharan Africa is varied and complex, but it includes two main production systems: the traditional livestock production system; and the commercial livestock production system. The traditional livestock production system covers both nomadic or transhumant pastoralism and sedentary farming. Under nomadic or transhumant pastoralism, pastoralists shift from one grazing area to another depending on availability of feed and water. Under sedentary farming, livestock producers graze their herds on natural pastures most of the time. This feed source is supplemented with crop residues and weeds during periods when natural pastures are in short supply.

Examples of nomadic or transhumant pastoralism in sub-Saharan Africa include the Maasai in Kenya and the Karamajong in Uganda. But even within these traditional groups there is great variety. For example de Leeuw et al. (1984) reported herd sizes ranging from 35 head of cattle among small-scale traditional Maasai pastoralists to 367 head among large-scale Maasai pastoralists. In the case of Uganda, Laker (1993) reported herd sizes ranging from 82 to 117. On the other hand Gryseels and Goe (1984) based on a survey of farmers in Ethiopia (around Debre Zeit and Debre Berhan), reported herd sizes of about 4 cattle per household. In the case of Zanzibar in Tanzania, the herd size varies from 2 to 5 heads of cattle for beef production in the traditional sector to 10 dairy cattle for milk production in the same sector (Biwi 1993). The herd structure in Table 7 is thus closer to that in the small-scale sedentary livestock sector than to that under nomadic or transhumant pastoralism.

Base female reproduction

First calving marks the beginning of a cow's productive life. The estimates of age at first calving, before research, are obtained from Mukasa-Mugerwa(1989). The age at first calving in the traditional sector is an average for the *Bos indicus* (Zebu) cattle and the age at first calving in the commercial sector is an average for the *Bos taurus* and *Bos indicus* ¥ *Bos taurus* crosses. Estimates of calving rates are based on Brumby and Trail (1986).

Base mortality rates

Estimates of mortality rates before research are based on McIntire (1988) and Konandreas et al. (1983). The shift from intensive dipping to strategic dipping is assumed to be associated with a slight increase in mortality rates. However, the introduction of better methods for the management of acaricide resistance and of high quality vaccines are likely to lead to reductions in the mortality rates of livestock.

Milk production parameters

Estimates of lactation off-take and lactation lengths are from Mwenya (1993). Suckling is necessary for calves in the traditional sector because Zebu cattle do not yield milk without suckling calves. The technologies developed under ACIAR-funded projects PN8303, PN9047 and PN9118 are likely to impact on both lactation off-take and lactation length for cattle in sub-Saharan Africa.

Beef production parameters

The killing out rate is the ratio of carcass weight to live weight of an animal. The technologies developed under PN8303 and PN9407 are likely to impact on live weights of cattle. Estimates of off-take rates[8] are obtained from Mwenya (1993). Although the off-take rate is very low in indigenous cattle, they contribute much more than exotic cattle and their crosses because of their larger number. Generally in this region indigenous cattle constitute 70 to 90% of the total cattle population (Mwenya 1993).

2.4 Prices, and demand and supply elasticities for beef and cows milk

Data on the prices of beef and cows milk are obtained from ILCA (1993). The price data are for 1986. However, FAO (1994) published information on indices of prices received by farmers in a number of African countries. From this information it was estimated that prices rose at a rate of 10% annually. This rate of increase in prices received by farmers was used to estimate the price in 1990, the base year for the analysis in this paper.

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[8] Off-take comprises all exits (sales, gifts, transfers, culling, emergency slaughter, and home consumption) except mortality (von Kaufmann et al. 1990).

The demand and supply elasticity for beef and cows milk in the 70 regions of the world recognised in the research evaluation model was obtained from the ACIAR Economic Evaluation Unit's database.

2.5 The research costs

Compared with other ACIAR projects, project PN8303 was a small budget project which cost A$206 600 for the three-year period from 1983–84 to 1985–86. The research costs for the three projects were as follows:

Project number	Project activity	Total research cost $A (m), 1991	Number of projects	Start of project	End of project
PN8303	Ecology, epidemiology and control of ticks and tick-borne diseases	$0.26	1	1983	1986
PN9047	Develop better methods to manage tick resistance to acaricides	$1.13	1	1993	1995
PN9118	Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia.	$1.50	1	1993	1996

2.6 The before-research and after-research cost of production for beef and cows milk

The annual costs are estimated using the ILCA model (von Kaufmann et al. 1990). These estimates are conditional on the assumptions set out in Table 7. The rest of this section discusses the parameters and major assumptions on which the estimates of annual costs are based.

Cattle acquisition (A_0)

At a point in time t, cattle acquisition costs, A_t, can be divided into two components: the annual cost, S_t, associated with the capital investment cost of purchasing cattle to set up the herd in year 0, and the cost of additions to the herd after it is set up, E_t. In the year t, the cost of cattle acquisition, A_t, as follows:

$$A_t = S_t + E_t \quad (1)$$

with

$$A_t = (\Sigma_a N_{a0} {*} W_{a0} {*} P_{lw}) \, (1 + r)^T r / \{[1 + r^T - 1] \quad (2)$$

$$E_t = (\Sigma_a M_{at} {*} W_{at} {*} P_{lw}) \, (1 + r)^T r / \{[1 + r^T - 1] \quad (3)$$

where:

a stands for a given age group of cattle as indicated in Tables 6 and 7;
N_{a0} is the number of cattle in age group a at time 0, after taking into account mortality and other exits from the herd,
M_{at} is the number of cattle added to cattle in age group a at time t, after taking into account mortality and other exits from the herd;
W_{at} is the live weight of an animal in age group a at time t;
P_{lw} is the price per kilogram of live weight of cattle (ILCA 1993)
r is the rate of interest.
t stands for time which ranges from 0, the initial year to T, estimated to be 10.

The cattle acquisition costs are annualised assuming an average life of cattle of 10 years and an annual interest rate of 8%. Cattle acquisition costs increase ‘after research’ because live weights increased after research and prices of cattle partly depend on live weights.

Herding labour

The herding labour cost, H, in period t has two components: a wage or fixed period remuneration and the monetary value of share of milk yield paid in kind to the herdsman.

$$H = R + m*M_t*P_{mt} \tag{4}$$

where

R	is the fixed monetary remuneration to the herdsman;
m	is the proportion of milk off-take that forms part of the herdsman’s pay package;
M_t	is the total milk off take in period t
P_{mt}	is the price of milk at time t.

The estimate for average monetary remuneration for herdsmen is obtained from Itty et al. (1995). Herdsmen are estimated to consume about 5% of milk off-take as part of their pay package.

Crush, paddock, tethering and buildings

The costs to cover crush, paddock, tethering and buildings, C_t, is the sum of two categories of cost which are related to herd size. The first, B_t, is a fixed component to cover the annualised cost of constructing and maintaining crushes, paddocks and buildings. An estimate for this fixed component was based on Itty et al. (1995). The second component covers the cost of tethering and is the product of R, the unit cost of tethering (labour costs plus cost of ropes) and N_t the number of cattle to be tethered. Thus:

$$C_t = B_t + R*N_t \tag{5}$$

Water

Based on Konandreas et al. (1983), water costs are estimated to be about \$A39.

Forage production

The cost of land used in forage production is estimated as follows:

$$L = G*P_L \tag{6}$$

where

L	stands for the total cost of land dedicated to livestock production;
G	is the number of hectares dedicated to livestock production;
P_L	is the opportunity cost of land, estimates of which are from McIntire (1988).

Forage production costs at time t, F_t, cover five annualised major cost components: the opportunity cost of land used in forage production, C_o, the cost of fencing, C_{f1}, the cost of fertiliser, C_{f2}, the cost of seed, C_s, and the cost of labour for land clearing and preparation, C_l. Thus

$$F_t = C_o + C_{f1} + C_{f2} + C_s + C_l \tag{7}$$

where

C_o is equal to L, the opportunity cost of land per hectare times the number of hectares used in forage production;

C_{f1} is equal to the perimeter of the area for forage production times the cost per metre of fencing materials;

C_{f2} is equal to the area (hectares) used for forage production times the quantity of fertilisers (kg) used per hectare times the cost of fertilisers per kilogram

C_s is equal to the area (hectares) used for forage production times the quantity of seed (kg) used per hectare times the cost of seed per kilogram

C_l is equal to the area (hectares) used for forage production times the number of person days needed per hectare for land clearing and preparation times the cost of labour per day.

Feed supplementation

Feed supplementation costs are estimated as the product of the quantity of purchased supplementation feed times the price of feed. In the traditional sector, feed supplementation is about 8 kilograms per year per lactating cow. In the case of commercial sector, all cattle are given supplementary feed irrespective of whether they are lactating or not. These higher levels of feed supplementation are not within the purchasing ability of the small-scale farmer in the traditional sector (Abate et al. 1993).

Minerals

The estimate of the annual cost of minerals per head of cattle is based on Itty et al. (1995). This cost is for the supply of mineral licks for the animals and is estimated at about $A0.30 per animal.

Veterinary treatments

Veterinary treatments costs, V, fall in two categories. One type, V_1, is per head of cattle and age class and the other, V_2, is per 100 kilogram of live weight and age of cattle. In the ILCA model (von Kaufmann et al. 1990) cattle are subdivided into three main age groups for the purpose of estimating veterinary treatment costs, namely cattle in the 0–1 age group, 1–2-year-old cattle and those older than 2 years.

$$V = V_1 + V_2 \tag{8}$$

$$V_1 = v_{11}*N_1+v_{12}*N_2+v_{13}*N_3 \tag{9}$$

$$V_2 = v_{21}*W_1+v_{22}*W_2+v_{23}*W_3 \tag{10}$$

v_{1j} is the cost of veterinary treatment per head of cattle in age group j. These costs are estimated at about $A0.30, $A1.12 and $A1.52 for cattle in the 0–1, 1–2 and over 2 years old age groups, based on Itty et al. (1988).

v_{21} is the cost of treatment per 100 kilogram of live weight for cattle in age group j. These costs are estimated at about $A0.59 per head of cattle based on Itty et al. (1988).

N_j is the number of cattle in age group j

W_j is the total weight of cattle in age group j after accounting for mortalities and other removals from the herd

Veterinary and livestock services

This cost covers access to qualified veterinary staff for expert advice. Based on Itty et al. (1995) this cost is estimated at about $A0.79 per head of cattle in the traditional sector. In the commercial sector this cost component is higher after research because of the added cost of vaccination.

Fences

The cost of fencing is estimated at about $A25 per annum per herd. The costs in the initial year are slightly higher because of set-up costs.

Dipping costs

In a literature review on the cost of dipping, Laker (1993) reported the following costs:

Country	Annual cost of dipping per animal	Source
Zambia, Kenya, Tanzania	US$2.50	Laker (1993, p.16)
Kenya	US$1.20 to $6.00	Laker (1993, p.16 and 19)
Burundi	US$2.00	Laker (1993, p.17)

In this paper, a before-research dipping cost per head of cattle is estimated at $A4.2 in the commercial sector and $A2.1 in the traditional sector. This is consistent with data on dipping costs in Zimbabwe where intensive dipping strategies were more rigorously adhered to for most of the time. The after-research cost for dipping is estimated to be half of the before-research cost.

2.7 Impact on the unit cost of production of beef and cows milk

PN8303: Ecology, epidemiology and control of ticks and tick-borne diseases.

The column in Table 7 labelled 'before research' gives values for key parameters in the dynamics of a herd before research. The impact of PN8303 on milk production is shown to have been negligible: neither lactation off-take nor lactation length were affected by research. However, the research had some impact on the live weights of cattle. These parameter changes are introduced in the ILCA (von Kaufmann et al. 1990) model to estimate the costs before and after PN8303. These costs are summarised in Tables 8 and 9 which give, respectively, the before- and after-research costs of producing beef and milk based on a herd structure shown in Table 7.

Table 8. The before-research cost of producing beef and milk in sub-Saharan Africa[a] (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cattle acquisition—annualised[b]	280	220	201	204	185	169	174	175	167	154	149
Land	9	28	28	28	28	28	28	28	28	28	20
Herding labour	10	63	66	73	77	68	61	64	66	64	50
Crush, paddock, tethering and buildings	27	71	66	66	64	61	59	58	56	54	30
Water	39	39	39	39	39	39	39	39	39	39	28
Forage production	51	116	116	116	116	116	116	116	116	116	116
Feed supplementation	0.13	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.31
Minerals	1.23	4.11	3.75	3.78	3.68	3.46	3.36	3.28	3.16	3.01	1.66
Veterinary treatments	11	37	34	34	30	28	29	29	28	25	25
Veterinary and livestock services	61	203	199	199	198	196	195	194	193	192	130
Fences	33	25	25	25	25	25	25	25	25	25	18
Dairy equipment	20	15	15	15	15	15	15	15	15	15	11

Table 8. (cont'd) The before-research cost of producing beef and milk in sub-Saharan Africa[a] (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Additional costs											
Dipping costs[c]	4	12	13	14	15	16	18	20	22	24	27
Vaccine: tick fever	24	79	67	63	64	64	63	63	63	64	64
Total cost	568	913	873	882	863	830	827	831	823	804	669
Total output–milk (tonnes)		2.18	2.34	2.88	3.14	2.48	2.03	2.23	2.36	2.22	1.96
Total output–beef (tonnes)		0.49	0.48	0.47	0.47	0.47	0.46	0.47	0.47	0.48	0.47

[a] Estimates of the costs in this table are based on a herd as described in Table 7

[b] Annualised cost of acquiring livestock assuming a rate of interest of 8% per annum and a life span of 10 years. The actual outlays in year 0 to year 10 are as follows: $A1878, $A1474, $A1349, $A1370.8, $A1242.33, $A1133, $A1167, $A1176, $A1119, $A1032, $A1000 as estimated using the ILCA model (von Kaufmann et al. 1990).

[c] These estimates are based on the estimates by Perry et al. (1990) for years 1 to 10 of the cost on current dipping services in Zimbabwe.

Sources: The sources used in the deriving the estimates in the table are discussed in the text of the paper.

Table 9. Estimated cost of producing beef and milk in sub–Saharan Africa[a] after research under PN8303 (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cattle acquisition – annualised[b]	295	225	205	207	188	173	177	178	169	156	152
Land	9	28	28	28	28	28	28	28	28	28	20
Herding labour	10	63	66	73	77	68	61	64	66	64	50
Crush, paddock, tethering and buildings	27	71	65	66	64	60	59	57	55	53	30
Water	51	39	39	39	39	39	39	39	39	39	28
Forage production	51	116	116	116	116	116	116	116	116	116	116
Feed supplementation	0.13	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.31
Minerals	1.22	4.07	3.72	3.75	3.65	3.42	3.32	3.24	3.12	2.97	1.64
Veterinary treatments	11	37	34	34	31	29	30	29	28	26	25
Veterinary and livestock services	63	210	206	206	205	202	201	200	199	197	133
Fences	33	25	25	25	25	25	25	25	25	25	18
Dairy equipment	20	15	15	15	15	15	15	15	15	15	11
Additional costs											
Dipping costs[c]	5	16	16	16	16	16	18	20	21	24	26
Vaccine: tick fever	20	68	54	50	50	49	46	44	43	42	40
Total	596	919	874	880	859	825	820	821	810	790	650
Total output–milk (tonnes)		2.18	2.34	2.88	3.14	2.48	2.03	2.23	2.36	2.22	1.96
Total output–beef (tonnes)		0.51	0.51	0.50	0.49	0.49	0.48	0.49	0.50	0.50	0.49

[a] Estimates of the costs in this table are based on a herd as described in Table 7

[b] Annualised cost of acquiring livestock assuming a rate of interest of 8% per annum and a life span of 10 years. The actual outlays in year 0 to year 10 are as follows: $A1878, $A1474, $A1349, $A1370.8, $A1242.33, $A1133, $A1167, $A1176, $A1119, $A1032, $A1000 as estimated using the ILCA model (von Kaufmann et al. 1990).

[c] These estimates are based on the estimates by Perry et al. (1990) for years 1 to 10 of the cost on current dipping services in Zimbabwe.

Sources: The sources used in the deriving the estimates in the table are discussed in the text of the paper.

From estimates of the before- and after-research costs and production levels in Table 8 and Table 9 the following unit costs are estimated.

A project on the ecology, epidemiology and control of ticks and tick-borne diseases	Before research PN8303	After research PN8303	Change in levels due to research	Percent change
Output of beef over 10 years (tonnes)	6.39	7.01	0.62	9.68
Output of milk over 10 years (tonnes)	24	24	0	0.00
Total cost of the herd over 10 years ($A, 1990)	8,884	8,884	–$A40.61	–0.46
Beef – Cost of producing beef over 10 years ($A, 1990)	4,442	4,442	–$A20.30	–0.46
Milk – Cost of producing milk over 10 years (0.5)[a]	4,442	4,442	–$A20.30	–0.46
Beef – Cost per unit[b] ($A/tonne, 1990)	695	631	–$A64.25	–9.24
Milk – Cost per unit[c] ($A/tonne, 1990)	187	186	–$A0.85	–0.46

[a] The 0.5 denotes the proportion of total or joint costs allocated to the commodity.
[b] The price of beef in Zimbabwe (in 1990) is estimated at $A720.
[c] The price of milk in Zimbabwe (in 1990) is estimated at $A280.

The project PN8303 (Ecology, epidemiology and control of ticks and tick-borne diseases in sub-Saharan Africa) is estimated to have led to an increase of about 9% in the production of beef and to a reduction of about 0.5% in the total joint cost of producing both beef and milk. This is equivalent to a reduction of about 9% in the unit cost of beef. The much lower cost reduction associated with milk production is because the project did not lead to increased output of milk.

PN9407: Develop better methods to manage tick resistance to acaricides

The column in Table 7 labelled 'After research PN9047' indicates the impact of project PN9047 on the values for key parameters in the dynamic model of a herd. The impact of PN9047 is shown to have been an increase in the production of milk and beef. Both lactation off-take and lactation length increased slightly as a result of the research.

The research also increased the live weights of cattle. These parameters are introduced in the ILCA model (von Kaufmann et al. 1990) to estimate the costs before and after PN9047. These costs are summarised in Tables 10 and 11 which respectively give the before-research and after-research costs of producing beef and milk based on a herd structure shown in Table 7.

Table 10. Estimated cost of producing beef and milk in sub-Saharan Africa[a] before research under PN9047 (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cattle acquisition—annualised[b]	280	221	203	209	193	180	186	189	182	170	166
Land	9	28	28	28	28	28	28	28	28	28	20
Herding labour	10	63	66	73	77	67	61	64	66	64	50
Crush, paddock, tethering and buildings	27	71	65	65	64	60	59	57	55	53	30
Water	39	39	39	39	39	39	39	39	39	39	28
Forage production	39	105	105	105	105	105	105	105	105	105	105
Feed supplementation	0.13	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.31
Minerals	1.22	4.07	3.71	3.75	3.64	3.42	3.32	3.23	3.12	2.97	1.64
Veterinary treatments	11	38	34	35	31	29	30	30	28	26	25

Table 10. (cont'd) Estimated cost of producing beef and milk in sub-Saharan Africa[a] before research under PN9047 (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Veterinary and livestock services	63	210	206	206	205	202	201	200	199	197	133
Fences	33	25	25	25	25	25	25	25	25	25	18
Dairy equipment	20	15	15	15	15	15	15	15	15	15	11
Additional costs											
Dipping costs[c]	2	8	8	8	8	9	9	10	11	12	14
Vaccine: tick fever	23	76	62	57	58	57	54	54	53	53	52
Total cost	557	904	861	870	852	821	818	821	811	791	653
Total output–milk (tonnes)		2	2	3	3	2	2	2	2	2	2
Total output–beef (tonnes)		0.56	0.56	0.55	0.55	0.55	0.54	0.55	0.55	0.55	0.55

[a] Estimates of the costs in this table are based on a herd as described in Table 7.

[b] Annualised cost of acquiring livestock assuming a rate of interest of 8% per annum and a life span of 10 years. The actual outlays in year 0 to year 10 are as follows: $A2014, $A1524., $A1377, $A1395, $A1267, $A1161, $A1193, $A1199, $A1140.23, $A1052, $A1020 as estimated using the ILCA model (von Kaufmann et al. 1990).

Sources:The sources used in the deriving the estimates in the table are discussed in the text of the paper.

Table 11. Estimated cost of producing beef and milk in sub-Saharan Africa[a] after research under PN9047 (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Cattle acquisition—annualised[b]	308	240	220	223	206	191	197	199	191	178	173
Land	9	28	28	28	28	28	28	28	28	28	20
Herding labour	10	69	72	80	84	74	66	69	71	69	55
Crush, paddock, tethering and buildings	26	70	64	64	63	59	57	56	54	52	29
Water	51	39	39	39	39	39	39	39	39	39	28
Forage production	57	123	123	123	123	123	123	123	123	123	123
Feed supplementation	0	0	0	0	0	0	0	0	0	0	0
Minerals	1	4	4	4	4	3	3	3	3	3	2
Veterinary treatments	12	40	36	36	32	30	31	31	29	27	26
Veterinary and livestock services	61	205	201	201	200	198	196	195	194	193	130
Fences	33	25	25	25	25	25	25	25	25	25	18
Dairy equipment	20	15	15	15	15	15	15	15	15	15	11
Additional costs											
Dipping costs	6	18	17	17	12	8	7	6	6	7	7
Vaccine: tick fever	20	68	64	69	60	49	47	46	45	43	41
Total	615	947	909	926	893	843	835	836	824	802	662
Total output–milk (tonnes)		2.62	2.77	3.40	3.68	2.91	2.39	2.60	2.76	2.58	2.29
Total output–beef (tonnes)		0.57	0.56	0.55	0.54	0.54	0.53	0.54	0.55	0.55	0.54

[a] Estimates of the costs in this table are based on a herd as described in Table 7.

[b] Annualised cost of acquiring livestock assuming a rate of interest of 8% per annum and a life span of 10 years. The actual outlays in year 0 to year 10 are as follows: $A2417, $A1815, $A1626, $A1636, $A1485, $A1356, $A1387, $A1390, $A1320, $A1219, $A1181, as estimated using the ILCA model (von Kaufmann et al. 1990).

Sources: The sources used in the deriving the estimates in the table are discussed in the text of the paper.

From estimates of the before- and after-research costs and production levels in Tables 10 and 11 the following unit costs are estimated.

A project to develop better methods to manage tick resistance to acaricides	**Before PN9047**	**After PN9047**	**Change due to research**	**% change**
Output of beef over 10 years (tonnes)	7	9	1.31	18.24
Output of milk over 10 years (tonnes)	24	28	4.23	17.82
Total cost of the herd over 10 years ($A, 1990)	8,760	9,091	331.38	3.78
Beef – cost of producing beef over 10 years ($A, 1990)	4,380	4,545	165.69	3.78
Milk – cost of producing milk over 10 years (0.5)[a]	4,380	4,545	165.69	3.78
Beef – cost per unit ($A/tonne, 1990)[b]	609	534	74.43	12.23
Milk – cost per unit ($A/tonne, 1990)[c]	184	162	21.97	11.91

[a] The 0.5 denotes the proportion of total or joint costs allocated to the commodity.

[b] The price of beef in Zimbabwe (in 1990) is estimated at $A 720.

[c] The price of milk in Zimbabwe (in 1990) is estimated at $A 280.

PN9118: Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia

The column in Table 7 labelled 'After research PN9118' indicates the impact of project PN9118 on key parameters in the dynamic model of a herd. For farmers adopting vaccines developed under PN9118 there is an increase in the farm-level output of milk and beef. Both lactation off-take and lactation length increase as a result of the research. There is also an increase in the live weights of cattle. Tables 12 and 13 respectively summarise the before-research and after-research cost of producing beef and milk based on a herd structure shown in Table 7 and derived using the ILCA model (von Kaufmann et al. 1990).

From estimates of the 'before' and 'after' research costs and production levels in Tables 12 and 13 the following unit costs are estimated.

Project on improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia	**Before PN9118**	**After PN9118**	**Change in levels due to research**	**% change**
Output of beef over 10 years (tonnes)	7	9	2.01	27.89%
Output of milk over 10 years (tonnes)	24	32	8.63	36.33%
Total cost of the herd over 10 years ($A, 1990)	8,814	9,664	849.51	9.64%
Beef – cost of producing beef over 10 years ($A, 1990)	4,407	4,832	424.75	9.64%
Milk – cost of producing milk over 10 years (0.5[a])	4,407	4,832	424.75	9.64%
Beef – cost per unit[b] ($A/tonne, 1990)	613	525	87.41	14.27%
Milk – cost per unit ($A/tonne, 1990)	186	149	36.33	19.58%

[a] The 0.5 denotes the proportion of total or joint costs allocated to the commodity.

[b] The price of beef in Zimbabwe (in 1990) is estimated at $A 720.

[c] The price of milk in Zimbabwe (in 1990) is estimated at $A 280.

2.8 The adoption of the results from the project

Table 14 shows the adoption rates assumed in the estimation of realised and potential benefits from the three animal sciences projects based in Africa.

Table 12. Estimated cost of producing beef and milk in sub-Saharan Africa[a] before research under PN9118 (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cattle acquisition—annualised[b]	280	221	203	209	193	180	186	189	182	170	166
Land	9	28	28	28	28	28	28	28	28	28	20
Herding labour	10	63	66	73	77	67	61	64	66	64	50
Crush, paddock, tethering and buildings	27	71	65	65	64	60	59	57	55	53	30
Water	39	39	39	39	39	39	39	39	39	39	28
Forage production	39	105	105	105	105	105	105	105	105	105	105
Feed supplementation	0	0	0	0	0	0	0	0	0	0	0
Minerals	1.22	4.07	3.71	3.75	3.64	3.42	3.32	3.23	3.12	2.97	1.64
Veterinary treatments	11	38	34	35	31	29	30	30	28	26	25
Veterinary and livestock services	63	210	206	206	205	202	201	200	199	197	133
Fences	33	25	25	25	25	25	25	25	25	25	18
Dairy equipment	20	15	15	15	15	15	15	15	15	15	11
Additional costs											
Dipping costs	2	8	8	8	8	9	9	10	11	12	14
Vaccine: tick fever	23	76	72	68	59	57	56	55	55	54	53
Total cost	557	904	871	890	864	823	820	823	814	794	655
Total output–milk (tonnes)		2.18	2.33	2.87	3.13	2.47	2.02	2.22	2.36	2.21	1.96
Total output–beef (tonnes)		0.56	0.56	0.55	0.55	0.55	0.54	0.55	0.55	0.55	0.55

[a] Estimates of the costs in this table are based on a herd as described in Table 7

[b] Annualised cost of acquiring livestock assuming a rate of interest of 8% per annum and a life span of 10 years. The actual outlays in year 0 to year 10 are as follows: $A 2014, $A 1524, $A 1377, $A 1395, $A 1267, $A 1161, $A 1193, $A 1199, $A 1140, $A 1052, $A 1020, as estimated using the ILCA model (von Kaufmann et al. 1990).

Sources:The sources used in deriving the estimates in the table are discussed in the text of the paper.

PN8303 (Ecology, epidemiology and control of ticks and tick-borne diseases)

The reviewers of the ACIAR project PN8303 noted the following (Elder et al. 1986, p.12):

> The results obtained by the project have been discussed with national authorities and have already resulted in the initiation of field tests to evaluate the effectiveness of strategic dipping procedures which have been suggested by models formulated under the project. Such tests are now being carried out in Burundi, Zambia and Zimbabwe and if successful, will be extended in the future.

There has been a shift in dipping practices from intensive weekly dipping to less frequent but strategic dipping in sub-Saharan Africa. In the case of Zimbabwe this shift has been expressed in the Animal Health Cattle Cleansing Regulations introduced by the Zimbabwe Ministry of Lands, Agriculture and Water Development (1993). In these regulations, instead of requiring cattle owners to dip their cattle every week irrespective of tick challenge levels, the regulations require dipping in only those cases where cattle are tick infested. Section 3 of the regulations defines tick infested herds as follows:

> An individual animal shall be deemed to be tick-infested if it has ten or more engorged ticks attached to it.

> A herd of cattle shall be deemed to be tick-infested if there are - a)- ten or more live ticks on each of a number of cattle of the cattle amounting to more than 10% of the herd; b)-ten or more engorged ticks on any one animal in the herd; or c) five or more engorged ticks on each of at least five heads of cattle in the herd.

The regulations then stipulate that:

> An owner of cattle shall, if the cattle are deemed to be tick-infested, cause them to be dipped at regular intervals of not more than seven days until they are tick-free.

Estimates of adoption rates with respect to PN8303 in Table 14 give the proportion of farmers adopting the results from the project. The adoption rates in the rest of Africa are modified to take into account the fact that the before-research situation in many of those countries did not correspond to a rigorously applied practice of intensive dipping (see Table 4, for example).

Table 13. Estimated cost of producing beef and milk in sub-Saharan Africa[a] after research under PN9118 (1990, $A), assuming a herd size of 16 with attributes shown in Table 7.

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Cattle acquisition—annualised[b]	308	240	220	223	206	191	197	199	191	178	173
Land	9	28	28	28	28	28	28	28	28	28	20
Herding labour	10	73	75	85	90	80	73	77	80	78	63
Crush, paddock, tethering and buildings	27	72	67	69	69	67	66	65	64	63	40
Water	51	39	39	39	39	39	39	39	39	39	28
Forage production	57	123	123	123	123	123	123	123	123	123	123
Feed supplementation	0.13	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.31
Minerals	1.24	4.14	3.86	3.97	3.98	3.84	3.78	3.74	3.68	3.57	2.25
Veterinary treatments	12	40	37	38	35	34	35	36	34	33	32
Veterinary and livestock services	62	206	203	204	204	203	202	202	201	200	137
Fences	33	25	25	25	25	25	25	25	25	25	18
Dairy equipment	20	15	15	15	15	15	15	15	15	15	11
Additional costs											
Dipping costs	6	18	15	12	9	7	6	5	5	6	7
Vaccine: tick fever	33	109	93	92	91	86	83	82	81	80	78
Total	628	994	946	959	940	903	898	901	892	872	732
Total output–milk (tonnes)		2.84	3.00	3.70	4.07	3.34	2.85	3.14	3.36	3.20	2.89
Total output–beef (tonnes)		0.57	0.56	0.54	0.54	0.53	0.53	0.54	0.54	0.54	0.54

[a] Estimates of the costs in this table are based on a herd as described in Table 7

[b] Annualised cost of acquiring livestock assuming a rate of interest of 8% per annum and a life span of 10 years. The actual outlays in year 0 to year 10 are as follows: $A 2417, $A 1833, $A 1672, $A 1720, $A 1623, $A 1536, $A 1592, $A 1620, $A 1569, $A 1481, $A 1457, as estimated using the ILCA model.

Sources:The sources used in the deriving the estimates in the table are discussed in the text of the paper.

PN9047 and PN9118

In Zimbabwe the commercial farms which run about 1.4 million head of cattle out of the 5.7 million national herd are able to adopt the new technologies developed under PN9047 and PN9118 and cover their own costs. Estimates of adoption at this stage reflect adoption in this sector. Delivery to the traditional sector, and adoption in that sector, may require additional expenses on farmer education and extension services and (with respect to PN9118) the establishment of a cold chain system required for the delivery of vaccine services. While there is likely to be some adoption in the traditional sector which will generate additional benefits, these benefits are not included in the analysis since the associated costs of delivery of the vaccines to this sector are not known.

What is estimated in Table 14 are the potential future adoption rates for the results from the research projects PN9047 and PN9118 in the collaborating countries, focusing on those farmers who can readily adopt the technologies. These estimates are conservative because they do not take into account the potential for technical spillovers to the rest of sub-Saharan Africa where similar problems to those addressed in the two projects are common and where farmers are likely to adopt the technologies developed. However, similar to the issue of adoption in the traditional livestock sector in Zimbabwe, spillovers to other countries may require additional costs to facilitate the uptake of the new technologies in those countries.

3. ESTIMATION OF THE WELFARE IMPACTS OF ADOPTING ACIAR PROJECT CONTROL STRATEGIES FOR TICKS AND TICK-BORNE DISEASES

This section estimates the welfare impacts of the following:

- changing from intensive weekly dipping to strategic dipping in the control of ticks and tick borne diseases in sub-Saharan Africa as a result of project PN8303 (Ecology, epidemiology and control of ticks and tick-borne diseases in sub-Saharan Africa);
- adopting better methods for managing acaricide resistance as a result of project PN9047;
- adopting improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia as a result of project PN9118.

The welfare benefits from the three projects accrued to consumers and producers in the following regions:

- Sub-Saharan African collaborators in the project;
- the other countries in Africa and in the rest of the world are affected differently depending on whether they are net exporters or net importers of beef and cows milk; and
- Australia.

The reviewers of the project (Elder et al. 1986) noted the following benefits which accrued to Australia as a result of ACIAR project PN8303. In New South Wales, cattle tick control policy in the Tick Quarantine Area has been the subject of tick population studies via the TICK models and that policy was modified. This had an important influence on cattle movement. The Queensland Department of Primary Industries adapted the CLIMEX and TICK models to study the appropriateness of cattle tick control policy. A working party reviewed the position of the tick line in Queensland and the cattle movements associated with this. The governments of the Northern Territory, Western Australia and Victoria have sought and have been given advice relating to outbreaks of various species of ticks.

Table 14. Adoption rates assumed in the estimation of potential benefits from three Animal Sciences projects PN8303, PN9047 and PN9118 based in Africa.

Year no.	Calendar year	PN8303 Zimbabwe	PN8303 Rest of Africa	PN8303 Australia	PN9047 Zimbabwe	PN9047 Australia	PN9118 Zimbabwe	PN9118 Australia
0	1984	Start[a]	Start[a]	Start [a]	na	na	na	na
1	1985	0	0	0	na	na	na	na
2	1986	0	0	0	na	na	na	na
3	1987	0	0	0	na	na	na	na
4	1988	0	0	0	na	na	na	na
5	1989	0	0	0	na	na	na	na
6	1990	0	0	0	na	na	na	na
7	1991	0	0	0	na	na	na	na
8	1992	0.1	0.05	0.0141	na	na	na	na
9	1993	0.15	0.1	0.0141	Start[a]	Start[a]	Start [a]	Start[a]
10	1994	0.2	0.1	0.0141	0	0	0	0
11	1995	0.25	0.1	0.0141	0	0	0	0
12	1996	0.3	0.1	0.0141	0	0	0	0
13	1997	0.3	0.1	0.0141	0	0	0	0
14	1998	0.3	0.1	0.0141	0	0	0	0
15	1999	0.3	0.1	0.0141	0	0	0	0
16	2000	0.3	0.1	0.0141	0.1	0.17	0	0
17	2001	0.3	0.1	0.0141	0.2	0.2	0.25	0.2
18	2002	0.3	0.1	0.0141	0.2	0.3	0.35	0.2
19	2003	0.3	0.1	0.0141	0.3	0.3	0.45	0.2
20	2004	0.3	0.1	0.0188	0.3	0.3	0.55	0.2
21	2005	0.3	0.1	0.0188	0.3	0.3	0.6	0.2
22	2006	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
23	2007	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
24	2008	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
25	2009	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
26	2010	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
27	2011	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
28	2012	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
29	2013	0.3	0.1	0.0188	0.3	0.3	0.7	0.2
30	2014	Truncate[b]	Truncate[b]	Truncate[b]	0.3	0.3	0.7	0.2
31	2015				0.3	0.3	0.7	0.3
32	2016				0.3	0.3	0.7	0.3
33	2017				0.3	0.3	0.7	0.3
34	2018				0.3	0.3	0.7	0.3
35	2019				0.3	0.3	0.7	0.3
36	2020				0.3	0.3	0.7	0.3
37	2021				0.3	0.3	0.7	0.3
38	2022				0.3	0.3	0.7	0.3
39	2023				0.3	0.3	0.7	0.4
					Truncate[b]	Truncate[b]	Truncate[b]	Truncate[b]

[a] Start denotes the start of the project

[b] Truncate is used to indicate that the flow of benefits is cut off after 30 years. Benefits from all projects are estimated under the assumption that benefits will flow for 30 years. The cut off is introduced to enable the treatment of all projects on the same basis in terms of time horizon.

The potential technical spillovers to other countries and regions are not included in the analysis because of lack of data on the likely extent and magnitude of the impact to these regions. However, the foundations for realising these technical spillovers to other regions was laid during the project. For example, the final report for PN9047 notes the following as examples of activities which are likely to enhance technical spillovers from the project:

- Research linkages, during the project, involving the following scientists at Onderstepoort Veterinary Institute (OVI), Onderstepoort, South Africa: A.M. Spickett (OVI), J.P. Opdebeeck, A.G. Knowles, J.Y.M. Wong who are interested in immunological cross-reactivity in ticks that infest cattle and the potential of antigens from *Boophilus microplus* to vaccinate cattle against other species of ixodid ticks. Research linkages between I. McKay, A.M. Spickett (OVI) and S.C. Barker are based on their common interest in genetic variation among species of cattle ticks.
- Arthur Spickett (OVI) won an Australian Society for Parasitology Invited Lectureship Travel Grant to visit the University of Queensland and to be a key note speaker at the Annual Meeting of The Australian Society for Parasitology, Heron Island, Qld, Australia, in September 1993. This strengthened the link between the University of Queensland and the OVI.
- Research linkages with the United Nations Food and Agriculture Organisation's World Acaricide Resistance Reference Centre (WARRC), Berlin, Germany involving R. Thullner (WARRC) with S. C. Barker, P. E. Green and J. P. Opdebeeck on research relating to resistance to acaricides in ticks of cattle, the larval packet test and DNA diagnostic tests for resistance to acaricides.
- There is also potential 'spillover' to cattle producers in southern USA, Central & South America, and African countries where B. *microplus* causes economic losses (in addition to Zimbabwe). For example, a presentation was made at the Third International Seminar on Acaricide Resistance in Acapulco (September 1995) highlighting the urgent need for and potential benefit of DNA diagnostic tests for resistance to organophosphate and other acaricides. The diagnostic kits produced in PN 9047 will be widely used. Indeed, the kit will represent the first such diagnostic test and for the first time resistance to an acaricide may be managed in a rational and coordinated way.

Use is made of standard research evaluation equations in the estimation of welfare benefits. These equations have been discussed extensively elsewhere (for example, Alston et al. 1995; Davis et al. 1987). In sub-section 3.1, the base case results are discussed. The base case is described by the data in Tables 1–14. Subsection 3.2 discusses sensitivity analyses where some of the assumptions made in the base case are varied to assess how sensitive the results in the paper are to changes in the base case assumptions.

3.1 Summary of results for the base case

The results summarised in this section are dependent mainly on total output of beef and milk in the collaborating countries (Table 1), the share of the commercial sector in the livestock sectors of the collaborating countries (Table 2), the cost savings due to research (section 2.7), and the adoption rates assumed in the analysis (Table 14). In section 3.2 some of these assumptions are changed to indicate the sensitivity of these results to changes in the respective parameters.

PN8303 (Ecology, epidemiology and control of ticks and tick-borne diseases)

Table 15 is a summary of the benefits from project PN8303. Over a period of 30 years at a discount rate of 8% per annum, the project is likely to generate total benefits of $A2.06 million distributed as follows: $A1.93m accrues to African country collaborators (Burundi, Kenya, Malawi, Zambia, Zimbabwe, Mozambique, Sudan, Tanzania and Uganda) and $A 0.13 million accrues to Australian producers and consumers. The distribution of benefits by commodity is as follows: $A1.91 million are attributed to beef and $A 0.15 million are attributed to milk production. Taking into account the research costs of $A0.26m yields a net present value of benefits of $A 1.90 million and an internal rate of return of 25% per annum.

Table 15. The aggregated flow over time of estimated benefits (over 30 years a rate of discount of 8% per annum) accruing to beef and milk producers in the livestock sector due to the adoption of results from ACIAR project PN8303 (1990, $A'000).

Year no.	Calendar year	Benefits to Africa[a,b]	Benefits to Australia[b]	Total benefits[b]	Research costs adjusted for inflation[b]	Net benefits[b]
		Milk and beef	Milk and beef	Milk and beef	Milk and beef	
1	1984	0.00	0.00	0.00	97.39	–97.39
2	1985	0.00	0.00	0.00	87.52	–87.52
3	1986	0.00	0.00	0.00	120.53	–120.53
4	1987	0.00	0.00	0.00	0.00	0.00
5	1988	0.00	0.00	0.00	0.00	0.00
6	1989	0.00	0.00	0.00	0.00	0.00
7	1990	0.00	0.00	0.00	0.00	0.00
8	1991	0.00	0.00	0.00	0.00	0.00
9	1992	54.44	19.26	73.70	0.00	73.70
10	1993	124.09	19.26	143.35	0.00	143.35
11	1994	206.06	19.26	225.32	0.00	225.32
12	1995	311.45	19.26	330.72	0.00	330.72
13	1996	440.26	19.26	459.53	0.00	459.53
14	1997	440.26	19.26	459.53	0.00	459.53
15	1998	440.26	19.26	459.53	0.00	459.53
16	1999	440.26	19.26	459.53	0.00	459.53
17	2000	440.26	19.26	459.53	0.00	459.53
18	2001	440.26	19.26	459.53	0.00	459.53
19	2002	440.26	19.26	459.53	0.00	459.53
20	2003	440.26	19.26	459.53	0.00	459.53
21	2004	440.26	34.25	474.51	0.00	474.51
22	2005	440.26	34.25	474.51	0.00	474.51
23	2006	440.26	34.25	474.51	0.00	474.51
24	2007	440.26	34.25	474.51	0.00	474.51
25	2008	440.26	34.25	474.51	0.00	474.51
26	2009	440.26	34.25	474.51	0.00	474.51
27	2010	440.26	34.25	474.51	0.00	474.51
28	2011	440.26	34.25	474.51	0.00	474.51
29	2012	440.26	34.25	474.51	0.00	474.51
30	2013	440.26	34.25	474.51	0.00	474.51
NPV $A, m 1990	na	1.93 (c)	0.13 (c)	2.06 (c)	0.26 (c)	1.97 (c)

Table 15. (cont'd) The aggregated flow over time of estimated benefits (over 30 years a rate of discount of 8% per annum) accruing to beef and milk producers in the livestock sector due to the adoption of results from ACIAR project PN8303 (1990, $A'000).

Year no.	Calendar year	Benefits to Africa[a,b]	Benefits to Australia[b]	Total benefits[b]	Research costs adjusted for inflation[b]	Net benefits[b]
		Milk and beef	Milk and beef	Milk and beef	Milk and beef	
Benefits to Beef $A, m 1990	na	1.78[c]	0.13[c]	1.91[c]	na	na
Benefits to Milk $A, m 1990	na	0.15[c]	0.00[c] ns	0.15[c]	na	na
Internal rate of return						25%[d]

a: Only includes benefits to sub-Saharan African countries (Burundi, Kenya, Malawi, Zambia, Zimbabwe, Mozambique, Sudan, Tanzania and Uganda) that collaborated in the ACIAR project or in the FAO/DANIDA project.
b: The flows of benefits and costs from year 1 to year 30 are expressed in thousands of dollars.
c: These values are expressed in millions of dollars.
d: This revises the internal rate of return estimate of 30% reported in Beckmann (1996) which contained an error.
na: Not applicable. ns: Not significant

PN9047 (Develop better methods to manage tick resistance to acaricides)

From Table 16, over a period of 30 years at a discount rate of 8% per annum, the potential benefits from project PN9047 are estimated to be about $A12.34 million distributed as follows: $A4.05 million is likely to accrue to Zimbabwe and $A8.28 million to Australian producers and consumers. The distribution of benefits by commodity is as follows: $A6.09 millions are attributed to beef and $A 6.24 million are accrue to milk production. Taking into account the research costs of $A 1.13 million yields a net present value of benefits of $A 11.21 million and an internal rate of return of 33% per annum.

PN9118 (Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia)

Finally, from Table 17, over a period of 30 years at a discount rate of 8% per annum, project PN9118 is likely to generate total benefits of $A 35.26 millions distributed as follows: $A 23.78m accrues to Zimbabwe and $A 11.47 million accrues to Australian producers and consumers. The distribution of benefits by commodity is as follows: $A 20.54 millions are attributed to beef and $A 14.72 million are attributed to milk production. Taking into account the research costs of $A1.5m yields a net present value of benefits of $A 33.76 millions and an internal rate of return of 40% per annum.

Table 16. The aggregated flow over time of estimated potential benefits (over 30 years a rate of discount of 8%) likely to accrue to beef and milk producers in the livestock sector due to the adoption of technology based on results from ACIAR project PN9047 (1990, $A'000).

Year no.	Calender year	Benefits to Zimbabwe[a,b]	Benefits to Australia[b]	Benefits to the rest of the world[b]	Total benefits[b]	Research costs adjusted for inflation[b]	Net benefits[b]
		Milk and beef	Milk and beef		Milk and beef	Milk and beef	
1	1993	0.00	0.00	0.00	0.00	442.36	–442.36
2	1994	0.00	0.00	0.00	0.00	440.16	–440.16
3	1995	0.00	0.00	0.00	0.00	427.34	–427.34
4	1996	0.00	0.00	0.00	0.00	0.00	0.00
5	1997	0.00	0.00	0.00	0.00	0.00	0.00
6	1998	0.00	0.00	0.00	0.00	0.00	0.00
7	1999	81.32	229.57	0.00	310.90	0.00	310.90
8	2000	325.28	229.57	0.00	554.86	0.00	554.86
9	2001	325.28	638.38	0.01	963.67	0.00	963.67
10	2002	731.88	1280.61	0.01	2012.50	0.00	2012.50
11	2003	731.88	1563.86	0.02	2295.76	0.00	2295.76
12	2004	731.88	1563.86	0.02	2295.76	0.00	2295.76
13	2005	731.88	1563.86	0.02	2295.76	0.00	2295.76
14	2006	731.88	1563.86	0.02	2295.76	0.00	2295.76
15	2007	731.88	1563.86	0.02	2295.76	0.00	2295.76
16	2008	731.88	1563.86	0.02	2295.76	0.00	2295.76
17	2009	731.88	1563.86	0.02	2295.76	0.00	2295.76
18	2010	731.88	1563.86	0.02	2295.76	0.00	2295.76
19	2011	731.88	1563.86	0.02	2295.76	0.00	2295.76
20	2012	731.88	1563.86	0.02	2295.76	0.00	2295.76
21	2013	731.88	1563.86	0.02	2295.76	0.00	2295.76
22	2014	731.88	1563.86	0.02	2295.76	0.00	2295.76
23	2015	731.88	1563.86	0.02	2295.76	0.00	2295.76
24	2016	731.88	1563.86	0.02	2295.76	0.00	2295.76
25	2017	731.88	1563.86	0.02	2295.76	0.00	2295.76
26	2018	731.88	1563.86	0.02	2295.76	0.00	2295.76
27	2019	731.88	1563.86	0.02	2295.76	0.00	2295.76
28	2020	731.88	1563.86	0.02	2295.76	0.00	2295.76
29	2021	731.88	1563.86	0.02	2295.76	0.00	2295.76
30	2022	731.88	1563.86	0.02	2295.76	0.00	2295.76
NPV $A, m 1990		4.05[c]	8.28[c]	0.00009[c]	12.34[c]	1.13[c]	11.21[c]
Benefits to Beef $A, m 1990	na	2.09[c]	4.00[c]	ns[d]	6.10[c]	na	na
Benefits to Milk $A, m 1990	na	1.96[c]	4.28[c]	ns[d]	6.24[c]	na	na
Internal rate of return							33%

[a] Only includes benefits to one sub-Saharan African country, Zimbabwe that collaborated in the ACIAR project.

[b] The flows of benefits and costs from year 1 to year 30 are expressed in thousands of dollars.

[c] These values are expressed in millions of dollars.

[d] ns: not significant.

Table 17. The aggregated flow over time of estimated benefits (over 30 years a rate of discount of 8% per annum) accruing to beef and milk producers in the livestock sector due to the adoption of results from ACIAR project PN9118 (1990, $A'000).

Year no.	Calendar year	Benefits to Zimbabwe[a,b]	Benefits to Australia[b]	Benefits to the rest of the world[b]	Total benefits[b]	Research costs adjusted for inflation[b]	Net benefits[b]
		Milk and beef	Milk and beef		Milk and beef	Milk and beef	
1	1993	0.00	0.00	0.00	0.00	468.02	–468.02
2	1994	0.00	0.00	0.00	0.00	553.92	–553.92
3	1995	0.00	0.00	0.00	0.00	526.32	–526.32
4	1996	0.00	0.00	0.00	0.00	121.82	–121.82
5	1997	0.00	0.00	0.00	0.00	121.12	–121.12
6	1998	0.00	0.00	0.00	0.00	0.00	0.00
7	1999	0.00	0.00	0.00	0.00	0.00	0.00
8	2000	648.23	1475.24	0.04	2123.52	0.00	2123.52
9	2001	1270.56	1475.23	0.05	2745.84	0.00	2745.84
10	2002	2100.32	1475.22	0.06	3575.60	0.00	3575.60
11	2003	3137.54	1475.20	0.07	4612.82	0.00	4612.82
12	2004	3937.76	1475.20	0.08	5413.04	0.00	5413.04
13	2005	5082.31	1475.19	0.09	6557.59	0.00	6557.59
14	2006	5082.31	1475.19	0.09	6557.59	0.00	6557.59
15	2007	5082.31	1475.19	0.09	6557.59	0.00	6557.59
16	2008	5082.31	1475.19	0.09	6557.59	0.00	6557.59
17	2009	5082.31	1475.19	0.09	6557.59	0.00	6557.59
18	2010	5082.31	1475.19	0.09	6557.59	0.00	6557.59
19	2011	5082.31	1475.19	0.09	6557.59	0.00	6557.59
20	2012	5082.31	1475.19	0.09	6557.59	0.00	6557.59
21	2013	5082.31	1475.19	0.09	6557.59	0.00	6557.59
22	2014	5082.27	3319.23	0.15	8401.65	0.00	8401.65
23	2015	5082.27	3319.23	0.15	8401.65	0.00	8401.65
24	2016	5082.27	3319.23	0.15	8401.65	0.00	8401.65
25	2017	5082.27	3319.23	0.15	8401.65	0.00	8401.65
26	2018	5082.27	3319.23	0.15	8401.65	0.00	8401.65
27	2019	5082.27	3319.23	0.15	8401.65	0.00	8401.65
28	2020	5082.27	3319.23	0.15	8401.65	0.00	8401.65
29	2021	5082.27	3319.23	0.15	8401.65	0.00	8401.65
30	2022	5082.23	5900.91	0.21	10983.36	0.00	10983.36
NPV $A, m 1990		23.78	11.47	0.00	35.26	1.50	33.76
Benefits to Beef $A million, 1990	na	16.25[c]	4.29[c]	ns[d]	20.54[c])	na	na
Benefits to Milk $A million, 1990	na	7.53[c]	7.18[c]	ns[d]	14.72[c]	na	na
Internal rate of return							40%

[a] Only includes benefits to one sub–Saharan African country, Zimbabwe that collaborated in the ACIAR project.

[b] The flows of benefits and costs from year 1 to year 30 are expressed in thousands of dollars.

[c] These values are expressed in millions of dollars.

3.2 Sensitivity analyses

The results in Tables 15, 16, and 17 depend on the description of the base case scenario presented in Tables 1 to 14. This sub-section assesses the effect on the key results of a change in the key assumptions. Thus, instead of assumptions in the base case it is assumed in turn that:

- the realised unit cost reductions are half of those used in the base;
- the adoption rates are half those in Table 14; and
- the technologies are immediately applicable to all farmers in the livestock sectors of the collaborating as opposed to what is assumed in Table 2.

The estimates of total benefits ($A million, 1990) under the different assumptions in the sensitivity analyses are as follows:

Scenario	PN8303 Ecology, epidemiology and control of ticks and tick-borne diseases	PN9047 Develop better methods to manage tick resistance to acaricides	PN9118 Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia
Base case	$A 2.06	$A 12.34	$A 35.24
Unit cost savings equal to half in base case	$A 1.01	$A 4.06	$A 14.49
Fifty percent lower adoption rates	$A 0.52	$A 3.23	$A 8.79
Wider applicability within collaborating countries	$A 4.77	$A 14.07	$A 49.23

As expected, reducing unit cost savings and reducing adoption rates for the technologies developed in the three projects would lead to lower levels of benefits compared to the base case. Lower unit cost savings could be a result of some of the inputs being more expensive than assumed in the base case or the physical impacts realised being lower than those in Table 7. If the technologies are more widely applicable then the estimated benefits would be much higher. However, as indicated earlier in this paper, increasing the applicability of the technologies and the levels of adoption may in many cases require additional expenditure to cover farmer education and extension services costs.

4. IMPACT OF THE PROJECTS ON SCIENTIFIC KNOWLEDGE

A measure of impact on scientific knowledge, albeit an imperfect one, is the number of publications and presentations arising from the research undertaken in a research project. Appendix A lists the publications from the three animal sciences projects based in Africa. With respect to PN8303, the project led to the publication of over 40 scientific articles. Fourteen of these articles were published in international journals and the rest appeared as part of the proceedings of an international conference held in 1987 and published by ACIAR. A number of articles were published some time after the end of the project because of normal lags between the time experimental work is done and the time the results are written up for publication.

5. IMPACTS OF THE PROJECTS ON HUMAN AND INSTITUTIONAL RESEARCH CAPACITY

Elder et al. (1986) note the following impacts of PN8303 human and institutional capacity building:

First, African scientists were trained in experimental design and analysis techniques needed in the study of the ecology and epidemiology of ticks and tick-borne diseases. Elder et al. (1986) note the following:

> Much of the data collected by research groups in Central and East Africa prior to the involvement of the CSIRO workers in the ACIAR project was incapable of ready analysis and interpretation. The CSIRO researchers in the project rectified this by supervising experimental designs and data requirements before project implementation, and this improved the scientific capability of African research workers and quality of analyses of data obtained.

Second, Elder et al. (1986) indicate that human capacity building impacts were also achieved through visits of ACIAR project officers to collaborating African research institutes and visits by African scientists to the CSIRO Long Pocket Laboratories to process and interpret their own data under supervision of CSIRO scientists.

Third, Elder et al. (1986) point out that a significant source of human research capacity building impacts of the project was the opportunities for joint authorship of scientific articles between the CSIRO scientists and the African scientists. By the time of the review of the project, six published papers involved joint authorship between African scientists and CSIRO scientists.

However, the major impacts on human research capacity building are likely to occur when the 3-host tick model is completed and used as a basis for training of African scientists in experimental designs, data analysis and other research techniques required in the study of the ecology and epidemiology of ticks and tick-borne diseases.

PN9047 (Develop better methods to manage tick resistance to acaricides) had a wider range of formal and informal training activities. Appendix B summarises the training activities under the project.

6. CONCLUDING REMARKS

This paper has discussed the completed project assessment of three completed ACIAR projects. Over a 30-year time horizon, the three projects are estimated to generate benefits equal to about $A50 million: with the following distribution by project:

Project no.	Project title	Estimated benefits
PN8303	Ecology, epidemiology and control of ticks and tick-borne diseases in sub-Saharan Africa	$A2.06
PN9047	Develop better methods to manage tick resistance to acaricides in Zimbabwe and Australia	$A12.34
PN9118	Improved methods for the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia.	$A35.24

Most of these benefits are estimated to accrue to the farmers and consumers in the traditional cattle sector of sub-Saharan Africa. Furthermore, most of these benefits have not yet been realised since it is only a few years since the projects were completed and some of the technologies are in their early stages on the adoption time path. However, these estimates are conservative since they do not include the potential benefits from the possible spillovers of the technologies to other sub-Saharan African countries.

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APPENDIX A IMPACT OF THE PROJECTS ON SCIENTIFIC KNOWLEDGE

Project PN8303

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Kaiser, M.N., Sutherst, R.W., and Bourne, A.S. 1991. Tick (Acarina: Ixodidae) infestations on zebu cattle in northern Uganda. Bulletin of Entomological Research, 81, 257–262.

Project PN9047

Papers for international journals

Barker, S.C. Internal transcribed spacers and 5.8s rRNA: variation among populations of the cattle tick *Boophilus microplus* from Australia, Kenya, South Africa and Brazil. (in preparation for Molecular & Biochemical Parasitology).

Barker, S.C. Internal transcribed spacer 2 and 5.8s rRNA: variation among populations of the cattle ticks *Rhipicephalus appendiculatus, R. zambeziensis* and *R. evertsi.* (in preparation for Molecular & Biochemical Parasitology).

Baxter, G.D. & Barker, S.C. The acetylcholinesterase gene of the cattle tick, *Boophilus microplus* (Acari: Ixodidae). (in preparation for Nucleic Acids Research).

Knowles, A.G. & Opdebeeck, J.P. Uniformity of protective antigens among isolates of the cattle tick, *Boophilus microplus.* (submitted to Applied Parasitology).

Knowles, A.G., Opdebeeck, J.P. & Spickett, A.M. Conservation of protective antigens and antigenic cross-reactivity between ixodid ticks infesting cattle in Zimbabwe, South Africa and Australia. (subrnitted to Parasite Immunology).

Knowles, A.G. & Opdebeeck, J.P. Immunolocalisation of cross-reactive antigens in the midgut and salivary glands of ixodid ticks. (in preparation for International Journal for Parasitology).

Knowles, A.G. & Opdebeeck, J.P. Immunolocalisation of protective antigens in the bite site of the cattle tick, *Boophilus microplus.* (in preparation for Parasite Immunology).

Wong, J.Y.M & Opdebeeck, J.P. Purification and immunogenicity of cattle tick, *Boophilus microplus*, acetylcholinesterase. (in preparation for Molecular Biochemical Parasitology).

Projects and theses submitted to the University of Queensland or in advance preparation

Condon, F. 1993. Genetic variation in ticks: an investigation using arbitrary primed polymerase chain reaction. BSc (Honours) Project Report, Department of Parasitology.

Knowles, A.G. Antigens of ixodid ticks of cattle. (PhD thesis to be submitted in March 1996).

Ma, J. 1994. Genetic identification of ticks species. Report for part of a Postgraduate Diploma in Biotechnology.

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Barker, S.C. & Tonion, K. (1992). Variation in ribosomal DNA and diagnosis of closely related species of African cattle ticks. Joint Annual Meeting of The Australian and New Zealand Societies for Parasitology, Auckland, New Zealand.

Knowles, A.G. & Opdebeeck, J.P. (1993). Homogeneity in the expression of protective antigens in the cattle tick, *Boophilus microplus.* Annual Meeting of The Australian Society for Parasitology, Heron Island, Qld., Australia.

Knowles, A.G. & Opdebeeck, J.P. (1994). Cross-reactive antigens in the Ixodidae. Annual Meeting of The Australian Society for Parasitology, Nelsons Bay, NSW, Australia.

Baxter, G.D. & Barker, S.C. (1995). Molecular genetics of resistance to organophosphate acaricides in *Boophilus microplus.* III International Seminar of Animal Parasitology – Resistance and Control of Ticks and Flies of Veterinary Importance, Acapulco, Mexico.

Knowles, A.G. & Opdebeeck, J.P. (1995). Cross-reactive antigens in the salivary glands and rnid-gut of ixodid ticks. International Conference on the TickHost-Pathogen Interface. Kruger National Park, South Africa.

Wong, J.Y.M. & Opdebeeck, J.P. (1995). Purification and irnmunogenicity of tick acetylcholinesterase as a preliminary to developing an assay for resistance. International Conference on the Tick–Host–Pathogen Interface. Kruger National Park, South Africa.

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Project PN 9118

Publications in scientific journals

Molloy, J.B., Waldron, S.J. and Jorgensen, W.K. 1995. Identification of an immunodominant 40 kDa antigen common to the Australian T and Dixie vaccine strains of *Babesia bovis* and the development of diagnostic tests specific for these strains. Veterinary Parasitology, 60, 229–240.

Bock, R.E., deVos, A.J., Lew, A., Kingston, T.G. and Fraser, I.R. 1995. Studies on failure of T strain live *Babesia bovis* vaccine. Australian Veterinary Journal, 72, 296–300.

Lew, A.E., Dalrymple, B.P., Jeston, P.J. and Bock, R.E. Long template PCR amplification of a variable array of tandem repeats; comparison with hybridisation and other PCR methods for the characterisation of *Babesia bovis* isolates. (Manuscript in preparation)

Lew, A.E. and Bock, R.E. Application of molecular markers for the differentiation of vaccine ad field isolates. (Manuscript in preparation)

Molloy, J.B., Bowles, P.M., Bock, R.E., Turton, J., Katsande, T.C., Katende, J.M., Mabikacheche, L., Waldron, S.J., Blight, G.W. and Dalgliesh, R.J. Validation in Australia and Africa of an ELISA for the detection of antibodies to *Babesia bovis* in cattle. (Manuscript in preparation).

Conference presentations and other non referred publications

Bock. R.E., de Vos, A.J., Lew, A. and Kingston, T.G. 1994. Studies on failure of T strain *Babesia bovis* vaccine. Proceedings of the Conference of the Queensland Division of the Australian Veterinary Association, Brisbane, February 1994, 48–58.

Bock, R.E., de Vos, A.J., Jorgensen, W.K., Dalgliesh, R.J. and Lew, A. 1994. Living babesiosis vaccines for cattle—the Australian experience. Paper presented to the 8th International Congress of Parasitology, Izmir, Turkey, 10–14 October 1994.

Dalgliesh, R.J., Bock, R.E., Molloy, J.B., Lew, A., Jeston, P., Bowles, P., de Vos, A.J. and Jorgensen, W.K. 1994. Molecular epidemiology of *Babesia bovis* and its relevance to vaccines. Proceedings of 7th International Symposium on Veterinary Epidemiology and Economics, Nairobi, 15–19 August 1994 (published in special issue of The Kenya Veterinarian, 18, 287-289 (1994).

Jorgensen, W.K., de Vos, A.J. and Dalgliesh, R.J. 1993. Methods for diagnosis of babesiosis in developing countries—present and future trends. Proceedings of FAO expert consultation on the use of applicable biotechnological methods for diagnosing haemoparasites, Merida, Mexico 4–6 October 1993 (published 1994, J. Hansen, ed.), 65–84.

Katsande, T.C. and Turton, J.A. 1995. Progress on the production of frozen *Anaplasma* and *Babesia* whole blood vaccines at the Central Veterinary Laboratory in Harare. Presented to the Zimbabwe Veterinary Association Congress, Juliasdale, 11–15 September 1995.

Dalgliesh, R.J., Molloy, J.B., Bock, R.E. and Jorgensen, W.K. 1995. Do parasite antigens on erythrocytes determine host-parasite relationships in *Babesia* infections of cattle?: lessons from malaria. Presented to the 2nd Tick–Host–Pathogen Interface Conference, Berg-en-dal, South Africa, 28 August –1 September 1995.

Turton, J.A. and Katsande, T.C. 1995. Bovine babesiosis and anaplasmosis vaccines in Zimbabwe. Presented to the 2nd Tick-Host-Pathogen Interface Conference, Berg-en-dal, South Africa, 28 August–1 September 1995.

Dalgliesh, R.J. and Jorgensen, W.K. 1996. Research on tick fever:Australia benefits from collaboration with Zimbabwe. Newsletter– Integrated Control of Ticks and Tick-borne diseases (G. Uilenberg, ed.) 1996 (submitted)

Dalgliesh, R.J. 1996. Collaborative research on the diagnosis and control of bovine babesiosis and anaplasmosis in Zimbabwe and Australia: an Australian perspective. Commonwealth Veterinary Association/Mauritius Veterinary Association Conference, Mauritius, 31 July–2 August 1996 (Submitted).

APPENDIX B A SUMMARY OF TRAINING ACTIVITIES IN PN9047 AND PN9118 (AS AT 23 JANUARY 1996)

PN9047

Formal postgraduate training at the University of Queensland

Chigagure, N. Microsatellite DNA and ecological genetics of the cattle tick *Boophilus microplus.* 17 months of PhD candidature completed.

Condon, F. 1993. Genetic variation in ticks: an investigation using arbitrary primed polymerase chain reaction. BSc Hons, Department of Parasitology.

Knowles, A.G. Antigens of ixodid ticks of cattle. (PhD thesis to be submitted in March 1996).

Ma, J. 1994. Genetic identification of ticks species. Report for part of a Postgraduate Diploma in Biotechnology. Department of Parasitology.

Wickramasurya, R. 1995. The antigenicity of acetylcholinesterase of human, eel and tick. BSc Hons, Department of Parasitology.

Lee, E. The acetylcholinesterase gene of ixodid ticks. Bsc Hons, Department of Parasitology. January 1996–

Informal training

Postdoctoral fellows:

Wong, J. April 1994 July 1995. Project 9047, together with a University of Queensland Re-Entry Fellowship awarded to Dr Wong, provided her the opportunity to resume her career.

Baxter, G. March 1994 to present. Dr Baxter continued his postdoctoral training while working on the project in close association with Drs Barker & Opdebeeck.

Miller, C.M.D. January 1996 –. Dr Miller has been awarded a University of Queensland Re-Entry Fellowship (2 yrs) and joined the project in January 1996.

Research assistants:

Scott, L. January–July 1995. Training in molecular biology and tick biology at the University of Queensland.

Lee, E. August–December 1995. Training in molecular biology and tick biology at the University of Queensland.

Chigagure, N. Summer course at ANGIS (Australian National Genomic Information Service), January 1996, Sydney.

Advanced training in acaricide resistance testing was provided by P.E. Green in Brisbane and Harare. Trainees included Mazhowu, G.W.A. (Head of Tick Section, CVL, Harare), Bero, A. (Technician, CVL, Harare) and Chiguvi, A. (Research Officer, CVL, Harare).

Project PN9118

Study tours/training visits

Molloy, J. June/July 1993, February/March 1995 and February/March 1996 visited the International Livestock Research Institute (ILRI) in Nairobi, Kenya to collaborate with scientists at ILRI in assessing developmental diagnostic tests for tick-borne diseases.

Katsande, C. August/November 1993 visited the Tick Fever Research Centre (TFRC) for specialised training on practical aspects of vaccine production, preparation and examination of specimens, monitoring of infections in cattle and routine serological testing.

Turton, J. September/November 1993 visited TFRC for specialised training on practical aspects of vaccine production, preparation and examination of specimens, monitoring of infections in cattle and routine serological testing.

Hove, T. April 1994 visited TFRC and the Animal Research Institute (ARI) for training in vaccine production and marketing of vaccines and to review other aspects of QDPI's diagnostic and research program, as it relates to the control of parasitic diseases in production animals.

Lew, A. August/September 1994 visited ILRI to participate in studies on genomic analysis using techniques developed at ILRI.

Dalgliesh, R., Katsande, C. and Ushewokunze-Obatolu, U. August 1994 attended the 7th International Symposium on Veterinary Epidemiology and Economics held in Nairobi, Kenya.

Bock, R. October 1994 attended the 8th International Congress of Parasitology at Izmir in Turkey and visited the Kimron Veterinary Institute in Israel to review their production procedures for vaccines against tick-borne diseases and their research program on vaccine improvement.

Mabikacheche, L. October/November 1994 visited ILRI for training in diagnostics and in January 1995 visited Onderstepoort Veterinary Institute (OVI) for training in diagnostic methods and vaccine production procedures related to tick-borne diseases.

Dalgliesh, R., Turton, J. and Ushewokunze-Obatolu, U. August/September 1995 attended the 2nd Tick–Host–Pathogen Interface Conference, Berg-en-dal, RSA.

ACIAR ECONOMIC EVALUATION UNIT

Working Paper Series

1. Fearn, M., Davis, J.S. and Ringrose-Voase, A. 1994. Project development assessment: Management of clay soils for lowland rice-based cropping systems: Project 8938.
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