Sustainable Parasite Control in Small Ruminants

An international workshop sponsored by ACIAR and held in Bogor, Indonesia 22–25 April 1996

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Hosted by: Central Research Institute for Animal Sciences (CRIAS)

Sponsored by: Australian Centre for International Agricultural Research (ACIAR)
Australian Agency for International Development (AusAID)
International Livestock Research Institute (ILRI)

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Le Jambre, L.F. and Knox, M.R. 1996. Sustainable Parasite Control in Small Ruminants. Proceedings of a workshop, Bogor, Indonesia, 22–25 April 1996. ACIAR Proceedings No. 74. 110p

ISBN 1 86320 196 3

Production editor: Peter Knight
Typesetting and page layout: Sun Photoset Pty Ltd, Brisbane, Australia
Printed by: Watson Ferguson & Co., Brisbane, Australia

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Opening Address
Minister of Agriculture Republic of Indonesia

Mr Ambassador of Australia to Indonesia.
Distinguished workshop delegates, participants, guests, ladies and gentlemen.

First of all, let us thank God that we were given the opportunity to gather here at the Balai Penelitian Ternak (Research Institute for Animal Production) — Ciawi today. I personally would like to extend a warm welcome to those of you from overseas.

It is a great pleasure to be with you this morning at the inaugural function of the workshop on sustainable control of parasites in small ruminants, that is being jointly sponsored by the Indonesian Agency for Agricultural Research and Development (AARD) and the Australian Commonwealth Scientific Industrial Research Organization (CSIRO), and supported by the Australian Centre for International Agricultural Research (ACIAR) and the International Livestock Research Institute (ILRI). I was informed that ACIAR has been involved in 22 projects in Indonesia, seven of which are in the livestock sector. I assume that it is a positive indication of the competitive advantage of Indonesia with regard to expertise available within the country, apart from any particular interest of Australia in agricultural production in general.

This workshop, as I understand, will focus on small ruminants (sheep and goats) and parasites. However, the approach could well be extended in general terms to other diseases in livestock and poultry.

Indonesia is developing from an agrarian to an industrial country. However, agriculture will continue to play an important role in the next Five-Year Development Plan, particularly in food security and supporting an expanding agro-industrial sector. Livestock production in Indonesia has emerged as a new growth area in the agricultural sector along with fisheries and horticulture.

There is no doubt that animal products will always be in demand and are very essential in human resource development. The economy of Indonesia is rapidly expanding towards a middle-class economy, and with an increasing population, it is apparent that the demand for meat, milk and eggs will increase. The national livestock production is projected to grow at an annual rate of 6.4% over the current Five-Year Development Plan. Demand for meat will grow by about 7% annually over this same period. Therefore, small ruminants will play an important role in meeting this increasing demand.

Livestock production in Indonesia is a labour-intensive enterprise in which over 95% of small ruminants are raised on smallholder farms. Numerically, Indonesia has the largest small ruminant population in Southeast Asia with 11.8 million head of goats and 6.5 million head of sheep, and ranks third in Asia after China and India. For sustainable production systems, it is apparent that proper management practices should be implemented including genetic improvement, feeding and nutrition, and disease control to ensure the achievement of optimal production levels.

An animal production system that does not take into account the effects of disease would be incomplete. In addition, under intensive production systems, the role of genetics, nutrition and management technology are inconceivable and incomplete unless due consideration is given to economic measures and benefits. The task, therefore, in front of animal production research workers and scientists is to develop appropriate means for their implementation that are technically feasible, economically viable, socially acceptable and environmentally sound. To achieve this, I have great expectations that research could provide solutions to some of the major production problems.

In years to come, Indonesia will face major changes, which include greater pressure on natural resources, and transformation of economic structures that are expected to shift from primary agriculture towards secondary industries and tertiary service sectors to cope with global changes. The General Agreement on Tariffs and Trade (GATT) is an example of the globalisation pressure on economic policies that need accurate anticipation and responsive means. It is apparent that basic changes in global information, communication and economic integration will force regional cooperation to be implemented, which obviously will generate fundamental policy changes in investment patterns, production, consumption, commerce and transportation.

A recent example is Mad Cow disease in cattle that has become a world issue and created a big problem for the cattle industry in England. I am therefore interested to know what you can come up with in dealing with the genetic potential of indigenous animals in various countries that have adapted to the local environment against parasitic and other diseases.

I trust that cooperative measures could be taken in order to reduce the heavy burden of research and development. I expect that great challenges are in front of us in meeting the demand for meat, milk and eggs in the future.

The initiation of collaborative research projects would greatly enhance the development of sustainable parasite control in sheep and goats. It cannot be argued against or avoided that we have to depend upon each other in dealing with world problems such as disease control and information flow. Cooperation and collaboration between research scientists and development practitioners within the Asia–Australasian region has been longstanding and in general would be advantageous in solving our production problems. I have great confidence in the Central Research Institute for Animal Sciences (CRIAS) of AARD to play a significant role in this respect.

CRIAS has been involved in collaborative research with USAID under the Small Ruminant–Collaborative Research Support Program (SR–CRSP). Further, the Small Ruminant Production Systems Network for Asia (SRUPNA) with support from the International Development Research Center (IDRC/Canada), also has a coordination unit at CRIAS covering most countries in Asia. The collaboration has produced significant results among researchers at the Balai Penelitian Ternak (Research Institute for Animal Production) here at Ciawi and the Balai Penelitian Veteriner (Research Institute for Veterinary Science) in Bogor. I am sure that the experience gained over the years will be a positive asset in future collaboration and I assure you that Indonesia welcomes future activities of international scope that are mutually beneficial.

I have great expectations that the workshop will produce optimal strategies for cooperative approaches to sustainable parasite control in small ruminants. I look forward to supporting an international project and hope that our mutual research priorities will lead to a more productive future in our respective countries.

Finally, it is my pleasure to officially declare this workshop on Sustainable Parasite Control in Small Ruminants open.

Bogor, April 22, 1996
Prof. Dr Syarifuddin Baharsyah

Introduction

L.F. Le Jambre, M.R. Knox and G.D. Gray

RUMINANTS are an important and integrated component of the agricultural production systems in Asia. Roundworm and fluke parasites are a major world-wide constraint on livestock production. However, control which relies entirely on anthelmintics is at risk due to the widespread occurrence of anthelmintic resistance. In order to break this absolute dependence on chemicals for parasite control, a group of scientists from the University of New England and CSIRO decided that there was an urgent need to set in place sustainable control systems which did not rely on anthelmintics alone to achieve control. The question then arose: what was to share the load of parasite control with anthelmintics?

To find out what is going to be possible in the way of parasite control in the future, the group decided to hold an international conference to assist with identifying the likely candidates. The conference was called: Novel Approaches to the Control of Helminth Parasites of Livestock and received support from AusAID's International Seminars Support Scheme as well as pharmaceutical companies and Rural Industry Research Funds.

The goal of the conference was to identify the most promising methods of parasite control from among the four major themes of the conference: (1) vaccine development; (2) breeding for helminth resistance; (3) novel targets for biological control agents and chemicals; (4) grazing management to control parasites.

The conference was attended by 140 delegates from 20 different countries; truly, an international conference with about half of the delegates from other countries.

Novel Approaches to the Control of Helminth Parasites of Livestock Conference

The conference heard that the rate at which anthelmintic resistance was spreading was faster than many delegates had expected. A recent survey of sheep farms in southern Australia found that only 9% of farms had worms that were not resistant to any drug. Animals in other countries are worse than those in Australia. During the conference an FAO official described the sheep industry in South America as in a state of crisis. For example, the conference was told that in Paraguay about 75% of farms had nematodes resistant to benzimidazoles, levamisole and ivermectin. In New Zealand, a strain of *Ostertagia circumcincta*, a major ruminant parasite, has been isolated from goats and this worm cannot be controlled with any anthelmintic. It is expected that this strain will spread into the sheep flock.

The conference found that there were no new anthelmintics in the development stage nor were any of the vaccines likely to reach the market before the year 2000. Even then, the vaccines would not provide complete control but only assist other control measures. More positive results were presented from Malaysia (ACIAR Project 9132, Strategies for sustainable control of gastrointestinal parasites of ruminants using urea–molasses blocks), which built on earlier ACIAR-supported studies in Fiji and Tonga (Project 8913, Ecological and host-genetic control of internal parasites of small ruminants in the Pacific Islands), that showed that a rotational grazing system consisting of 10 paddocks grazed in sequence for 3.5 days at a time could reduce the frequency of anthelmintic treatment of sheep and goats in the wet tropics to once per year. Animal husbandry was also shown to have an impact on the control of fasciolosis (ACIAR Project 9123, Control of fasciolosis in cattle and buffalo in Indonesia). Several different methods of selecting sheep that can cope with parasites also were presented to the conference. These ranged from the New Zealand approach of selectively breeding for sheep that can harbour large parasite burdens and still remain productive, to the Australian approach of breeding sheep that resist infection with parasites.

Based on the reports of success of both grazing management and selective breeding for resistance, many conference delegates recognised that there was sufficient knowledge to commence the development of sustainable parasite control programs (SPCPs) for small ruminants in both temperate and tropical countries. SPCP would include a minimal anthelmintic dosing program to reduce both the rate of development of anthelmintic resistance and the cost of control, transfer of technology to assess anthelmintic resistance levels before control failures occur, a grazing management system which requires little anthelmintic dosing, and the introduction of the latest technology to assist in breeding of lines of sheep selected for their innate resistance to internal parasites. It was envisaged that anthelmintics, grazing management and resistant hosts would all be used in an integrated system to achieve sustainable parasite control.

Workshop on Sustainable Control of Parasites in Asia

Delegates at the *Novel Approaches to the Control of Helminth Parasites of Livestock Conference* representing CSIRO, the University of New England, the new International Livestock Research Institute (ILRI) and the countries of South and Southeast Asia were in agreement that it would be important to commence developing SPCPs for the region. As a first step in initiating this process it was proposed to hold a workshop: (1) to assess the feasibility of developing SPCPs in participating countries; (2) to formulate a strategy for cooperative approaches to SPCPs.

Four categories of delegates were invited to attend the workshop. One group represented national research and development organisations and could speak on the national policy for development priority for small ruminants. Another group were researchers from countries of South and Southeast Asia who addressed issues of epidemiology of parasites of small ruminants, control measures now in practice, perceived effects of parasites on production and the host genetic resources in a country relating to disease resistance. A third group were scientists who had experience with recent research innovations, the application of which could provide SPCPs. The fourth group were representatives of international research and development agencies, such as ACIAR, FAO and ILRI, and who are interested in ensuring that parasite control in small ruminants in developing countries be improved.

The workshop was organised in four sessions. The first consisted of papers that addressed the importance of small ruminants to the country's (or region's) economy and the priority given to the development of the industry by national or international agencies. The second session concentrated on small ruminant parasitology and parasite epidemiology in the delegates' countries. The third session consisted of papers that presented new methods of parasite control that could be integrated into a SPCP. The final session consisted of a series of workshop sessions that addressed the basic problems of instituting SPCP.

We, the Australian workshop organisers, the editors and ACIAR, particularly Dr John Copland of the Animal Sciences Program and Peter Lynch of the Communications Unit, would like to thank all who contributed their time, enthusiasm, thought, imagination and insight which is evident in the following papers. Special thanks are due to Dr Andi Djajanegara and his team from CRIAS for their heroic efforts to ensure that the workshop ran smoothly so that the participants could concentrate on the issues.

The papers presented in each of the sessions and a summary of the workshop outcomes follow.

Prospects for Small Ruminant Development in Indonesia

Faisal Kasryno[1]

INDONESIA, with a population of more than 200 million people, is the world's fourth most populated country. About two-thirds of its population still depend on agriculture for their livelihood even though the per capita income has risen to about US$1000. Many smallholders raise goats and sheep as an integral part of their farming system and this provides liquidity to meet short-term cash needs.

In recent years, Indonesia has observed dramatic changes in the patterns and levels of small ruminant production and consumption. With high domestic demand for all small ruminants and a ban on the export of live animals, Indonesia remains a net importer of meat. However, some studies have shown that Indonesia has the potential for sheep and goat exports to other ASEAN countries.

In Indonesia, constraints to increased livestock production, including sheep and goat production, are biological, economic and cultural. In addition, the international meat trade is limited by health and sanitation restrictions imposed on importers. Other limitations include the lack of implementation of meat standards, grading and packing systems and poor infrastructure.

Small ruminants in Indonesia are extremely important to smallholders. They provide insurance against shortage of cash, as well as good quality food in the form of animal protein. In many regions, animals are an important component of farming activities of the smallholder. The year-round family needs are provided by food crop production, while the primary reason for keeping animals is to accumulate cash.

The role of animals within these farming activities has been remarkably well demonstrated on the island of Java, where small ruminants, such as goats and sheep, are kept by many farmers. Sheep and goats are relatively easy to raise, with minimal inputs and low maintenance costs achieved by utilising residues from cropping activities for grazing. Although small ruminants have a high reproductive rate and a ready market, production levels are still considered low.

Some research through the Small Ruminant–Collaborative Research Support Program (SR–CRSP) has included both on-station and village-level studies for the past 13 years. The on-station studies have covered breeding, feeds and feeding, management and environment, sociology, economics, and health disciplines and have produced numerous technology packages and technology components. The Sheep Prolificacy project and the Hair Sheep project have expanded the strength and intensity of the breeding, nutrition and health experiments. In addition, on-farm technology models have been tested starting in 1984 through an Outreach Pilot Project (OPP) in West Java, and a similar program, called the Outreach Research Project (ORP), in Sei Putih, North Sumatra (SR-CRSP Annual Reports 1988–1992).

Various research outputs produced by research institutes, universities, and private voluntary organisations in terms of technical brochures, newsletters, training materials, video presentations, scientific publications, policy briefs and other forms of research extension have affected traditional farm practices and farmers' visions of the future. Various annual reports of the SR–CRSP have shown many advantages of the technology packages and technology components that have both direct and indirect impacts when applied by producers.

Studies on goats, however, have been minimal although goats constitute around two-thirds of the small ruminants in the country and are found in significant numbers in many provinces. Basic production data on goats under different conditions and genetic improvement schemes are still lacking.

This paper examines the prospects for small ruminants and the characteristics of the rural small ruminant industry.

[1] Director-General of AARD, Agency for Agricultural Research and Development, Indonesia

Overview of the Small Ruminant Economy

Small ruminant population

According to the 1993 Agriculture Census, there are 11.4 million goats and 4.8 million sheep raised by 581 000 farmers. Sheep and goat farming in Indonesia is concentrated on Java, the most populous of Indonesia's more than 13 500 islands. This is because West Java is the largest due to its size of population and highest per capita income, and because the terrain has abundant raw materials for feed production.

Nearly 92% of small ruminants in Indonesia are raised by smallholders and less than 1% are raised under fully commercialised operations. This fact indicates the important role of smallholders as the breeders of the potential stock from which the national small ruminant production will derive. Furthermore, the national development program for increasing livestock population, including sheep and goats, through the distribution of livestock into rural areas and other areas outside Java, has allowed small ruminants to be even more widely distributed among farms as an additional income-generating activity.

Small ruminant numbers in the Asian region increased from 620 million in 1988 to 685 million in 1992 (FAO data). Terrill (1985) reported that the upward trend of sheep and goat numbers in the world is only about 1%/year while the rate of increase in Asia over five years (1988–1992) was 2.4%. In comparison, the annual increase of sheep and goat numbers (1989–1993) in Indonesia reached 3.2% and 1.2%, respectively (DGLS 1994).

Trend of production and consumption

During the period 1990–1994, national meat production increased by 9.4%/year (Table 1). The largest growth was exhibited by pork (12.2%/year), followed by chicken (9.6%/year) and beef (9.3%/year). On the other hand, goat and sheep (lamb and mutton) production showed a moderate annual growth of 6.4% and 6.0%. Even though small ruminant production exhibited a moderate growth rate, its share of the national meat production decreased over time, due to the increasing importance of chicken. In 1990, the percentage of goats and sheep to national meat production was 8.80%, and decreased to 7.7% in 1994. For the same period, chicken increased from 49.5% to 51.6% of national meat production.

Among livestock products, the demand for meat increased faster compared to eggs and milk. For the past five years (1990–1994) the demand for meat increased by 9.5%/year. On the other hand, demand for milk and eggs just increased by 6.2% and 5.1%/year, respectively (Table 2). At the present rate of consumption, Indonesia has become self-sufficient in egg production, but not in meat and milk. Even though the proportion of meat imported to total meat demand is small (0.74%), its growth rate for the past five years is very high, i.e. 26.7%. Conversely, at this moment the contribution of domestic milk production to national milk demand is relatively small, i.e. 41.51% of the average milk demand of 780 thousand t/year (1990–1994).

Based on the total meat demand of 1.4 million tonnes in 1994, the meat consumption per capita in Indonesia is only 7.64 kg. This rate of consumption

Table 1. Trends of national meat production ('000 t) by kinds of livestock, 1990–1994[1].

Kinds of livestock	1990	1991	1992	1993	1994	Trend (%/year)
Beef cattle	259.2	262.2	297	346.2	358.2	9.3
	(25.2)	(23.9)	(24.0)	(25.1)	(24.4)	
Buffalo	44.3	47.5	45.0	51.2	53.6	4.6
	(4.3)	(4.3)	(3.6)	(3.7)	(3.6)	
Goat	58.3	57.0	68.8	71.2	72.1	6.4
	(5.7)	(5.2)	(5.6)	(5.2)	(4.9)	
Sheep	31.7	37.4	30.2	40.1	41.2	6.0
	(3.1)	(3.4)	(2.4)	(2.9)	(2.8)	
Pork	123.8	110.0	149.9	169.3	184.1	12.2
	(12.0)	(10.0)	(12.1)	(12.3)	(12.5)	
Horse	1.7	1.5	1.8	1.6	1.7	0.6
	(0.2)	(0.1)	(0.1)	(0.1)	(0.1)	
Chicken	508.7	583.5	646.6	698.6	758.3	9.6
	(49.5)	(53.1)	(52.2)	(50.7)	(51.6)	
Total	1027.7	1099.1	1239.2	1378.2	1469.2	9.4
	(100)	(100)	(100)	(100)	(100)	

[1]Figures in parentheses are the percentages of total national meat production.
Source: Directorate General of Livestock Services, Jakarta. (Adopted from Adnyana et al. 1996).

is still low compared to the neighboring countries of Singapore, Malaysia, Taiwan, and Japan. In the United States, the rate of meat consumption in 1990 was 117 kg of which the contribution of non-chicken meat was 58% of total meat consumption (Soekarto 1987). In Indonesia, the contribution of non-chicken meat on domestic meat demand in 1994 was indicated by the share of non-chicken meat production, i.e. 49%. Rusasta and Simatupang (1990) reported that the contribution of non-chicken meat on per capita meat consumption is around 47%, of which the share of small ruminants is 7%. This indicates that there is a wide opportunity to expand the domestic market, especially for small ruminant meat, through increasing per capita consumption.

Export and import pattern of Indonesian livestock product

The total value of livestock exports in 1994 was 28% lower than in 1990 (Table 3). The share of export

Table 2. Trends of meat, egg, and milk consumption ('000 t) in Indonesia, 1990–1994.

Description	1990	1991	1992	1993	1994	Trend (%/year)
Meat	1031.7	1105.2	1251.2	1388.2	1483.6	9.5
Domestic production	1027.7	1099.2	1239.2	1378.2	1469.2	9.4
Import	4.0	6.0	12.0	10.0	14.4	26.7
Egg	418.2	442.6	502.9	503.8	509.3	5.1
Domestic production	418.2	442.6	502.9	503.8	509.3	5.1
Import	0.0	0.0	0.0	0.0	0.0	0.0
Milk	621.4	807.0	810.1	785.8	873.3	6.2
Domestic production	302.4	315.2	321.3	339.0	340.1	3.1
Import	334.0	507.8	514.4	511.0	554.5	9.2
Export	15.0	16.0	25.5	64.2	11.3	15.5

Source: Directorate General of Livestock Services, Jakarta. (Adopted from Adnyana et al. 1996).

Table 3. Value (US$ thousand) of livestock product exported from Indonesia, 1990–1994[1].

Description	1990	1991	1992	1993	1994	Trend (%/year)
Beef cattle	0.0	0.0	0.0	29.2	77.8	—
	(0.00)	(0.00)	(0.00)	(0.05)	(013)	
— Cattle meat	0.0	0.0	0.0	29.2	77.8	—
Dairy cattle	16286.4	14196.1	8857.9	4650.5	3440.5	–7.15
	(19.5)	(20.76)	(11.21)	(811)	(5.57)	
— Milk	16075.7	14195.7	8591.9	4647.5	3359.6	–37.32
— Butter and cheese	110.7	0.4	266.0	3.0	80.9	–6.18
Pig	12604.0	14116.4	13588.5	15917.0	13867.1	3.09
	(15.10)	(20.64)	(17.19)	(27.76)	(22.97)	
— Live animal	12604.0	14116.4	13588.5	15917.0	13718.1	2.88
— Pork	0.0	0.0	0.0	0.0	149.0	—
Poultry product	1457.2	2085.0	3145.9	3025.6	4958.2	27.08
	(1.75)	(3.05)	(3.98)	(5.28)	(8.21)	
— Broiler meat	254.1	459.3	1658.1	1673.1	3462.5	50.82
— Egg for consumption	126.3	62.1	21.6	160.9	68.3	–1.96
— Egg for hatching	190.6	273.5	369.8	4.9	1.3	–38.52
— DOC	811.5	1013.6	763.5	834.8	1063.7	3.63
— Duck's feather	74.7	276.5	332.9	351.9	362.4	23.27
Mutton and lamb	0.7	0.0	0.0	0.0	160.1	—
	(0.0)	(0.0)	(0.0)	(0.0)	(0.27)	
Leather, bone, horn	53139.1	37999.2	53450.0	33709.9	37873.3	–8.05
	(63.65)	(55.56)	(67.62)	(58.80)	(58.80)	
Total	83487.4	68396.7	79042.3	57332.2	60377.0	–8.22

[1]Figures in parentheses are the percentage of the total value of livestock product exported. Source: DGLS 1995. (Adopted from Adnyana et al. 1996).

value was dominated by conventional products such as leather, bone, and horns which achieved more than 60% in 1994. Among livestock products considered as new commodities which have made an important contribution and have positive growth rates are pig and poultry products and their derivatives. Export value of pigs in 1994 was 30% and poultry 8% of total exports. The poultry product exhibited the highest growth rate for the five years (1990–1994), i.e., 27.4%/year, due to the spectacular achievement of broiler meat exports with a growth rate of 50%/year.

On the other hand, there is not yet a contribution by small ruminant products to the generation of exchange earnings (Table 3). On the contrary, in order to meet domestic demand, Indonesia increased its imports by 7%/year from 1990 to 1994 of small ruminant products (Table 4). Even though the value and proportion of this importation is relatively small compared to other livestock products (beef cattle, dairy cattle, and poultry), this can be avoided by considering the advantages of small ruminant production compared to large ruminant production in terms of capital needed, labor utilisation, and variability and flexibility of feed resources. As well, Indonesia can use domestic resources in the development of small ruminant production. In 1994, the proportion of import value of small ruminants, pork, poultry, beef cattle and dairy cattle were 0.14%, 0.10%, 2.56%, 11.42% and 20.99% respectively.

Prospect of International Markets

World production of small ruminant meat

The major producing countries for goats and sheep are China, Australia, New Zealand, Pakistan, and India. They contribute 12%, 7%, 6%, 5%, and 5% respectively. In this regard, the Indonesian contribution is very small, i.e., 0.88% of the total world small ruminant meat production but its growth rate is higher than world growth rate and with high consistency (Table 5). The world SR meat production growth rate is relatively low, i.e., 1.53%/year, due to a decreasing trend in New Zealand (2.85%), and the

Table 4. Value (US$ thousand) of livestock product imported by Indonesia, 1990–1994[1].

Description	1990	1991	1992	1993	1994	Trend (%/year)
Beef cattle	16017.9	14266.7	25612.6	31850.9	63184.0	37.08
— Cattle meat	(11.20)	(6.50)	(11.01)	(10.09)	(11.42)	
— Cattle for breeding	8022.4	8876.7	12862.0	11318.7	18035.9	19.00
— Cattle for fattening	7995.5	0.0	4451.58	3419.4	1580.9	−26.97
	0.0	5390.0	8299.1	17112.8	43567.2	66.46
Dairy cattle	71166.2	99589.2	118623.7	123380.5	116132.3	10.76
	(49.76)	(45.39)	(50.99)	(39.09)	(20.99)	
— Milk	55964.0	74482.0	91483.1	96517.0	90921.2	11.23
— Butter and cheese	15202.2	25107.2	27140.6	26863.5	25211.1	9.13
Pig	1345.6	15.2	118.1	51.1	528.7	−38.81
	(0.94)	(0.01)	(0.05)	(0.02)	(0.10)	
— Pork	29.6	15.2	45.5	51.1	436.5	73.52
— Pig for breeding	1316.0	0.0	72.6	0.0	92.2	−82.64
Poultry Product	4784.5	4601.2	5412.6	7694.5	14187.0	29.85
	(3.35)	(2.10)	(2.33)	(2.44)	(2.56)	
— Broiler meat	226.0	192.2	1402.1	779.4	3436.2	58.06
— Egg for consumption	0.0	0.0	0.0	0.0	374.6	—
— Egg for hatching	1.1	0.0	9.6	12.6	17.0	55.09
— DOC	4557.4	4409.0	4000.9	6902.5	10358.2	23.31
Small-ruminant meat	591.0	724.5	1121.6	897.9	790.7	6.94
	(0.41)	(0.33)	(0.48)	(0.28)	(0.14)	
Leather	49100.8	100206.7	81774.4	151769.2	358357.7	45.20
	(34.33)	(45.67)	(35.15)	(48.08)	(64.78)	
Total	143006.0	219403.5	232663.0	315644.1	553176.4	31.31

[1]Figures in parentheses are the percentage of the total value of livestock product imported. Source: DGLS 1995. (Adopted from Adnyana et al. 1996).

rest of the world (–0.63%). For other major producing countries the growth rates are positive with a range of 3.29%/year in Australia and 11.15%/year in Pakistan. All of the major producing countries with positive growth rates also exhibited a high rate of consistency.

Table 5. Average and growth rate of small ruminant meat production of major producing countries, 1989–1993.

Countries	Average[1] (tonne)	Growth rate (%/year)	Correlation coefficient (r)
Indonesia	172 (0.88)	3.69	0.90
India	1035 (5.29)	4.17	0.93
Pakistan	1044 (5.34)	11.15	0.94
New Zealand	1135 (5.80)	–2.85	–0.56
Australia	1363 (6.97)	3.29	0.7
China	2336 (11.94)	8.75	0.99
Others	12483 (63.78)	–0.63	–0.52
World	19568 (100)	–0.63	–0.52

[1]Figures in parentheses are percentages of the total volume of small ruminant meat production. Source: DGLS 1995. (Adopted from Adnyana et al. 1996).

Export pattern of major small ruminant producing countries

Among the major producing countries, New Zealand and Australia contribute 46% and 23% of world small ruminant (SR) meat exports (Table 6). The growth rate of SR meat export is relatively low, i.e., 0.95%/year, due to a decreasing trend in New Zealand and the rest of the world, i.e., 2.53% and 2.28%/year, respectively. It is interesting to note here that India and China, which both have a positive growth in SR meat production, exhibited a negative growth in exports. Pakistan was no longer considered an exporting country. This indicates that there was a reallocation of meat production for domestic consumption in those countries.

World small ruminant meat import situation

The world SR meat imports for the five years (1989–1993) fluctuated with the average of 857 million tonnes per year (Table 7). Most of the major importing countries exhibited a negative trend, except Saudi Arabia and France with growth rates of 22.02% and 7.74%/year, respectively. For Indonesia, import growth is relatively high, i.e., 31.92%/year, but its proportion is very low, and the magnitude of its imports will not affect the availability and price of various commodities in the world market.

Table 6. Average and growth rate of volume of fresh, chilled or frozen small ruminant meat exported from major producing countries, 1989–1993.[1]

Exporting countries	Average[1] (tonne)	Growth rate (%/year)	Correlation coefficient (r)
China	2894 (0.34)	–12.24	–0.85
India	7556 (0.88)	–2.55	–0.63
Australia	193430 (22.52)	14.02	0.90
New Zealand	391420 (45.57)	–2.53	–0.49
Others	263640 (30.69)	–2.28	–0.77
World	858940 (100)	0.95	0.32

[1]Figures in parentheses are percentages of the total volume of world small ruminant meat exports. Source: FAO Trade Year Book, Rome (some issues).

Table 7. Average and growth rate of volume of fresh, chilled or frozen of small ruminant meat to major importing countries, 1989–1993[1] (tonne).

Importing countries	Average[1] (tonne)	Growth rate (% per year)	Correlation coefficient (r)
Indonesia	394 (0.005)	31.92	0.92
Saudi Arabia	28674 (3.34)	22.02	0.95
Iran	43346 (5.06)	–2.70	–0.06
Japan	64300 (7.50)	–3.84	–0.76
UK	111481 (13.00)	–3.09	–0.51
France	139389 (16.26)	7.74	0.98
Others	469836 (54.79)	–2.42	–0.76
World	857420 (100)	–0.17	–0.06

[1]Figures in parentheses are percentages of the total volume of world small ruminant meat imports. Source: FAO Trade Year Book, Rome (Some Issues).

Development of an Indonesian composite breed of sheep

Genetic improvement through crossbreeding to increase sheep productivity using the effect of heterosis or hybrid vigor has been carried out by one of the Agency for Agricultural Research and Development (AARD) research stations in Sei Putih, North Sumatra. Introduction of tropical hair sheep genotypes for crossing with local Sumatra sheep was based on the adaptability, reproductivity and faster growth. St. Croix and Barbados Blackbelly are among hair sheep breeds chosen for crossbreeding.

According to Subandriyo et al. (1996) the cross breed between St. Croix (crossbred 50% St. Croix and 50% Local Sumatra) and Barbados Blackbelly (crossbred 50% Barbados Blackbelly and 50% Local Sumatra) has produced a synthetic or composite genotype of 25% St. Croix, 25% Barbados Blackbelly, and 50% Local Sumatra with a mean birth weight of 2.45 kg, significantly higher than St. Croix (2.23 kg), Barbados Blackbelly (2.15 kg), and Local Sumatra (1.68 kg). This difference continues until weaning, when the composite breed has 13.14 kg, compared to Barbados Blackbelly (11.73 kg), St. Croix (11.67 kg), and Local Sumatra (8.67 kg), which means improvement of between 36% and 51% in weaning weight compared to Local Sumatra. The survival rate also improved to 93% for the composite breed compared to other parental breeds (85%). Ewe productivity measured as total lamb weaning weight per ewe per year indicated that the composite breed has the highest (35 kg), compared to Barbados Blackbelly (33 kg), St. Croix (27 kg), and Local Sumatra (20 kg). Therefore, in addition to year-around reproductivity and its adaptability to a hot–humid tropical environment, all these improvements in productivity in the composite breed suggest that Indonesia has brighter prospects for meeting the minimum liveweight of small ruminant exports.

Challenges for the Future

It is known that the future of the national economy in general, and agriculture in particular, will depend on the availability and the quality of natural, human, infrastructure and capital resources, science and technology, institutions, rules and regulations. For example, livestock development will have to contend with limited natural resources, in both quantity and quality, due to competition with non-agricultural uses. Furthermore, livestock technologies have to be applicable under conditions of low agricultural productivity due to low quality of breeds, low inputs, inefficient production practices and low managerial ability. However, capital resources seem to be the most limiting factor. Therefore, agro-industrial approaches need to be in place to fill in the gaps in terms of local materials, value added, labor absorption and improved foreign exchange.

Research outputs in the form of biological products such as new animal breeds, new varieties of grass and legumes, vaccines and the like need an institution to maintain and reproduce them as demanded by users. So far, there is only one institution that maintains and reproduces rice varieties. Moreover, livestock facilities and infrastructure in the villages are limited and hence no supporting improvement in quantity and quality of livestock products has been realised.

Middle-eastern countries have further enhanced the possibilities for small ruminants to become important export commodities. For example, the Agency for National Export Development (1988) estimated an annual demand of some 500 000 small ruminants by Saudi Arabia to be sacrificed during the period of Idul Adha. One suggestion from that study was that Indonesia should develop a pilot breeding program for the Javanese Fat-tailed (JFT) sheep, and that, considering the Saudi Arabian demand in 1988, consumers might be willing to pay more than US$250 per head for this species (Adnam 1988).

The Indonesia-Thailand-Malaysia Regional Development Project (ITMRDP) is one example of how future challenges for agricultural sector development in Indonesia can be met. North Sumatra, Aceh and West Sumatra (Indonesia), 14 provinces in southern Thailand, and four states of North Peninsular Malaysia are in *The Triangle Growth Center.* A proposal was submitted by the Government of Malasia (1993) to the Indonesian Coordinating Minister for Production and Distribution whereby sheep, rubberwood, fruits and vegetables were selected as the agricultural commodities considered to have bright prospects for the future and which needed to be developed as export commodities from North Sumatra and Aceh.

The challenge to increase productivity and expand sheep-raising in these two provinces will have to include the study of sheep diseases such as *MCF or coryza.* Sheep are believed to be carriers of the disease and the two provinces, particularly Aceh, are also the sites for Bali cattle development. It is known that Bali cattle, which are particularly susceptible to *MCF*, are one of Indonesia's most important species of livestock and will be developed throughout the country. If the disease cannot be eliminated, the sheep contribution to the ITMRDP will be minimal. On the other hand, expansion of sheep production in North Sumatra and Aceh will be supported by estate crop plantations. The most promising result of a study on the integration of sheep and tree cropping is the mutual sharing of resources between sheep and plantations.

Furthermore, development programs for the livestock sub-sector including small ruminant species should also take advantage of the forages available in the eastern islands, in terms of comparative and competitive advantages with other agricultural commodities. The effort will support decentralisation to balance the interests of the central and the local authorities in overall agricultural development.

Conclusions and Policy Implications

Because of the specific taste of meat compared with livestock products (eggs and milk), meat in the Indonesian diet has been considered a superior item. In future, by increasing the per capita income of people, demand for meat (especially goats and sheep) may increase much faster than other livestock products. This is indicated by the high growth rate of meat imports (26.7%/year), and the value of small ruminant meat imports of 6.94%/year for the four years (1990–1994).

The performance of the small ruminant industry can be improved through better technologies related to breeding, feeding and management practices, and institutional arrangements among the participants in order to fulfill the market opportunities, both domestic and international. An institutional prototype in the pig and broiler industries can be adopted in the development of the small ruminant enterprise. Collaboration between groups of farmers and traders/exporters is badly needed, as well as government intervention through bilateral negotiations in the encouragement of small ruminant exports.

If Indonesia and other countries can improve small ruminant production and enter the world market, they would compete with the major competitors, Australia and New Zealand. Both are efficient in the production, post-harvest, and distribution (export) of its product. The potential demand countries in the world market are Saudi Arabia, France, Iran, Japan and the United Kingdom. These represent the opportunity and the challenge for the countries which have the opportunity and resources to expand domestic production.

With respect to changes in strategies and policies for agricultural sector development, small ruminant research and development in Indonesia is adapted to match the demand for research outputs and new challenges, and towards increasing the welfare, ability and skill of the farmers.

The present productivity of small ruminants is considered low compared to that obtained at experiment stations. The economic importance of small ruminant production is obvious since the potential for income generation could be a considerable share of total farm income. The potential is clearly observable and demonstrated in West, Central and East Java, the most densely populated provinces in the country, where small ruminant production seems to fit and complement the prevailing farming system. In order to increase the productivity and role of the small ruminant in generating family income, adaptive research should be conducted for specific locations in the country such as these.

The national development program for increasing livestock population, including sheep and goats, should be directed toward distribution of livestock in newly developed transmigration areas. Outside Java, small ruminants can be even more widely distributed among farm households as an alternative income-generating activity.

Increased small ruminant productivity, particularly for export promotion objectives, implies the need for establishing a small ruminant breeding centre to provide farmers with certified breeding stock in order to produce liveweights that meet export standards.

Small ruminant production must be compatible with the national goal of improving farmer welfare, and so must meet improved economic feasibility and profitability levels.

The success of on-farm trials of sheep production integrated with plantation crops such as rubber, oil palm and other estate crops implies that small ruminant export promotional efforts require mutual understanding between the livestock and estate crop subsectors of resource sharing and added values generated from the system.

Small ruminant export promotion requires not only improvement in animal production and farmers' welfare but also improvement in the international trade standards such as minimum liveweight and live animal export regulations.

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Small Ruminant Production in India

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Abstract

With its economy traditionally based on agriculture, India is a great source of genetic biodiversity in plants and animals. Vastly different agroclimatic and socioeconomic conditions result in a wide geographic distribution of livestock in an ecosystem providing functional sustenance to man. Among livestock, small ruminants are reared by the poorest sections of rural populations with very small holdings. While the sheep population has remained fairly static over the years, the goat population has shown an annual growth rate of 1.34%. In north-western and semi-arid regions of the country, small ruminants are browsed or grazed on natural lands or wastelands and, in intensive crop production areas, in irrigated and rainfed regions, on crop residues. In the southern peninsular and eastern regions, flocks are maintained primarily on grazing.

The indiscriminate migratory nature of sheep and goat grazing is hampering developmental programs and practices. Grazing practices often lead to land degradation and forage depletion. Technologies have been developed in various institutes to improve degraded range and wasteland under perennial pasture and silvi-pastoral systems. For optimal growth, supplement feeding to grazing is advantageous to early animal slaughter. Under crossbreeding programs, feed supplementation has resulted in lambs attaining 25 kg body weight at 130 days.

Though considerable disease control and eradication measures have been undertaken, losses through pox, enterotoxemia and ecto- and endoparasites occur. Research into the control of parasitic problems should be increased. Effective programs of sheep and goat development should be addressed using a systems approach involving each major component of the production system. Such programs should include sustainability for efficient land use, nutrient recycling and flow, feed and fodder improvement, pasture development and systematic post-harvest technologies including marketing, pricing and trade.

INDIA has a resource of great animal genetic diversity. The country has some of the world's best dairy buffalo breeds, draught cattle, carpet wool sheep and most prolific goats. It is estimated that the country has a population of 196 million cattle, 77 million buffaloes, 99 million goats, 45 million sheep, 1.83 million horses, mules and donkeys, one million camels, 10.8 million pigs and 258 million poultry (1987 Census). The agroecology of the country greatly influences breed distribution as well as the production of different breeds.

Sheep and goat farming in India has remained nomadic, transhumane or crop–livestock mixed farming. Sheep and goats are reared mainly by the poorest people in the lower strata of society and serve as either main or supplementary income to these categories. Average flock size varies 40–100 in the north-western region and 5–15 in the south. Often flocks of several families are combined and looked after by a single individual or a group of 2–3 people, depending on flock size. There are also a few farmers, particularly in the north-western region, owning very large flocks — their animals are grazed on a contract basis. Both species are raised primarily for meat. In the north-western region, goat milk and sheep wool are important in addition to meat. The general management of both species is extensive grazing on natural rangelands and wastelands, particularly in the north-west and southern regions, and semi-intensive stubble grazing in parts of the southern and eastern regions and other cropped areas.

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Genetic Resource

India has 20 well-defined breeds of goat and 40 breeds of sheep. Others are being identified in different agroclimatic regions. However, the majority (about 75%) is nondescript. There is large intermixing among the breeds in different regions where two or more breeds exist on contiguous tracts. Breeder societies to ensure conservation of a breed or type by maintaining flock books and animal registers are almost non-existent. Central and state farms maintain flocks of indigenous breeds to produce rams and bucks for distribution to farmers.

Of the breeds of sheep, **Marwari** in Rajasthan and Gujarat, and **Deccani** in Maharashtra are numerically the most important and the largest contributors to meat production. **Marwari, Pattanwadi, Nali, Magra, Jaisalmeri** and **Chokla** are the largest contributors to carpet wool production. Among goat breeds, **Marwari** in Rajasthan, **Kutch** in Gujarat and **Black Bengal** in West Bengal, Bihar and other eastern states are numerically the most important. For meat production, **Black Bengal** and **Barbari** are famous; for milk production, **Jamunapari, Beetal** and **Jhakrana** are the breeds of choice. Goats of temperate Himalayan regions (where rainfall is scanty) grow fibres of good quality and finest undercoat called 'cashmere' or 'pashmina'. All the milk breeds are found in the north-western region of the country, whereas southern and western regions grow mainly dual-purpose breeds (milk and meat). The highly prolific meat breeds are found in the eastern region.

Holding Pattern

Average sheep flock size varies 40–100 in the north-western region, 5–15 in the southern region. Results of a survey (Table 1) indicate that in the arid zones where major sheep populations exist, more than 75% of farmers have large holdings. Results of a survey of goat rearing (rural Mathura) reveals that the majority of farmers have small holdings as well as small flock sizes (Table 2). Over the years, the sheep population has been stable, with negative growth over some years (Table 3), while the overall goat population has an annual growth rate of 0.90–4.62%.

Table 1. Classification of sheep breeders by land holding size and flock size.

Flock size	Landless nil	Marginal <1 ha	Small 1–2 ha	Large >2 ha	Total
<30	2	3	12	18	35
30–60	10	–	10	30	50
>60	4	4	18	48	74
Total	16	7	40	96	159

Table 2. Classification of goat breeders by land holding size and flock size in rural Mathura.

Flock size	Landless nil	Marginal farmers	Total households
Small (1–5 does)	50 (33.33)	64 (42.67)	114 (76.00)
Medium (6–10 does)	9 (6.00)	12 (8.00)	21 (14.00)
Large (more than 10 does)	7 (4.67)	8 (5.33)	15 (10.00)
Overall	66 (44.00)	84 (56.00)	150 (100.00)

Table 3. Population and annual growth rate in India.

Year	Human population (million)	Growth rate (%)	Sheep population (million)	Growth rate (%)	Goat population (million)	Growth rate (%)
1951	361.10	na	39.65	na	47.15	3.50
1956	na		39.25	–0.20	55.41	3.50
1961	439.23	2.16	40.23	0.50	60.90	1.98
1966	na		42.02	0.88	64.59	1.32
1972	548.16	2.48	39.96	–0.98	67.50	0.90
1977	na		40.83	0.45	77.37	2.92
1982	658.18	2.50	48.57	3.79	95.25	4.62
1987	na		44.84	–1.53	110.21	3.14
1992	843.93	2.32	44.61	–0.10	117.60	1.34

Socioeconomic Importance of Small Ruminants

In India, small ruminants are raised on the basis of low investment. The vast majority are owned by poorer rural families, and much of the meat and milk produced is for home consumption. The direct contribution of small ruminants to the Indian economy is estimated at Rs.66 109 million annually (Table 4). The socioeconomic impact of goat farming is perhaps evident in the sharp increase in the goat population during the post-independence period. Small ruminant rearing normally involves low-cost technology which readily attracts landless labourers and marginal farmers. On average, each small ruminant provides an annual net return of about Rs.250 to its owner. Five to 10 animals generate additional income and partial-to-full employment of family members who would be otherwise unemployed. Small ruminants do not need expensive housing and flocks can be multiplied and replenished easily. Part of the annual grazing cost is realised in many parts of the country by land owners, without much effort, as the manure (sheep and goat droppings) is valuable, particularly to smallholders on low-fertility soils. Slaughter by-products, skins and fibres provide raw material to consumer industries such as leather and woollen textiles (carpets, druggets, etc.).

Table 4. Annual contribution of small ruminants in 1992 to the Indian economy.

Products	Quantity (t/year)			Estimated value (Rs. million)
	Sheep	Goat	Total	
Meat	201640	480150	681600	40901.14
Milk		2338540	2338540	11692.70
Wool	41600		41600	1664.00
Skin	38520	109440	147960	8877.60
Pashmina		40	40	20.00
Offal	44339	117252	161591	3.23
Manure	7492472	18359953	25852425	2585.20
Blood	55984	126896	182880	365.76
Total				66109.63

Husbandry Systems for Small Ruminants

Sheep farming in India has remained nomadic, transhumane or crop–livestock mixed. Sheep are reared mainly by the poorest people in the lower strata of society and serve either as the main or supplementary source of income in this category. Average flock size varies from 40–100 in the north-western region to 5–15 in the southern region. Often the flocks of several families are combined and grazed by a single individual or group of 2–3 people, depending on flock size. A few farmers own very large flocks but graze their animals using hired labour. In the north temperate and north-western regions, sheep wool is important as well as meat, but in southern and eastern regions sheep are raised primarily for meat. Generally sheep management is by extensive grazing on natural rangelands and wastelands, especially in the north-western and southern regions, and by semi-extensive stubble-grazing in parts of the southern and eastern regions and other cropped areas.

The migration of sheep and goats in search of food and water is considerable. It is estimated that in the dry arid region about 30% of the sheep population remains on migration of different types, i.e. permanent, seasonal and temporary. Temporary migration depends mostly on the monsoon. If there is good rain in desert districts, the intensity of migration is less. In temporary migration the sheep begin to move in October and return to their home tracts at the onset of the monsoon. In the western Himalayas, sheep flocks move from one state to another and remain on migration for the whole year. At the onset of hot summer months these animals may return to hilly tracts and forest ranges of the arid regions.

The western region has a dense sheep population. The grazing resource is available in these districts only during the monsoon season. After October–November, the majority of these sheep start migrating to districts of the middle and southern states in search of grazing. Contracts for grazing are decided between the group leader of the shepherds and the village head or local goat official. This regulates grazing and avoids overstocking and overcrowding. The right to graze on open fields is obtained by payment, quite often made in kind (grains) instead of cash.

In the mountainous regions, sheep-rearing is predominantly semi-migratory. The sheep flocks in mountain valleys are maintained by their owners for 4–5 months under stall-fed conditions in winter, then handed over to a *Chopan* (a common professional shepherd) for grazing in alpine pastures where the flocks remain from April–May to October–November.

In Deccani plateau and the southern region there is very limited migration, and that only for short distances. In Karnataka sheep are managed on: (i) stall feeding, (ii) local grazing, and (iii) migratory and semi-migratory grazing. Stall feeding and local grazing are practised in Mandya district and the southern part of Karnataka, where flock size is less than 40 and the animals are raised for mutton production. In Northern Karnataka, migratory and semi-migratory grazing is practised mostly during lean months. Groups of shepherds join and take sheep distances of 200–300 km for grazing. District migratory routes have been identified.

The farmers of Central India pay a premium for penning sheep and goats in their fields since this ensures improved soil fertility for cropping. Following crop harvest, the animals are let loose to utilise the crop residues and feed for themselves. This practice continues till the rains set in, after which the crop farming operations recommence and the animals graze in forest areas.

Grazing Practices

Goats and sheep in north-western arid and semi-arid regions are browsed or grazed on natural range and wastelands during the monsoon season. After kharif crop harvesting, they are grazed on the crop stubbles. Beginning September–October, the non-migratory flocks graze on uncultivated areas, the migratory flocks on harvested fields and reserve forests on the migratory routes. Sheep are put into folds on private fields in lieu of stubble grazing and payments made to the flock owners. During the extreme summer months, flocks are grazed during the cooler hours of the day and at nights. The animals are brought to water at noon. Goats are generally maintained browsing on natural vegetation and tree loppings. Only lactating animals are given supplementary feeding such as clusterbean, pearl millet, unprocessed isaphogol or oilcakes. In some areas supplementation with cultivated fodders like lucerne or berseem is also practised.

In the southern peninsular and eastern region flocks are maintained primarily by grazing and rarely given supplementary feed, except occasionally groundnut or horse gram hulls. Most grazing is in harvested fields or forest areas, along roadsides and on hill slopes. Flocks are generally grazed throughout the day, though grazing in the very early hours is avoided to help prevent parasite infestation, except during summer. Farmers with very few goats/sheep generally take their flocks with them for tethering while they work in the fields.

In the north temperate region, stationary flocks are grazed in harvested fields, along waterways, in forests and in permanent pastures of common grazing land. Sheep are allowed to graze for about seven hours daily; some flocks are given supplementary feed such as tree leaves. Migratory flocks are primarily grazed on alpine pastures during summer and on harvested fields, forest areas and other uncultivated fallow lands during winter. Tree leaves and pods of fodder trees constitute an important feed resource during winter and early spring, when the flocks are in the foothills and on the plains. In the north-eastern region of the country plenty of plant material is available almost all year, facilitating rearing of famous Bengal and Assam Hill goats.

The excessive plant biomass available all year is converted into meat and milk.

About 150 000 pashmina-producing goats are reared in the valley of Lahaul and Spiti in Himachal Pradesh and Rupsub and Changthang in the Laddak area under free-range grazing or the transhumane system depending upon flock sizes.

Grazing practices currently followed for both species of small ruminants are quite indiscriminate. There is no control over grazing and no effort to improve the grazing land. There is continuous degradation of the land and depletion of forage availability.

Controlled grazing

It is essential to adopt controlled grazing practices according to forage resources in particular areas. This has been extremely difficult in India. According to estimates, about 1.5 tonnes of dry forage is available per hectare of natural rangeland. This can barely support three sheep or goats per hectare. Grazing should be controlled according to stocking capacity. Under grazing conditions of natural rangeland, lambs barely attain body weights of 15–16 kg and kids 12–13 kg at six months of age. Under exclusive grazing conditions, adult annual body weight remains at about 25–30 kg in sheep and 20–25 kg in goats throughout the year.

Grazing on reseeded pasture

Technologies have been developed by various Indian Council of Agricultural Research (ICAR) institutes and state agricultural universities to improve degraded rangeland and wastelands under perennial pastures and silvi-pastoral systems. Suitable grass and legume forages have been identified for different agroclimatic zones and soil conditions. Forage availability has been increased 2–3 times by bringing rangeland under silvi-pastoral development, under which 5–10 sheep/ha can be maintained, compared with 2–3 sheep/ha on natural grazing land under controlled conditions. This technology has not yet been adopted by farmer–landowners rearing small ruminants. Considerable effort is needed to transfer the technology of silvi-pastoral development to rearing small ruminants. In rainfed cultivated areas, it is important to introduce perennial legumes, particularly for grazing kids and lambs for meat production.

Supplementary feeding systems

Grazing alone is inadequate to support reasonable growth in kids and lambs. The normal slaughter age of kids and lambs under field conditions is about the year it takes to attain body weight of 20–25 kg. It is possible to attain this weight by 5 to 6 months of age through supplementary feeding or stall feeding. However, this system is unpopular with farmers because of economic constraints and non-availability of feed. It has been observed that a complete feed of 50% concentrate and 50% roughage would produce satisfactory growth in kids and lambs at dry matter intake levels of 4% of body weight. Thus supplementation at the rate of 2% of body weight for kids and lambs is desirable to achieve faster growth rates. It is also necessary to reduce the cost of feeding by evolving cheaper methods of feeding for kids and lambs. Browsing and supplementation of kids have shown a daily growth rate of 120 g to achieve targeted body weights of 25 kg at 6 months and 30 kg at 9 months of age.

Intensive feeding systems

Several feedlot experiments have been conducted under the All India Coordinated Research Project on sheep breeding for meat production under completely stall-fed conditions. In this system, lambs have performed better than kids. Cross-bred lambs (mutton synthetic) have attained body weights of 25 kg at 120–130 days of age by being fed rations of 50% concentrate and 50% tree fodder such as *Zizyphus nummularia* (Pala) and *Prosopic cineraria* (Khejri). It is necessary to reduce the cost of feeding by using cheaper resources available in different areas. The cost of production of meat needs to be worked out under various feed management regimes, and the best method adopted for field conditions.

Wool Production

Of the total quantity of wool being utilised, approximately half is used in the carpet sector, and half in the apparel and footwear sectors. The present rate of growth of wool production is expected to produce about 52 million kg of wool by the year 2000, of which approximately 5 million kg will be of apparel quality and 30 million kg of medium-type wool. The rest will be of a coarse wool type which can be improved to medium carpet-type wool. With an expected annual growth rate of about 2% in wool production and about 0.8% in sheep population, it may be possible to have a population of 60 million sheep which may produce 90 million kg of wool, of which about 15 million kg may be of apparel type, by the year 2020. Export earnings from different woollen products from 1984–85 to 1990–91 show an increase from Rs.3170 million to Rs.6160 million.

Meat Production

It is estimated that about 28% of the total sheep population is slaughtered every year and 132 million kg of mutton produced annually. This quantity is far short of the required quantity of 43 million kg of mutton. Currently only 13% of total meat produced is contributed by sheep.

Foreign exchange earnings through the sale of meat are currently mainly through the export of buffalo meat. However, there is scope to increase the export of meat from sheep and goats. The export value of meat and meat products was about Rs.3300 million during 1992–93. The quantity and value of total meat exports during 1988–90 to 1992–95 have increased by Rs.1820 million to 4800 million. The slaughter rate in relation to animal population is estimated at 1.45%, 3.45%, 35.6% and 26.2% for cattle, buffalo, sheep plus goats and pigs, respectively.

Skin, Leather and Leather Products

Production of leather and its export as semi-processed and processed products are important components of the sheep and goat production system. India's share of world production of goatskin is about 37%, and that of sheepskin, 6.6%. The export of leather and leather goods in 1993–94 is reported to be worth Rs.42 350 million. About 1.2 million people are involved in the leather industry.

Research Efforts and Priorities

Breed improvement

Research efforts have so far concentrated on evaluating the important native breeds for body weight at different ages, wool production and quality, and, in the case of mutton breeds, average daily gain, feed conversion efficiency and carcass characteristics. Crossbreeding native breeds has been done with **Rambouillet Merino** sheep for improving wool production and quality, and **Dorset/Suffolk** for improving mutton production.

In crossbreeding programs, the European dairy goat breeds **Saanen, Alpine** and **Toggenberg** and the native breeds **Beetal** and **Jamnapari** have been used for improving milk production. Crossbreeds of **Sangamneri** of Maharashtra with **Angora** goats have produced mohair at 75% and 87% of the Angora inheritance.

More detailed study is needed in India, especially for accurate measurements of the population and production statistics for different breeds of goats and sheep. The existing native breeds of goats and sheep should be properly characterised and evaluated, while threatened breeds should be conserved in situ or ex situ with greater emphasis on selection. Perhaps evolving dual-purpose breeds, particularly meat and milk for goats and mutton and carpet wool for sheep, is warranted. Nucleus herds maintained by the government and developmental agencies involving progressive farmers may raise the quality of both bucks and rams.

On the basis of experience gained during the last decade or so, it has been observed that crossbreeds produced by upgrading native breeds with exotics have not performed well under management conditions prevailing in arid and semi-arid areas. Further, as observed, it has not been possible to produce fine wool with desirable staple length from higher crosses in the arid and semi-arid regions. Apparel wool production may be intensified only in temperate areas such as the northern temperate hilly region and Nilgiri and Kodai hills of the southern region. In these areas three-quarter crosses of **Rambouillet** or **Merino**, including **Bharat Merino**, may be propagated, and annual clips to meet requirements for apparel manufacture may be obtained.

The medium type wool-producing breeds such as **Nali, Chokla, Pattanwadi, Marwari, Magra, Jaisalmeri, Kheri** and **Malpura** may be improved further through selective breeding by distributing good quality rams of the respective breeds. Coarse carpet wool and hairy breeds such as **Sonadi, Deccani, Shahabadi, Coimbatore and Bolangir** may be upgraded to produce dual-type animals by using rams of medium wool-producing breeds such as **Muzzaffarnagri, Nali, Magra** and **Malpura** or half-breeds of the respective indigenous breeds with **Rambouillet** or **Bharat Merino**. Non-woolly breeds such as **Mandya, Nellore, Madras Red, Mecheri** and **Ganjam** may be restricted to selective breeding by using superior rams of the respective breeds for enhancing mutton production.

For large-scale production of half-breed rams to upgrade coarse wool breeds, a large number of half-breed rams or medium wool-producing superior breeding rams is necessary. Ram production centres should be developed for the medium type wool breeds and for producing half-breeds in the respective breeding tract by using either **Rambouillet** or **Bharat Merino** rams. It is desirable to produce three-quarter **Rambouillet** by upgrading indigenous breeds as a substitute for **Rambouillet** rams in large-scale ram production.

Goat breeds can be improved by supplying superior bucks to village flocks. Health cover through vaccination and prophylaxis can further improve production. Performance recording and increased selection pressure must be implemented. Hairy goat breeds may be improved through crossbreeding with **Angora** bucks.

Priority areas for research in sheep and goat breeding include: survey; evaluation and improvement of indigenous sheep breeds for carpet wool and mutton production, with special emphasis on improved fertility; animal genetic resource conservation and evaluation through extensive field surveys, supported by studies of gene marker characters; ex situ and in situ conservation of threatened breeds; improvement and utilisation of **Bharat Merino** and **Avikalin** sheep; testing created genotypes at many locations; developing feeding systems for increased animal growth and nutrition efficiency; creation of disease-free zones for mutton production; studies of the storage and keeping qualities of meat.

Farming systems

Feed and fodder resource development aims to increase fodder production through various systems including silvi-pastoral production. Dry matter availability of the natural grazing land available is about 0.5 t/ha, which can support only one animal per ha. Technologies have been developed to increase forage production to 2–3 t/ha by bringing the land under silvi-pastoral development. This would increase stocking capacity to 4–6 animals/ha. Research into feed resource development for sheep production has been carried out largely at the Indian Grassland and Fodder Research Institute, Jhansi, the Central Arid Zone Research Institute, Jodhpur, and CSWRI, Avikanagar. The work comprises the establishment of pastures in arid and semi-arid areas and temperate hilly regions, the introduction of legumes into grass pastures, the development of two-tier and three-tier silvi-pastoral systems, and the intercropping of fodder and cereal crops. Different varieties of grass species suitable for arid and semi-arid climates have been tried for pasture development. The Cenchrus species (Anjan grass), i.e. *Cenchrus ciliaria* and *Cenchrus setigerus*, have been found suitable for semi-arid climates, with dry matter production of 2–4 t/ha, depending on rainfall. *Lasiurus sindicus* (Sewan grass) has been found quite suitable for hot arid areas. Different sowing methods for grass seeds have been tried for the establishment of pastures. Production of tree fodders from different species has been estimated and technologies developed to increase forage production from the fodder trees and pasture systems. According to current rates, the establishment cost of silvi-pasture on one hectare of land is approximately Rs.1200.

Feeding and nutrition

The major emphasis of research into small ruminant nutrition in India has been the evaluation of various feeds, fodders and pastures, the utilisation of agro-industrial by-products, developing feeding systems under extensive grazing management and the intensive feeding to lambs of complete rations for mutton production. Recently, on-farm studies have been initiated utilising agro-industrial by-products and forest grasses.

Intensive efforts are necessary to ensure adequate feed availability year-round, through the development of wastelands, silvi-pastoral systems, integrated farming systems of horticultural and plantation crops, and the identification and description of available feed resources. More research is necessary into water and soil–plant–animal relationships concerning mineral macro- and micronutrients.

Specific studies of feeding behaviour, with attention to increasing voluntary feed intake, and the potential utilisation of forages of particular legume shrubs and trees are warranted. Fodder banks could be established at strategic points. On-farm research into intensive meat production from goats and sheep with low-cost balanced feeds must be formulated, utilising locally available feedstuffs. Appropriate processing machinery for chaffing, grinding and pelleting should be designed locally, and the nutrient density of processed feeds assessed for various production traits.

Work is also needed on nutrition manipulation to maximise meat and wool production, with the objectives of evolving economic rations for sheep and goat production, to utilise coarse roughage after amelioration with different softening agents, to screen various by-products and non-conventional feed resources for their utility in sheep and goat rations, and to estimate the energy and protein requirements of sheep and goats.

Priority areas include feed resource development for arid, semi-arid and temperate regions, and the utilisation of non-conventional feed resources in sheep and goat rations. Grazing studies of different types of pastures and rangelands and improving the utilisation of high-tannin and high-lignocellulose feeds are also important.

Reproduction

Technologies developed for the preservation of ram semen in liquid form, and to freeze and store ram semen in 0.25 mL straws, need to be further refined. Post-thaw motility of more than 50% has been achieved in **Malpura** ram semen.

Research into the optimisation of sheep production through physiological manipulation should be emphasised. Research programs should include cryopreservation of ram semen to utilise frozen embryo transfer technology, to freeze embryos after in vitro fertilisation, and their use in surrogate mothers to increase the production of improved sheep germplasm. Studies of the augmentation of fertility in sheep breeds and rabbits are the priority area. Development of embryo transfer technology and the application of MOET technology research involving developing techniques for cloning, sexing, in vitro maturation, multi-ovulation, embryo-splitting, cryopreservation of embryos, cryopreservation of ram semen and the utilisation of frozen semen, with an improvement in the conception rate, are emphasised.

Health cover

Most common diseases prevalent in sheep and goats have been identified, and necessary control and eradication measures have been undertaken. Common diseases encountered include pox, enterotoxemia, blue tongue and ecto- and endoparasites among sheep, and pox, enterotoxemia, contagious ecthyma, fascioliasis and mange among goats.

Current emphasis in sheep health research lies in the epidemiology of various diseases and in the preparation of vaccines against some important viral diseases. Studies have been undertaken of viral pathogens causing pneumoenteritis. The prevalence and epidemics of chlamydia, pneumonia and abortions are also being studied. Epidemiology of blue tongue is being investigated. Emphasis is also being given to the economic effects of diseases, the cost of their control, and their impact on productivity. Pneumonia due to adenoviral infections and the sporadic occurrence of sheep pox with special reference to breaks in immunity are being investigated.

Efforts to control Johnes disease through regular vaccination and culling have resulted in a decreased incidence of the disease. Antibiotic sensitivity tests are being done in species with suspected bacterial infections. Prevalence rates of enteric parasites have been recorded. Investigations are being undertaken to control gastrointestinal parasitosis by using different products. Technology for a disease and information system for organised sheep farms has also been developed by the CSWRI for monitoring diseases.

It is important that the regular use of anthelmintics should be practised to prevent endo- and ecto-parasitism. Endemic maps for rinderpest, blue tongue and foot-and-mouth diseases may assist health programs implementing suitable prophylactic vaccination. Efforts should be made to improve the existing rinderpest and sheep pox vaccines and to produce goat pox and blue tongue vaccines.

Research in disease diagnosis and the development of control measures will give major thrust to overcoming parasitic problems. The prophylaxis calendar has been developed, modified and economised. Efforts will aim to develop quick diagnostic techniques and prophylactic and control measures.

The development of appropriate flock health technologies, and diagnostic techniques for economically important diseases should be addressed. For disease diagnosis and prophylaxis, DNA recombinant techniques, monoclonal antibodies and hybridoma techniques should be applied.

Economics, Marketing and Development

There is a need to undertake micro-level studies on the economics of goat production under intensive and semi-intensive management systems, including marketing. In an economic assessment study carried out by IASRI, New Delhi, the maintenance cost of sheep and the costs of wool and mutton have been worked out. The average daily cost of maintenance of a lamb was of the order of 41 paise for males and 43 paise for females. In the case of young males, the daily cost per hogget ranged from 55 paise at 3–6 months old to 104 paise at 9–12 months, while for young females it ranged 57–101 paise for the same age group. Average daily cost of an adult sheep was about Rs.1.32 for males and 88 paise for females. The component of labour cost accounted for the greatest percentage of gross cost, followed by feed, interest on fixed capital, depreciation of sheep, miscellaneous expenses and interest on working capital. Average cost per kg of wool including and excluding family labour in Malpura tehsil was Rs.23.16 and Rs.11.61, respectively, whereas in Tonk tehsil these were respectively Rs.17.13 and Rs.8.78. The apportioned cost per kg mutton with and without the inclusion of family labour was of the order of Rs.15.10 and Rs.7.20 respectively in both tehsils.

There is a possibility of setting up viable hygienic slaughterhouses in important production centres, with forward linkage between producers and consumers. Processing units for slaughterhouse by-products could be promoted in rural areas needing the economic value of the by-products — this area needs more study.

Studies of surveying, sampling and end-use suitability of wool and speciality hair will aim to evaluate and better utilise wool produced on the farms, and to assess products for quality and improve them with different techniques. The utilisation of wool, as such, and in blends with other natural and man-made fibres, will be the priority area.

Transfer of Technology

Transfer-of-technology programs will aim to test and transfer technologies being developed for increasing meat and wool production and for wool utilisation from sheep and meat production from goat. The transfer of technology should be system-based, taking the package as a farming system involving all components of the soil, crops and animal systems including grassland forage agronomy, animal nutrition, animal physiology and health, product utilisation and socioeconomic studies of farm facilities and farmer income.

Socio-Economic Importance, Production Systems, Research and Development of Small Ruminants in Pakistan

A. Ghaffar, M. Anwar and M.Q. Khan[1]

Abstract

The present small ruminant population in Pakistan is estimated to be more than 73 million, of which Punjab province has 33.21%, Baluchistan 33.57%, Sind 18.22%, North West Frontier Province (NWFP) 12% and Northern Areas 3%. The annual growth rate of the goat population is 4.7%, compared to 1.60% of sheep and 0.78% of cattle. The goat is preferred for meat and the buffalo for milk in most parts of Pakistan. The small ruminants supply almost as much red meat as that supplied by large ruminants, and among small ruminants goats and sheep contribute 60% and 40% respectively. Goat meat production in Pakistan is increasing annually by approximately 7%.

Of 4.684 million households owning small ruminants, 59% are farm or land owning, whereas 41% are non-farm or landless households. However, at the provincial level the proportion varies considerably. Flock size varies widely from less than five to over 200. There are more larger sized flocks in Baluchistan and in Northern Areas. A great majority are mixed goat and sheep flocks.

Small ruminant production systems prevailing in the country are described as nomadic, transhumant, household and sedentary. However, the latter two systems are considered the same because of the similarity of management. The vast majority of small ruminants are produced under transhumant and household/sedentary systems. The transhumant flocks are usually much larger than the household/sedentary flocks. Housing for the household flocks is limited to open corrals to protect animals from predators. Breeding and management practices in vogue are discussed.

PAKISTAN is a country of 796 095 sq. km with a human population of 128.01 million. The human population is increasing at the rate of 2.9% per annum. Twenty-eight per cent of the population is involved in labour. For administrative purposes, Pakistan is divided into four provinces. In area, Baluchistan constitutes 43.6%, Sind 17.8%, Punjab 25.8% and NWFP 9.4% while respective percentages for human population are 5.1%, 22.6%, 56.1%, and 13.1%. FATA (Federally Administered Tribal Areas) comprises 27 220 sq. km with a population share of 2.6%.

The current contribution of the livestock subsector to national GDP is 8.04% and to agricultural GDP 24%. The share of livestock products to the human food basket is about 30%. Livestock is an essential part of the mixed farming system in the country. Farm animals play an important role in cultural, social and religious lives, and provide insurance against failed crops.

Social and Economic Importance of the Small Ruminant Industry

Small ruminants (sheep and goats) contribute significantly to the national economy in Pakistan. The primary purpose of raising small ruminants is to produce slaughter stock. They supply almost as much red meat as that supplied by cattle and buffalo. However, the meat supplied by small ruminants is preferred over that supplied by the large ruminants and, hence, the total value of goat and sheep meat is greater. Goat meat is preferred over sheep meat in most parts of the country, especially in the provinces of Punjab and Sind. Small ruminants, especially goats, are a major source of livelihood for a large

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number of livestock farms in the arid regions where crop and dairy farming are not possible. A still larger number of farmers practice mixed farming systems in the irrigated tracts where goats are an important component among other livestock (Hasnain 1985). Most householders that own small ruminants in Pakistan can be termed subsistence farmers.

Sheep and goats, being small sized ruminants, fit well into the agricultural production system. The animals are well integrated in the varied socio-economic system and climatic situation prevailing in Pakistan. The rangelands constitute the single largest land use in the country and small ruminants derive over 60% of their feed requirements from these lands. It has been suggested that intensified systems of feeding and management could play a leading role in increasing the meat productivity of goats and sheep (Economides 1983). Small ruminants are reared by farmers as a subsidiary occupation, more as a way of life rather than as a commercial enterprise (Hasnain 1985).

Small ruminants account for 875 000 tonnes of meat which is 41.13% of the total meat produced in the country including poultry. Nearly 39.2 million skins produced annually earn about Rs.1400 million in foreign exchange through their export. Annual production of about 53.1 tonnes of wool results in production and export of hand-knitted carpets worth Rs.2000 million annually. Small ruminants produce 687 000 tonnes of milk which was 4.72% of total milk produced during the fiscal year 1993–94. In spite of a large off-take of small ruminants, the number is constantly on the increase. Table 1 shows the comparison of human population and small ruminants for the past two decades. The number of small ruminants available per thousand persons is constant, however, goats exhibit an increasing trend ascribed to prolificacy and resistance to diseases.

Population and Distribution of Small Ruminants

The population of sheep and goats is 29.0 and 43.7 million, respectively. Pakistan is the second largest goat and sheep producing country in the South Asian region and ranks 11th in the world. Table 2 shows the population of goats and sheep for the decade ending June 1995, Table 3 presents the percentage growth per annum of the various ruminant species and Table 4 exhibits the latest small ruminant population in different provinces of Pakistan. The annual growth rate of the goat population (4.7%) is remarkable when compared with that of sheep and cattle (1.60% and 0.78%, respectively). However, the population of buffalo has also grown at a higher rate (5.04%) compared to goats. The trend points toward a preference for these two species — buffalo for the milk and goats for the meat. Currently the goat population is increasing by 1.7 million every year.

Table 2. Small ruminant population of Pakistan for the decade ending June 1995 (millions).

Year	Population		Yearly increase	
	Goats	Sheep	Goats	Sheep
1985–86	30.8	23.3	—	—
1986–87	31.2	23.7	0.4	0.4
1987–88	32.6	24.5	1.4	0.8
1988–89	34.0	25.1	1.4	0.6
1989–90	35.4	25.7	1.4	0.6
1990–91	37.0	26.3	1.6	0.6
1991–92	38.6	27.4	1.6	1.1
1992–93	40.2	27.4	1.6	0.6
1993–94	42.0	28.3	2.2	0.6
1994–95	43.7	29.0	1.7	0.7

Source: Government of Pakistan (1995).

Table 1. Comparison of human and small ruminant populations in Pakistan (1976–95).

Year	Human	Sheep	Goats	Total	PCS[1]	PCG[2]	PCT[3]
1976	72.120	19.5	22.5	42.0	0.270	0.311	0.582
1981	84.254	22.8	26.7	49.5	0.271	0.317	0.581
1986	100.000	23.7	31.7	55.4	0.237	0.317	0.554
1991	113.780	26.3	37.0	63.3	0.231	0.325	0.556
1992	117.310	27.4	38.7	66.1	0.234	0.330	0.563
1993	120.830	27.7	40.2	67.9	0.230	0.332	0.562
1994	124.450	28.3	42.0	70.3	0.227	0.337	0.565
1995	128.010	29.0	43.7	72.7	0.227	0.341	0.568

[1]PCS Number of sheep per capita.
[2]PCG Number of goats per capita.
[3]PCT Number of small ruminants per capita.

Table 3. Growth of small ruminant population in Pakistan over the decade ending June 1995.

Ruminant species	Population 1984–85 ($\times10^6$)	Population 1994–95 ($\times10^6$)	Increase ($\times10^6$)	Growth per annum (%)
Goats	29.7	43.7	14.0	4.71
Sheep	25.0	29.0	4.0	1.60
Cattle	16.5	17.8	1.3	0.78
Buffalo	13.1	19.7	6.6	5.04

Source: Government of Pakistan (1995).

Table 4. Small ruminant population estimates for various provinces of Pakistan.

Year	Population ($\times10^6$)		Estimate (%)	
	Goats	Sheep	Goats	Sheep
NWFP[1]	6.12	2.61	14.0	9.0
Punjab	15.73	8.41	36.0	29.0
Sind	10.05	3.19	23.0	11.0
Balochistan	10.48	13.92	24.0	48.0
NA[2]	1.31	0.87	3.0	3.0
Pakistan	43.69	29.0	100	100

[1]NWFP = North West Frontier Province.
[2]NA = Northern Areas.
Source: Government of Pakistan (1995).

Among the provinces, Punjab has the largest proportion of goats (36%), followed by Baluchistan (24%), Sind (23%), NWFP (14%) and the Northern Areas (3%). On the other hand, Baluchistan has a largest proportions of sheep (48%) followed by Punjab (29.0%), Sind (11.0%), NWFP (9.0%) and NA (3.0%). Most flocks are mixed goats and sheep, regardless of the nature of the tract and the type of production system. However, some all-goat or all-sheep flocks are also discernible. In the mountains sheep are gradually replaced by goats as higher altitudes are reached. This phenomenon is attributed to the goats' ability to climb and graze on slopes.

Pattern of ownership

Two types of ownership are recognized, the landed or farm households and landless or non-farm households. Table 5 presents the proportion of farm and non-farm households owning small ruminant flocks with a total of 4.684 million households owning small ruminants. Of these about 59% are farm households and 41% non-farm households. This means that the national ratio of land-owning and landless households involved in small ruminant raising is three to two. At the provincial level, the proportion of the two types of small ruminant owning households varies considerably. In Punjab, the proportion is almost the same as at the national level. However, among other provinces NWFP has a farm to non-farm ratio of 73:27, followed by Sind (52:48) and Balochistan (65:35). It is evident that Sind has much more landless small ruminant herdsmen than any other province. Of the total 4.684 million flocks (households owning small ruminants) in the country, NWFP has 16.1% (0.753 million), Punjab 64.71% (3.031 million), Sind 13.21% (0.619 million), and Balochistan 6.0% (0.281 million).

Table 5. Households owning small ruminants by household type (province).

Province	Household Numbers ($\times10^6$) by Household Type		
	Farm	Non-farm	Total
NWFP[1]	0.547 (72.6)	0.206 (27.4)	0.753
Punjab	1.703 (56.2)	1.328 (43.8)	3.031
Sind	0.320 (51.7)	0.299 (48.3)	0.619
Balochistan	0.182 (64.8)	0.099 (35.2)	0.281
Pakistan	2.752 (58.76)	1.932 (41.24)	4.684

[1]NWFP = North West Frontier Province.
Note: Values in parentheses are the percentage of households by household type.
Source: Agricultural Census Organization (1993).

Flock size

Flock size varies widely, from less than four to over 200. The distribution of flocks according to size in individual provinces is presented in Table 6. In Punjab, 60% of flocks have one to four sheep or goats and only 8% have larger sized flocks. In NWFP 54%, in Sind 48% and in Balochistan 20% of flocks have only one to four goats or sheep. All these provinces have more larger sized flocks than Punjab. In fact, in Balochistan and the Northern Areas 73.4% and 68.5% of the flocks, respectively, are of larger size. On the basis of the 1986 livestock census, Ishaque (1993) has reported average flock size for goats as 4.7 in NWFP, 3.8 in Punjab, 6.4 in Sind, 19.4 in Balochistan and 3.0 in the Northern Areas.

Types of Small Ruminant Husbandry Systems

The prevailing production systems in Pakistan have been described by Ishaque (1993) as nomadic, transhumant, household and sedentary, and frequencies of these systems in various provinces have been given in Table 7. The prevalence of the nomadic system was highest in Baluchistan (73%) and lowest in the Punjab (26%), compared to other systems, and that of transhumant and household/sedentary systems was highest in the Punjab (47% and 27%, respectively) and lowest in Baluchistan (3% each). These frequencies might have changed considerably. Furthermore, for small ruminants, household and sedentary systems can very well be treated as the same for essential similarity of management. Although no recent data are known to exist for the frequencies of prevalence of production systems, it can safely be contended that the vast majority of small ruminants are managed under transhumant and household/ sedentary systems. For nomads in Pakistan, Ishaque (1993) has quoted an estimate of their population to be 0.911 million, of which about 15% were stated to be herdsmen. These systems are reviewed briefly.

Nomadic flocks

A study sponsored by the Government of Pakistan on 'Historical Social and Economic Perspectives of Development Strategy of the Nomads of Pakistan' estimates the population of nomads in Pakistan as 0.911 million, of which about 15% are herdsmen. Distribution of nomads by province is NWFP 32%, Punjab 22%, Sind 15%, Baluchistan 25% and Northern Areas 6%. This system has little significance in small ruminant production.

Transhumant system

This system involves routine annual migration of goat and sheep flocks, mostly combined goat–sheep flocks, to their summer and winter pastures on established routes. For instance, in Kaghan and Swat river valleys in NWFP the flocks move up to spend summer at the high alpine ranges in the north and migrate down with the onset of winter to as far south/south east as Islamabad and even Jhelum in the Punjab (Hasnain 1985). A recent field study of the Kaghan Valley (Ahmed 1993) indicated that more than 80% of the transhumant flocks belonged to the high mountain regions of Kaghan and Naran, migrating with the onset of winter down to the Haripur–Khanpur area or even further towards Punjab, and moving back in the summer to their high mountain pasture regions. The overall number of goats in the flocks of the Kaghan Valley was higher compared to sheep, the average being 52% goats to 48% sheep. The flock strength ranged from 100 to 250 animals. An occasional small flock of 20–30 animals was also met (Ahmed 1993).

Table 6. Households owning small ruminants by flock size.

Flock size	NWFP[1]	Punjab	Sind	Baluchistan	Pakistan
1–4	0.410 (54)	1.929 (60)	0.298 (48)	0.056 (20)	2.593 (55)
5–15	0.243. (32)	0.971 (32)	0.227 (37)	0.090 (32)	1.530 (33)
16–30	0.60 (8)	0.143 (5)	0.064 (10)	0.041 (16)	0.0310 (7)
31–50	0.022 (3)	0.048 (2)	0.019 (3)	0.027 (9)	0.0117 (33)
51–75	0.008 (1)	0.017 (1)	0.006 (1)	0.018 (7)	0.050 (2)
76–100	0.004 (*)	0.007 (*)	0.002 (*)	0.011 (4)	0.025 (1)
101–150	0.003 (*)	0.006 (*)	0.001 (*)	0.012 (5)	0.023 (*)
151–200	0.001 (*)	0.004 (*)	—	0.007 (2)	0.012 (*)
> 200	0.0	0.007 (*)	—	0.013 (5)	0.022 (*)

[1]NWFP = North West Frontier Province.
Note: Values in parentheses are the percentage of households by household type.
Source: Agricultural Census Organization (1993).
(*): Values < 0.5%.

Table 7. Distribution of production systems by province (per cent).

System	Pakistan	NWFP[1]	Punjab	Sind	Baluchistan
Nomadic	44	50	26	44	73
Transhument	38	33	47	37	21
Household	12	17	18	12	3
Sedentary	6	—	9	7	3

[1]NWFP = North West Frontier Province.
Source: FAO (1974).

Table 8. Distribution of home and transhumant pastures ($\times 10^3$ hectares).

Province	Home pastures	Home and transhumant pastures	Total
NWFP[1]	3 128	5 532	8 660
Punjab	7 353	2 878	10 231
Sind	5 604	5 323	10 927
Baluchistan	6 696	27 562	34 258
NA[2]	—	6 986	6 986
Pakistan	22 781	48 282	71 062

[1]NWFP = North West Frontier Province.
[2]NA = Northern Areas.
Source: Ishaque (1993).

In the Northern Areas, the transhumant system is the only prevalent system of goat and sheep production. The overall pattern is similar to that in the Kaghan Valley. The winter migration occurs from the north-western high alpine regions to the lower Hunza and Gilgit Valley areas, the homeland of the flock owners. The summer migration takes place in the alpine pasture areas. The system is also prevalent in other parts of the country. In all these regions, the migration is partly because of high temperatures during summer and partly because of the shortage of feed and water (Ishaque 1993).

The system has its own hazards. The flocks may face periods of drought causing heavy mortality (Hasnain 1985). The grazier may have to pay for periods of grazing over the pasture/rangelands. Furthermore, over-grazing may cause severe depletion of nutritious vegetation. In such cases, flock owners for months may graze their flocks on the roadsides, harvest stubbles and trees. Table 8 shows the distribution of home and transhumant pastures for various provinces.

Household/sedentary system

The management of household and sedentary systems is essentially the same (Ishaque 1993). Hence, these two can be grouped together as one production system. The animals are taken out for grazing early in the morning and are brought back late in the afternoon, and this happens in the same locality throughout the year. Small ruminants under this system are reared either by the farmers as a subsidiary occupation or by the poor landless herdsmen (Ahmed and Alvi 1988). The system is prevalent in most areas of the four provinces except those which have been mentioned in the preceding section to be under the transhumant system.

The flocks are usually grazed on Shamlaat (common village property), roadsides, or canal banks. They are also grazed on stubbles after crops have been harvested from the fields. Trees are lopped by the grazier to make available tree leaves as a feed. Shamlaat is used to provide good grazing. However, overgrazing has generally affected their utility and, in many instances, encroachments have greatly reduced their grazing area. Rarely, some concentrates are provided to milking small ruminants.

In this system, the flocks containing both goats and sheep are grazed together. However, in many instances, goats and sheep may be kept separate, and may follow each other closely. In mixed flocks the goats usually act as mascots (Hasnain 1985). Generally several flocks in a village or a locality are grazed together by a hired shepherd who may himself own few goats and sheep. The animals are collected for grazing from the owners early in the morning and brought back to the households late in the afternoon. The village shepherd is paid by each flock owner for his grazing service in cash or kind. A common payment in vogue is a 50% share in the progeny of the grazed flock (Ahmed and Alvi 1988). Flocks raised under this system are usually much smaller in size compared to transhumant flocks. Small ruminant housing is rather primitive, and is limited to open corrals. The corrals have mud walls or, more commonly, thorny bushes, to make safe enclosures to confine the flocks at night. This arrangement protects the animals from predators and also prevents them from wandering.

The existing production sytems will not be able to meet the increasing demand of mutton. Substantial improvements in the system using feedlots will have to be introduced. A crucial factor will be organised marketing. Establishment of large export-oriented feed lots is an encouraging development. Research particularly on the economic traits of different breeds of sheep and goats and their profitability in feedlots needs to be augmented together with a massive training program to man research and developmental activities.

Breeding-Management Practices

Breeding of small ruminants is not an organised activity. It is customary to allow bucks/rams in the flocks all the time throughout the year, resulting in kidding/lambing almost all year round. There are, however, peaks of breeding activity in autumn and spring causing subsequent corresponding peaks of births. The main breeding season is early autumn (September–October), followed by a lower breeding peak in spring, (March–April). Although sheep have a more defined breeding season compared to goats, there is a proportion of small ruminants that continue the cycle. Young lambs and kids are not weaned at a predetermined stage. Culling may generally be carried out at about six months of age. Some males may be selected for breeding on the basis of conformation and retained in the flock. All other males are disposed of, but all females are generally retained and no records are maintained. Surplus animals are either taken to nearby livestock markets for sale, or they are sold to traders who visit the villages regularly. Bucks/rams and does/ewes may usually be maintained even beyond their profitable age. Females breed for four or five kiddings/lambings, which means up to the age of about six years. Bucks/rams likewise are serviceable up to five to six years. There is a fairly high incidence of multiple births or a high twining rate in some breeds of goat.

Current Research and Development Activities for Small Ruminants

Concerning the world's foodstuffs, it has been asserted that the goal of continually increasing their yield potential must remain paramount (Borlaug 1994), and that increased productivity is the only way to ensure low food prices. This guarantees the food and income security of consumers, and underpins the entire economic growth process, while still generating profits for farmers. This concept holds largely true for the livestock sector, and more so for small ruminant raising, where increased animal productivity — and not the animal numbers — is the key to ensure food and income security for both the consumer and the farmer. To achieve this target, the following are the ongoing activities:

- selection of more prolific breeding animals based on performance records employing the Best Linear Unbiased Prediction procedures and production of genetically superior rams and bucks;
- distribution of superior rams/bucks among farmers to increase number of lambs weaned per ewes/does bred;
- monitoring and performance evaluation of registered flocks in two pilot areas in Swat (NWFP) and Okara (Punjab);
- development of a fine wool breed through crossing Rambouillet and Kaghani breeds;
- to avoid mortality and to ensure timely availability of vaccines, there are three veterinary research institutes actively engaged in the production of biologics;
- Asian Development Bank assisted Livestock Development Project is providing excellent extension services to farmers to enhance animal productivity through better health coverage and creating awareness among farmers of the need to use modern animal husbandry practices.

Priorities for future research and development of small ruminants

- Epidemiology of endoparasites of small ruminants and improvement in the diagnosis of parasitic diseases;
- investigation of causes of abortions in small ruminants and the role of different agents under Pakistani conditions;
- demonstration and application of multi-nutrient block technology and development of livestock feeds and feeding strategies for the various ecological zones in the country;
- introduction of feedlot systems for meat production, utilising growth promoters;
- establishment of open nucleus flocks of various breeds of small ruminants in the public and private sector to produce genetically superior rams/bucks to distribute to farms for genetic improvement;
- organisation of training courses for farmers, field staff and planners;
- field surveys should be organised at regular intervals to monitor productivity at the farm level;
- the private sector must be encouraged to participate in the production of vaccines and diagnostic kits to ensure availability.

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Opportunities for Increasing the Economic Contribution of Small Ruminants in Asia

C. Devendra[1]

Abstract

The potential for increasing the economic contribution of small ruminants in Asia is discussed in the context of their wide distribution across ecosystems, value as genetic resources, productivity, significance of ownership, economic relevance, production and post-production. Approximately 57% and 23% of the total world population of 574 million goats and 1138 million sheep respectively are found in Asia. India, China, Pakistan and Bangaladesh account for about 84% and China, India and Pakistan 72% of the total populations of goats and sheep respectively in Asia. They are concentrated mainly in rainfed semi-arid and arid, and sub-humid and humid lowland and upland areas in mixed farm situations, where about 83% of the total small ruminant populations can be found. The significance of ownership especially by poor people, is associated with several objectives to meet short-term socio-economic needs, security and survival in which these species enable diversification of resources to reduce risks, alleviation of poverty, promotion of linkages between system components, and stability of farm households. Data are given on the nature and extent of economic contribution. The strategy for increasing this contribution is associated with involving the rainfed lowland and upland areas, increased efficiency of use of the genetic resources, targetting the poor to address poverty, and wider use of improved technologies through community-based participation at the farm level to seek environmentally sustainable development.

GOATS and sheep maintain a particularly valuable economic and ecological niche in Asian agriculture. This importance is reflected in a bewildering variety of breeds, their degree of adaptation, wide and unique distribution across ecosystems, varied roles and contributions. In Asia, they are found high in the Himalayas, in the arid and semi-arid areas of Pakistan, India and Mongolia, as well as in the high rainfall, high humidity countries of Southeast Asia, including Indo-China.

Their economic contribution is especially significant to the poor and landless people throughout the developing countries. Associated with their wide distribution across ecosystems, they produce food, fibre and skins, make a significant contribution to human nutrition, total farm income, and the stability of farming systems.

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The purpose of this paper is to focus on the economic importance and contribution of small ruminants in Asia, examine opportunities for increasing productivity from priority agroecological zones and strategy for sustainable development in the future.

Small Ruminant Resources

Table 1 presents the size of the goat and sheep populations in Asia. The size of individual populations is considerable, with goats and sheep accounting for 56.5% and 22.6% of the total world population and 30.2% and 22.7% as percentage of total grazing ruminants (buffalo, cattle, goats and sheep) in Asia respectively. Some specific features within species are as follows:

Goats: The largest populations were found in India (35.2%), China (29.3%), Pakistan (12.0%), and Bangaladesh (7.8%). These countries together accounted for about 84% of the total population of goats in Asia. The ratio of sheep to goats is 1:1.3. The FAO Data

Bank for Global Animal Genetic Resources indicates that there exist 147 breeds.

Sheep: The largest populations are found in China (43.7%), India (17.8%), Pakistan (11.0%) and Mongolia (5.8%). China, India and Pakistan together accounted for about 72% of the total population of sheep in Asia. There exists an estimated 231 breeds of sheep.

Table 1. Goats and sheep populations in developing countries of Asia (FAO 1993).

Species	Population	As % of total world population	Annual rate of growth (1983–93, %)
Goats	334.1	56.5	3.3
Sheep	251.3	22.6	1.1

Although the number of sheep breeds is higher than that of goats, this is due to the many exotic breeds of sheep that have been used, including their crossbreeds, in Asia. In respect of goats, the number of breeds is a good reflection of the number of indigenous breeds present.

Corresponding to the relative population of goats and sheep, the volume of goat meat produced is higher than that of sheep. Current levels of goat meat, and mutton and lamb production are 64.0% and 22.6% of the total world output respectively. It is pertinent to note that all these meats produced are used for domestic consumption within countries and productivity of both species has not as yet become affected by regional trade.

Associated with the relative size of the goat and sheep populations is their distribution within the various ecosystems (lowland irrigated rainfed lowland, uplands and highlands) in Asia. Data on this aspect are limited, but Table 2 provides some useful information on the magnitude and relative concentrations of cattle and small ruminants in the rainfed lowland and upland areas. Between species, the small ruminant populations were higher than that of cattle. Additionally, the size of the individual populations was large, and accounted for as much as 96.8% and 83.0% of the total populations of cattle and small ruminants in Asia.

Table 2. Relative size of cattle and small ruminant (goat and sheep) populations in the lowland and upland areas of Asia (CGIAR Technical Advisory Committee 1992).

Ecoregion	Cattle	Small ruminants (goats and sheep)
Rainfed: arid and semi-arid tropics and sub-tropics	179	221
Rainfed humid/sub-humid tropics and sub-tropics	186	265
Total	365	486
As % of total population in Asia	96.8	83.0

Value of Small Ruminants

Goats and sheep are valued for a variety of important contributions. Thus, farmers raise them with several objectives to meet the socio-economic, cultural and recreational needs. Small size is especially significant as it relates directly to economic, managerial and biological advantages. This is associated in turn with the following benefits (Devendra 1980; Devendra and Burns 1983):

- income: important means of earning supplementary income;
- food: provide animal proteins (milk and meat) for the nutritional well-being of peasants and especially the undernourished;
- security: source of investment, security and stability;
- employment: creation of employment, including effective utilisation of unpaid family labour;
- fertiliser: contribution to crop production, and farm fertility through the return of dung and urine;
- by-product utilisation: they enable economic utilisation of non-marketable crop residues to generate value-added products, e.g. meat, fibre and skins;
- social values: ownership has been shown to increase cohesiveness in village activities and religious ceremonies;
- recreation: socio-economic impact of animal ownership also includes a recreational contribution to small farmers.

The various benefits together with their small size enable farming families to spread risks through diversification. These risks, especially environmental, are much greater in the more marginal and rangeland areas where rainfall and available feeds are sparse, typical of the arid and semi-arid tropics. Since both species are heavily concentrated in these same areas, their effective use here becomes especially important. Additionally, small ruminants in these marginal areas provide the main, if not the only, means of livelihood, combining economic and food security, nutrition and means of survival. In these circumstances the importance of both species especially to the very poor and landless peasants increases with decreasing quality of grazing and feed availability in harsh environments.

Sustainable Development

Considered in the context of their relevance to farming systems and varied contribution, small ruminants are very valuable to sustainable development (Devendra 1995). This recognition now places increased emphasis on the development of the wider importance of both species, with regard to the following components:

- diversification and efficient use of natural resources and reduction of socio-economic risks;
- promotion of linkages between system resource components (land, water and crops);
- alleviation of poverty;
- community-based participatory processes; and
- production to post-production and consumption systems.

Economic Contribution

It is appropriate to assess the nature and extent of the economic contribution of small ruminants. Table 3 summarises the situation specific case studies in a number of countries in Asia. The components of income generation are sale of animals for meat and breeding, milk and manure in decreasing order of importance. The magnitude of these individual component contributions from Table 3 were: sale of animals 27.2%–75.8%, milk 19.7%–84.8%, and manure 1.0%–4.5% of total farm income.

Attention is also drawn to the other aspects of the results in a number of the studies cited involving both rainfed lowland and upland areas in both semi-arid/arid and sub-humid/humid regions:

(i) For migratory herds in semi-arid areas involving the poorest farmers and the landless (Raut and Nadkarni 1974; Kumar et al. 1986; Deoghare and Bhattacharyya 1994), goats and sheep presently provide a most valuable source of income. In these studies, the sale of animals and milk provided between 27.2% and 84.8% of the total farm income.

Table 3. Economic contribution of small ruminants to total farm income in Asia.

No.	Animal product	Location	Result	Reference
1.	Goats and sheep	India	27.2–32.8%	Raut and Nadkarni (1974)
2.	Goats	India	Return per unit of rupee was higher[2]	Chauhan and Balishter (1983)
3.	Goats and sheep	Indonesia	17.1% — lowland 25.9% — rubber plantation 13.9% — upland	Knipscheer et al. (1983)
4.	Goats Milk Manure	India	75.8% 19.7% } of total income 4.5%	Kumar et al. (1986)
5.	Goats Milk Manure	India	13.4–30.0% 66.6–84.8% } of total income 1.0–3.4%	Singh and Ram (1987)
6.	Goats and manure	Pakistan	46.9% of total costs	Amir (1988)
7.	Goats	China	50–55% of total income	Devendra (1992)
8.	Goats	Indonesia	16.7–20.3%[3]	Devendra (1992)
9.	Goats and milk	Vietnam	58%	Devendra (1992)
10.	Goats and sheep	India	Goats were more remunerative than sheep	Oberoi et al. (1992)
11.	Goats Milk Manure	India	30.1% 68.9% } of total income 1.0%	Deoghare and Bhattacharyya (1993)
12.	Goats Milk Manure	India	43.1% 54.0% } of total income 2.9%	Deoghare and Sood (1994)
13.	Goats Skin	Pakistan	net profit shown	Iqubal et al. (1994)
14.	Goats Milk Manure	India	30.7% 67.8% } of total income 1.5%	Deoghare and Bhattacharyya (1994)

[1]As % of total cost of production in stationary and migratory herds.
[2]Compared to buffalo in studies on both marginal and landless farmers.
[3]Based on a farming systems study (1985–1991) in Batumarta, Indonesia, involving cash crops, rubber, cattle and also indigenous poultry.

(ii) In these same situations, raising goats is often the principal source of income, and often the main means of survival especially in harsh environments such as in Cholisthan in Pakistan and Rajasthan in India.

(iii) In the humid countries in Southeast Asia, goats and sheep also produce an important but evidently smaller level of income (Devendra 1992).

(iv) The one study in the lowland and upland areas in Indonesia (Knipscheer et al. 1983) is interesting in that it suggests a higher contribution from the upland areas (39.8%) compared to the lowlands (17.1%) by small ruminants to total farm income. This observation is consistent with the data in Table 2 concerning the high concentration of small ruminants in upland areas.

Post-Production Aspects

One aspect of the economic importance of small ruminants that is inadequately addressed in most countries concerns post-production. In animal production systems, it is especially important to link production with post-production systems in which there is organised collection, transportation and marketing to include products and by-products from them. These aspects are generally neglected throughout the developing countries resulting in:

(1) Reduced revenue to farmers. Observations in several countries in Asia suggest that farmers generally receive 55%–66% of the total value of the animal, the remaining 40%–45% going to middlemen and/or butchers whose total effort in terms of production process time is about one to two days.

(2) Reduced revenue from the sale of animals as well as their products. These involve the meat, skins, by-products and derivation of value-added products from skins. Recent studies in India indicate that goats transported for more than 400 km for 15–38 hours showed weight losses of 9%–10% which in quantitative terms is quite high. These data exclude losses also due to the effects on poorer quality products, by-products and also herd wastage (Naidu et al. 1991).

(3) The animals slaughted specifically for meat production are of doubtful quality. In several countries, animals from unknown background and production systems with no reference to consumer preferences are slaughtered at random. The majority of animals sold (70%–80%) are 1–2 years old.

(4) Where the demand for both meats and consumption is widespread, and organised programs are not in place, there is serious erosion of the breeding population in which increasingly younger animals are slaughtered. The net effect is reduced output of goat meat. Surveys in two states in India indicated that 50%–73% of the goats slaughtered were below six months of age, and 26%–50% were 6–12 months of age (Naidu et al. 1991).

The components in post-production systems that merit attention are:

- collection — methods of collection including transportation are important since these affect slaughter weight;
- handling — includes mode, duration and management during transportation;
- marketing — distinct outlets, organisation and their capacity;
- slaughter facilities — size, adequacy, hygiene, strategic location, and methods to salvage by-products;
- consumer requirements — nature, extent and characteristics. These need to be addressed in relation to changing trends (preferences, incomes and purchasing power).

Strategy for Development

Rainfed lowlands and uplands

Agricultural development in the past has overemphasised the use of the lowland irrigated areas and since arable land is scarce, attention now needs to shift to the rainfed, lowland and upland areas. The justification for this is linked to the magnitude and relative concentrations of small ruminants (goats and sheep) in these areas (Table 2). These sizeable populations depend exclusively on the available feed resources which result mainly from crop production. Lack of feed is the main constraint to production as well as the seasonality of production and drought periods of variable lengths which seriously hamper productivity. In many situations therefore, strategic supplementation to ensure optimum performance of animals is essential.

Since these rainfed lowlands and upland areas are fragile and also complex, research and development efforts will be more difficult, but holistic, multidisciplinary efforts are more than likely to provide major benefits, productivity and impact.

Small ruminant resources

Given the considerable genetic diversity in Asia, increased efficiency in the use of genetic resources is essential. In particular, much greater use can be made within species of several 'improver breeds' in a manner that is consistent with clear production objectives, better understanding of indigenous knowledge and traditional systems of management. It is equally important to ensure conservation of the more important germplasm.

Targetting the poor: poverty and the environment

The ownership of small ruminants by poor people and inadequate control of grazing is often identified with environmental degradation, which in the marginal areas is associated with a complex web of interactions between poverty, population dynamics, agricultural growth and survival. The latter is of no significance to poor people whose main objective is subsistence living and who perceive that inefficient use of natural resources and environmental degradation are unimportant if their immediate needs and short-term survival is assured. In common-property pastoral farming, farmers carry extra small ruminants as insurance against drought. This often leads to overgrazing. Development strategies must therefore target the poor as direct beneficiaries in which integrated natural resource use, inter-disciplinary and community-based participatory approaches are important.

Use of improved technologies

The use of research results and especially that of improved technologies are responsive approaches to overcoming existing constraints. Given the diversity of many important small ruminant breeds, the focus should be on addressing non-genetic factors such as improved nutrition which is especially critical. The approach should be aimed at achieving a balanced feed supply, balanced energy/protein ratios, and correcting any critical nutrient deficiencies with low-cost supplements. Increased use of leguminous forages can make a significant contribution to the nutrition of small ruminants.

Nutritional strategies

Feeding and nutrition represent the principal constraints to production and strategic intervention is a most important means of increasing the productivity of goats. The situation has recently been reviewed in depth (Leng and Devendra 1995) and involve the following approaches:

- intensifying the use of crop residues which include:
  - — improvement of potential digestibility;
  - — strategies to enhance rumen function;
  - — manipulating net rumen microbial growth;
  - — provision of by-pass nutrients;
  - — demonstration of profitable responses;
  - — ensure post-production facilities for efficient marketing.
- enhancement of the utilisation and digestability of straws through alkali treatment;
- strategic supplementation.

On-farm interventions and utilisation of research results

On-farm intervention and the utilisation of research results are overriding considerations and merit very high priority. An essential pre-requisite for this is detailed diagnosis of the dynamics of small farm systems that are sensitive to socio-economic issues. The components of this approach are:

- understanding of traditional systems;
- problem definition;
- formulation of appropriate interventions based on real rather that perceived needs; and
- integration of interventions into effective development policy.

Community-based participation

Greater community-based and also private sector participation is especially valuable in alleviating constraints to goat production. It includes creating greater access to agricultural services, inputs, credit and also more active decision-making and management of smallholding farmers' own affairs, including common property issues. An additional dimension associated with community-based participatory processes is the involvement of women. Considerable evidence and information clearly point to the fact that since women are closely associated with goat production, gender issues merit special attention in program formulation and implementation.

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Genetic Resources of Asian Small Ruminants

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Abstract

The Asia and Pacific region has some 36% of the world's goat breeds and 25% of sheep breeds, with a high proportion of these concentrated in China, India and Pakistan. The small ruminant breeds of tropical and subtropical Asia generally have evolved in extreme environments, and many are expected to have desirable genes and genotypes for disease and parasite resistance, and adaptation to climatic stress and low quality feedstuffs. There is now a clear recognition of the potential value of these indigenous breeds, particularly in the context of developing sustainable production systems, but knowledge of the productive capacity and adaptation of these breeds is at best rudimentary, and often completely lacking. As this is a global problem, UN Food and Agriculture Organisation (FAO) has as a priority activity a Global Strategy for the Management of Farm Animal Genetic Resources. The technical program of this strategy is outlined, with particular emphasis on the identification, documentation and characterisation of animal genetic resources. The better management and utilisation of these resources requires a new paradigm in the application of genetics, integrating quantitative and conservation genetics, and the crucial need for education and training in this area is emphasised.

CONTROL of the global human population growth rate is a major imperative facing humankind, but whether or when that is achieved, there remain the other major imperatives — feeding that population, conserving global biodiversity and achieving sustainable agriculture.

The Convention on Biological Diversity, now ratified by some 130 countries, specifically refers to agriculture, addressing the objectives as to conserve diversity, to use it in a sustainable manner, and to share benefits arising from the utilisation of genetic resources. While there has been a substantial recognition of the need for conservation of animal genetic resources over the past 25 years (promoted particularly by FAO, e.g., FAO 1984, 1992), the Convention on Biological Diversity has provided a catalyst for action. FAO has the technical responsibility for management of the global domestic animal genetic resources, and within the past few years it has established an Animal Genetic Resources Group that is actively developing a global program. In November 1995, an FAO conference of member governments made two major decisions in relation to animal genetic resources: (i) it provided an intergovernmental mechanism for animal genetic resources by broadening FAO's long-established Commission on Plant Genetic Resources to a Commission on Genetic Resources for Food and Agriculture; and (ii) it approved as a priority activity for FAO a Global Strategy for the Management of Farm Animal Genetic Resources. Most importantly, the Global Strategy is being designed to harmonise fully with the Convention on Biological Diversity.

The more than 40 species of domestic animals contribute directly and indirectly some 30–40% of the total value of food and agriculture production. This contribution will most likely rise with increasing development of sustainable plant-animal production systems, and increased demand for animal products in the developing world. Equally, the already high proportion of global animal production that is based on low-input systems will remain, or even increase. Thus increased production will depend on identifying, and improving, those breeds that are best suited to each such system.

Increased production through genetic means may be achieved by selection in some indigenous breeds, by crossbreeding between indigenous breeds, or by

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crossbreeding indigenous breeds with exotic breeds (if and where that is appropriate). This last option, in terms of crossing with exotic breeds from temperate regions, has been pursued far more often than it should have been, with many failures (Barker 1994), but importantly, there is now increasing recognition of the potential value of existing indigenous breeds. These breeds often show desirable traits and may carry desirable genes for specific physiological, behavioural, disease and parasite resistance traits, and for adaptation to climatic stress and low quality feedstuffs. Consequently, these breeds are more likely to be successful components of sustainable production systems.

What Genetic Resources are Available?

The global animal genetic resources almost certainly comprise some 4500 breeds, although the true number is not known. What is of immediate concern, however, is that many breeds have become extinct, and many more are at risk. The FAO Global Databank for Animal Genetic Resources currently contains 3882 breeds of 28 mammalian and avian species, with population size data available for 2924 of these breeds. Of those with population data, 873 or 30% are classified as at high risk of loss (FAO 1995). To illustrate, summary data for seven major mammalian species are given in Table 1. Development of this databank has been a major step towards increasing our knowledge of the global animal genetic resources. However, it is clear that the information is still incomplete — note that even basic population size data were available only for 2924 of the 3882 breeds that are listed (i.e. 75%). Even that

Table 1. Numbers of breeds of each of seven major species of domestic livestock that are recorded in the FAO Global Databank for Animal Genetic Resources, and the numbers estimated to be at risk.

Species	Numbers of breeds			Per cent at risk
	Recorded	With population size data	At risk*	
Ass	77	24	9	37.5
Buffalo	72	55	2	3.6
Cattle	787	582	135	23.2
Goat	351	267	44	16.5
Horse	384	277	120	43.3
Pig	353	265	69	26.0
Sheep	920	656	119	18.1
Total	2944	2126	498	23.4

*Estimated from breeds with available population data.

75% is surely an overestimate, as most of the breeds not yet identified and listed will be located in developing countries where breeds are poorly identified and population numbers are unlikely to be known.

It should be emphasised that in the broad context of the global animal genetic resources and the development of the FAO databank, the term "breed" is used to include strains and populations, the members of which are distinguished from other such groups in local, national or regional usage. Thus for example, the Databank includes the Katjang goat breed of Indonesia, Malaysia and Thailand as three separate breed entries, and similarly the Indo-Chinese goat breed of Laos, Cambodia and Vietnam as three separate breed entries. This is appropriate in terms of national breed definitions, but it must be recognised as a national definition. It says nothing about whether the three breeds in each case are genetically distinct. It is genetic differentiation (or lack of differentiation) that matters when utilisation and breed improvement is being considered. To illustrate, suppose that good experimental data were available showing that the Katjang in Java had high genetic resistance to helminth parasites. On this basis, it could not be stated categorically that the same would be true for the Katjang in Malaysia or Thailand, or even for that matter for the Katjang in Sulawesi. The separate populations have the same breed name, and in fact are phenotypically rather similar, but they may or may not be genetically different. This point is of fundamental importance, and will be dealt with later using recent results on the swamp buffalo populations of Southeast Asia.

The FAO Global Program for the Management of Farm Animal Genetic Resources

While the Convention on Biological Diversity recognises each country's sovereignty over its genetic resources, utilisation of those resources and the development of breeding programs for genetic improvement often will be more efficient on an international or regional basis. Even in planning a national program, it would be useful to have information on the same or similar breeds in other countries that might provide useful genetic material for the breeding program. That is, in the management and utilisation of animal genetic resources, countries are interdependent.

Thus FAO, which has the international mandate for improving agriculture and food production, with particular emphasis on developing countries, has established a Global Management Program. The program is country-based, with a coordinating institution in each country linked to a regional focus. Regional focal points are planned for Asia and the Pacific; Europe; the Americas and Caribbean; Africa; and the Near East and Mediterranean. The first of these, for Asia and the Pacific, has been established already in Bangkok. The whole program will be coordinated by FAO headquarters in Rome. However, it is the technical aspects of the program that are particularly relevant to the objectives of this workshop, in relation to determining priorities for small ruminant development.

This technical program comprises seven elements (Hammond and Leitch 1996):

i. Global information system for domestic animal diversity;
ii. Characterizing animal genetic diversity;
iii. In situ conservation;
iv. Ex situ conservation;
v. Global action plan and guidelines;
vi. International instrument — the Commission on Genetic Resources for Food and Agriculture;
vii. A global management entity (still to be established).

Managing animal genetic resources at the national, regional or global level necessitates knowing what these resources are, i.e. identification, documentation and charaterisation. The databank referred to earlier is part of the Global Information System (DAD-IS: Domestic Animal Diversity — Information System) that is being designed not just as a static store of data, but also as a continuously updated system that is readily accessible through the Internet. In addition to the breeds databank, the information system includes (or will include, as it is still under development) links to other specific genetic databases, a bibliography on animal genetic resources, education and training modules in animal conservation genetics, modules on experimental design and data analysis, and the database that will be developed as part of the second aspect of the technical program, i.e. characterising genetic diversity.

Ideally, the choice of breeds for selection programs would be based on objective evaluation. Unfortunately, scientists are not in this ideal situation, and data on productive performance, adaptive traits and specific traits such as parasite resistance are absent or inadequate for most breeds. While some breeds might be selected for detailed evaluation on the basis of currently available information, resources are limited, and it will not be possible to evaluate all breeds that might contribute to future breeding programs. The solution is to characterise the genetic diversity within and between breeds, and to determine the genetic relationships of the breeds. Detailed evaluation studies, or choice of breeds for further development, could then concentrate on those breeds that are genetically most distinct.

Thus FAO is planning a global research project to measure genetic distances among selected breeds (Barker et al. 1993). This project, the Global Project for the Measurement of Domestic Animal Genetic Diversity (Project MoDAD) will utilise microsatellite markers, and initially will analyse genetic variation in 14 species (Table 2). The methods derive from studies in evolutionary genetics, and have already been used in an ACIAR-funded analysis of Southeast Asian water buffalo populations (see below). Specific studies such as this, perhaps, for example, of Asian small ruminant breeds, will supplement the FAO Global Project and will be encouraged, although they need to be designed to be compatible with the Global Project, so that the results obtained can be incorporated into the MoDAD database.

Table 2. Species to be analysed initially in Project MoDAD.

Cattle[1]	Ass	Chicken
Sheep	Horse	Domestic goose
Goat	Camel[2]	Duck
Pig	Lamoid[3]	Turkey
Buffalo	Rabbit	

[1]Includes all Bos as well as, yak, banteng and mithan.
[2]Includes dromedary and bactrian.
[3]Includes llama, aipaca, guanaco and vicuna.

Characterisation of Genetic Diversity — Water Buffalo as an Example

The swamp buffalo populations of Southeast Asia are remarkable in their phenotypic similarity, and no specific breeds are recognised. Twelve swamp populations (from Thailand, Malaysia, Philippines, Indonesia and Australia), three populations of Lankan buffalo and two of Murrah breed river buffalo (from Sri Lanka and Malaysia) were analysed for 53 protein-coding loci, and a subset of 11 of these (eight swamp, one Lankan and the two Murrah) also were analysed for 21 microsatellite loci. The results, summarised as dendrograms of the relationships among the populations (Fig. 1) show that the Lankan buffalo clearly is river type, while the differences between the protein-coding and microsatellite based dendrograms can be interpreted as resulting from small founding populations reducing genetic diversity in the Australian population, and probably also in those of Sabah and

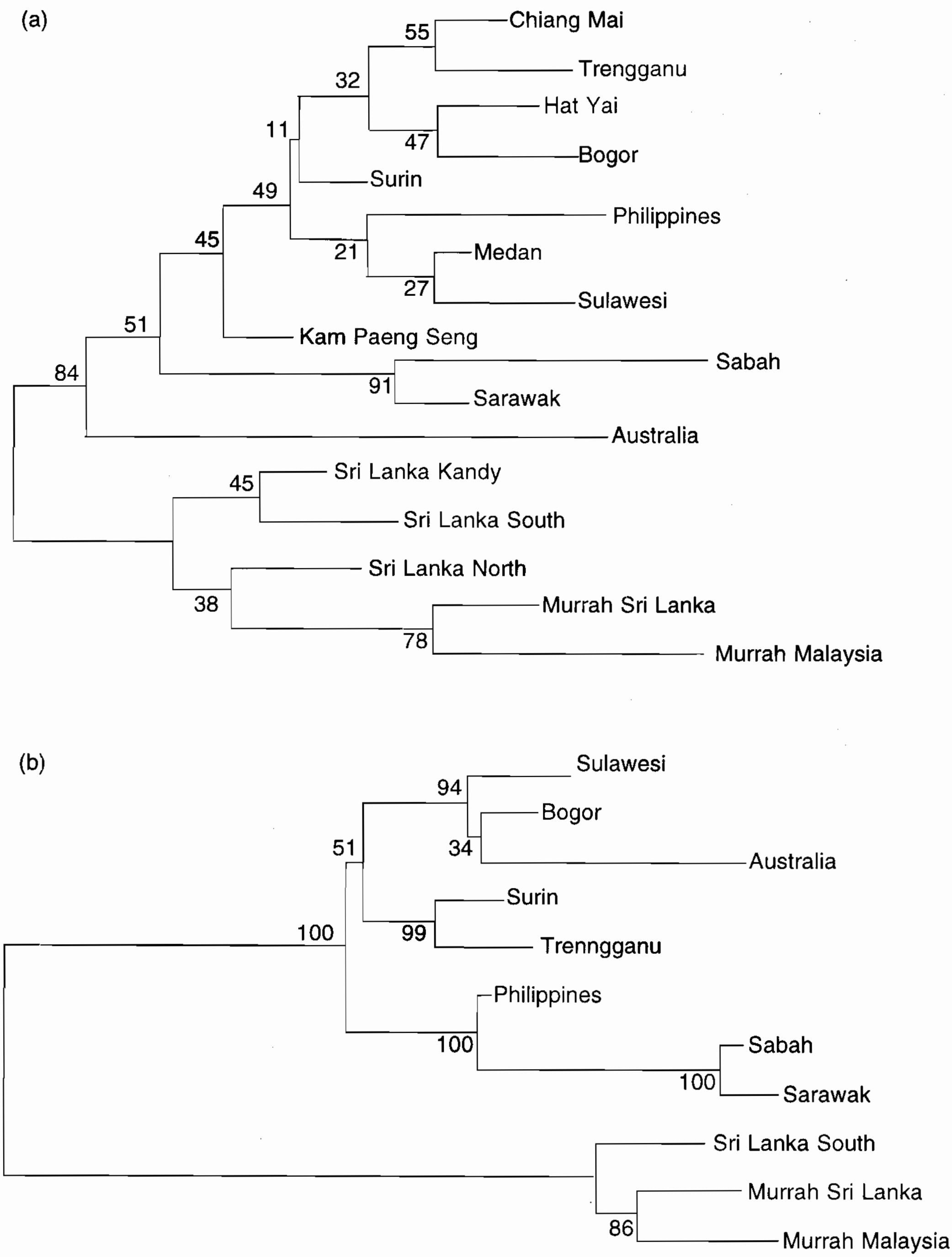

Figure 1. Dendrograms of relationships among southeast Asian water buffalo populations, derived from D_A genetic distances (Nei et al. 1983) and computed as neighbour-joining trees (Saitou and Nei 1987) — (a) using 53 protein-coding loci for 17 populations, and (b) using 21 microsatellite loci and a subset of 11 of these populations.

Sarawak. Thus the microsatellite based dendrogram gives a clearly superior picture of the relationships among these populations. Most importantly in view of the phenotypic similarity of the swamp populations, they are genetically quite distinct. The genetic differentiation of these populations is of the same order of magnitude as that among the well-recognised and long established breeds of cattle, goat, sheep and pigs in Europe (Barker et al. 1996a, b).

Asian Small Ruminant Resources

The numbers of sheep and goat breeds listed in the FAO databank, both total global and for the Asia and Pacific region, are given in Table 3. The Asia and Pacific region has 36% of all goat breeds and 25% of all sheep breeds, but with the major part of the breed diversity in very few countries (Table 4). Thus for goats, 66% of all breeds in the region are to be found in China, India and Pakistan. These three countries also account for 57% of the sheep breeds, with a further 36% in Australia, Iran, Mongolia and New Zealand. However, none of the breeds of either species in the Asia and Pacific region are recorded in the databank as showing resistance to internal parasites. Of course, this is not to say that none do show such resistance, and it may well be simply a reflection of how little is known about these small ruminant resources.

Table 3. Numbers of breeds of sheep and goats that are recorded in the FAO Global Databank, and the numbers in the Asia and Pacific region.

Species	Numbers of breeds			Per cent at risk
	Recorded	With population size data	At risk*	
Global				
Sheep	920	656	119	18.1
Goat	351	267	44	16.5
Asia & Pacific				
Sheep	226	155	15	9.7
Goat	126	96	6	6.3

*Estimated from breeds with available population data.

Education and Training

The lack of information on breed variation in parasite resistance for all sheep and goat breeds of Asia and the Pacific is just one illustration of general ignorance. Yet, as noted earlier, many of these indigenous breeds may carry desirable genes for various adaptive traits, and are likely to be successful components of sustainable production systems.

Table 4. Numbers of goat and sheep breeds in each country of the Asia and Pacific region (extracted from DAD-IS, April 1996).

Country	Goats	Sheep
Australia	2	31
Bangladesh	1	1
Cambodia	1	—
China	35	43
China-Taiwan	1	—
Fiji	4	—
India	28	66
Indonesia	3	3
Iran	8	26
Japan	3	—
Korea-South	1	—
Laos	1	—
Malaysia	1	1
Mongolia	4	19
Myanmar	2	1
Nepal	5	6
New Zealand	5	18
Pakistan	33	41
Papua New Guinea	—	1
Philippines	2	1
Sri Lanka	2	3
Thailand	2	—
Vietnam	2	1
Totals	146	261

Increasing animal production by genetic improvement traditionally has meant the application of quantitative genetic principles. Clearly the focus now has to be broadened to include conservation genetics, if scientists are to meet the objective of managing animal genetic resources in terms of better understanding, developing, using and maintaining their biodiversity. Consequently, the coming generations of animal scientists need to be aware of the significance of animal genetic resources and trained in this new paradigm of conservation/quantitative genetics. The nature of this university education and topics/curricula that should be considered have been discussed by Malmfors et al. (1994) and Vangen and Mukherjee (1994).

Educating the coming generations to ensure future management and utilisation obviously is crucial, but the need for appropriate action is urgent, and training of the present generation of animal breeders and animal scientists is equally important. Given the limited resources that are available in any one country, such training must be based on a regional co-operative approach, and should involve the International Livestock Research Institute (ILRI) as part of their activities in Asia. Organisation of this training at just one centre will be most efficient, and will have the added advantage of bringing together the geneticists, breeders and administrators from different countries, thus facilitating their subsequent collaboration and the integration of regional endeavours.

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Rationale and Means of Government Intervention in Small Ruminant Development through Health Improvements

E. Fleming[1] and I. Patrick[2]

SMALL ruminants have important social and economic roles in village communities in some countries. They are a form of asset and a status symbol as well as being an important source of protein and income. Compared with large ruminants they have the ability to produce more rapidly and, being of a lower asset value, a loss through disease or poor nutrition is easier to handle in an economic sense than is the loss of a larger animal. Improving the health and profitability of small ruminants has a significant influence on the welfare of smallholders in developing countries.

The purpose of this paper is to review the main reasons for government intervention to improve animal health for small ruminant development in developing Asian and Pacific countries. An evaluation is made of the various measures that governments could select in this intervention. Illustrative examples are mainly based on small ruminants in Asia, particularly from research results reported in these Proceedings, work undertaken in an AusAID project—the Eastern Islands Veterinary Services Project (EIVSP)—and various ACIAR projects.

Reasons for Government Intervention

There are two main reasons for government intervention to improve the health of small ruminants. The first is the government's duty and desire to alleviate poverty, and the second is to overcome market failure (without introducing government failure). In developing countries, especially in semi-arid and arid regions where livestock are an important source of working capital, failure of livestock markets exists in the form of incomplete markets, imperfect information, externalities and 'public good' characteristics (that is, goods which exhibit non-rivalry in their consumption and have benefits from which others cannot be excluded nor rejected by others).

The following discussion begins with poverty alleviation. Market failure arguments are then classified into eight issues which may justify government intervention to support small ruminant development through animal health improvements. Each of these reasons is now explained, with some illustrative examples.

Poverty alleviation

The alleviation of poverty is a goal of all governments. For this to be attained it is clear that the development process must start in the sector that employs between 40% and 80% of the labour force and provides between 30% and 50% of national income.

A more sustainable, self-reliant agricultural sector producing a marketable surplus will promote employment in all sectors of the economy, increasing demand for household goods which predominantly subsistence producers could not otherwise afford. Improvements in welfare in the agricultural sector would increase the demand in rural areas for marketing, transport and other service industries as well as arresting rural-urban migration. In the longer term, a decline in the rate of population growth would be expected as wealthier, healthier producers require less children as farm labour and as a form of superannuation. In Indonesia between 1970 and 1987, rapid technological change in agriculture was accompanied by a surge in rural employment and a decline in poverty by 41%.

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The role of small ruminants, in particular, is extremely important in this process of poverty alleviation. Subsistence farmers usually live in dry areas where the opportunities for cropping are limited; therefore, there is greater dependence on livestock in the farming system. In the driest area of Indonesia, Nusa Tenggara Timor (NTT), approximately 70% of the population is defined as below the absolute poverty line as opposed to a national average of 29% (Kameo 1995). While cattle have a role to play in terms of long-term sustainability and use as collateral, small ruminants such as goats can play an important role in both the short and long term through their ability to reproduce quickly and survive in tough conditions. With correct management practices and infrastructural support, they help farmers produce a marketable surplus and break the poverty cycle. Livestock are commonly the only 'cash crop' that smallholders have; without them, they have little access to the cash needed to buy agricultural inputs that will raise crop yields (ILCA 1992). Correct health management, which includes disease monitoring and control, is required to ensure this process occurs.

An ability to take advantage of the means of animal health improvements usually requires livestock producers to purchase some veterinary inputs in which disease control technologies are embodied. Yet subsistence producers typically find it difficult to obtain cash to make these purchases. Also, they are more adversely affected by the risks associated with the effects of diseases and the vagaries of disease control measures, and have less knowledge of, and more restricted access to, information about diseases and control measures. In other words, subsistence producers suffer more severely than other producers from the various forms of market failure outlined in the following sections.

External costs of disease in animals

A compelling reason for government intervention to improve the health of small ruminants by remedying market failure is to reduce the external costs of disease and disease control measures. External costs of disease in small ruminants are the costs incurred by others as a result of the disease which do not have to be met by the owners of the animals through normal market mechanisms. Furthermore, it does not pay those people incurring the costs to undertake control measures, as they would only be able to appropriate a minuscule portion of the benefits of control. (Although control measures would be in the form of a public good, Johnston (1975b) correctly refers to disease control as intermediate between a private and public good in the sense that there are both public and private benefits to be shared from control measures. However, the implications for government intervention for public good reasons are the same.)

A government may overcome this problem of non-appropriability of benefits by 'internalising the externality', which means making the owners of the animals bear the costs they impose on others by permitting the disease to persist in their animals, or using public funds to undertake control measures on behalf of all livestock producers and other potential victims of the spread of disease. Two categories of external costs are discussed below.

Externalities between producers

External costs can be imposed by one livestock producer on other livestock producers through the spread of infectious diseases which lower animal productivity on a number of farms (Johnston 1975a). The farmer responsible for allowing such a disease to spread does not have to pay the cost of its effect on livestock profitability on other farms. Because control of such diseases is largely a public good, it does not pay the individual producers—or even local authorities (Winrock International 1983)—to undertake their own control measures because they cannot appropriate anywhere near the full benefits of such measures. (Another type of externality occurs in international trade where external costs are incurred through the closure of an export market due to contaminants residing in exported products from one or a small number of exporters. This situation tends to be rare in developing Asian and Pacific countries where exports of ruminant products are minor.)

Although it is useful for individual producers to attempt to control parasites such as *Haemonchus* spp and flukes (liver and stomach), long-term control and efficient use of chemical treatments depend on the participation of all producers. These parasites can be spread by either intensive grazing or cutting feed from infected areas and hand feeding. Control requires treatment programs plus improved management of stock and pasture. For the individual producer to capture the full benefits of parasite control, the entire community must be involved in the program.

The costs of emergent disease control resistance often have to be met not by the current generation of livestock producers but by future generations. Munro and Adams (1991) highlight the potential need for genetic diversity in animal production systems in future generations to counter environmental changes such as the reduced effectiveness of chemotherapeutics in controlling parasites.

Environmental degradation

The implementation of control measures for animal diseases can result in environmental degradation, the costs of which must be met by all members of society. Continuing high use of chemical controls by individuals may lead to a more rapid resistance to useful treatments as well as having only direct negative effects on environmental quality.

Government programs to ensure correct and efficient use of chemicals within a farming system can lead to a lower quantity of chemicals used and, through the development of integrated pest management systems (such as 'Wormkill' in Australia), a lessened chance of parasite resistance.

Decreases in livestock mortality and morbidity rates will also mean that less stock will be required by individual producers to maintain their present standards of living. This might or might not have a positive effect on the environment. On the positive side, stocking rates might decrease because less stock are required to produce the same level of output. This would benefit the existing pasture country through less grazing pressure and reduce the pressure for land clearing for grazing country. It would, in turn, lead to less intensive grazing and hence a reduced chance of disease and parasite epidemics.

On the other hand, higher productivity and profitability might be an inducement to livestock producers to expand livestock activities and intensify grazing activity, leading to worse environmental pressure than previously as smallholders increase adult stock numbers and produce a greater marketable surplus. Any small ruminant program must take into account both the potential benefits and costs to the environment of an improvement in animal health.

Information deficiencies for decision-making on animal health

Lack of knowledge of the presence and impact of animal health problems is acknowledged as one of the greatest obstacles to animal health improvements among ruminants (e.g., Johnston 1975a). Information deficiencies retard progress in animal health by causing sub-optimal decision-making by both livestock producers and public institutions with responsibility for the development of ruminant production systems. They mainly occur in the following four areas.

The incidence of disease and extent of its damage

Producers and government decision-makers often have imperfect knowledge of the incidence of disease and the extent of its damage. Lack of epidemiological data is a major stumbling block to the formulation of effective animal health programs. The data are difficult to obtain for two reasons. Firstly, many farmers do not report livestock deaths and in many cases dispose of a sick animal or consume it before it dies of disease. This has occurred with anthrax outbreaks in Indonesia, when local smallholders have killed and consumed contaminated cattle rather than letting them die. It is difficult for a smallholder, with only one or two breeding cows, to let an asset disappear without receiving any benefit at all.

Secondly, even if farmers were prepared and able to report disease outbreak and animal health problems, in many cases the disease reporting infrastructure is still rudimentary in many countries. This, plus a lack of skilled and equipped veterinarians in these areas, leads to an inability to build information databases concerning the extent of animal health problems and the most efficient means of their control.

The benefits of disease control measures

Livestock producers have lived with disease for generations; to a certain extent their farming structure has built poor productivity into an existing farming system. An example of this is in West Timor where in some areas as many as 80% of cows are affected by brucellosis, rendering them infertile. These cows are not disposed of but maintained because they are still a useful asset. Any introduction of disease control programs must take into account farmers' perceptions and uses of livestock, and be accompanied by an intensive extension component to ensure disease control does fit within the farming system.

Appropriate levels of disease control

There is a choice not only between alternative diseases to control but also, within a disease, between levels of control. Once again, lack of data makes this choice difficult. Brucellosis control in West Timor is again a useful example. If brucellosis is defined as a significant animal health issue, how should it be controlled? There are a few options, the main two being a test-and-slaughter campaign and a vaccination campaign. The suitability of each depends on the incidence of the disease, the understanding of cattle movements within the entire region, cultural sensitivities and cost. A test-and-slaughter campaign has been undertaken in South Sulawesi, with many problems encountered including payment of compensation, incorrect testing and cattle identification problems. Vaccination programs have been undertaken in West Timor for a number of years with greater success but with many management problems. While experiences from more developed countries, such as Australia, have been useful, local issues still influence success rates.

Lack of data makes it difficult for governments to allocate scarce resources efficiently between various animal health projects. Decisions on funding are seldom influenced by economic efficiency alone; there is often greater sensitivity to political and social considerations. Pressure to pay more attention to efficiency concerns can be enhanced by greater transparency in public decision-making when choosing between animal health options. Such transparency rests on the wide availability of information on animal health problems and solutions.

Interactions between environmental effects and the impacts of, and resistance to, diseases

Lack of knowledge concerning the epidemiology and biology of animal health problems in developing countries is often accompanied by a lack of understanding of the farming and social systems within which potential programs are to be implemented. Any program introduced must be sustainable economically, environmentally and socially.

Decisions made by governments which influence small ruminant production systems through policy-making and the implementation of animal health projects can be ill-informed through lack of information about environmental influences on animal health status in particular. One example concerns the difficulty in getting accurate information about resistance to disease among small ruminants which 'is not expressed on a continuous scale ... disease resistance traits may be difficult and costly to measure' (Raadsma 1995).

Gaps in animal health technology available to producers

There is a substantial gap in knowledge of techniques to counter animal health problems between Asian and Pacific small ruminant production systems and similar systems elsewhere in the world, witnessed by the efforts to boost in-country research capability and activity (Gray et al. 1995). The accumulation of technology through adaptive research in the former systems would proceed at too slow a pace if left to private individuals to fund and carry out that research work.

In eastern Indonesia, an example of a semi-arid tropical environment, there is a lack of research data concerning the control of both internal and external parasites in small ruminants. While it is known that *Haemonchus* spp are highly fecund and can rapidly contaminate grazing areas, there is not much information available on the biology of the parasite. With regard to paramphistomes, no useful anthelmintics are currently available in Indonesia, nor is there sufficient information to develop strategic control programs.

Research work in Australia and New Zealand on resistance by parasites to anthelmintics and breeding for resistance and resilience to infectious diseases in sheep (Morris et al. 1995; Woolaston and Eady 1995) is an example of a research area where one country can provide knowledge through applied research in small ruminants which could be usefully applied in Asian and Pacific countries.

Economies of size in disease control

Effective control of animal disease typically demands (a) infrastructure, such as laboratories; (b) a skilled corps of professionals to monitor the health status of animals, drug efficacy and anthelmintic resistance,[1] and to undertake inspections and assays (see, for example, Le Jambre, these Proceedings) and to operate testing regimes; and (c) an ability to perform these functions in a timely fashion. The need for a critical mass of resources close to the livestock systems means there can be economies of size in disease control which are unlikely to be funded by private individuals. These economies can be best exploited through public institutions, such as regional veterinary institutions.

The Government of Indonesia has made it a priority to ensure a fully functioning animal health system throughout the eastern islands. It understands that if it intends to improve the welfare of smallholders in this semi-arid region by encouraging livestock production, a well-equipped and trained workforce within a supporting infrastructure is required which allows the efficient and timely transfer of material and data from the farm level to the national level and back again. While intending to introduce a fee for service when farmers can afford it, the Government realises that, without government assistance, these farmers would not be able to set up a diagnostic service for themselves and hence would undertake a socially unacceptable level of disease control.

[1] Government intervention to evaluate the efficacy of anthelmintics is justified by the dynamics of resistance among small ruminant species and breeds within a species, and according to location and circumstances. It is virtually impossible to rely on efficacy monitoring by the manufacturers or suppliers of the drugs.

Differences in risk attitudes between private and public decision-makers

A majority of livestock producers in less-developed countries are smallholders (that is, a maximum of four breeding cows and/or 10 breeding does). These farmers, many of whom are below the poverty line, are in no position to invest scarce financial resources in what they may regard as a risky venture — if cash reserves are invested in treating a livestock disease there can be no guarantee that the animal will survive. The farmer may consider it a less risky option to save the reserves for other less risky options.

The implication here is that small livestock producers are likely to be more risk averse than the government in investing in animal health improvements. Benefits derived from such investment are likely to be highly uncertain (for example, Woolaston, these Proceedings). Consequently, livestock producers might be less willing than the government to invest, resulting in a social under-investment in these improvements.

Differences in time preference rates between private and public decision-makers

Small livestock producers are likely to have a higher discount rate when making private investments than the government would use in making public investments. That is, they discount future cash flows more heavily. Given an often substantial lag between an investment in animal health improvements, or breeding for host resistance to parasites, and the benefits which flow from that investment, a higher private discount rate might lead to a level of investment that is less than socially desirable.

Any farmer below the poverty line is thinking of the short term: feeding family members today is the highest priority. A reliance on farmer investment in animal health must wait until smallholders are able to change their emphasis from survival to profit-making. A problem with livestock distribution programs in developing countries which aim to improve the welfare of the 'poorest of the poor' is that, because these producers are not able to think long-term, they sell their asset when they have completed their responsibilities to the respective projects because they need the cash today. This is despite strong evidence of long-run gains by building up to a viable herd size before selling surplus animals (Patrick 1995).

Any program which aims to improve the long-term welfare of predominantly subsistence producers must overcome, through incentives and education, this difference in time preference between the farmers and the government.

Distortions in markets for animal health inputs

Government policies which inflate prices of animal health inputs can discourage their use and lead to higher levels of animal diseases than is socially desirable. Tariffs and import quotas on imported animal health inputs, or major components of these inputs, raise prices to small ruminant producers and reduce quantities applied by them.

Distortions in markets for animal products

Distortions in the market prices of animal products can influence decisions to invest in animal health inputs and undertake animal health control activities through their effects on the returns to these investments and activities. Also, market prices do not always reflect accurately the value of animals to households as small ruminant producers do not maintain livestock purely for economic reasons. Other factors already mentioned such as status, collateral value, use for ploughing and manure may well be more important than livestock productivity and profitability, and lead to a less than optimal allocation of resources in animal health.

Forms of Intervention

Forms of intervention by a government to improve the health of small ruminants would obviously depend on the nature of market failure which prompts that intervention. Eight main (not mutually exclusive) options exist, listed below with subjective rankings of potential effectiveness from [5] (most effective) to [1] (least effective) in the context of developing Asian and Pacific nations:

- research, notably into breeding for resistance and improved use of parasite control inputs, and to improve understanding of the flock-pasture system [4–5];
- extension of knowledge of the technical aspects of animal health and flock and pasture management [4–5];
- modifying animal health input prices, through animal health projects, subsidised prices of animal health inputs and removal of distortions in markets for animal health inputs [2–5];
- education and training [3–4];
- regulation [1–4];
- output incentives [1–4];
- modifying property rights [1–2];
- disease loss insurance [1].

Research

Research into animal health tackles a wide range of causes of under-investment in animal health activities in small ruminant industries. It is primarily aimed at overcoming gaps in animal health technology, but can also contribute significantly to improved information to private and public decision-makers on health improvements, internalising some of the external costs of disease, exploitation of size economies in animal health activities, overcoming divergences in risk and time preference rates between private and public decision-makers, improved regulatory interventions by governments, limiting external costs imposed on future generations of livestock producers, and dealing to some extent with equity concerns.

Despite the fact that public research is considered a necessary condition for health improvements in small ruminants, it not given an exclusive rank of [5] for effectiveness for three main reasons. Firstly, various types of research—notably, into improved parasite control technologies—can result in benefits largely appropriable by private drug manufacturers and suppliers. A prima facie case needs to be established that the private sector is unwilling and/or unable to undertake the applied and adaptive research necessary to improve control measures. Then, it needs to be established whether the appropriate form of government intervention is sole or cooperative research work, or whether another form of intervention (for example, regulation) is preferable. Secondly, the impact of research work depends on the presence of incentives to producers in the recommendation domain to take advantage of the better knowledge of the health of their animals and how they can improve it. Extension and other forms of disseminating information help to transform research output into improved livestock husbandry practices. Thirdly, national research capacity is crucial to successful control of disease through the use of improved technologies. Adequate capacity is not guaranteed, and depends heavily on other forms of government intervention such as recurrent funding, infrastructure, and education and training.

Three forms of public research into animal health are briefly noted below, with emphasis placed on parasite control in small ruminants in Asia.

Breeding for host resistance and resilience, and lower control costs

Gray et al. (1995) provide numerous examples of the potential gains and issues involved in breeding for resistance and resilience to infectious diseases, or lower control costs, in small ruminants. Further examples are provided by Woolaston and Barker in these Proceedings. Breeding programs, especially when combined with research into effective biological control treatments, can reduce the external costs of parasite resistance to drugs imposed on future generations of producers, by lessening reliance on costly anthelmintics and other drugs, and on current and future generations, by enabling the sale of chemical-free animal products.

Research into improved use of parasite control inputs

Research is needed into the improved use of parasite control inputs to account for the multiple factors influencing resistance and resilience to disease (O'Meara and Raadsma 1995), where gaps exist in private sector research activities. An example of this research is a study which examined the role of ivermectin in controlling scabies in goats in Lombok (West Nusa Tenggara). There was both a decrease in the clinical signs and a removal of the mites as indicated by scrapings. There was also a positive effect on body weights of treated animals. Other work is being done in Nusa Tenggara to control *fascioliasis*, *trypanosoma* (surra) and *thelazia* (eye worm). Examples of innovative approaches to parasite control in small ruminants which extend the effective life of existing control measures are provided by Knox, Le Jambre and Waller in these Proceedings.

Research into livestock systems

Research into livestock systems can be especially useful in understanding the flock-pasture system, and appreciating the incidence of parasites and role of parasite control in that system. Barger (these Proceedings) reviews grazing strategies to improve the effectiveness of anthelmintics in small ruminants.

Control of parasite diseases needs to be integrated into the livestock production system (Barker, these Proceedings), requiring research into environmental factors closely identified with specific parasite control measures. Environmental changes, or their avoidance, offer an indirect and useful means of reducing the impact of disease on small ruminant productivity, but depend heavily for their effectiveness on research, extension and the presence of incentives to producers to change existing practices. Research into improved nutrition (e.g., Gray 1995; Petch 1995; Sanyal, these Proceedings), improved housing and reduced social stress (e.g., Munro and Adams 1991; Saithanoo, these Proceedings) and the introduction of evasive grazing strategies exemplify beneficial environmental changes. Separate examples of evasive grazing strategies using rotational grazing to control helminthiasis are provided in these Proceedings by Sani, Saithanoo and Barger, although rotational grazing has proved impracticable in some circumstances, such as in rubber plantations in

Sumatra (Gatenby et al. 1995) and under communal grazing conditions (Alam, these Proceedings; Ducusin and Faylon, these Proceedings). Research into the maintenance of genetic diversity (Munro and Adams 1991) is an example of the avoidance of an adverse environmental change.

Farming systems research is being undertaken in Nusa Tenggara to consider the role of management in parasite prevalence rates. Sanyal (these Proceedings) stresses the key role of government in funding interdisciplinary research of this nature into sustainable control of gastrointestinal parasites in small ruminants in India. The Cattle Health and Productivity Survey has provided a source of information on livestock-based farming systems in Indonesia which is being used as a basis for developing *thelazia* and fluke control programs (Patrick 1995).

The research work by Waller (these Proceedings) exemplifies the advantages of not focusing parasite control measures exclusively on the host animal. He discusses research into biological control agents that operate largely outside the animal in the parasite cycle.

Extension and dissemination of information

Extension

Extension is not given an effectiveness rank of [5] because it depends on the presence of two other factors, in particular, to be totally effective: incentives to producers in the recommendation domain to take advice on how to improve the health of their animals; and research output in a form relevant to, and readily understood by, these producers. The successful extension of advice on technical aspects of animal health to small ruminant producers depends on the generation of knowledge and techniques through the research process.

Given the importance of providing inducements to producers to adopt health-improving activities and technologies, disease control needs to be studied in the context of the overall 'flock-pasture system' (Gray 1995). This entails extension work to introduce desirable environmental changes and prevent environmental degradation, mentioned in the previous section. A study of the economics of animal health inputs and activities, and their effect on whole-farm profitability, is central to the success of any extension work.

Dissemination of information

Governments can intervene to generate information flow which is not attractive to the private sector because of its public good nature. There are commonly large gaps in the availability of information about diseases and their control between countries and within a country—across regions and between researchers, extension agents and farmers. Efficient transmission and processing of information can bridge these gaps, and improve information available to both farmers and public decision-makers concerned with animal health on matters such as the incidence and extent of diseases, expected benefits of disease control measures, and appropriate levels of disease control.

There is a legitimate role for governments in creating and/or strengthening linkages which enhance this transmission of accurate, pertinent and timely information. Two such linkages warrant special attention: (a) between international researchers and domestic researchers; and (b) research-extension-farmer linkages. The value of the former is in processing information available through networks such as FAO's information system for identifying, documenting and characterising animal genetic resources (Barker, these Proceedings).

Modifying animal health input prices

Animal health projects

The implementation of animal health projects based on small ruminant systems can offer opportunities to producers to obtain veterinary inputs below market prices. Such projects provide a useful way of introducing producers to health management practices which they might otherwise reject because of unfamiliarity with the benefits that can be gained from usage of purchased inputs integral to these practices. As projects have a specific completion date, there is a time limit to the availability of the cheaper inputs. Their success depends on more accurate targeting of those producers whose practices it is desirable to change, leading to a sustainable and more profitable farming system at normal market prices.

Use of animal health projects also provides the opportunity for governments to redress three other shortcomings in animal health activities. Firstly, a shadow price can be placed on the discount rate used in project selection, to adjust for differences between private and social time preference rates. Secondly, governments can assume within projects some of the risks associated with disease control measures that are faced by individual livestock producers, thereby overcoming the problem of differences in risk attitudes between private and public decision makers. Finally, projects offer governments an opportunity to direct animal health assistance to those producers who are most in need of help.

Subsidised prices of animal health inputs

The subsidisation of the prices of animal health inputs is a more general means of encouraging their use, thereby providing incentives to better animal health care by producers. It is likely to be especially useful for subsistence livestock producers who otherwise would not be able to afford these inputs, or where there are good social reasons to discriminate between alternative means of disease control. Its disadvantages are its distortionary effects and probable unsustainability in the long term.

Subsidies for slaughter of diseased animals

Where the best solution for controlling disease in small ruminants lies in their slaughter, the provision of a subsidy to cover the cost of slaughtering animals — and their replacement value — may be an appropriate way of compensating producers and encouraging them to participate in the slaughter program. This approach is likely to be most effective where, as noted above, farmers kill and consume contaminated cattle rather than let them die because they cannot afford to lose such an asset with no financial benefit.

Removal of distortions in markets for animal health inputs

Where existing government policies inflate prices of animal health inputs, discouraging their use and leading to higher levels of animal diseases, their removal can bring about small ruminant development through animal health improvements.

Education and training

Education and training in animal health are public goods that are needed at various levels (e.g., tertiary education for present and future generations of scientists and policy-makers, and technical training for research technicians, extension personnel and farmers) and in various forms (e.g., on-the-job training, short courses and formal qualifications). They offer social benefits that occur with a better educated and trained work force through investments that are not attractive to the private sector. A large part of these benefits come by improving animal health through enhanced research and extension processes in, among other things, breeding, disease control and nutrition.

Regulation

Government regulation to prevent the incidence or spread of infectious animal diseases, or adverse consequences of their control, is aimed primarily at reducing external costs. Quarantine is perhaps the best known example of a successful type of disease regulation. Regulatory monitoring of point-of-sale drug quality can also be justified by the difficulties individual producers face in checking that the contents conform to the designation on drug product labels. Licensing of health input suppliers is an alternative approach to ensuring drug quality.

As a form of government intervention, regulation works best when there is effective enforcement and the imperative to prevent some occurrence is very strong—conditions that normally apply with quarantine. Otherwise, efforts to regulate behaviour have not had a particularly good track record, usually because of scarce public resources, poor public knowledge of the situation and circumstances in which regulation is to be introduced, and lack of public commitment to effective enforcement. Also, coercion is not a good means of influencing the behaviour of a large number of small farmers whose actions the government finds difficult to control. While achieving temporary changes in producer behaviour, it is very difficult to sustain these changes in the long term as coercion requires continuous enforcement.

Even where regulation is not employed as a means of achieving public goals in disease control in small ruminant production, a sound regulatory framework is essential to the operation of any market-based inducements for producers to improve animal health.

Output incentives

Output subsidies

Higher output prices can encourage greater usage of animal health inputs through their derived demand effect. As a measure to improve animal health, however, output subsidies which raise prices to producers tend to be weak (especially where livestock production is largely for subsistence purposes), are difficult to sustain in the long term, and can have distortionary effects on the livestock economy. A preferred (that is, less distortionary and more sustainable) way of raising farm-level animal product prices is to improve the livestock product marketing system. One such means is the public provision of marketing infrastructure (transport, communications and the like) which reduces marketing costs.

Output subsidies can also be used to discriminate between outputs from farms with different disease status, to offset the divergences between private and social costs of disease control due to externalities and information deficiencies (Johnston 1975a). Such a measure would be administratively difficult to operate, however, and unlikely to be effective unless there are genuine differences in demand for products, according to the disease status of the animals, which are not currently being reflected in market prices.

Whole-farm support

An alternative, and probably more effective, means of providing output incentives which lead to better animal husbandry by smallholders and landless livestock owners is the provision of whole-farm support that is de-linked from product prices, and so avoids many of the market distortions associated with direct price support. The aim is to encourage these producers to consider the longer-term benefits of a larger, healthier flock or herd. If they need to sell stock in order to purchase crop inputs or pay for education, the government could provide credit facilities or cash grants that would take the pressure off the use of stock for carry-on finance. If they were required to work off-farm in order to provide food for the family, the government may be able to provide food rations in order to encourage them to remain on the farm and look after the stock.

If there were no reason in the short term to sell stock and every opportunity to provide improved livestock management, the subsistence producer would be able to afford the time to breed up a productive and viable flock or herd. If each producer had a viable number of livestock which were able to self-replace and provide a marketable surplus, he or she would be in a better position to improve animal health and undertake sound husbandry practices, either individually or as part of a program.

Modifying property rights

The modification of property rights in small ruminants to improve animal health is a measure aimed at internalising the external costs of disease. Governments can intervene in livestock markets through the assignment of property rights to animals which are disease-free, reflected in higher market prices for such animals. The role of the government is to provide, or encourage the provision of, facilities which enable producers to certify in the market-place that their animals are free of specified diseases. The difficulty here is ensuring that the market differentiates efficiently between disease-free and diseased stock. Also, it does not overcome the non-appropriation problem associated with externalities (Johnston 1975a). Overall, assigning property rights is likely to be an impractical solution to health problems in small ruminants in Asian and Pacific countries.

Disease loss insurance

Johnston (1975a) provides a good assessment of the likely success of providing disease loss insurance as a means of cattle tick control in Australia. Its principal purpose is to overcome some of the riskiness associated with disease control measures. Johnston highlights the difficulties of identification and valuation, and of verifying damage claims, in establishing such insurance schemes. Their practicality in developing Asian and Pacific countries is highly dubious.

Conclusion

Ali and Byerlee (1991), Alauddin et al. (1993), Patrick (1995) and others have shown that livestock smallholders in developing countries have considerable potential to increase productivity through technically more efficient use of resources currently used in livestock systems. A major part of this potential lies in improving the health of their livestock through better husbandry and management practices. In the past, market failure has combined with poverty and inappropriate forms of government intervention to set obstacles to the realisation of this potential; yet governments do have an important role to play in removing these obstacles in the future.

Successful intervention by a government to improve animal health for small ruminant development depends crucially on its ability to identify, value (in terms of private and social costs) and prioritise the major causes of socially sub-optimal levels of animal health. It also depends on the ability of government to select a suitable mix of intervention measures acknowledging the interdependencies between these measures. In this respect, research, extension and ensuring producers face an appropriate set of incentives would provide the core of such a mix.

Government interventions through such a mix should involve the private sector wherever possible. An example is collaborative public and private research into improved disease control inputs, and their dissemination, which offers scope for reducing the public burden by getting input supply firms and producers to participate in research and extension activities which otherwise would be the sole responsibility of the government.

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Priority Assessment for Small Ruminant Development in Sub-Saharan Africa, Asia, South Pacific and Australia

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Abstract

The Australian Centre for International Agricultural Research (ACIAR) uses regional priority ranking as one of many criteria in determining which research projects to fund.

This paper discusses, from a welfare economics perspective, the regional priorities for small ruminant development activity in ACIAR's mandate regions.

It highlights some of the features of the Information System which has been developed at ACIAR to support research priority setting and decision-making and presents information which may be useful in generating discussions about various aspects of future directions for livestock research.

The paper is divided into five sections:

- factors important to the development of a small ruminant industry;
- the economic importance of small ruminants;
- the methodology, data and the key parameters used in establishing the priorities;
- the priorities of small ruminant development in ACIAR's mandate regions; and
- conclusions.

THIS paper discusses an economic analysis undertaken to identify regional priorities by commodity groups in the mandate regions of the Australian Centre for International Agricultural Research (ACIAR). The analysis uses a partial equilibrium, traded-good, multi-regional model. It makes use of demand and supply information about small ruminant products and about 44 other commodities.

Factors Important to the Development of a Small Ruminant Industry

Factors important to the development of a small ruminant industry are: human population growth, human food requirements and the possible contribution of small ruminants to food supply. Table 1 summarises FAO (Food and Agriculture Organization) data and projections to the year 2000 (FAO 1994a) on human population, gross domestic product and income per head, production of bovine meat, sheep and goat meat, pig meat and poultry meat, average dietary energy supply and the dietary contribution of meat, milk, fats and oils to average dietary energy.

Population growth

Population growth is a major determinant of demand for food in general and for small ruminant products in particular. FAO (1994a) published past and predicted (to the year 2000) levels and rates of growth of population in selected regions. Compared to the 1970s and 1980s, the decade to the year 2000 is expected to be characterised by a reduction in population growth. The projected annual growth of 1.7%, while lower than rates in the previous two decades, will add almost one billion people to the world population. Thus despite the slowdown in population growth there will be an increase in demand for food. Over 93% of that increase will be in the developing countries, the populations of which, rising at 2% annually, will approach 5 billion by 2000. Finally, the population of the developed countries is projected to grow at 0.5% annually, with about 70 million added during the 1990s.

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Table 1. Projections to the year 2000 on human population growth, gross domestic product, production of livestock products, and average dietary energy supply from livestock products.

Variable	Region	Levels		Growth rate	
		Actual 1990	Projected 2000	Actual 1980–90 (%)	1900–2000 (%)
Population (millions)	World	5 294	6 263	1.8	1.7
	Developing	4 046	4 948	2.1	2.0
	Developed	1 248	1 315	0.7	0.5
Gross Domestic Product (billions US$)	World	15 415	20 816	2.9	3.0
	Developing	3 500	5 670	3.6	4.9
	Developed	11 914	15 146	2.7	2.4
Income per head (US$)	World	2 912	3 324	1.1	1.3
	Developing	865	1 146	1.4	2.9
	Developed	9 544	11 519	2.1	1.9
Production ('000 t)				Growth rate	
				Actual 1978–88	1988–2000
Bovine meat	World	53 656	60 627	1.0	1.3
	Developing	19 384	24 809	2.0	2.7
	Developed	34 272	36 116	0.5	0.4
Sheep and goat meat	World	9 474	11 593	2.4	2.2
	Developing	5 340	7 052	3.1	3.1
	Developed	4 134	4 541	1.6	0.9
Pig meat	World	69 615	85 966	3.7	2.2
	Developing	31 203	46 168	6.9	4.4
	Developed	38 412	39 798	2.0	0.3
Poultry meat	World	39 659	57 988	4.8	3.8
	Developing	14 136	25 548	6.9	5.9
	Developed	25 523	32 440	3.8	2.5
Level of average dietary energy supply Kcal/head/day		1988 levels	2000 levels projected	Absolute change 1988–2000	Percentage change 1988–2000
	World	2 537	2 647	110	4.3
	Developing	2 246	2 420	174	7.7
	Developed	3 454	3 502	48	1.4
Dietary energy supply from meat, milk, fats and oils Average dietary energy supply (%)		1988 actual	2000 projected		
	World	23.4	24.2	not applicable	not applicable
	Developing	16.6	19.1	not applicable	not applicable
	Developed	37.0	37.7	not applicable	not applicable

Source: Compiled from FAO (1994a).

Income per head of population

Income per head of population is another important determinant of demand for agricultural commodities. Table 1 suggests that real income per head, globally, is likely to increase by 1.3% annually. However, aggregate growth rates conceal substantial differences between regions. For example, the developed countries are projected to grow at 1.9% per year to the year 2000, while the developing countries as a whole are projected to grow at 2.9%. It should be noted though that countries in the Far East are projected to grow at 4.3% per year and Africa at 0.8%.

Table 1 shows projections for the supply of individual meats: bovine, sheep and goat, pig and poultry. From 1988 to 2000 the total supply of the four meats is likely to grow at 2.3% per year: from developing countries at 4.2% year; and from developed countries at 0.9% per year.

FAO (1994a) concluded that, as a result of the relatively rapid growth of meat output in the developing countries, 47% of overall meat production could be located in these countries by the year 2000, compared with 39% in the late 1980s.

Table 1 also shows that between the years 1988 and 2000, the average daily dietary energy supply is projected to increase. More importantly, the contribution of meats, milk, fats and oils to the dietary energy supply is projected to increase globally.

Economic Importance of Small Ruminants

In most countries, sheep and goat meat is not traded — the quantity produced is enough to satisfy domestic demand. However, FAO (1994a) predicts that in the period to the year 2000, trade in sheep and goat meat is likely to increase, with gross exports growing globally at about 2.1% per year. Gross imports are likely to grow at 2.5% per year in the same period, with most of this growth (4.5% per year) occurring in developing countries.

Sheep and goat meat is important in ACIAR mandate regions. FAO data (1994b) shows that, while globally sheep and goat meat accounts for just over 5% of total meat produced, there are major regional differences.

In South Asia, sheep and goat meat represents up to 39% of total national production of meat products — with Pakistan, Nepal and Bangladesh recording sheep and goat meat production at about 38.7%, 21.6% and 21.4% respectively.

In Africa the share of sheep and goat meat in total meat production is highest in Ethiopia where it is about 33%. In 11 other countries or regions sheep and goat meat accounts for over 10% of total meat production.

In China and Mongolia sheep and goat meat represent about 4% and 61% respectively.

In Southeast Asia sheep and goat meat is up to 2.4% of national meat product.

Assessing the Priority of Small Ruminant Development

Research resource allocation in the public sector has become more complex over the last few decades. Demand for a more systematic and accountable basis for such allocations has increased from public sector decision-makers in research institutions and elsewhere. Accountability for public expenditure in general is increasingly demanded.

The value of intuitive management judgment should not be underestimated. However, decisions based largely on such judgment are becoming less acceptable and there is increased demand for them to be complemented by more systematically based information.

Such information can provide continuity in periods of senior management change. Moreover, the very exposure of decision-makers to the generation of the information — as distinct from the information itself — can significantly enhance judgment. The more complex the decision-making environment becomes the more likely this is to be the case.

Research Prioritisation Methodologies

While many approaches have been used in priority-setting exercises, they can be broadly categorised as:

- methods of research evaluation-based welfare theory in economics; and
- subjective scoring model methods.

Of the many reviews of these approaches the most recent and significant is that of Alston and colleagues (1995), which among other things (a) highlights the important differences between the research evaluation and scoring approaches, (b) shows that, while subjective scoring model methods are simple and quick to apply, they can easily provide inconsistent orderings and therefore provide doubtful priority indicators.

Obviously this need not always be the case, and each method will always depend crucially on the quality of information used and the way it is used. The important point is that the research evaluation method, if used consistently, be based on a considerable body of welfare theory-based literature which has been subject to the considerable peer review and scrutiny needed for a strong scientific method basis for the analysis and information generated.

ACIAR initially used a scoring model approach to support priority-setting but soon recognised its deficiencies. ACIAR has subsequently developed an information system based on research evaluation methods.

The following, based on Davis (1995) describes:

- how this systematic approach can be extended to priority-setting within a research area for a specific research program; and
- how ACIAR has used this type of analysis to support aggregate priority-setting and project level evaluations.

(a) This is an abbreviation for a given region. See Appendix A for details of the countries in this region.

Outline of a possible research evaluation approach to priority-setting

The research evaluation based framework used in ACIAR's information system is based on an integrated technical (physical) and economic model of the research process. This model is used to determine the potential welfare impacts of research options. A simplified schematic representation of this model is shown in Figure 1. The model is discussed in detail elsewhere (see for example, Davis et al. (forthcoming) and Davis and Fearn 1992). One outcome of the set of activities associated with the development of ACIAR's information system, as well as similar systems in for example the Philippines and Thailand, was the identification of a set of seven steps important to consider when developing priority-setting systems. These are to:

- review existing and past decision-making systems;
- identify the level of decision-making for focus by the information system;
- identify and clarify research objectives;
- develop or choose quantitative measures which indicate achievement of objectives;
- develop a database to support information generation;
- develop effective information presentation procedures;
- institutionalise the information system and support structure.

Rigid adherence to these steps is not essential. However, unless most are at least considered, then the likelihood of adoption of the system by decision-makers could be significantly reduced because the information produced may not suit them or the decision-making environment.

A detailed discussion of the issues relating to these steps is provided in Davis and Ryan (forthcoming). Two aspects are highlighted. First, the importance of having an institutionally based information system to complement other sources is emphasised. Second, a simplified outline of the research process is discussed to illustrate the technical and economic relationships used to generate the information included in the system.

The third step is one of the most important and is highlighted in the third row from the bottom of Figure 1. It is important to clearly identify and specify the research objectives of the research institution or group. The third row from the bottom of Figure 1 mentions two of the many possible objectives, namely:

- maximising the welfare gains to the country, or
- maximising the welfare gains to a subgroup, for example, poor farmers.

(a) This is an abbreviation for a given region. See Appendix A for details of the countries in this region.

If a systematic information system is to be effective, this step is crucial. Most groups are hesitant to clarify these objectives. Unless they do, however, the basis for decision-making will be unclear and transparency not achieved.

Figure 1 illustrates the interactions for one animal product and two production environments. The model used at ACIAR is more general than this. For example, it can allow for spillovers between many production environments and aggregate these into geographically or politically meaningful areas, such as countries; and it can also allow for spillovers to other products.

The remaining part of this subsection briefly discusses the important sets of information which are required before one can estimate research benefits using the model. Figure 2 summarises this information.

Specification of production environments

The first task is to clearly specify the characteristics of production environments important in determining the potential applicability and impact of particular types of research. This requires a good understanding of the nature of the research, and of the production systems within which the products likely to be influenced by the research are produced. There are many dimensions which could be important. The following illustrate some of the important areas:

- technical, biological, physiological factors — for example, weather conditions, soil qualities, and other geographical features have a significant impact on agricultural production;
- farmer-related factors — for example, farm size, management capacity, other farm activities, and cultural characteristics which might affect attitudes toward agricultural production;
- infrastructure factors which might influence the relative costs of some inputs between different locations;
- institutional and government policy factors which may differ between locations and influence production conditions differently.

Depending on the level of detail required there could be thousands of these production environments. For example, in ACIAR's aggregate priority analysis the number of production environments ranged from about 10 to 100. These were required to represent homogeneity in research applicability. However, for some applications these production environments are very aggregated. For agricultural products emphasis was placed primarily on technical characteristics which affect plant and animal growth. FAO's agro-ecological zone classification system was used as the primary base. Davis (1991) discusses this issue and how it relates to modelling the spillover effects of research. To minimise the complexity of the prioritisation activity the number of production environments identified should be kept to a minimum.

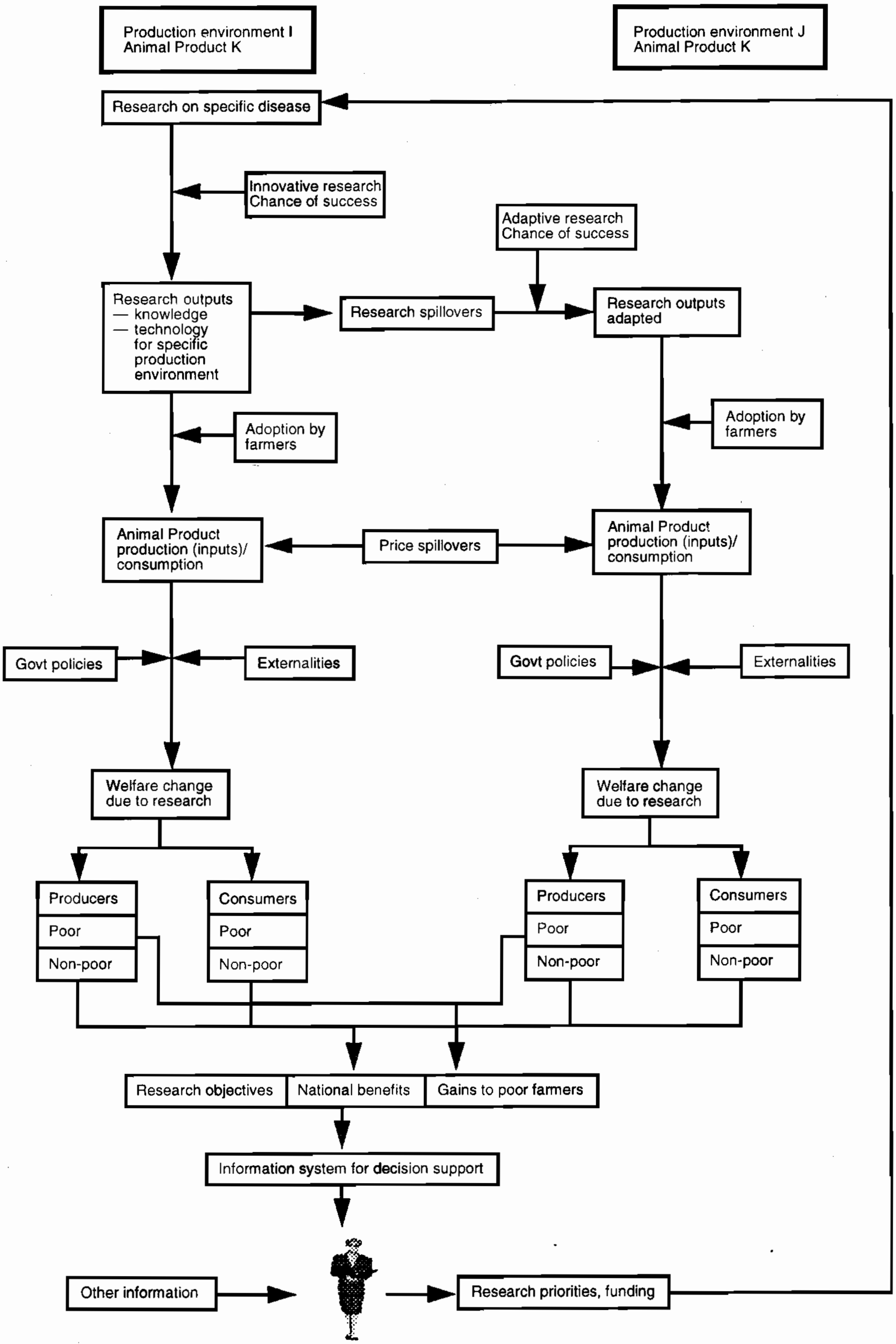


Figure 1. A simplified schematic representation of the research process model used in ACIAR's Information System.

	Animal group or product:				
Parameter	**Disease:**				
(i) Specify production environments	**Production Environment (PE)**				
	PE1	**PE2**	**PE3**	**PE4**	**PE5**
(ii) Define the research focus	?	?	?	?	?
Information required					
(iii) Chance of research success					
(iva) Estimate the direct net impact of research on the cost of production in the production environment where research is conducted.					
(ivb) Estimate the spillover effects — i.e. the effect of research undertaken in one environment on the cost of production in other production environments.					
(v) Research lag					
(via) Lag to start of adoption					
(vib) Adoption rate					
(vic) Ceiling adoption level					
(viia) Quantity of commodity produced in a given production environment					
(viib) Quantity of commodity consumed in a given production environment					
(viic) Price of commodity produced in a given production environment					
(viid) The elasticity of supply of a commodity produced in a given production environment					
(viie) The elasticity of demand of a commodity produced in a given production environment					
(viii) Potential cost of research for each year					
Estimate from welfare model					
(ixa) Change in producer welfare					
(ixb) Change in consumer welfare					
(ixc) Change in total welfare in a production environment					
Change in welfare of a country					

Figure 2. Information required to estimate potential welfare impacts.

Definition of the research focus

It is important to determine on what the research is likely to focus. Depending on how the priorities are to be used and the level of decision-making they are to support, different levels of research focus might be important. For example, in animal diseases:

- Is research going to address each and every disease affecting each and every animal in a country?
- Does research focus on solving a particular problem by using selected strategies — for example, vaccine development, chemical treatment or management strategies?
- Is research focused on livestock in selected production environments?

Defining the research focus can be achieved in many ways. However, it is important to interact with a cross-section of groups; for example, decision-makers, farmers and other users such as the private agribusiness sector. The more types of research foci and production environment classifications, the larger the number of research options there will be to prioritise. In Figure 2 this is represented by the number of columns which would need to be added to the table.

Chance of research success

The chances of the research being successful can depend on a range of factors; for example:

- the international level of knowledge of the issue being researched relevant to the particular production environment;
- the capacity of the research group to address the research issues;
- the facilities and resources available to the group; and
- the potential research impact required or expected.

Quantification of the chance of research success can be complex. It can be measured as a simple 0–1 index or as a probability distribution. Some useful discussion of this parameter and guidelines for consistent estimation are found in detail in, for example, Bantilan and Davis (forthcoming).

The expected net cost impact of the research

Once the research has generated new knowledge of some aspect of the input, production, processing or consumption chain, before it can have an impact on community welfare it must influence the cost of production in some manner. To effectively determine this influence a clear understanding of the input use, outputs expected and associated costs before and after the impact of the research is required. This process is referred to as a cost analysis of the farm level production activity in each production environment. A recent illustration of this type of analysis is given by Lubulwa and co-workers (1995). In the case of livestock sector research an effective cost analysis is likely to require at least the following:

- a model of the herd or animal unit dynamics;
- a model of the feed requirements and potential supplies;
- a detailed assessment of all inputs used and the associated costs of these inputs;
- an assessment of the negative impact of the technology on the costs of other activities in the community.

In the case of animal diseases, important parameters within these models are likely to be:

- the effect of the disease on morbidity and therefore animal growth rates, etc.;
- the mortality effects;
- the reproduction rate effects.

These estimates are required for research focused on each production environment and therefore the potential spillover impacts, if successful, on the other production environments. Some discussion of this area is given in Davis (1991).

Research lag

The eventual level of welfare gains will depend on just how long the research is likely to take. Clearly, if two areas of disease research are likely to have the same annual welfare impact but one is likely to take longer, then it will usually be better to undertake the quicker one first. If one is likely to have a greater welfare impact but take longer, then a discounted comparison is required. The length of the research lag becomes important.

Adoption expectations

Once a technology is developed from the research knowledge it must be adopted by farmers or others before it can begin to have an impact on community welfare. This adoption dimension is often quite complex. However, what is often regarded as lack of adoption by farmers in fact is an indication that the developed technology is not applicable or is irrelevant for many farmers. The technology may not be lower cost than existing technologies if the research was originally developed for a different production environment. Important aspects of the notion of adoption are:

- the length of the lag between the completion of the research or even development of the final technology and the commencement of adoption — it often takes time for farmers to become aware of the technology, receive supplies of some aspects of it or trial it on a small scale to check for site-specificity dimensions;
- the rate of adoption for a particular production environment; and
- the eventual ceiling level of adoption — even if the technology is applicable there may still be some farmers who never adopt it.

Production and consumption aspects

To fully appreciate the economics of the impact of the research the following information is required about the particular environment:

- the level of production of the product;
- the level of consumption of the product;
- the price of the product;
- the price responsiveness of producers and consumers of the product or the supply and demand elasticities;
- any government interventions which might distort the price.

If the welfare gains to subgroups within production environments are important aspects of research objectives then this information will be required at the level of disaggregation required. It is important to recognise that the more disaggregated the objective, the less readily available this information is likely to be.

Research costs

If some areas of research are likely to require different levels of research inputs then the costs could vary significantly. If this is the case, information on the levels and time flow of these costs is required.

Estimation of expected welfare changes

Once all the above information is available a welfare impact assessment can be made using one of the research evaluation models. This effectively provides a theoretical basis for 'weighting' all these factors. Figure 3 is a simple illustration of how the annual welfare benefits are estimated. The area represented by ES (abcd) (total welfare change or economic surplus) is the annual potential welfare gain from the research. CS and PS are the shares of these gains received by consumers and producers of the product respectively. There is detailed discussion of these measures by, for example, Alston and co-workers (1995) and Davis et al. (1987).

The welfare areas in Figure 3 can be combined with all other factors discussed above to give a current value estimate of expected welfare gains. The equations below illustrate this for the model used at ACIAR for aggregate priority-setting. This is discussed by, for example, Davis and colleagues (1987), and is one of the variations included by Alston and co-workers (1995).

The production environment welfare gains from research are given as:

$$PV(G_{yf}) = \sum_{t=1}^{T} \frac{p_{yt} x_{ft} k_{yf}}{(1+r)^t} Q_{sft} + \sum_{t=1}^{T} \frac{p_{yt}(Q_{dft} - Q_{sft}) \sum_{i=1}^{n} \beta_i x_{it} k_{yf}}{(1+r)^t \sum_{i=1}^{n}(\beta_i + b_i)} + \sum_{t=1}^{T} \frac{p_{yt} b_f \left(\sum_{i=1}^{n} \beta_i x_{it} k_{yf} \right)^2}{2(1+r)^t \left(\sum_{i=1}^{n}(\beta_i + b_i) \right)^2}$$

$$+ \sum_{t=1}^{T} \frac{p_{yt}\beta_f}{2(1+r)^t} \left[x_{ft} k_{yf} - \frac{\sum_{i=1}^{n} \sum_{i=1}^{n} \beta_i x_{it} k_{yf}}{\sum_{i=1}^{n}(\beta_i + b_i)} \right]^2 \quad .....(1)$$

where:

$PV(G_{yf})$ is the expected present value of total welfare benefits to production environment "f" from research undertaken in production environment "y" for the commodity of interest, summed over "t" years (t=1...T).

p_{yt} is an index of the relative strength of the research system in production environment "y" where the research is undertaken in year "t" ($0 \leq p_{yt} \leq 1$).

x_{ft} is the expected level of adoption of the technology generated by the research in production environment "f" in year "t" ($0 \leq x_{ft} \leq 1$).

k_{yf} is the cost reducing effect of research undertaken in production environment "y" on output in production environment "f", (f=1....n). For the production environment where the research takes place this k_{yy} is the direct effect of the research; for the remaining n−1 countries producing and/or consuming the commodity the "k_{yf}" will be the spillover effects of research. For many countries this is likely to be zero.

r is the social discount rate in real terms.

Q_{sft}, Q_{dft} is the quantity of the commodity produced and consumed in production environment "f" in time period "t" without research, that is, the initial output and consumption.

b_f and b_i are the slope parameters ($\alpha Q/\alpha P$) of the demand function in the fth or ith production environment/region. Note that:

$$b_i = \varepsilon_{di}[Q_{dit}/P_{it}]$$

where ε_{di} is the elasticity of demand for the commodity in production environment "i" evaluated at the original equilibrium quantities and prices, Q_{dit} and P_{it}. Note because negative signs are included in the demand specification the absolute values for these parameters are entered in the formulae.

β_f and β_i are the slope parameters ($\alpha Q/\alpha P$) of the supply function in the ith or jth production environment/region. Also note:

$$\beta_i = e_{si}[Q_{sit}/P_{it}]$$

where ε_{si} is the elasticity of supply for the commodity in production environment "i" evaluated at the original equilibrium quantities and prices, Q_{sit} and P_{it}.

n is the number of countries/regions where the commodity of concern is produced or consumed.

These types of formulae highlight the inconsistencies which can arise if a simple scoring model is used. Scoring models use the sets of information discussed above, or usually subsets of these, as 'important criteria', score them from say 1 to 10, give them a weight and then add everything to give the ranking score. The chances of this subjective process matching the theoretically based 'weighting' system are relatively remote. In many cases criteria are added when they should be multiplied, etc.

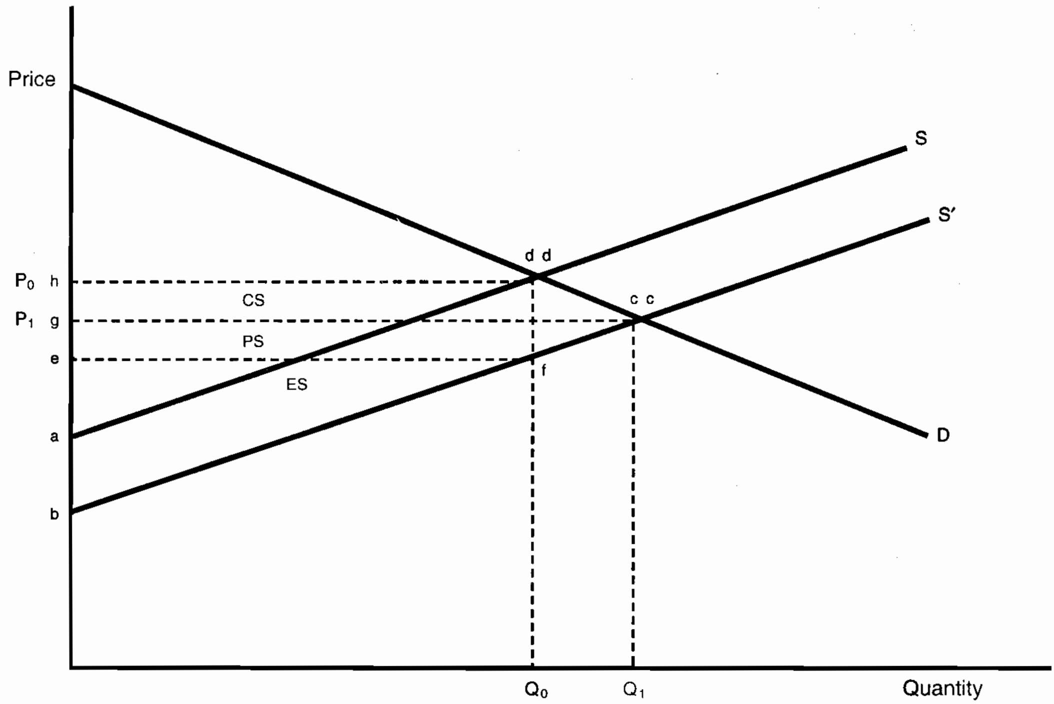
It can be seen from the discussion above that a detailed priority-setting exercise, based on research evaluation methods in the area of welfare theory, can be demanding in terms of data requirements. Indeed it took ACIAR several years to develop the databases to support its aggregate system. This is what has often deterred many from using this more rigorous approach and caused them to revert to a less transparent and more subjective scoring model approach.

However, while the cost of setting up the database is high, it is relatively cheaper to maintain the database. It is possible to use the basic framework and build on it over time. This would involve using an absolute minimum number of production environments, aggregate research foci and very subjective estimation of the important parameters. These would still be combined using a simple version of the welfare model to provide a preliminary estimate of expected welfare effects at possibly a national rather than specific interest group level.

The rest of this paper discusses results from the use of this approach in developing commodity and regional priorities at ACIAR.

The ACIAR Information System: A Brief Overview

During the early days of ACIAR's development it was decided that it was important to develop an institutional-based information system to support decision-making at various levels. Reasons for this decision included: the increased importance of public sector accountability; the diverse nature of ACIAR's mandate research areas and the need to be able to make comparisons between them; and an expectation that the scientific expertise would change over time and therefore an institution-based information system that drew on this expertise and evolved with it was important.



The following notation is used.

Po	is the price of the agricultural product before research
P1	is the price of the agricultural product after research
Qo	is the quantity produced and consumed of the agricultural product before research
Q1	is the quantity produced and consumed of the agricultural product after research
S	is the supply function for the agricultural product before research
S'	is the supply function for the agricultural product after research
D	is the demand function for the agricultural product
a	is the intercept of the supply function before research
b	is the intercept of the supply function after research
c	is the point of intersection between the demand and supply curve after research which gives the price after research as P1
d	is the point of intersection between the demand and supply curve after research which gives the price before research as Po
df	is the cost saving per unit of output due to research
ES	is the total change in economic surplus which is given by the area 'abcd'
PS	is the change in producer surplus and is given by the area 'efcg'
CS	is the change in consumer surplus and is given by the area 'gcdh'
ES	is equal to the sum of PS and CS.

Figure 3. A simple illustration of welfare gains from research estimation.

The database components of ACIAR's information system

A detailed account of the evolution of the ACIAR information system is provided by Davis and Ryan (forthcoming, chapters 8–11). Figure 4 summarises the components of the system. Its important components are discussed below.

A project management database

This database is called the Project Information System of ACIAR (PISA). It is a complete record of the information set for each project funded by ACIAR since its inception. The information ranges from the detailed budgets to the publications and the country/commodity focus of the project. The database has been designed to produce a range of reports, some used to assist day-to-day project management, others to provide summary information for all projects or various groups of projects. PISA provides project-related information used to support day-to-day project management by Program Coordinators. At an aggregate level it provides a summary of the ACIAR-wide status of the program; for example, the share of research funds for each geographical mandate region and changes in these over time. This type of information is provided to the executive, for example, the Board of Management. PISA is maintained as a LOTUS NOTES database.

A research evaluation database

This database has been developed with the view to making use of extensive research evaluation literature produced during the last four decades. The methodology that has evolved has been adapted to suit decision-making in ACIAR. This has involved incorporating more detailed technical parameters in the underlying models and involving technical scientists in the collection of data used in the subsequent analysis. The model currently used has been fashioned to include most aspects of the research process as described in Figure 5.

The technical aspects of the research process, and therefore the model, focus especially on estimates of the relative strengths of the research systems in different countries, the potential for research output to spill over to other countries, and potential adoption levels of the final technologies. Estimates of the information used to represent the components were made in consultation with research managers and technical experts. While current estimates require further verification and validation, they represent a comprehensive set of data.

The economic components of Figure 5 have been modelled using a multi-region traded-good model with the concept of producer and consumer surplus used to estimate the potential welfare effects of the research. To accommodate this part of the model a range of data sets has been added to the database. This includes production, consumption (both commercial and subsistence), prices and elasticities. As well as the basic data the database includes a full set of the estimates of the potential welfare changes due to research. The important assumption used for the base case set of welfare changes is that the research results in a 5% reduction in the cost of producing a unit (usually a tonne) of the commodity.

In its current form the database includes data and estimates of the parameters for 70 countries or aggregations of countries that represent the whole world. In many cases the information is included for all countries of the world, both developed and developing. This is necessary to facilitate incorporation of any world price effects which might flow from the technology spillovers to developed countries. In addition to the 70 political or geographic regions, the technical research spillovers are estimated using up to 75 different production environment classifications. This spillover information is therefore available for each production environment for each country, although each country will contain only a small subset of possible production environments. The research evaluation database is stored as MICROSOFT EXCEL spreadsheets.

Project development assessments

Project development assessments are a relatively more recent addition to ACIAR's Information System and have developed for a number of reasons. Important among these has been the need to develop a means of comparison between projects from the diverse program areas within ACIAR. They also provide a mechanism for demonstrating under what types of conditions technically attractive projects in what appear to potentially lower benefit commodities will generate high welfare gains. In addition these activities have been found to provide a useful interdisciplinary interaction which often results in clearer project specification and direction.

Completed project assessments

In preparation for the Parliamentary Sunset review of ACIAR in 1992, it was decided to commission a set of completed project economic assessments. The primary basis for choosing the projects to assess was that the benefits from them had started to flow and that they were identifiable. Menz (1991) gives a detailed description of the 12 assessments completed for the Parliamentary Sunset review. Fearn (1991) describes a completed project assessment of research on tuna fish bait biology, while Lubulwa and Davis (1994) document the evaluation of four completed projects in the area of post-harvest technology. Some trends do appear in these studies. The large majority is on issues relevant to commodities in the top two priority commodity groups for the region where the research was undertaken. Some of the projects with high levels of benefits are also in this category. Similar trends appear in other completed project evaluations. An example is a set of 11 projects based in Sub-Saharan Africa and assessed recently (see Lubulwa 1995a,b, Lubulwa and Hargreaves 1995; Lubulwa, Gwaze et al. 1995, Lubulwa, Wafula et al. 1995; Beckmann 1996).

Aggregate priority assessment information

Clear determination of ACIAR's objectives is crucial to the development of summary information supporting priority assessments. This clarification is continuing. Maximising mandate regional benefits has always been given prominence; however, currently Australian benefits also receive attention. The large set of welfare gain information estimated in the research evaluation database has been employed to support priority assessments. These estimates provide an indication of the likely ordering, for the commodities considered, of regional welfare gains which might result from successful research. Discussion of these priority assessments, with special emphasis on small ruminant development, follows.

The Priorities for Small Ruminant Development in ACIAR-mandate Regions

The term 'small ruminant products' refers to sheep meat, goat meat and wool and manure. While manure is an important livestock sector product in a number of countries, it is not explicitly included in the analysis. These are analysed in the context of 45 major agricultural products using data from FAO (1994b). In addition an aggregate commodity 'sheep and goat meat' is included in the analysis to make it possible to compare results in this paper with earlier analyses by Davis and Lubulwa (1995).

Small ruminant development is assessed for the following six regions under ACIAR's mandate:

- South Asia;
- Southeast Asia;
- China;
- South Pacific and Papua New Guinea;
- Sub-Saharan Africa; and
- Australia.

In addition, results are reported for West Asia and North Africa (WANA); and Latin America. Since ACIAR currently has no activities in Latin America or WANA, the results for these regions are reported in the final tables, but not discussed in detail. The results of priority assessments are summarised in Tables 2–9, each of which contains four types of information.

Estimates of the monetary measures of the potential regional welfare gains from research

These gains are estimated assuming that research is undertaken on problems relevant to the region and generates a 5% unit cost reduction for each commodity. In this case the regions are those mandated for ACIAR. The information presented in Tables 2–9 assumes that the research has no direct impact on other livestock products. In some cases this will not be appropriate, for example, poultry meat and eggs. If research is likely to have an impact on both, then the research benefits should be added together and the total compared with the other commodities. This is done where appropriate in Tables 2–9, for example for cotton seed and cotton lint and for palm oil and palm kernels production.

In Tables 2–9 the rows printed in italic give the potential gross welfare gains from research into livestock products included in the research evaluation analysis in ACIAR's Information System. This information refers to the average regional benefit from research focused on problems important to the production environments most prevalent in the region. These benefits are calculated assuming the research results in a standard 5% reduction in the unit cost of producing the commodities.

It has been found that this type of presentation format is not always the most convenient for quick use by decision-makers to aid priority-setting. Break-even relativities are often preferred to present the estimates. Graphs of the monetary benefits are increasingly being used as an alternative format for presentation of the results.

Break-even relativities for the commodities

This information gives estimates of potential regional welfare gains expressed as break-even relativities for the commodities included in the analysis. These relativities are calculated by ordering the commodities from highest regional benefits to lowest and then dividing the highest by each commodity's expected gains in the region.

Relativities between the geographical regions

These are calculated by dividing the highest regional welfare gains, that is, in China, by each of the highest gains in the other regions.

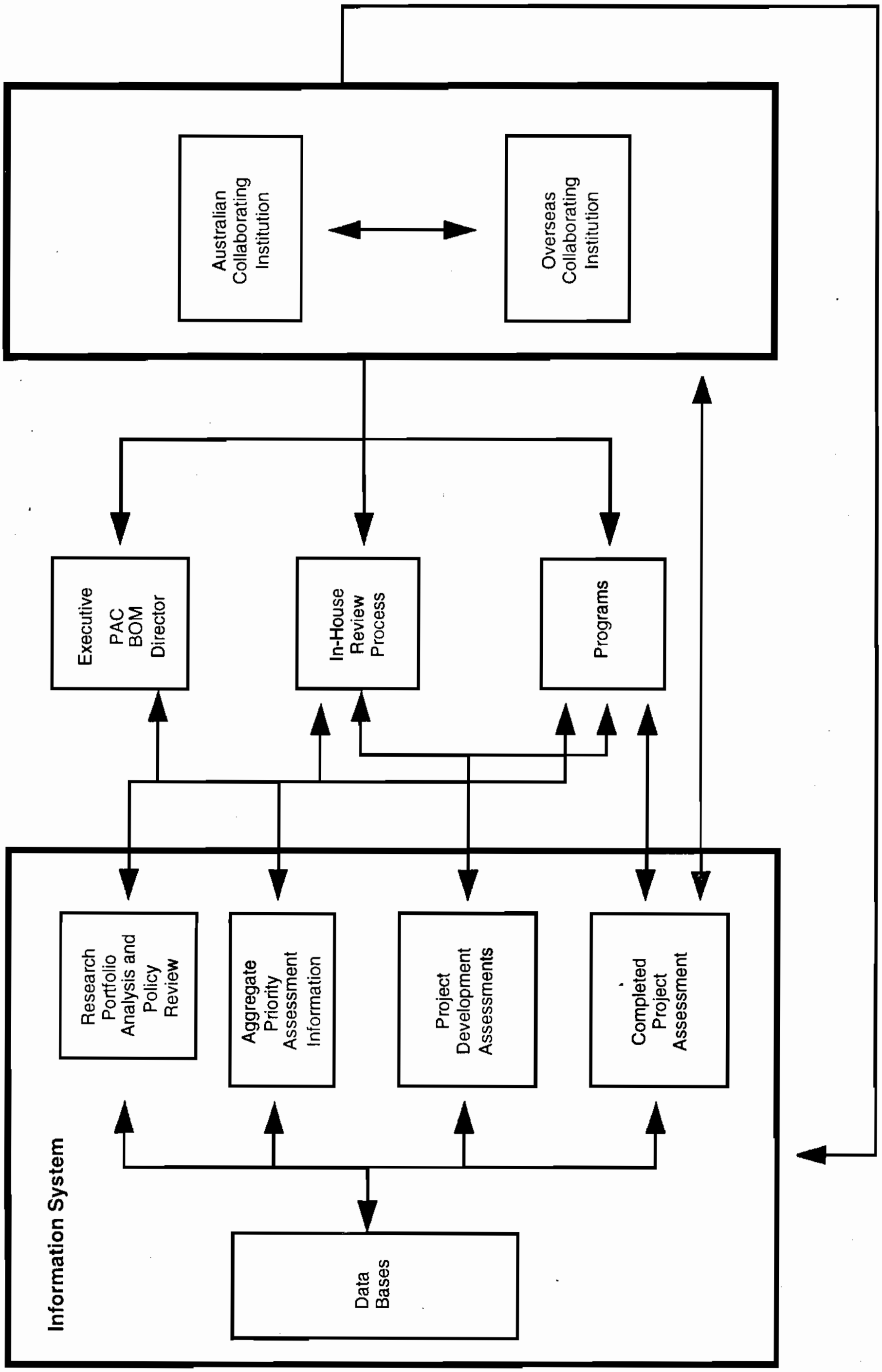


Figure 4. An illustration of the information system interface with decision-making groups for ACIAR.

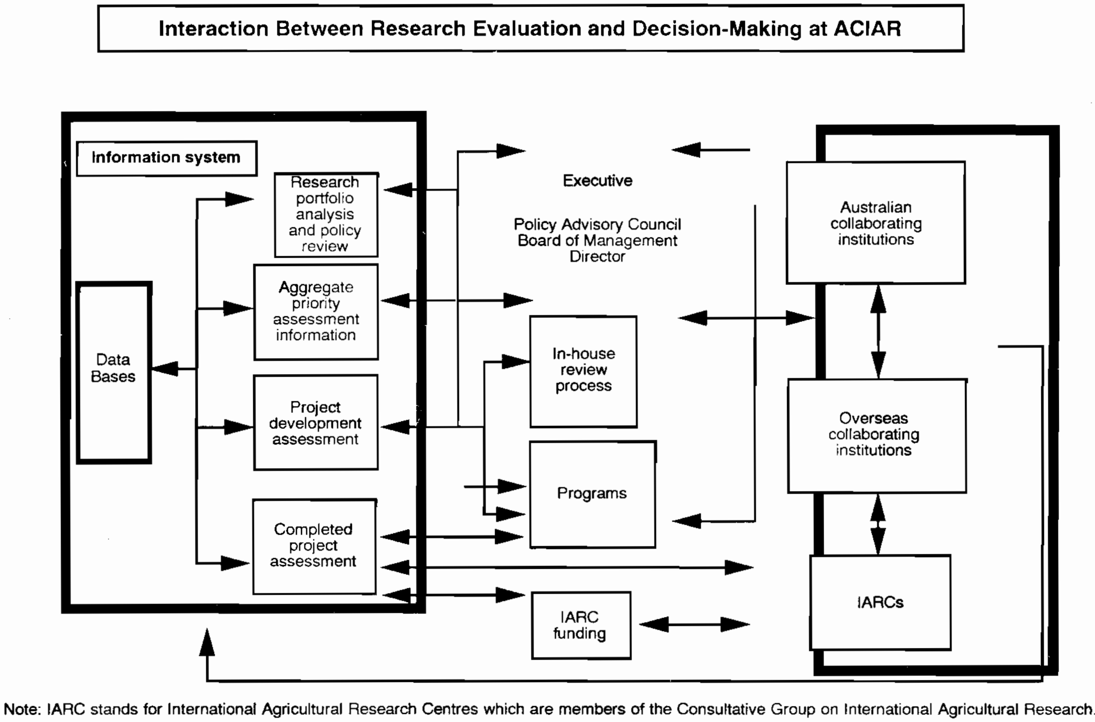


Figure 5. An illustration of the information system interface with decision-making groups for ACIAR.

The priority groupings of commodities in a region

This information indicates within which of six priority groups a commodity in a given region falls. The following six priority groups have proved useful and the following relativity ranges have been found to be appropriate.

Priority grouping	Range of break-even relativity
1	0–10
2	11–20
3	21–40
4	41–80
5	81–160
6	> 160

Care is required in using this type of summary information to support decision-making. In ACIAR it is not used to dictate that research should be supported for only the highest expected gain commodities, but as a screening device. That is, research focusing on commodities in the 4, 5, and 6 priority groups are flagged as requiring closer scrutiny of the likely level of welfare gains which may result. The trend is toward having more detailed economic assessments included with these types of projects to demonstrate more clearly that, as well as scientifically attractive attributes, there are high potential regional welfare gains.

Priority Assessment, Small Ruminant Development, by Region

South Asia

Table 2 shows that the commodity likely to generate the highest welfare benefits in South Asia is rice (see column 3). Small ruminants as a group fall in a high priority group 2, exceeded only in importance by milk and beef and buffalo among the livestock products. However, two other points emerge. (i) Goat meat is more important in South Asia than sheep meat production. A disaggregated analysis shows that in South Asia goat meat is likely to generate almost twice as much welfare benefit as sheep. An explanation of this difference in welfare impacts is related to the fact that more goat meat than sheep meat is produced in South Asia FAO

(1994b). (ii) Sheep and goat are kept in South Asia for meat rather than for wool. Wool production in South Asia is in a low priority group 6.

Southeast Asia

Table 3 shows that the commodity likely to generate the highest welfare benefits in Southeast Asia is rice (see column 3). Small ruminants as a group fall in a lower priority group 4, exceeded in importance by pig meat, poultry eggs, milk and beef and buffalo among the livestock products. However, each of the two commodities treated separately falls in lower priority groups — goat meat is in the low priority group 5 while sheep meat is in an even lower priority group of 6, where it is ranked marginally higher than the production of duck meat. Table 3 again shows that (i) goat meat is more important than sheep meat production in Southeast Asia — a disaggregated analysis shows that in Southeast Asia, goat meat is likely to generate twice as much welfare benefit as sheep — the explanation of this difference in welfare impacts is provided, which show that more goat meat than sheep meat is produced in Southeast Asia; and (ii) sheep and goat are kept in Southeast Asia for meat rather than for wool. Wool production in Southeast Asia is in a low priority group 6.

China

Table 4 shows that the commodity likely to generate the highest welfare benefits in China is rice (see column 3). Small ruminants as a group fall in a medium-priority group 3 exceeded in importance only by pig meat and poultry eggs among the livestock products. However, each of the two commodities treated separately falls in a lower priority group 4. Even in China sheep and goat meat rank higher than wool. Wool production falls in a low priority group of 5.

South Pacific and Papua New Guinea

Column 3 of Table 5 shows that the commodity likely to generate the highest welfare benefits in the South Pacific and Papua New Guinea is fuelwood (non-coniferous). Sheep and goat meat as a group are likely to generate less than $0.5 million of welfare benefits. Small ruminants as a group fall in a low priority group 6.

Sub-Saharan Africa

Column 3 of Table 6 shows that the commodity likely to generate the highest welfare benefits in Sub-Saharan Africa is fuelwood (non-coniferous). Sheep and goat meat as a group fall in a high priority group 2, exceeded in importance only by milk and beef production among the livestock products. However, each of the two commodities treated separately falls in a lower priority group 3.

Latin America and West Asia and North Africa

Tables 7 and 8 show results for Latin America and West Asia and North Africa. These results are not discussed here because ACIAR does not have projects in those two regions of the world. However, these two regions do benefit indirectly through spill-overs from research undertaken under ACIAR projects in its mandate regions.

Australia

Table 9 reports results for Australia and shows that the agricultural commodity likely to generate the highest level of benefits is wool. However, sheep and goat meat production is also in the top priority group of 1 in Australia.

Table 9 shows the break-even relativities for an objective which would maximise welfare gains to Australia. These estimates assume that the research effort would focus attention on research problems associated with the production environments important to Australia and not necessarily those important to other ACIAR mandate regions.

The impact of ACIAR-funded research on Australian agricultural production is likely to be important because the Australian collaborating institution usually has as its primary objective the maximisation of welfare gains to Australia. Conflict between this objective and a developing-country regional benefits objective such as held by ACIAR could influence the choice of project and the emphasis in terms of research issues addressed.

Table 9 estimates the benefits to Australia of research undertaken in Australia and focuses on the important domestic production environments for the commodity. If the objective of Australian research institutions is to maximise the gains to Australia then it seems likely that Australian livestock research institutions will place research emphasis on more (all) livestock products than might be the case for a collaborating partner country. That is, all livestock products are in the high priority groups for Australia but not for the other mandate regions. This may not pose too many problems — most products are important in at least one of the regions. (The exception is wool, high priority for Australia but not for any of the other regions, based on regional benefits objectives). Therefore it should be possible to match an Australian research institution's interest with those of at least one of the mandate regions.

Table 2. South Asia — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	South Asia commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Rice	1	1	505.5	1	1
2	*Milk*	*2*	*1*	*356.0*	*1*	*1*
3	Fuelwood (non-coniferous)	2	1	232.8	2	1
4	Wheat	3	1	151.9	3	1
5	Sugar	8	1	123.0	4	1
6	Pulses All	4	1	118.1	4	1
7	Cotton Lint and Seed	8	1	75.4	7	1
8	Potatoes	7	1	72.1	7	1
9	Groundnut	12	2	47.7	11	2
10	Saw and Veneer Logs (non-coniferous)	11	2	40.0	13	2
11	Sorghum	11	2	38.2	13	2
12	*Sheep and Goat Meat*	*18*	*2*	*29.2*	*17*	*2*
13	Millet	17	2	25.0	20	3
14	Banana/Plantain	21	3	22.2	23	3
15	*Eggs (poultry)*	*27*	*3*	*21.5*	*24*	*3*
16	Maize	23	3	20.8	24	3
17	*Goat meat*	*ne*	*ne*	*19.2*	*26*	*3*
18	Coconut	33	3	17.3	29	3
19	Prawns/shrimps	30	3	ne	ne	ne
20	Oranges and Tangerines	55	4	11.6	44	4
21	Soybean	75	4	11.3	45	4
22	*Sheep meat*	*ne*	*ne*	*10.6*	*48*	*4*
23	Charcoal	77	4	9.8	52	4
24	*Pig meat*	*162*	*6*	*8.7*	*58*	4
25	Demersal/Other Pelagic	53	4	ne	ne	ne
26	*Beef and Buffalo*	*27*	*3*	*7.4*	*68*	*4*
27	Fuelwood (coniferous)	67	4	7.1	71	4
28	Herrings and Others	64	4	ne	ne	ne
29	Saw and Veneer Logs (coniferous)	67	4	6.5	78	4
30	Cassava	67	4	6.0	84	5
31	Poultry meat	140	5	6.0	84	5
32	Other Industrial Round Wood	98	5	4.8	105	5
33	*Wool*	*136*	*5*	*3.8*	*133*	*5*
34	Rubber	183	6	3.5	144	5
35	Coffee	146	5	3.3	153	5
36	Tilapias	156	5	ne	ne	ne
37	Pulpwood	324	6	1.3	389	6
38	Sweet Potato	351	6	1.0	506	6
39	Mackerels and Others	421	6	ne	ne	ne
40	Tunas, Bonitos etc	842	6	0.5	1011	6
41	*Duck Meat*	*ne*	*ne*	*0.3*	*1665*	*6*
42	Lobsters	2105	6	0.2	2528	6
43	Cocoa	4210	6	0.0	0	6
44	Pitprops	301	6	0.0	0	6
45	Palm Oil and Palm Kernel	0	6	0.0	0	6
46	Mussels	ne	ne	ne	ne	ne
47	Oysters	ne	ne	ne	ne	ne
48	Clams	ne	ne	ne	ne	ne
	Regional relativity		2.7	0.0		

Notes: * Italic type denotes a livestock product; ne: not estimated.

a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 3. Southeast Asia — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	Southeast Asia commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Rice	1	1	225.3	1	1
2	Saw and Veneer Logs (non-coniferous)	1	1	211.2	1	1
3	Fuelwood (non-coniferous)	1	1	187.6	1	1
4	Palm Oil and Palm Kernel	2	1	151.6	1	1
5	Rubber	3	1	66.3	3	1
6	Sugar	9	1	30.8	7	1
7	Coconut	9	1	24.2	9	1
8	Banana/Plantain	10	1	20.0	11	2
9	*Pig Meat*	*14*	*2*	*19.5*	*12*	*2*
10	*Poultry Meat*	*19*	*2*	*19.3*	*12*	*2*
11	Cassava	12	2	19.1	12	2
12	Maize	16	2	15.1	15	2
13	*Eggs (poultry)*	*18*	*2*	*14.8*	*15*	*2*
14	Demersal/Other Pelagic	15	2	ne	ne	ne
15	Prawns/Shrimps	16	2	ne	ne	ne
16	Cocoa	28	3	10.6	21	3
17	Coffee	18	2	10.2	22	3
18	*Beef and Buffalo*	*25*	*3*	*10*	*23*	*3*
19	Tilapias	27	3	ne	ne	ne
20	Other Industrial Round Wood	33	3	6.8	33	3
21	Clams	ne	ne	ne	ne	ne
22	Charcoal	63	4	5.5	41	4
23	Soybean	83	5	4.9	46	4
24	*Milk*	*95*	*5*	*3.7*	*61*	*4*
25	Tunas, Bonitos etc	57	4	ne	ne	ne
26	*Sheep and Goat Meat*	*65*	*4*	*3.4*	*66*	*4*
27	Mackerels and Others	61	4	ne	ne	ne
28	Herrings and Others	67	4	ne	ne	ne
29	Saw and Veneer Logs (coniferous)	143	5	2.4	94	5
30	*Goat Meat*	*ne*	*ne*	*2.3*	*98*	*5*
31	Oysters	ne	ne	ne	ne	ne
32	Cotton Lint and Seed	200	6	2.0	113	5
33	Pulpwood	111	5	1.9	119	5
34	Pulses All	143	5	1.7	133	5
35	Sweet Potato	133	5	1.5	150	5
36	Groundnut	167	6	1.3	173	6
37	*Sheep Meat*	*ne*	*ne*	*1.3*	*173*	*6*
38	*Duck Meat*	*ne*	*ne*	*1.2*	*188*	*6*
39	Potatoes	133	6	0.8	282	6
40	Mussels	ne	ne	ne	ne	ne
41	Lobsters	ne	ne	ne	ne	ne
42	Oranges and Tangerines	222	6	0.6	376	6
43	Wheat	667	6	0.3	751	6
44	Sorghum	500	6	0.3	751	6
45	Millet	2000	6	0.0	0	6
46	*Wool*	*0*	*6*	*0.0*	*0*	*6*
47	Fuelwood (coniferous)	0	6	0.0	0	6
48	Pitprops	0	6	0.0	0	6
	Regional relativity		5.8			5.4

Notes: * Italic type denotes a livestock product; ne: not estimated.

a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 4. China — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	China commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Rice	1	1	1 218.0	1	1
2	*Pig Meat*	*2*	*1*	*601.3*	*2*	*1*
3	Sweet Potato	4	1	350.2	3	1
4	Maize	4	1	338.9	4	1
5	Wheat	5	1	248.3	5	1
6	*Eggs (poultry)*	*11*	*2*	*173.8*	*7*	*1*
7	Potatoes	5	1	139.1	9	1
8	Cotton Lint and Seed	9	1	107.5	11	2
9	*Poultry Meat*	*31*	*3*	*67.0*	*18*	*2*
10	Soybean	19	2	66.5	18	2
11	Fuelwood (coniferous)	20	2	ne	ne	ne
12	Sugar	26	3	58.9	21	3
13	Pulses All	20	2	55.6	22	3
14	Fuelwood (non-coniferous)	20	2	ne	ne	ne
15	Saw and Veneer Logs (coniferous)	26	3	ne	ne	ne
16	*Sheep and Goat Meat*	*39*	*3*	*50.1*	*24*	*3*
17	*Milk*	*46*	*4*	*37.4*	*33*	*3*
18	Groundnut	40	3	32.2	38	3
19	*Beef and Buffalo*	*139*	*5*	*27.0*	*45*	*4*
20	*Goat Meat*	*ne*	*ne*	*26.4*	*46*	*4*
21	*Sheep Meat*	*ne*	*ne*	*24.0*	*51*	*4*
22	Prawns/shrimps	67	4	ne	ne	ne
23	Saw and Veneer Logs (non-coniferous)	41	4	ne	ne	ne
24	Other Industrial Round Wood	62	4	ne	ne	*ne*
25	Oranges and Tangerines	129	5	23.5	52	4
26	*Wool*	*97*	*5*	*13.0*	*94*	*5*
27	*Duck Meat*	*ne*	*ne*	*12.4*	*98*	*5*
28	Sorghum	89	5	9.5	128	5
29	Millet	81	5	8.9	137	5
30	Pitprops	163	6	ne	ne	ne
31	Rubber	276	6	6.2	196	6
32	Mackerels and Others	214	6	ne	ne	ne
33	Demersal/Other Pelagic	227	6	ne	ne	ne
34	Cassava	276	6	3.8	321	6
35	Palm Oil and Palm Kernel	289	6	3.3	369	6
36	Mussels	ne	ne	ne	ne	ne
37	Cocoa	0	6	0.0	0	6
38	Coconut	0	6	0.0	0	6
39	Charcoal	0	6	ne	ne	ne
40	Pulpwood	413	6	ne	ne	ne
41	Tunas, Bonitos etc	463	6	ne	ne	ne
42	Lobsters	0	6	ne	ne	ne
43	Tilapias	0	6	ne	ne	ne
44	Banana/Plantain	1 286	6	3.8	321	6
45	Coffee	5 786	6	0.3	4 060	6
46	Herrings and Others	5 786	6	ne	ne	ne
47	Oysters	0	6	ne	ne	ne
48	Clams	0	6	ne	ne	ne
	Regional relativity		1			1

Notes: * Italic type denotes a livestock product; ne: not estimated.

a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 5. South Pacific and Papua New Guinea — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	South Pacific and Papua New Guinea commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Tunas, Bonitos etc	1	1	ne	ne	ne
2	Saw and Veneer Logs (non-coniferous)	1	1	5.7	1	1
3	Fuelwood (non-coniferous)	1	1	5.6	1	1
4	Sugar	3	1	2.0	3	1
5	Banana/Plantain	4	1	1.5	4	1
6	Coffee	7	1	1.4	4	1
7	Palm Oil and Palm Kernel	6	1	1.0	6	1
8	Cocoa	12	2	1.0	6	1
9	Saw and Veneer Logs (coniferous)	30	3	0.4	15	2
10	Coconut	30	3	0.3	20	2
11	Demersal/Other Pelagic	20	2	ne	ne	ne
12	*Pig Meat*	*20*	*2*	*0.3*	*20*	*2*
13	Sweet Potato	30	3	0.2	30	3
14	Pulpwood	30	3	0.2	30	3
15	*Milk*	*59*	*4*	*0.1*	*59*	*4*
16	Rice	59	4	0.1	59	4
17	Prawns/Shrimps	59	4	ne	ne	ne
18	Tilapias	59	4	ne	ne	ne
19	Cassava	0	6	0.0	0	6
20	Groundnut	0	6	0.0	0	6
21	Maize	0	6	0.0	0	6
22	Millet	0	6	0.0	0	6
23	Oranges and Tangerines	0	6	0.0	0	6
24	Potatoes	0	6	0.0	0	6
25	*Beef and Buffalo*	*0*	*6*	*0.0*	*0*	*6*
26	Cotton Lint and Seed	0	6	0.0	0	6
27	*Wool*	*0*	*6*	*0.0*	*0*	*6*
28	Wheat	0	6	0.0	0	6
29	Pulses All	0	6	0.0	0	6
30	Rubber	0	6	0.0	0	6
31	*Sheep and Goat Meat*	*0*	*6*	*0.0*	*0*	*6*
32	Sorghum	0	6	0.0	0	6
33	Soybean	0	6	0.0	0	6
34	Charcoal	0	6	0.0	0	6
35	Fuelwood (coniferous)	0	6	0.0	0	6
36	Other Industrial Roundwood	0	6	0.0	0	6
37	Pitprops	0	6	0.0	0	6
38	Mackerels and Others	0	6	ne	ne	ne
39	Lobsters	0	6	ne	ne	ne
40	Herrings and Others	0	6	ne	ne	ne
41	Mussels	ne	ne	ne	ne	ne
42	Oysters	0	6	ne	ne	ne
43	Clams	0	6	ne	ne	ne
44	*Sheep Meat*	*ne*	*ne*	*0.0*	*0*	*6*
45	*Goat Meat*	*ne*	*ne*	*0.0*	*0*	*6*
46	*Eggs (poultry)*	*0*	*6*	*0.0*	*0*	*6*
47	*Poultry Meat*			*0.0*	*0*	*6*
48	*Duck Meat*	*ne*	*ne*	*0.0*	*0*	*6*
	Regional relativity		192.8			203.8

Notes: * Italic type denotes a livestock product; ne: not estimated.
a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 6. Sub-Saharan Africa — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	Sub-Saharan Africa commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Fuelwood (non-coniferous)	1	1	77.6	1	1
2	Cocoa	9	1	13.0	6	1
3	Saw and Veneer Logs (non-coniferous)	6	1	12.6	6	1
4	Cassava	10	1	12.4	6	1
5	*Milk*	*8*	*1*	*10.7*	*7*	*1*
6	Palm Oil and Palm Kernel	9	1	8.6	9	1
7	*Beef and buffalo*	*9*	*1*	*7.4*	*10*	*2*
8	Charcoal	9	1	5.9	13	2
9	*Sheep and Goat Meat*	*11*	*2*	*5.1*	*15*	*2*
10	Other Industrial Round Wood	17	2	4.4	18	2
11	Rice	22	3	3.8	20	3
12	Millet	26	3	3.3	24	3
13	*Goat Meat*	*ne*	*ne*	*3.3*	*24*	*3*
14	Maize	27	3	2.9	27	3
15	Tilapias	22	3	ne	ne	ne
16	*Eggs (poultry)*	*22*	*3*	*2.7*	*29*	*3*
17	*Poultry Meat*			*2.7*	*29*	*3*
18	Sugar	25	3	2.6	30	3
19	Banana/Plantain	22	3	2.4	32	3
20	Pulses All	129	5	2.3	34	3
21	Groundnut	54	4	2.0	39	3
22	*Sheep Meat*	*ne*	*ne*	*2.0*	*39*	*3*
23	Saw and Veneer Logs (coniferous)	65	4	1.9	41	4
24	Fuelwood (coniferous)	54	4	1.3	60	4
25	Pulpwood	50	4	1.3	60	4
26	Herrings and others	59	4	ne	ne	ne
27	Cotton Lint and Seed	65	4	0.9	86	5
28	Sorghum	129	5	0.8	97	5
29	*Pig Meat*	*92*	*5*	*0.6*	*129*	*5*
30	Wheat	161	6	0.5	155	5
31	Demersal/Other Pelagic	129	5	ne	ne	ne
32	Potatoes	81	5	0.4	194	6
33	Soybean	215	6	0.4	194	6
34	Coconut	323	6	0.3	259	6
35	Coffee	215	6	0.5	155	5
36	*Wool*	*215*	*6*	*0.2*	*388*	*6*
37	Sweet Potato	323	6	0.2	388	6
38	Tunas, Bonitos, etc	323	6	ne	ne	ne
39	Rubber	645	6	0.2	388	6
40	Oranges and Tangerines	645	6	0.1	776	6
41	Mackerels and Others	645	6	ne	ne	ne
42	Prawns/Shrimps	645	6	ne	ne	ne
43	Lobsters	645	6	ne	ne	ne
44	Pitprops	645	6	0.0	0	6
45	Mussels	ne	ne	ne	ne	ne
46	Oysters	ne	ne	ne	ne	ne
47	Clams	ne	ne	ne	ne	ne
48	*Duck Meat*	*ne*	*ne*	*0.0*	*0*	*6*
	Regional relativity		17.8			15.7

Notes: * Italic type denotes a livestock product; ne: not estimated.
a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 7. West Asia, North Africa— gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	West Asia, North Africa commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Wheat	1	1	70.6	1	1
2	*Milk*	*2*	*1*	*36.6*	*2*	*1*
3	*Beef and Buffalo*	*3*	*1*	*35.0*	*2*	*1*
4	Oranges and Tangerines	3	1	24.0	3	1
5	*Sheep and Goat Meat*	*3*	*ne*	*22.5*	*3*	*1*
6	*Sheep Meat*	*ne*	*ne*	*18.2*	*4*	*1*
7	Pulses All	5	1	17.1	4	1
8	Rice	5	1	14.5	5	1
9	Sugar	6	1	12.6	6	1
10	Cotton Lint and Seed	4	1	12.5	6	1
11	Saw and Veneer Logs (coniferous)	5	1	11.8	6	1
12	*Eggs (poultry)*	*9*	*1*	*9.9*	*7*	*1*
13	*Poultry Meat*	*9*	*1*	*9.6*	*7*	*1*
14	Herrings and Others	7	1	ne	ne	ne
15	Fuelwood (non-coniferous)	7	1	7.9	9	1
16	Maize	11	2	7.4	10	1
17	Potatoes	10	1	6.6	11	2
18	Fuelwood (coniferous)	7	1	6.1	12	2
19	*Wool*	*14*	*2*	*4.7*	*15*	*2*
20	*Goat Meat*	*ne*	*ne*	*4.4*	*16*	*2*
21	Other Industrial Round Wood	34	3	2.2	32	3
22	Saw and Veneer Logs (non-coniferous)	22	3	2.2	32	3
23	Mackerels and Others	46	4	ne	ne	ne
24	Demersal/Other Pelagic	58	4	ne	ne	*ne*
25	Pulpwood	80	4	1.0	71	4
26	Banana/Plantain	107	5	0.9	78	4
27	Soybean	80	4	0.8	88	5
28	*Duck Meat*	*ne*	*ne*	*0.5*	*141*	*5*
29	Millet	92	5	0.0	0	6
30	Tunas, Bonitos etc	214	6	ne	ne	ne
31	Prawns/Shrimps	214	6	ne	ne	ne
32	Groundnut	641	6	0.1	706	6
33	*Pig Meat*	*641*	*6*	*0.1*	*706*	*6*
34	Cassava	0	6	0.0	.0	6
35	Palm Oil and Palm Kernel	0	6	0.0	0	6
36	Cocoa	0	6	0.0	0	6
37	Coconut	0	6	0.0	0	6
38	Coffee	0	6	0.0	0	6
39	Sweet Potato	0	6	0.0	0	6
40	Rubber	0	6	0.0	0	6
41	Sorghum	0	6	0.0	0	6
42	Charcoal	80	4	0.0	0	6
43	Pitprops	71	4	0.0	0	6
44	Lobsters	0	6	ne	ne	ne
45	Tilapias	0	6	ne	ne	ne
46	Mussels	ne	ne	ne	ne	ne
47	Oysters	ne	ne	ne	ne	ne
48	Clams	ne	ne	ne	ne	ne
	Regional relativity		18.1			17.3

Notes: * Italic type denotes a livestock product; ne: not estimated.

a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 8. Latin America — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	Latin America commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	Soybean	1	1	119.9	1	1
2	Fuelwood (non-coniferous)	1	1	101.9	1	1
3	*Milk*	*2*	*1*	*68.5*	*2*	*1*
4	*Beef and Buffalo*	*2*	*1*	*60.3*	*2*	*1*
5	Oranges and Tangerines	3	1	59.7	2	1
6	Sugar	2	1	58.7	2	1
7	Coffee	1	1	53.0	2	1
8	Saw and Veneer Logs (coniferous)	2	1	45.2	3	1
9	Herrings and Others	2	1	ne	ne	ne
10	*Poultry Meat*	*5*	*1*	*37.9*	*3*	*1*
11	Saw and Veneer Logs (non-coniferous)	3	1	35.0	3	1
12	Demersal/Other Pelagic	3	1	ne	ne	ne
13	*Pig Meat*	*2*	*1*	*28.7*	*4*	*1*
14	*Eggs (poultry)*	*5*	*1*	*28.2*	*4*	*1*
15	Maize	4	1	28.1	4	1
16	Rice	4	1	26.5	5	1
17	Pulpwood	6	1	24.0	5	1
18	Cocoa	6	1	47.5	3	1
19	Wheat	7	1	17.0	7	1
20	Charcoal	11	2	17.0	7	1
21	Prawns/Shrimps	6	1	ne	ne	ne
22	Fuelwood (coniferous)	9	1	12.7	9	1
23	Cassava	9	1	11.6	10	2
24	Banana/Plantain	9	1	9.3	13	2
25	*Sheep and Goat Meat*	*11*	*2*	*9.0*	*13*	*2*
26	*Sheep Meat*	*ne*	*ne*	*7.0*	*17*	*2*
27	Cotton Lint and Seed	14	2	6.6	18	2
28	Pulses All	16	2	5.9	20	3
29	*Wool*	*17*	*2*	*5.2*	*23*	*3*
30	Sorghum	25	3	4.6	26	3
31	Potatoes	22	3	4.4	27	3
32	Oysters	ne	ne	ne	ne	ne
33	Other Industrial Round Wood	26	3	4.2	29	3
34	Clams	ne	ne	ne	ne	ne
35	Rubber	36	3	2.9	41	4
36	Palm Oil and Palm Kernel	44	4	2.6	46	4
37	*Goat Meat*	*ne*	*ne*	*2.4*	*50*	*4*
38	Tilapias	53	4	ne	ne	ne
39	Mackerels and Others	56	4	ne	ne	ne
40	Lobsters	56	4	ne	ne	ne
41	Tunas, Bonitos etc	72	4	ne	ne	ne
42	Coconut	253	5	0.8	150	5
43	Mussels	ne	ne	ne	ne	ne
44	*Duck Meat*	*ne*	*ne*	*0.3*	*400*	*6*
45	Sweet Potato	507	6	0.1	1 199	6
46	Millet	0	6	0.0	0	6
47	Pitprops	507	6	0.0	0	6
48	Groundnut	1 013	6	0.1	1 199	6
	Regional relativity		11.5			10.2

Notes: * Italic type denotes a livestock product; ne: not estimated.

a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Table 9. Australia — gross present value of regional welfare benefits (measured in $USm over 30 years with 12% discount rate) assuming a regional research focus, break-even relativities, and regional commodity research priority groupings.

No.	Australia commodities	1985–88(a) Break-even relativity	1985–88(a) Priority group (1 = highest priority)	1988–90 Regional benefits	1988–90 Break-even relativity	1988–90 Priority group (1 = highest priority)
1	*Wool*	*1*	*1*	*68.0*	*1*	*1*
2	Wheat	1	1	48.8	1	1
3	Sugar	2	1	39.9	2	1
4	*Milk*	*2*	*1*	*39.4*	*2*	*1*
5	*Sheep and Goat Meat*	*2*	*1*	*34.7*	*2*	*1*
6	*Sheep Meat*	*2*	*ne*	*34.2*	*2*	*1*
7	Prawns/Shrimps	3	1	ne	ne	ne
8	Pulses All	9	1	21.3	3	1
9	*Beef and Buffalo*	*2*	*1*	*18.6*	*4*	*1*
10	Lobsters	5	1	ne	ne	ne
11	Cotton Lint and Seed	11	2	11.1	6	1
12	Saw and Veneer Logs (non-coniferous)	10	1	9.6	7	1
13	*Poultry Meat*	*11*	*2*	*9.3*	*7*	*1*
14	Rice	9	1	8.7	8	1
15	*Pig Meat*	*6*	*1*	*8.7*	*8*	*1*
16	Saw and Veneer Logs (coniferous)	10	1	7.8	9	1
17	Potatoes	10	1	6.8	10	2
18	Pulpwood	11	2	6.7	10	2
19	*Eggs (poultry)*	*13*	*2*	*4.7*	*14*	*2*
20	Oranges and Tangerines	17	2	3.9	17	2
21	Sorghum	16	2	3.7	18	2
22	Fuelwood (non-coniferous)	23	3	2.7	25	3
23	Oysters	ne	ne	ne	ne	ne
24	Banana/Plantain	63	4	1.4	49	*4*
25	Tunas, Bonitos etc	45	4	ne	ne	ne
26	Soybean	79	4	0.9	76	4
27	Maize	79	4	0.8	85	5
28	Other Industrial Round Wood	53	4	0.8	85	5
29	Fuelwood (coniferous)	90	5	0.8	85	5
30	Demersal/Other Pelagic	126	5	ne	ne	ne
31	*Gout Meat*	*ne*	*ne*	*0.5*	*136*	*5*
32	Charcoal	0	6	0.3	227	6
33	Groundnut	210	6	0.2	340	6
34	Millet	631	6	0.1	680	6
35	Mackerels and Others	631	6	ne	ne	ne
36	Pitprops	631	6	0.0	0	6
37	Mussels	ne	ne	ne	ne	ne
38	*Duck Meat*	*ne*	*ne*	*0.1*	*680*	*6*
39	Cassava	0	6	0.0	0	6
40	Palm Oil and Palm Kernel	0	6	0.0	0	6
41	Cocoa	0	6	0.0	0	6
42	Coconut	0	6	0.0	0	6
43	Coffee	0	6	0.0	0	6
44	Sweet Potato	0	6	0.0	0	6
45	Rubber	0	6	0.0	0	6
46	Tilapias	0	6	ne	ne	ne
47	Herrings and Others	0	6	ne	ne	ne
48	Clams	ne	ne	ne	ne	ne
	Regional relativity		18.4			17.9

Notes: * Italic type denotes a livestock product; ne: not estimated.

a: Sourced from Davis and Lubulwa (1995) based on 1985–1988 production data. Differences between the priority groupings of commodities in this paper and those in Davis and Lubulwa (1995) are due to differences in production data as updated in FAO (1994b).

Perhaps a more critical issue is the situation of an ACIAR project focusing primarily on the production environments of most importance to the collaborating partner country. In this case the potential gains to Australia will depend on the similarity in production environments and the expected spillovers of research impacts between these production environments. Given the diversity in production environments between countries, it is possible that the gains to Australia will be lower if such a research focus is included in the project. Thus a conflict between attaining maximum Australian benefits and maximum partner country gains is likely to arise.

The research evaluation database, through its modelling of research spillovers, contains information which may provide some insights into this issue. Although preliminary at that stage, Davis and Fearn (1991) provided some estimates of the benefits to Australia from the spillover of research results where the research is focused fully on the production environments of most importance to the countries in the mandate regions. The gains to Australia are likely to be smaller in this situation. Davis and Fearn show that, although in most cases there will still be gains, these are likely to be only 20–30% of those possible had an Australian focus been adopted. In many situations the project is likely to have a joint focus. Even then, a compromise in terms of Australian benefits will most likely occur.

One issue which may be important is whether the priorities using spillover gains to Australia are the same as or similar to those given by Australian-focused research. Davis and Fearn (1991) showed that for all regions, even though the absolute levels of benefits are different, the break-even relativities are similar. This suggests that the commodity emphasis is likely to be similar regardless of the type of research emphasis adopted. Clearly, the production environment emphasis for the research is likely to be of considerable importance. This conclusion applies to livestock products, but not necessarily to crops, fisheries and forestry.

Regional relativities

Relativities between the geographical regions are calculated by dividing the highest regional welfare gains, that is, for China, by each of the highest gains in the other regions. Results are given for each of the regions in the last row of Tables 2–9. China has a regional relativity of 1. All the other regions have higher figures. The higher the figure for regional relativity, the lower the ranking of that region with respect to China.

These relativities are summarised here for 1988–90 for ACIAR mandate regions.

Region	Regional relativity
South Asia	2.4
Southeast Asia	5.4
China	1.0
South Pacific	203.8
Sub-Saharan Africa	15.7
Australia	17.9

Conclusion

Tables 2–9 show that, taking into account all regions, the highest benefits from livestock research are likely to come from pig research in China. If the objective in investing in small ruminant research were to maximise regional welfare benefits, then the following would be the ACIAR mandate ranking of the different regions.

Region	Welfare benefit from sheep and goat over 30 years at 12% discount rate $USm	Break-even relativity (with respect to the commodity with the highest benefit in the region)	Priority group
China	50.0	24	3
Australia	22.5	2	1
South Asia	29.0	17	2
Sub-Saharan Africa	5.1	15	2
Southeast Asia	3.0	75	4
South Pacific	0.0	0	6

Care is required in using this type of information. In ACIAR, emphasis is placed on its use to highlight general trends and relativities aimed at focusing discussion on important issues. These tables of 'priorities' are not intended to be adopted as dicta but used in planning discussions to generate debate. There are often likely to be other strong reasons which may override potential research impacts and place more or less importance on some commodities — for example, in ACIAR's case there may be no Australian expertise for a particular livestock issue, there may be few researchable problems that can be identified, or the private sector may dominate research in that field.

It is seen from Tables 2–9 that there are some noticeable differences between regions in the number of livestock products in each of the six priority groups, e.g., South Pacific and Southeast Asia regions have no commodities in the group 1 set of relative benefits, while Sub-Saharan Africa has two of the seven commodities in this group. Perhaps not surprisingly, Australia has five livestock commodities in priority group 1. This information can be used as a basis for discussing whether, for example, consideration should be given to concentrating on a subset of ACIAR mandate regions and also whether certain livestock products should receive attention in some regions but not others. Clearly other information is required to finally resolve such decisions, but the potential relative benefits could be relevant to the discussions.

This paper highlights some features of the information system developed at ACIAR to support research priority-setting and decision-making. It presents a subset of this information which may be useful in generating discussions of various aspects of future directions for livestock research. There is still considerable scope to expand the range of information and also verify and validate much of the existing information. The information would be enhanced were estimates of such parameters as the production environment spillovers to be desegregated into research disciplines within a commodity.

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Small Ruminant Development in the Philippines

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Abstract

The potential value of small ruminant production in the Philippines is measured in terms of its suitability to smallhold farming systems which constitute the vast majority of the farming community. With 68% of the rural population living in poverty, small ruminant raising offers bright prospects of augmenting the dwindling supply of meat and milk in the country, providing economic employment to idle family members, providing additional income to families of smallholders and optimising utilisation of farm resources. The goat population in 1994 was reported to have reached 2.63 million head, about 99% of which was intended to supplement household income. Sheep raising, on the other hand, needs to be further promoted among smallhold farmers; its population as of 1994 was relatively low at 30 000–40 000 head. Among current production systems, integration with existing crops such as coconut promises to be rewarding, as farm by-products and residues, as well as the land, are put to better, more efficient use by the animals. Future R&D directions address such concerns as low productivity due to animal health, nutrition and feeding, housing, herd management, and husbandry practices; insufficient marketing systems to promote the commodity; inadequate credit facilities and incentives for smallhold ventures; lack of trained manpower; and unavailability of breeding stocks and production technology.

Global Population Growth and Food Requirements

POPULATION and income growth will remain important determinants of food supply and demand balances in the future. Having enough food for all is a fundamental concern.

Population in the developing countries will grow at an average of 1.7% per year, compared with 0.4% per year in the developed countries. The population of Southeast Asia, with about 440 million people in 1990, is projected to reach 690 million in 2020 (Rosegrant et al. 1995). In the Philippines, the 1990 population level of about 62 million is expected to reach 102 million by 2020.

Developing countries' consumption of food crops and livestock products will grow much faster than that of developed countries because of faster population growth (Table 1). For most cereals, demand in developing countries will grow by about 2% per year, while demand for meat will grow by about 3.2% per year. This relatively high consumption growth rate for livestock products will create pressure to increase output of crops to meet the strong demand for animal feeds.

Table 1. Projected average annual growth rates (%) in total demand for major commodities.

Commodity	Developed countries	Developing countries	Asia
Beef	0.37	2.81	4.11
Pigmeat	0.44	3.40	3.51
Sheepmeat	0.63	3.10	3.62
Poultry	0.93	3.28	3.90
Total meat	0.55	3.20	3.65
Eggs	0.77	3.27	3.48
Wheat	0.58	2.19	2.16
Rice	0.51	1.67	1.60
Maize	0.80	2.18	2.23
Other coarse grains	0.87	2.03	1.58
Total cereals	0.75	2.00	1.88
Roots and tubers	0.64	1.77	1.02
Soybeans	1.10	2.76	3.32

Source: IMPACT simulations results, as published in *Global Food Projections to 2020: Implications for Investment*, International Food Policy Research Institute (IFPRI) Discussion Paper 5.

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Average per capita demand levels of foodgrains and livestock products are expected to increase, but at a lower rate than in the past. In developing countries, the average annual expansion rate of per capita consumption of cereals would only be about 0.4%, from 240 kg per capita per year in 1990 to 270 kg per capita per year in 2020 (Table 2).

Declines in the rates of growth in per capita demand for meat in the developing world will be smaller than in the developed countries primarily because of the rapid dietary transitions that will continue to take place in many countries. The largest increases in meat demand will come from pigmeat and poultry, and China will account for much of this growth. Countries in Southeast Asia are also projected to exhibit strong per capita demand growth for most meat products. East Asian countries will remain the big consumers of beef.

The Philippine Scenario

After a period of stagnation during the early 1990s, the Philippines' gross domestic product (GDP) grew by around 5% in 1994, with a similar level of growth in 1995. This turnaround is primarily attributed to political stability and the pursuit of macro-economic policies by the current administration.

However, while growth rates have improved, the continued existence of significant levels of poverty has been alarming. Much of the poor is concentrated in the countryside, particularly in areas where the natural resource base is continuously depleted by a significant number of people for their livelihood. Poverty in the Philippines is largely rural, with 68% of the rural population living in poverty, as against 34% of the urban population. The vast majority of the rural poor are engaged in farming, with about two-thirds of the farming families considered poor.

The agricultural sector is central to the Philippine economy. However, despite periods of relatively high growth in the 1970s and 1980s averaging over 5% annually, and moderate growth in 1985–90 of around 3% annually, the rural economy did not benefit in terms of food self-sufficiency and improved quality of life for the rural poor.

Despite recent national GDP growth, agriculture continues to remain sluggish, growing by an average of around 1% annually in 1990–92 and 2% in 1993–94. The sector's performance in 1995 had been poor.

With the agricultural sector accounting for about a quarter of the country's GDP, half the employed work force, a fifth of the total export earnings, and agriculture-based industry over a tenth of GDP, the sector's growth is important in ensuring both higher levels of GDP for the country and improved quality of life of the rural poor.

The Challenge of Food Security

Each year there are more people in the world who do not get enough to eat. According to the United Nations Development Programme (UNDP), some 800 million people go to bed hungry every night. One in three children — about 180 million — are severely underweight, putting their healthy development and lives at risk. These numbers are likely to keep growing.

Experts have expressed concerns over a looming global food crisis primarily due to deteriorating agricultural systems caused by environmental degradation and the rapidly increasing population.

In the Philippines, the challenge of sustainable food security is immense. The increasing population of the country growing at an average of 2.4% annually, compounded by a lower growth rate in agricultural production, is a cause for alarm. This is evident especially among the poor in the countryside who cannot express their demand for food because they cannot afford to buy it. In a country like the Philippines where potential food sources abound, to allow such deprivation and suffering is intolerable.

Basic to the attainment of agri-industrialisation or any other economic development goal is a situation where every citizen of the nation is fed and gets proper nutrition. Until such time that food security is attained, all development efforts shall remain unfinished.

The problem of food insufficiency manifests itself not only in terms of starvation, but in malnutrition as well. It has been noted that malnutrition is a result of disparities in food production and distribution. It takes several forms but with only one known cure — an adequate and well-balanced diet.

The Philippine Livestock Development Plan

In view of the growing demand for more food and cheaper sources of protein in the medium-term period, the Philippines hopes to improve productivity of livestock and poultry and attain self-sufficiency in animal protein for human nutrition. In the end, it is expected that most Filipino families would have access to livestock and poultry products at affordable prices.

The R&D priorities of the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) and the National Agriculture and Natural Resources Research and Development Network (NARRDN), which the former coordinates, provides for the basis of the Philippines' Medium-Term Livestock Development Plan (1993–1998) of the Department of Agriculture (DA). The plan lays the foundation for a

Table 2. Projected annual per capita (kg) demand for livestock products and crops, 1990 and 2020: baseline scenario.

Commodity	Developed countries		Developing countries		Asia	
	1990	2020	1990	2020	1990	2020
Beef	25.78	25.59	4.41	6.29	1.49	3.21
Pigmeat	30.10	30.51	7.33	12.41	9.28	16.89
Sheepmeat	2.85	3.06	1.31	2.04	0.76	1.43
Poultry	18.73	21.97	3.47	5.68	2.18	4.43
Total meat	77.46	81.12	16.52	26.41	13.71	25.96
Eggs	14.58	16.29	4.31	7.01	4.03	7.28
Wheat	192.56	203.47	72.65	86.30	67.08	82.40
Rice	13.79	14.28	83.28	85.08	111.53	116.21
Maize	208.34	234.78	54.10	64.21	44.52	55.76
Other coarse grains	189.42	218.49	30.31	34.42	17.38	17.96
Total cereals	604.12	671.02	240.34	270.01	240.52	272.34
Roots and tubers	177.63	191.13	90.40	94.91	72.34	63.42
Soybeans	48.17	59.46	11.61	16.34	7.07	12.18

Source: IMPACT simulation results, as published in Global Food Projections to 2020: Implications for Investment, International Food Policy Research Institute (IFPRI) Discussion Paper 5.

productive and sustainable livestock industry that is anchored on specific commodity programs while moving holistically toward the development of the entire industry. An integrated approach is being adopted in the course of its implementation. The component programs are as follows:

- The breeding cattle development program. The program targets to double the beef cattle population to 3.0 million.
- The dairy program. Within the program period, a total of 216 dairy cooperatives with about 5000–6000 members will be organised, while 37 500 head of dairy animals will be infused.
- The carabao program. It hopes to stabilise the carabao population to 2.5 million. Likewise, the program will harness the full potential of the carabao as a milk animal which will at the same time contribute to the beef supply.
- The small ruminant program. The program target is to increase the population of sheep and goats to 3.4 million primarily to be raised by smallhold farmers as an economic project integrated in its farming operations.
- The poultry program. The priority activities have been designed to assist industry initiatives led by the private sector. The program will likewise attend to the conservation and improvement of indigenous chickens and ducks.
- The pig program. It will focus on the development of new markets for its products.
- Other component programs such as a stock farm development program, quarantine station and animal health, and post production and market support programs.

Social and Economic Importance of the Small Ruminant Industry

The Philippines produces barely 1% of its milk and 40% of its beef requirements. It is, however, almost sufficient in pork and poultry products. With the decline in livestock population during recent years, along with the continuing increase in human population, livestock products have become insufficient.

The potential value of small ruminant production in the country is measured in terms of its suitability to smallhold farming systems which constitute the vast majority of the farming community. With 68% of the rural population living in poverty, small ruminant raising offers bright prospects of augmenting the dwindling supply of meat and milk in the country; providing economic employment to idle family members; providing additional income to families of smallholders; and optimising utilisation of farm resources (Sumayao et al. 1993).

Goat farming

Goat farming forms an important and integral part of smallhold agriculture in the Philippines. There were 2.63 million head in 1994 (Table 3). Goats posted an annual average growth rate of 3.11% between 1980 and 1988, the highest so far among the ruminant population.

A majority of the goats are kept by smallhold farmers in rural and rural-fringe areas. About 99% are intended to supplement household income. The pattern of ownership and the number of goats raised are generally secondary and in small scale. A few large and commercial scale goat farms are found scattered in the provinces. The largest of these farms have no more than 400 breeding animals for meat (chevon) and/or milk production.

Table 3. Goat population, Philippines.

Year	Population (millions)
1980	1.67
1981	1.70
1982	1.78
1983	1.86
1984	2.36
1985	2.19
1986	2.17
1987	2.01
1988	2.12
1989	2.21
1990	2.19
1991	2.12
1992	2.30
1993	2.56
1994*	2.63

*Preliminary estimates.

Goats were believed to have been introduced to the Philippines during the early colonial periods. Since then, they have thrived and undergone genetic deterioration due to inbreeding, although some resistant and adaptable breeds have evolved under local conditions, such as the Dadiangas goats from Mindanao. From 1947 to date, exotic breeds of goats such as Anglo-Nubian, Saanen, Alpine, Toggenburg, and Jamnapari, among others, were imported from the USA, Australia, and India to upgrade the local breeds (PCARRD 1985).

Goat farming offers several advantages. Goats, being small animals, are commonly known in the Philippines as the 'poor man's cow' because their upkeep entails only a small initial investment and a correspondingly small risk of loss. This makes goat farming an attractive proposition for households and for subsistence farming especially for poor families. Because goats are small, both women and children can conveniently look after them. Also, they occupy only a small housing space.

The ability to thrive even on browse and the ability to digest cellulose efficiently are distinctive feeding characteristics of goats. Goats can survive in environments in which nutrition ordinarily cannot support cattle during the dry season. They can subsist on vegetation unpalatable to other ruminants.

Goats have other advantages over other ruminants such as they mature early, have high fertility, are capable of multiple births and undergo a short gestation period. Goats can be bred as early as 8-months old. Goats in the foundation herd could yield milk five months after conception. The first carcass or kid crop can be sold in less than a year.

In the Philippines, the increased production of milk and meat can help solve the problem of protein malnutrition. The short-life generation interval of goats makes it possible to increase production of both milk and meat in a relatively shorter time. Chevon, the meat of goat, is a popular delicacy in some places in the country and is part of the regular food intake of people, particularly in Northern Luzon.

Sheep raising

In the Philippines, as in other developing countries in Asia and the Pacific region, sheep raising offers good prospects and opportunities particularly for small- and medium-scale farmers who have very limited farmland areas. However, the raising of sheep in the country needs to be further promoted among smallhold farmers, as its population is very low.

Integrated into the traditional farming system, sheep raising can contribute to family nutrition and income. The Filipino family, traditionally a crop farmer, has an average of six members, with two to three members usually idle or unemployed. The inclusion of small ruminants, like sheep, in crop farming will provide them with employment and encourage the use of farm by-products to feed the sheep, thereby minimising the risk of a monocrop system.

In 1987, a total of 7308 head of sheep was reported based on a national survey covering the 12 regions of the country. In 1995, the number of head has reached 30 000 to 40 000.

Generally, farmers raising sheep in the Philippines own not more than seven hectares of land and have been raising sheep for at least five years. The animals are reared like goats, either tethered or let loose to feed on any available grasses or weeds in vacant lots or under plantation crops.

Most of the farms raising sheep are flat lands with an elevation of not more than 20 m above sea level. Sheep in mountainous farm areas are as productive as those kept in the lowlands.

Aside from the biological advantages of sheep in terms of size, early maturity and shorter reproductive cycle, the animals are easy to manage in flocks because they graze close together. This grazing behavior makes them effective feed utilisers and controllers under plantation crops like coconut, coffee, orchard, rubber, etc. Sometimes the animals are referred to as living mowers (PCARRD 1989).

Mutton or lamb easily finds acceptance among Filipino consumers, considering that mutton can be prepared just like chevon or goat meat. In the future, cottage industries could be established to process wool into carpets and home ornaments. Sheepskins may also be processed for leather.

Current Production Systems

Tethering

Tethering is the traditional method of raising small ruminants not only in the Philippines but throughout Asia. Farmers tie their animals with a rope of about 6–10 metres long and are brought to areas where vegetation abounds. The animals practically stay in the grazing area the whole day. They are transferred once or twice a day to areas where more native forage crops are available. Tethering requires the least labor. One to five animals can be easily handled by a woman or a child. Usually, small ruminants are raised by these members of the family, while cattle and carabaos are raised by the farmers themselves. Tethering, however, leads to overgrazing. Thus, there is a lack of feeds during the summer months.

Extensive production system

Herds of sheep and goats under the extensive management system are allowed to graze freely on communal areas, empty paddy fields or vegetable areas after harvest. While this system is common among goat raisers, the problem of uncontrolled breeding that leads to inbreeding is quite common. In a few semi-commercial farms where improved husbandry practices are employed, breed is controlled and an appropriate male-female ratio of 1:25 is practiced. Kids are not allowed to run with the breeders and male kids are separated from the female animals at the age of 3–5 months.

Integration with cropping system

This system enables the raising of sheep and goats as a complementary activity with existing crops. It involves the integration of small ruminant raising into established plantations such as coconut, rubber, oil palm, etc. Plantation undergrowth (mainly grasses, weeds, and legumes) can be used as feed.

The Small Ruminant-Coconut Systems Project (SRCSP), jointly funded by the Government of the Philippines and the International Development Research Center (IDRC), was piloted in Sta. Cruz, Laguna, Philippines in 1988. Hinged upon the premise that farm by-products and residues from the coconut plantation can be put to better use by the animals in the farm, the project team developed schemes to improve overall productivity.

The integration system adopted in the SRCSP depended on the judicious manipulation of the stocking rate, development of appropriate feeding systems, and a practical herd health program that would redound to high survival rate and better economic returns to the farmers. The project team introduced to the participating coconut farmers production systems that required minimum inputs on the farmers' part. These include:

(a) stocking of one (1) hectare of native grassland within a coconut plantation with 10 mature goats or 10 small ruminant equivalents (SRE);
(b) supplementation with mineral mixtures or regular administration of injectable calcium to breeding bucks to prevent posterior paralysis;
(c) construction of elevated animal sheds made of local materials such as bamboo and coconut, with a floor space of 1.5 square metres/animal;
(d) use of alternative materials to expensive barbed wire for fencing;
(e) adoption of the flexible grazing system (FGS) for the right grass-legume combination in the grassland-legume pasture of the coconut holdings;
(f) supplementation with leguminous plants during the dry-hot summer months when feed resources are scanty, and a cut-and-carry system during the wet season as animals are reluctant to graze in wet pasture;
(g) adoption of a planned health program which consists of separation of pregnant animals and neonates, deworming, vaccination, mineral supplementation, and the cut-and-carry system of feeding when necessary.

Semi-intensive or partial grazing

Animals are allowed to graze in communal grazing areas or under plantations for at least four hours. Then the animals are herded back to the stalls or barns and given forage or crop residues. This production system ensures close monitoring of the reproductive and health status of the animals. Moreover, concentrate and mineral supplementation is highly possible for the animals to receive the right amount of dry matter and essential nutrients.

Intensive production system

This system is characterised by the complete confinement of animals in elevated stalls and feeding of cultivated forage crops. A few commercial farms, R&D institutions, and government stock farms generally adopt this system. In general, the high costs of forage production, housing, and labor limit the use of this system in small ruminant production.

Future Research and Development Directions

Exercising its central leadership and coordination of national R&D efforts, PCARRD has spearheaded the development of the livestock R&D framework for 1995–2000. Such prioritisation carefully plans and allocates the utilisation of limited funds and manpower resources to derive optimum benefits.

The livestock R&D framework (Table 4) has been formulated through consultations and collective efforts of multi-agency, multi-disciplinary teams and a pool of experts. In the implementation of the plan, the collaborative relationships among R&D institutions is reinforced, and its effectiveness is multiplied by the pooling of efforts in networking activities and broadening of linkages with the private sector (Faylon and Roxas 1995).

Specifically, the small ruminant commodity team of the National Livestock Research and Development Network formed by PCARRD has identified priority R&D areas as follows (Faylon 1991):

Priority	Researchable areas:
1	Technology transfer system for small ruminants.
2	Effective and economical prevention and control of major diseases and parasites.
3	Nutrition and feeding systems for improved production.
4	Production and management system studies under different agroecological zones and socioeconomic situations.
5	Breeding and reproduction studies.
6	Processing and utilisation of products and by-products.

The small ruminant R&D network is currently composed of two national centres, four regional centres, and 12 cooperating stations. The national centres conduct basic and applied researches on small ruminants and have the capability to do research across a broad range of disciplines such as physiology, biochemistry, biology, systematics, genetics and biometry.

The regional centres conduct applied studies of major importance in the regions where the centers are located. These centers verify R&D results from the national centers which show potential for application in specific regions. The cooperation stations provide facilities and/or sites where adaptive trials or field experiments are undertaken considering the microenvironmental differences. There were about 92 completed R&D studies on small ruminants during the period 1986–1995. To date, there are nine on-going studies on small ruminants.

Studies to develop strategies to improve the production efficiency of goats as a source of meat and milk need to be undertaken, this in spite of the limited technical know-how on the appropriate

Table 4. The medium-term Philippine livestock R&D priorities, 1995–2000.

R&D priorities	Priority commodities
1. Animal health	All livestock commodities
1.1 Control and eradication of foot and mouth disease (FMD)	
1.2 Control and eradication of economically important diseases of swine, poultry and ruminants	
2. Genetic resource and biodiversity	
2.1 Characterisation, conception and improvement of indigenous livestock and forage crops	
3. Production systems research	
3.1 Commercial farms	Swine, poultry and cattle
3.1.1 Monitoring of production performance of selected farms	
3.1.2 Waste management	
3.2 Smallhold farms	All livestock commodities
3.2.1 Integrated total farm systems analysis	
3.3 Industry profile/state-of-the-art projects	All livestock commodities
4. Feed resources	Ruminant commodities
4.1 Development of technologies and strategies to promote consistent feeding among ruminants	
4.2 Regional performance trials	
5. Technology transfer	All livestock commodities
5.1 Technology promotion	
5.2 Technology commercialisation/incubator	
5.3 Applied communication	
5.4 Management information systems	
6. Policy advocacy and socioeconomic studies	All livestock commodities

husbandry of sheep. Specific for goats, some of the constraints to their greater utilisation for food are as follows:

- low productivity due to animal health, nutrition and feeding, housing, herd management and husbandry practices;
- insufficient marketing systems to promote the commodity;
- inadequate credit facilities and incentives for smallhold ventures;
- lack of trained manpower;
- unavailability of breeding stocks and production technology.

To address these constraints, the following strategies/directions shall be pursued over the medium term:

(1) supervised credit scheme to areas identified as goat production zones where there are available pasture/forage;
(2) meaningful extension services, with the active participation of the private sector/non-government organisations (NGOs), on disease control, emergency treatment, pasture improvement, feeding systems, marketing assistance, and farmers' training;
(3) feeding systems development for smallhold farmers, to include economics of pasture improvement in coconut and other plantations;
(4) development of a breed combination with good growth rate, reproductive performance, and optimum heat tolerance;
(5) establishment of marketing structures in addition to traditional outlets;
(6) involvement of farmers' associations and NGOs in the campaign to promote small ruminant production among farmers, and the conduct of training to increase the knowledge and skills of farmers.

While the steady expansion of the Philippines' human population continues to put pressure on land availability for livestock production and, eventually on the food security of the nation, the development of the small ruminant industry in the country remains a bright prospect, especially for the toiling masses.

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Small Ruminant Development in Vietnam

Luu Trong Hieu[1]

VIETNAM stretches north to south between latitude 24°N and 9°N. In general, the country has a tropical monsoon climate, but its altitude and topographical configuration create regional climatic variations.

Agriculture occupies 21% of the country's total area. With an agricultural land area of 6.9 million hectares, Vietnam has an extremely small area of arable land per capita, 1075 m^2. The distribution of arable land among different regions of the country is also uneven. In the Red River Delta where the pressure of the population on land is highest, only 590 m^2 of arable land is available per person, or 2400 m^2 per person actively engaged in agriculture. In the Mekong River Delta, these figures are 1730 m^2 and 4630 m^2 respectively.

It is estimated that another 2.8 million hectares can be brought under cultivation, of which over 1 million hectares have irrigation potential. On the negative side, Vietnam's agricultural land is threatened as a result of deforestation, soil erosion and exhaustion. Some 3 million hectares in the deltas have saline and/or acid sulfate soil.

Vietnam has two main granaries — the Mekong Delta and the Red River Delta lying far apart and linked to each other by a poor transport system. This creates problems for the exchange of commodities and the distribution of inputs. The length and topography of the country make it suitable for cultivation of tropical as well as subtropical crops. However agriculture has always been dominated by rice cultivation.

Food grain production, more than 85% of which consists of paddy, accounts for nearly 50% of gross agricultural production. Other food crops are maize, potato, sweet potato and cassava. Industrial crops and livestock production account for 24% and 26% of gross agricultural production respectively. In recent years, with the drive toward export crops, both areas under cultivation and production of export crops such as rice, tea, coffee, peanut, cashew nut and rubber have increased significantly.

The total population of Vietnam is now 73 million. According to the results of the 1989 census, the Vietnamese population was 64.4 million, reflecting an average growth rate of 2.1% since the previous census of 1979. The urban population is 20% of the total, and the two largest cities, Ha Noi and HoChiMinh City, have around 3 and 5 million people respectively. The official statistics indicate a steady decline in population growth rates, from 3.2% in 1976 to 2.1% in 1986, due mainly to a decline in the birth rate from 39.5 to 28 per thousand.

During the past decade, considerable progress has been made towards ensuring a basic food supply to the Vietnamese population through increased food grain production. In 1995, total food production in paddy equivalent achieved the target of 27 million tonnes, the highest recorded so far:

1991	21.9 million tonnes
1992	24.2 million tonnes
1993	25.2 million tonnes
1994	26.4 million tonnes

and the annual food output per capita increased accordingly:

1991	325 kg/person
1992	349 kg/person
1993	353 kg/person.

Consumption

While the major foodstuffs are cereals and starch-rich root crops, pork and fish are important animal protein sources in the Vietnamese diet. According to Phelan (1995), the average meat consumption in HoChiMinh City was estimated at 18.6 kg per capita per year comprising 10.8 kg pork, 4.0 kg beef or buffalo meat and 3.8 kg poultry meat.

There is a diversity in types and nutritive quality of meat and meat products. However, production within HoChiMinh City met only around 30% of the

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requirement during the period of 1991–1993. There is considerable movement of both meat and live animals from the Mekong Delta, the Western Highland and Central Vietnam to HoChiMinh City. Table 1 shows the meat requirement and supply in HoChiMinh City during 1991–1993.

Table 1. Meat requirement and supply in HoChiMinh City during 1991–1993.

	1991	1992	1993
Population (million)	4.3	4.4	4.6
Requirement per person			
Meat (kg/year)	13.2	15.6	16.8
Fish (kg/year)	20.4	19.2	21.6
Eggs (egg/year)	37.0	61.0	84.0
Requirement of HoChiMinh City			
Meat (1000 t/year)	56.0	69.0	77.0
Fish (1000 t/year)	85.0	87.0	99.0
Supply from HoChiMinh City			
Meat (1000 t/year)	19.6	22.0	22.6
Fish (1000 t/year)	11.8	10.5	18.2
Ratio between supply and requirement (%)			
Meat	34.8	31.9	29.4
Fish	13.7	12.4	18.4

Source: Statistical Yearbook, Vietnam.

There are disparities between social groups and the estimated 60% of the population below the poverty line have a meat intake much lower than the average. The total protein content in the diet may be sufficient but the average ratio 70% plant to 30% animal protein is not optimal. The ratio is less favorable in the poorest group where meat is a scarce source of protein.

The milk consumption per capita in Vietnam in 1993 was estimated around 2.5 litres. This low figure compares with 1.5 litres in 1991 and 2.0 litres in 1992. Consumption is higher in HoChiMinh City and surrounding areas. Although local consumption has increased rapidly, almost 90% of milk supplies in Vietnam are imported. Total imports in 1991 were 96 million litres and this rose to 130.4 million litres in 1992. In 1993, the total availability was 18.2 million litres liquid milk equivalent of fresh milk, 136.0 million litres liquid milk equivalent of condensed milk and 49.3 million litres liquid milk equivalent of powdered milk.

Livestock Production

To improve the diet of the population, there is a great need to increase livestock production based on better use of locally available feed resources and to increase subsidiary crops contributing to the availability of animal feed. Livestock production in Vietnam has been growing steadily over the past 10 years. Livestock and poultry production are shown in Table 2.

Table 2. Livestock and poultry population (thousands).

	1992	1992	1994
Pig	12140	14800	15570
Cattle	3151	3330	3460
Buffalo	2885	2960	2970
Goat	312.3	353	370
Sheep	3	3	—
Deer	12	12	—
Chicken	97500	102390	100627
Duck	27000	31000	32000

Source: Le Viet Ly, 1996.

The livestock production system in Vietnam remains very traditional. Its primary role is to satisfy the demands for draft power and organic manure in crop cultivation. Product offtake is constrained by strict limits on feed availability and quality. The major animal feed resources are the locally available by-products (rice bran, broken rice, waste paddy), crop residue (rice straw, sugar cane tops, bagasse, sweet potato leaves) and low quality native grasses.

Livestock production now is almost entirely managed by the family or private sectors. In the delta or coastal areas, the typical scale of family units is 1–2 buffalo, 2–3 cattle, 1–2 pigs and 5–10 laying hens, although in the south, larger scale family operations have developed rapidly mainly in duck, chicken, pig and sometimes beef and dairy cattle raising. Open access pasture in conjunction with family herd management has led to a sharp increase in cattle and buffalo numbers, accelerating pressure on already over-grazed lands. At the same time, migration to upland areas and development of marginal lands for food production have reduced available pasture areas.

Goat Production

The government considers dairy goats as an alternative to dairy cattle in view of their increasing importance and role in elevating welfare and nutritional status of rural poor families. Dairy goats are raised in the rural and suburban areas, involving women and children who are closely associated with the care and management of the species. Milk is produced for home consumption as well as for commercial sales.

In 1992, there were 312 000 goats in Vietnam of which 208 000 are in the North and 104 000 are in the South (Thong 1993; Lich 1993). Goats are raised around big cities such as Ha Noi, Hue, HoChiMinh

City, Da Lat, VungTau, DaNang, Hai Phong, and other provinces such as Long An, Tien Giang, Ben Tre, Ninh Thuan, Ninh Binh, Ha Tay, Bac Thai and Cao Bang. The goat population in Vietnam rose to 353 000 in 1993, 370 000 in 1994 and 410 000 in 1995.

The local goat, commonly named 'Grass Goat,' is small in size and a poor milk producer; meanwhile, the Bac Thao breed is a dual purpose goat and believed to be the crossing of Saanen, Alpine, Jamnapari and Beetel goats (Hung 1993).

In 1993, the University of Agriculture and Forestry of HoChiMinh City received 10 Anglo Nubian goats as a gift from the Southern Baptist Mission in the United States and the Ministry of Agriculture and Rural Development has received a herd of more than 500 dairy goats from the Government of India.

In HoChiMinh City, Tien Giang, Long An, Ben Tre and Dong Nai the average goat herd is small, an average of 10 to 20 does with one or two breeding bucks.

Farmers pay more attention to breeding does than bucks. Feeding practices vary between and within regions. In Tien Giang, Long An and Ben Tre provinces, dairy goat are fed Sesbania leaves, natural grasses, rice bran, coconut meal. Meanwhile, in HoChiMinh City, goats are fed crop residues such as peanut vines, agro-industry by-products such as soybean residue, mung bean sprouted waste, pineapple wastes. Goats are kept in barns and milked twice a day (Hung 1993).

Ninh Thuan Province in South Central Vietnam is the most developed region for goat and sheep production because it is the most arid region with average rainfall about 600–700 mm/year, and is related to an ethnical reference.

The average goat herd in Ninh Thuan is 80 head. Some families raise a herd of 700, but most of them raise 200 to 300. Goats and sheep graze in the morning in the hills and mountains in the natural herding grounds where sources of natural vegetation are available and return to their barns in the afternoon. Does with kids are given additional feed such as pea leaves, straw or molasses when they return to the barn. The barn for goats is very simple, with a wooden floor for a small herd, and only a fence for a larger herd (Mai 1993). There is a low incidence of disease outbreaks in dairy goats, with some common health problems like diarrhea, tympany, and scabies. It is also considered important to reduce the mortality rate of kids through preventive measures against infectious and parasitic diseases (Hung 1993).

Goat meat is the preferred meat in HoChiMinh City and other big cities, especially in restaurants where guests can be entertained to feasts with fried meat, curry and steamboat. In Ninh Thuan, the Cham people use goat meat in religious celebrations, i.e. the traditional Kate Festival. Goat milk is not only an excellent food to overcome malnutrition but it is also used as a kind of skin cream by women.

Conclusion

In view of its increasing importance and role in elevating the welfare and nutritional status of rural poor families, there is growing interest in goat-raising in Vietnam. In order to promote goat production, a national program on goat research and development should be established with the commitment of all parties concerned.

Genetic improvement has been given first priority. However, the existing local genetic resources should be fully studied before there is large scale use of imported breeds. The use of indigenous breeds will take on economic significance in view of their greater adaptability to adverse environmental conditions and to feed of lower nutritional value.

Feeding systems should focus on improving methods of processing the biomass such as cassava, sugarcane, multi-purpose trees with emphasis on their use as feed (An et al. 1993; An and Man 1994; Man et al. 1994; Tien et al. 1994; Binh and Chinh 1994). This will enable increases in the productivity and efficiency of livestock within the context of sustainable, integrated farming systems that make optimum use of the locally available resources, in a context where agricultural priorities are for human food and where there is maximum conservation of the environment. The integration of crops and livestock farming has increasingly gained importance as an integral part of the effort to optimise resource use and work towards sustainable animal production systems. The Mindanao Baptist Rural Life Center Simple Agro Livestock Technology usually called SALT2 combining Sloping Agricultural Land Technology and goat raising has been introduced in Vietnam. This goat-based agroforestry system will be of considerable value in improving agricultural production in environmentally fragile areas, specially in hilly areas.

Disease prevention is also emphasised and it is important that sustainable disease control should be followed to ensure a good environment. Minimal drenching, grazing management and resistant hosts would all be integrated into a program to achieve sustainable parasite control.

Finally there is an urgent need to establish an appropriate marketing system to link producers to the market. The opportunity for sustainable livestock production can only be exploited if these linkages are established.

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Priority in Small Ruminant Development in Malaysia

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Abstract

Small ruminant production has been an integral agricultural activity for years. Thus far, it has had a limited social and economic importance to the agricultural industry. Since 1985, efforts have been made to expand the small ruminant industry primarily through integration of sheep in the four million hectares of rubber and oil palm plantations. Goat farming in the plantations has not been given due emphasis on account of the browsing habits of goats.

While prolificacy and fertility have improved over the years from 54% to 81%, mortality and mutton (both sheep and goat meat) output have thus far been variable. Overall mortality ranged between 3.7% and 44.4%. Local production of mutton contributed merely 7% of the total demand in 1994. The shortfall in mutton production was made up by imports.

While smallholder production for supplementary income has been profitable, commercial management under plantation conditions continues to face problems. The constraints to optimal development are the lack of skills in sheep husbandry, high investment in relation to returns and problems related to health management, primarily pneumonia and helminthiasis. Currently, the relative success achieved in cattle integration is more appealing to plantation management.

Future prospects for overcoming existing constraints lie in the ability to demonstrate an attractive economic return from sheep integration. This entails human resource development, research into predisposing causes of respiratory problems and the need to overcome the problem of worm burden. Attempts 'to breed the wool out' in local and imported sheep is necessary in the development of a suitable breed for Malaysia.

SMALL ruminant production in Malaysia is relatively minor compared with other subsectors of the livestock industry. Early efforts to promote the small ruminant industry were primarily targeted towards goat farming. Traditionally, keeping a few goats and sheep around the villages by smallholders has been an integral part of agricultural activity.

Goats are indigenous to Malaysia. Goat-rearing was common among the estate workers and in rural areas. Goats were reared as a source of protein, both for meat and milk, and to supplement income.

Sheep rearing goes back to the colonial days when the British brought along a few animals for breeding purposes. However, the breed types are not known. In 1955, the Department of Veterinary Services (DVS) launched a sheep improvement scheme in Kelantan. Three decades later (1985), greater emphasis was given to the integration of sheep with permanent tree crops.

Social and Economic Importance of Small Ruminants

Until recent times, the economic importance of sheep and goats in Malaysia has been only to provide supplementary income from mutton production. Some milk from goats is consumed, mainly fresh, in the villages and in urban fringe areas. Currently, little use is being made of skins. Goat skins, however, are of some economic importance and are used in the leather trade and in handicraft production, e.g., shadow play (Wayang Kulit) and drums. Goats,

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Table 1. Annual consumption, production, importation self-sufficiency level of mutton, 1985–1994.

Year	Consumption tonnes	Production tonnes	Imports tonnes	Per capita consumption kg	Self-sufficiency level (SSL) %
1985	6302	580	5722	0.41	9.20
1986	6345	586	5759	0.49	9.24
1987	6595	496	6099	0.48	7.52
1988	6808	526	6282	0.49	7.73
1989	6548	590	5958	0.46	9.01
1990	7283	658	6625	0.50	9.03
1991	7437	672	6765	0.50	9.04
1992	9035	658	8377	0.59	7.28
1993	8836	607	8229	0.57	6.87
1994	9509	616	8893	1.00	6.48

Source: Department of Veterinary Services.

despite their low profile in the Malaysia livestock sector, have a special economic importance to the goat rearers as they have a preference for mutton and milk as a source of animal protein.

The human population in Peninsular Malaysia is 17 million, and its annual increase is about 2.35% (Department of Statistics 1994). Although mutton (meat of sheep and goat) is consumed by all, there is a segment of the Malaysian community that has a special preference for it. Consumers seem to prefer goat meat to that of sheep and mutton continues to command a higher price.

Mutton consumption patterns are affected by several factors. When feed is scarce, many farmers sell their animals. They are also sold for cash in times of need, both resulting in increased numbers of animals for slaughter. The availability and consumption of local mutton is also higher in Kelantan, Kedah, Negeri Sembilan and Johor as well as in urban areas.

The trend in consumption during the past decade showed that there has been a steady annual increase (Table 1) from 6302 metric tonnes in 1985 to more that 9509 metric tonnes in 1994, with an average annual rate of increase of 15%. During the same period, the estimated per capita consumption increased from 0.4 kg in 1985 to 1.0 kg in 1994.

The current local production of mutton is about 6.48% of the total requirement. About 60% of the local mutton production comes from goat meat. There has been an erratic trend in the local supply of mutton between 1985 and 1994. The total local production of mutton continues to be small. Previous efforts to promote small ruminant farming has not resulted in higher productivity or significant increase in mutton production. The deficiency was met by imports of frozen mutton and the slaughter of sheep and goats from Australia and New Zealand.

Promotion and Performance of the Small Ruminant Industry

Currently, the small ruminant population in Malaysia is 486 000 head which comprises 258 000 goats and 228 000 sheep (Table 2). The Livestock census of 1994 indicates a decrease of 5.6% of goats and an increase of 29.1% for sheep during the corresponding years. The net rate of increase in small ruminants for the corresponding years is 13.8% per annum. The reduction in the goat population is due to a high extraction rate and lack of emphasis on development.

Table 2. Population of sheep and goats in Peninsular Malaysia, 1985–1994.

Year	Goat	Sheep	Total
1985	273 586	78 305	351 891
1986	258 101	90 359	348 460
1987	269 113	128 383	397 496
1988	277 900	148 159	426 059
1989	283 240	181 002	464 242
1990	281 759	199 905	481 664
1991	288 516	234 901	523 417
1992	279 365	242 958	522 323
1993	277 065	244 023	521 088
1994	258 220	227 800	486 020

Source: Department of Veterinary Services 1995.

The goat population in Malaysia is mainly of the Katjang breed. It has also been crossed with the Jamnapari, Anglo Nubian, Alpine, Saanen, Toggenburg, Australian Feral and lately the Boer breed. The average birth and weaning weight of Kambing Katjang is 1.8 kg and 13.0 kg respectively. The average adult weight being 20–25 kg. Crossbred goats, however, are larger with an average weight of 36 kg for an adult male and 30 kg for an adult female.

The Malaysian indigenous sheep is known as Malin. They are of the thin tail variety with coarse wool whose average weight at birth is 1.7 kg, growing to an average weight of 17–20 kg at 12 months. An average adult would weigh between 17–22 kg. From 1985, various exotic breeds have been imported such as Dorset Horn, Wiltshire, Suffolk, Romney and Commercial Merino Border Leicester crosses by the Department of Veterinary Services. These animals were distributed to farmers to upgrade the local Malin sheep. Lately, the hair breeds of sheep, such as Santa Ines, Morada Nova and Barbados Blackbelly, were imported to be crossed with local animals. The general conclusion of all these crosses was that any crossbred was at least bigger than the Malin and that the temperate purebreds do not thrive or breed well in this country. The hair breed crosses are more adaptable to the environment and show higher productivity compared to the wool purebreds.

The Malaysian Government, through the Veterinary Services Department, is committed to the development of the small ruminant industry in Malaysia. This is being done by convincing the plantations sector to integrate sheep with oil palm and rubber crops, encouraging private sector involvement in food production, encouraging smallholders to develop technical skills through training, and providing health services.

Previously, Malaysia did not have a tradition of commercial sheep or goat farming. Although goats possess good attributes such as being small and hardy with a relatively high reproductive efficiency, the feeding habits of the animal tend to be damaging to the environment. It is most difficult to herd goats in a confined plot of land under a controlled grazing system and so not much attention has been given to goats. It is strongly believed that sheep farming in plantations will play a major social and economic role in the expansion of small ruminant production.

There are prevailing factors that favour the need to integrate ruminants in the plantations. There is a scarcity of agricultural land solely intended for livestock production. The bulk of the agricultural land is under rubber and oil palm crops which occupies around four million hectares. The plantation sector provides a huge potential for ruminant farming from the availability of forage or undergrowth. There is also the growing concern about environmental pollution from the excessive use of chemicals such as fertilisers and weedicides. Other factors which necessitate the integration of ruminants with tree crops are the fluctuating prices of the commodity and an acute shortage of manpower.

The Rubber Research Institute of Malaysia devoted some efforts to promoting goat and sheep farming on smallholder rubber farms in mid-1970s (Ani et al. 1985). This was intended to provide supplementary income to the farmers. This livestock–crop integration was not geared to maximise economic production but rather to broaden the income base and avert risk. Research findings by government agencies such as DVS, RRIM, MARDI, RISDA, and the local universities have shown the economic feasibility of 'sheep–rubber' integration (Tajuddin and Chong 1988).

Even though the innovation of integrating sheep under rubber crops has been well received by smallholders, commercialisation was started in the mid-1980s. Since then, many projects, each rearing a few hundred head to a couple of thousand, were established throughout the country. However, the overall success rate of these commercial projects is considered low as many could not progress well and some closed down after a few years of operation. Several constraints and problems were identified, such as:

- low productivity of natural forages under plantations leading to low stocking rate and performances;
- poor grazing management leading to low forage production and sustainability resulting in ineffective weed control;
- insufficient suitable breeding stock;
- unresolved health and disease problems;
- lack of experience and skill in sheep management.

To obtain continuous forage growth and high animal productivity in rubber plantations, a modified system of planting was adopted (Chong and Tajuddin 1994). This allows more light penetration and forage supply with improved grass in the interrows.

Until the mid-1980s, goat farming was preferred to sheep farming. During the mid-1980s, around 20 000 head of temperate wool breeder sheep were imported primarily from Australia to overcome the supply of breeding animals. These temperate wool sheep could not adapt well to the local climatic environment. Their reproductive performance and high mortality spurred the industry to find alternative sources of breeder animals (Table 3). From the late 1980s until the early 1990s, around 50 000 head of tropical wool sheep, the Longtail, were imported. These Longtail sheep adapted and bred fairly well.

However, the shearing of wool posed a burden to the farmers since wool is not a saleable commodity. Since 1993, more than 1000 head of different breeds of hair sheep were imported and kept at government farms and some rams where distributed to farmers for crossbreeding. Is is deemed wise 'to breed out the wool' by rapidly infusing these hair traits into the local breeding population (D.K.L. Low pers. comm.). The current composition of sheep type in the country is shown in Table 4.

Table 3. Lambing efficiency and mortality at government farms, 1990–1995.

Year	Lambs born	% Lambing	Mortality	% Mortality
1990	3487	54.66	997	28.6
1991	3781	61.74	859	22.7
1992	3868	65.4	867	22.2
1993	4749	70.3	1242	26.3
1994	4220	75.16	1114	26.4
1995	3199	80.98	1084	33.8

Source: Department of Veterinary Services.

Table 4. Composition of the standing sheep population.

'Breeds' or 'types'	Estimated numbers	% of total population
Malin	45000	20
Longtail (short crossed wool)	80000	35
Pure Temprate wool breeds	500	1.2
Crosses between Temprate breeds with Malin or Longtail	100000	44
Pure hair sheep	900	0.4
Crosses between hair sheep and wool sheep	1500	0.66
Total	228000	

NB: Nearly all the goats are the indigenous "katjang" breed.

Health and Disease Management

Diseases are the major constraints to expansion of the small ruminant industry in Malaysia. Health problems caused high mortalities and reduced productivity in both smallholder flocks and those at government farms. Tables 5 and 6 provide information on the major health problems encountered at government farms and their overall mortality rates. Parasitic gastroenteritis and respiratory infections are common to both goats and sheep.

Other than mortality from acute infection, worm infestation severely debilitates the animal and reduces productivity. *Haemonchus contortus* is by far the most common and damaging parasite in both sheep and goats. In the tropical humid climate of Malaysia and particularly more so within the micro-environment in the plantation, conditions are favourable for gastrointestinal nematodes the whole year round.

Table 5. Health problems encountered at government farms, 1991–1995.

	1991	1992	1993	1994	1995
Helminthiasis and diarrhoea	900	807	928	1006	596
Pateurellosis, pneumonia, respiratory and pulmonary	631	573	743	396	364
Arthritis, foot-rot and lameness	43	64	264	482	482
Debility, emaciation, anorexia and anemia	348	425	322	321	321
Others	340	145	245	252	252
Total	2262	2014	2502	2516	2015

Source: Department of Veterinary Services.

Table 6. Overall herd mortality rates at government farms, 1990–1995.

Year	Range of overall mortality	Average
1990	3.7–41.7%	21.1%
1991	9.9–29.4%	21.6%
1992	9.7–23.5%	20.9%
1993	15.8–44.4%	24.6%
1994	14.7–42.0%	25.8%
1995	8.7–31.8%	24.9%

Source: Department of Veterinary Services.

Currently, repeated and strategic drenching with suitable anthelmintics barely keeps the problem at bay. Resistance to many of the currently used anthelmintics is an emerging problem and deserves serious attention. Respiratory infections of various causes have been widespread, including pasteurellosis. Vaccination against pasteurellosis does not significantly reduce the incidence of respiratory problem in the flocks.

Melioidosis in both goats and sheep occurs in certain flocks. This is often related to the overgrazing of pasture or drinking from highly contaminated water. Caseous Lymphadenitis (CLA) is gradually becoming more prevalent in goats while imported hair sheep appear to be very susceptible to the disease. Vaccination has controlled the infection at the departmental farms. Although Clostridial infections are not prevalent, vaccines are used at the departmental farms.

Other than these primary infections, malnutrition and poor husbandry predispose the animals to ubiquitous organisms. The Department of Veterinary Services continues to evaluate the efficacy of vaccination for Pasteurellosis, and strives to institute short-term programs and long-term strategy to contain the problems of parasites and gastroenteritis.

Production Systems

Production systems are dependent upon the availability of grazing areas, the number of sheep/goats reared, management of the animals and on socio-economic factors. Thus intensity of production is being used as the basis for classification of the rearing system.

Smallholders in the villages

About 80% of sheep and goats are found around the villages and owned by the settlers themselves. They graze all over the village vicinity, along roadsides, in the orchards and sometimes at estate fringes.

The number of animals per smallholder ranges from 5 to 30 head with an average of around 10 head. The larger flocks (i.e., those with more than 20 head) may be herded, but the smaller flocks are usually left to roam freely. Unattended flocks may feed on the crops and flowering shrubs around many of the village households, causing a social nuisance. This is particularly so with goats.

Most farmers have individual sheds to house the sheep or goats at night, which is necessary to minimise losses from poaching, attack by wild dogs and predators. Flocks are released rather late, so grazing time ranges from 5 to 8 hours daily which may be inadequate. Some farmers provide additional feeds such as concentrate, cut grass and mineral licks.

Animals/tree-crop integration

This system is promoted widely to maximise the usage of limited available land resources. There are around 100 000 sheep found in the plantations, but farming goats in the plantations is objected to strongly and generally not practised. In this system, animals are reared under permanent crops like rubber, oil palm and orchards. Out of the four million hectares of plantation land, three million hectares are suitable for integration with livestock. The animals are allowed to graze under the tree crops at a stocking rate of 2–3 animals per hectare. The animals are herded in numbers up to a few hundred head per herdsman. In the evening, they are housed in permanent or semi-permanent sheds with raised slatted floors. This is necessary to minimise poaching, predators and attack by wild dogs. Young animals, especially pre-weaners, are not allowed to graze.

There is a tendency to graze the animals in areas near the sheds, underutilising an extensive grazing resource. This leads to overgrazing certain areas which aggravates the parasitic gastroenteritis problem. Water, concentrates and mineral licks are made available in the sheds.

Prime lamb production

Prime lamb production is carried out in a few small-to-medium sized farms. Weaned lambs at 3 to 4 months-old are fed palm kernel pellets and limited green fodder for a period of 4 to 6 months. The resulting lambs of between 30 to 40 kg live weight, yield prime lamb carcasses of 15 to 20 kg. Since this feedlotting is carried out with the lambs fully housed on slatted floors, mortality is generally low with minimal health problems. The weight gain achieved ranges from 80 gm to 120 gm daily. This practice appears to provide a reasonably fair return to the farmers. However, the limited supply of weaned lambs hinders the expansion of such downstream undertakings. There is a growing market for prime lambs, and demand exceeds supply.

Conclusion

In Malaysia, as in many other developing countries, the enthusiasm to develop a large ruminant subsector tends to overshadow the need to promote the small ruminants, i.e., goats and sheep. Efforts to promote sheep farming in the plantations over the past decade achieved only limited success. Malaysia is taking a hard look at the situation and at realigning the development strategy, including economic base research.

The small ruminant industry in Malaysia requires the infusion of suitable genetics, the effective coordination of implementation logistics, and the sustained pooling of expertise and experience from other countries to pave the way for a successful and profitable industry. Malaysian experience over the past decade in husbandry, breeding, feeding and disease control are invaluable, but the country may need another decade or two to develop a stable and profitable industry.

Acknowledgments

The author sincerely thanks the Director General of Veterinary Services of Malaysia, Dato' Dr Hadi

Dato' Hashim, for his permission to present this paper. The assistance from Dr Abdul Rahman Md Saleh, Dato' Dr Anwar Hassan, Dr Chee Yee Song, Dr Ibrahim Jalil for the preparation of this paper is much appreciated.

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Sustainable Control of Parasites in Small Ruminants — Country Paper: Fiji

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Abstract

This paper discusses the present state of the small ruminant industries in Fiji and acknowledges that these industries will remain an important source of meat for the nation. This is ensured by the multicultural nature of the society and strong demand for goat and sheep meats. The Fiji government continues to support the industries through the provision of research and extension services. However, the level of support is not likely to increase in the foreseeable future. Gastrointestinal parasites are the major cause of production loss in small ruminants in Fiji. Current parasite control methods rely heavily upon the use of anthelmintics. Given the occurrence of anthelmintic resistance there is a need for the development of sustainable parasite control measures. Optimising anthelmintic use, rotational grazing, improved nutrition, selection of resistant hosts, biological control, and anti-parasitic vaccines are identified as priority areas for research into the development of a sustainable parasite control program. The need for an integrated approach employing a number of control options is acknowledged, as is the need for external assistance in the development of the research program.

THE small ruminant population of Fiji has until recently consisted almost entirely of goats with a population of 187 235 being recorded in the National Agricultural Census of 1991 (Otanez et al. 1992). However, the past five years has seen the development of some 56 privately owned sheep farms carrying a total of about 2000 head.

The contribution of the small ruminant industry to Gross Domestic Product (GDP) is difficult to evaluate as the majority of small ruminants are sold live at the farm gate for home slaughter. This is a reflection of the preference by the purchasers (the majority of whom are Indian) for fresh meat.

Helminthosis is the major cause of production loss in the small ruminant industries of Fiji. Current control methods are based on frequent anthelmintic treatment; however, the threat of widespread anthelmintic resistance necessitates research into sustainable methods of parasite control.

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Fiji: Location, Geography and Climate

The Fiji archipelago consisting of more than 300 islands is located between latitudes 15°S and 22°S and longitudes 174°E and 177°W with a land area of 18 378 km^2 scattered over 230 000 km^2 of ocean. Of the total land area, 87% is located on the two main islands of Viti Levu (57% of total land area) and Vanua Levu (30% of total land area), 11% of land is classified as flats and coastal plains, 14% as moderately sloping and 75% as steep (Twyford and Wright 1965).

The major climatic influences on Fiji are the Southeast Tradewinds and the maritime influence that moderates ambient temperatures. The mountainous nature of the major islands and the prevailing trade winds combine to create three climatic zones: a wet zone on the windward sides of the high islands, a dry zone in the rainshadow areas and an intermediate zone. Annual rainfall ranges from 1800 to 3200 mm.

The Human Population

The 1986 population census recorded a total population of 715 375 (Bureau of Statistics, 1988). Of the total population at the time of the census 33% were Hindu by religion (non-beef eaters), 8% were Muslim (non-pork eaters) and 53% were Christian. At the time of the census 61% of the total population of Fiji was rurally based with 44% of economically active people being involved in agriculture. Current estimates place the total population of Fiji at 792 169 at the end of 1995 with an annual growth rate of 1.1%.

Table 1. The composition of the population of Fiji by race and location (1986 population census).

Race	Rural	Urban	Total
Fijian	221525	107780	329305
Indian	204171	144533	348704
Other	12654	24712	37366
Total	438350	277025	715375

Source: Adapted from Bureau of Statistics (1988).

The Small Ruminant Population

The latest agricultural census (Otanez et al. 1992) estimated the national goat population as being 187 235 goats on 24 027 farms (Table 2).

Of the total goat population 64% are owned by Indian farmers, 29% are owned by Fijian farmers and the balance are owned by farmers of other races. Of all goats 92% are maintained on crop farms (sugar 44%, other crops 45%, coconut plantations 3%) with only 8% of goats being reared on livestock production farms (Rothfield and Kumar 1980).

Table 2. Goat numbers and distribution in Fiji.

Division	Farms with goats	Goat numbers	Av. herd size	% of goat pop.
Central	1255	8718	6.95	5.2
Western	14703	106387	7.24	61.2
Northern	6871	58890	8.57	28.6
Eastern	1198	13240	11.05	5
Total	24027	187235	7.79	100

Source: Adapted from Otanez et al. 1992.

Social and Economic Importance of the Small Ruminant Industry

Social importance

Small ruminant farming is seen by farmers as a desirable activity for a number of reasons. These include:

- small ruminants are eaten by all sectors of the community (except vegetarians) and are not subject to religious taboos on their consumption;
- small ruminants are a form of investment and can be readily sold for cash;
- individually small ruminants have small land requirements so it is possible for persons with little land to raise one or two;
- the reproductive rate of small ruminants is high so the numbers can be easily built up again in the case of natural disaster.

As previously noted, the small ruminant industry is mainly associated with the Indian population. The reasons for this are:

- the absence of religious taboos on their consumption;
- their long tradition of livestock rearing;
- the higher relative consumption of goat meat by the Indian population.

This has not, however, prevented Fijian farmers from becoming involved in goat farming to take advantage of the good market price for live goats (av. $3.50/kg liveweight).

Economic importance

Imports of sheep and goat meat into the country remain high (Table 3). Small ruminant products make up 14.3% of all protein foods consumed (NFNC 1995) with cheap, imported, frozen sheep meat making up the bulk of small ruminant meats consumed. The popularity of sheep meats is due to its low price relative to other meat, which is reflected in its high elasticity of demand (Shedden Pacific 1986).

Accurate estimates of national goat production are difficult to obtain due to a consumer preference for fresh home killed meat. Nevertheless, estimates of local production continue to increase despite the rising level of imports. Local production of sheep meat is still negligible as the sheep industry is still developing; however, production is expected to increase as the industry expands.

The Small Ruminant Industry within Government's Policy Context

Since 1988 government policy has changed from one of self-sufficiency and food security, to one of deregulation and export-led growth. The policy change has seen funding being directed at infrastructure development and the improvement of medical and educational facilities with the aim of facilitating investment in the manufacturing and light industrial sectors. Government, however, continues to support

Table 3. Goat and sheep meat imports and estimated local production.

Year	Goats			Sheep			Total value local ($000)
	Local prod. (t)	Imports (t)	Value of prod. ($000)	Local prod. (t)	Imports (t)	Value of prod. ($000)	
1990	624	84.8	3744	7.8	8373	46.8	3790.8
1991	640	114.9	3840	10.7	9807	64.2	3904.2
1992	65	55.1	3906	16.5	11129	99	4005
1993	62	137.2	3726	16	10378	96	3822
1994	745	129.2	4470	20	9533	120	4590
1995	790	101	4740	24	10231	144	4884

Note: The value of production is based on a value of $6.00/kg carcass weight.
Source: Adapted from AH&P (1996).

Table 4. Small ruminant research staff and facilities.

Commodity	Stations	Area (ha)	Stock numbers	Animal sheds	Estab. staff	Computer	Vehicle
Goats	Sigatoka	110	434	5	2	Y	1
	Seaqaqa	10	224	1	1	N	1
Sheep	Dobuilevu	28	175	1	1	N	1
	Makogai	180	2595	2	1	N	1
	Nawaicoba	120	1893	1	2	N	1
	Wainigata	80	612	2	1	N	1
Total	6	936	6540	12	8		6

the small ruminant industries through the provision of extension and veterinary services, and the maintenance of livestock research stations for the supply of improved breeding stock and management systems research.

Research Facilities

Resources for small ruminant research are at present limited (Table 4). Facilities are rudimentary and generally consist of night sheds, office space, telecommunications, vehicles, microscopes, weighing facilities and animal sheds. In addition, use is made of the facilities provided by the Veterinary Pathology Laboratory and Fiji Agricultural Chemistry Laboratory.

Library facilities are scarce with the major reference library being located at the Fiji College of Agriculture. The literature available reflects the importance of crop agriculture with few livestock journals available.

Small ruminant research stations are staffed by diplomates from the Fiji College of Agriculture who have only little training in animal science and research methodology. While the services of more qualified staff are available, they are located some distance from the research stations and are generally involved in livestock extension work. There is an urgent need for staff training at both the graduate and post-graduate levels to increase knowledge of animal science and to develop an awareness of the importance of reseach.

Husbandry Systems

Small ruminants in Fiji are reared under four main husbandry systems: intensive, semi-intensive, extensive and smallholder systems (Table 5). The smallholder system is the most successful and enduring with the small stock numbers allowing close stock supervision and control. The goat development programs of the early 1980s saw a number of commercial goat farms set up based on the intensive and semi-intensive models. The intensive system was not widely adopted in Fiji. While being workable, it has been rejected by farmers due to the high establishment costs and labour requirements of the system, and the poor availability of feed supplements.

The semi-intensive farm was widely used as a model for the establishment of a commercial goat

Table 5. Characteristics of the main goat husbandry systems.

	Smallholder	Semi-Intensive	Intensive	Extensive
Stock numbers	Few	50-200	50-200	100+
Feed resource	Crop margins and roadsides	Natural or improved pastures	Chaffed roughage or crop by-products	Unimproved pastures
Grazing management	Tethering or free grazing with night housing/tethering	Grazed with night housing	Housed full time	Coconut estates and uninhabited islands unrestricted
Supplementary feeding	Yes low level	Yes	Yes	No
Stock segregation	No	Yes	Yes	No
Drenching	Infrequent	Yes	Yes	No
Stock density	Moderate	5-8 Does/ha		2-5 Does/ha
Breed improvement	No	Yes	Yes	No

industry with a number of 40 ha units carrying up to 200 does being established. However, most farmers failed to operate successfully due again to the high establishment costs, the poor supply of supplementary feeds, a failure of parasite control programs, and large losses due to theft and dog attacks.

The extensive system continues to operate successfully on an number of large coconut estates and uninhabited islands. However, the goats have become feral and are difficult to harvest.

Priorities for Research and Development of Sustainable Parasite Control

Gastrointestinal parasitism is the single most important cause of production losses in small ruminants in Fiji (Walkden-Brown and Banks 1987). The parasites of small ruminants in Fiji are presented in Table 6.

Parasitic infections may cause losses of up to 50% of kids under six months old in extensively managed goat flocks and may account for 28% of all mortalities in private goat herds (Hussein et al. 1983), and 35% of all mortalities in privately owned sheep flocks. An analysis of sheep deaths over three years on a government farm reveals that gastrointestinal parasitism was directly responsible for 53% of all mortalities and may have been implicated in a further 21% of deaths (starvation/abandoned lambs: 17%, Stress: 4%) (Table 7).

Of the total deaths 45% occurred in lambs before weaning and 18% occurred in hoggets before first mating. Ewe deaths accounted for 18% of the total with the majority of deaths occurring in the periparturient period.

Table 6. Gastrointestinal parasites of small ruminants in Fiji.

Species	Site	Frequency of observation[A]
Haemonchus contortus	Abomasum	+++
Trichostrongylus axei	Abomasum	+++
Trichostrongylus colubriformis	Small intestine	+++
Strongyloides papillosus	Small intestine	+++
Moniezia expansa	Small intestine	+++
Oesophagostomum columbianum	Large intestine	++
Trichuris spp.	Large intestine	+
H. similis	Abomasum	*
H. placei	Abomasum	*
Mecistocirrus digitatus	Abomasum	*

[A]+, Occasional; ++, Common; +++, Very Common; * Present in cattle and potentially infectious to goats and sheep but not yet identified in these species.

Source: Walkden-Brown and Banks (1987).

Table 7. Causes of sheep mortality at Nawaicoba Quarantine Station (% of total deaths).

Cause of death	1991	1992	1993	Mean
Worms	25	60	61	53
Abandoned lambs starvation	34	11	15	17
Stress	4	6	0	4
Dog attack	11	12	10	11
Other	15	11	14	15
Total	100	100	100	100

In the absence of an alternative to chemotherapy, the standard practise for parasite control has involved the use of a suppressive drenching program involving the treatment of stock at 3 to 4 weekly intervals (Walkden-Brown and Banks 1987). This practise is, however, undesirable as it has led to the development of anthelmintic resistance in the parasite population. Banks et al. (1987) have detected anthelmintic resistance on a number of small ruminant farms in Fiji (Table 8).

Table 8. Anthelmintic resistance in goat and sheep herds in Fiji.

Anthelmintic	Herds surveyed	Resistance detected	Percent
Fenbendazole (FBZ)	18	8	44
Levamisole (LEV)	21	8	38
Ivermectin	9	0	0
FBZ or LEV	24	13	54
FBZ and LEV	18	3	17

Research aimed at minimising the use of anthelmintics and optimising their use to prevent the development of widespread anthelmintic resistance is a high priority and has produced a number of options for improved parasite control. The epidemiological studies of Banks et al. (1990) resulted in the development of a 28 day, eight paddock rotation (Lawrence 1992). While the rotational grazing system has been successful in controlling gastrointestinal parasites, its uptake by farmers has been limited due to its high establishment costs and labour requirements.

Recent research has emphasised the important role of improved protein nutrition in moderating the effects of a concurrent parasitic infestation (Table 9). The use of a non-protein nitrogen supplement in the form of a urea molasses block (UMB) has resulted in major improvements in the subsequent lambing performance of set stock ewe hoggets in Fiji. The inclusion of fenbendazole in the urea molasses blocks to form a medicated UMB (MUMB) resulted in even greater production increases.

The selection of parasite resistant hosts presents an alternative method of minimising the effects of parasitic infestations. Results of research to date have indicated that while this may not be a viable option for use in goats it is likely to be successful in sheep (Table 10).

Other options yet to be explored and which should be given priority in any further research effort are the use of nematophagous fungi to destroy free living larval stages and the use of antiparasitic vaccines.

Table 9. The effects of protein supplementation with or without parasite control on the lambing performance of ewe hoggets.

	MUMB	UMB	Control
Ewes lambing	40	34	22
Lambs born	44	40	24
Total weight of lambs born (kg)	144	126	66
Lambs weaned	40	39	20
Total weight of lambs weaned	528	405	222
Mean weaning weight (kg)	13.2	10.4	11.2

Source: Manueli et al. 1995.

Table 10. The heritability of faecal egg count in Fiji goats and sheep.

Stock class	Stock numbers	Heritability estimate	S E
Weaner goats	1513	0.04	0.03
Adult goats	951	0.08	0.06
Weaner sheep	1826	0.23	0.07

Source: Woolaston et al. 1995.

While these techniques have been successfully employed on an experimental basis in a number of countries they are yet to be evaluated in Fiji.

It must be stressed, however, that no single method is likely to remain effective if applied in isolation, but that a combination of methods is likely to be the most effective. Therefore, research must continue to explore ways in which all of these methods can be used to develop an effective, sustainable parasite control regime, suited to the needs of the individual farmers.

Conclusions

Small ruminants are and will remain an important part of the Fiji livestock industry for both social and economic reasons. Given the short supply of small ruminant meats it is likely that they will retain their price premium for live sales for some time. The changing government policy has led to a diversion of funding away from agriculture, though research and advisory services are maintained. However, there is a need to upgrade research facilities and to carry out a staff training program to improve the existing research capability. This will require external assistance given the Government's present policies.

Gastrointestinal parasites remain the major cause of losses in small ruminant systems in Fiji. Reliance on suppressive drenching as a method of control has led to the development of anthelmintic resistance on a number of farms and the problem may be expected to worsen unless alternative control measures are developed. Rotational grazing has been shown to be an effective method of parasite control, but its uptake by farmers has been limited. The use of the Medicated Urea Molassses Block in a modified rotational grazing system is an important area for further reseach. Positive benefits from nutritional supplementation have been demonstrated and there is potential for exploiting host resistance to parasites in sheep. The use of nematophagous fungi and anthelmintic vaccines present control options that have considerable potential but are yet to be tested under local conditions. Chemotherapy will remain the major control method while alternative methods are being investigated, but methods for the optimal use of anthelmintics must be developed while alternative control measures are being investigated in order to prevent the widespread development of anthelmintic resistance.

Parasite control in Fiji must incorporate all possible control methods if it is to be sustainable. The development of sustainable parasite control incorporating all possible methods will require a committed research effort on the part of the Government. Given current limitations facing small ruminant research in terms of both facilities and manpower skills it is envisaged that external assistance will be required for the development of the research programs, facilities and staff.

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Gastrointestinal Parasitism in Small Ruminants in Malaysia

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Abstract

The main causes of disease in small ruminants are gastrointestinal strongyle and respiratory infections. This paper summarises current Malaysian findings on the epidemiology of trichostrongyle infections and procedures tested to provide options for control of the worm problem in small ruminants. Evidence of acquired immunity to trichostrongyle infection in sheep was observed at around eight months of age. A marked rise in egg shedding was observed in ewes six weeks before and after parturition. It is recommended that deworming programs should direct attention towards sheep under eight months of age and periparturient ewes. Studies on the bionomics of trichostrongyles in the field indicated that sheep can safely graze in an area for 3–4 days and that a heavily contaminated area should be free from grazing for 5–6 weeks. A nationwide survey demonstrated a high occurrence of resistance (34%) of *Haemonchus contortus* towards benzimidazoles. Levamisole resistance was detected on two of 10 farms investigated. Multiple resistance of *Haemonchus contortus* towards ivermectin and benzimidazole on an institution farm has been reported. The problem of anthelmintic resistance was found to be serious on other institution farms. Rotational grazing was demonstrated to be more effective than set stocking in reducing egg counts on two institution farms. The use of medicated mineral blocks has shown variable results in preventing reinfection.

THERE are presently three farming systems for small ruminants in Malaysia: institutional farms, the plantation, and smallholder farming operations. All three systems provide the animals with the same disease challenges. Gastrointestinal strongyle infections together with respiratory infections are the main causes of disease in small ruminants. These problems increase with intensification of the production system.

The spectrum of trichostrongyles in small ruminants has been documented (Sani 1987) and their effects upon the host is well known.

Effects of Parasites on Production

Thirteen goat herds belonging to smallholders were monitored in Selangor, Malaysia and the overall mortality rate of animals up to one year of age was very high, that is, 74%, ranging from 33% to 93% (Symoens et al. 1992). The major causes of death in all age classes was due to pneumonia and haemonchosis, especially in poorly managed farms. Zamri-Saad et al. (1994) established that even in mild haemonchosis (~2500 ± 151 adult worms) this appeared to have stressed the goats enough to induce immunosuppression to allow the development of the experimentally induced pneumonic pasteurellosis. Daud-Ahmad (1991) recorded a mortality of 80% among goats under one year of age in a herd, and post-mortems revealed that one-third of the deaths were due to trichostrongylosis.

Coccidiosis has often been mentioned as a serious problem of kids and young goats in Malaysia. However, results indicated that coccidiosis causes only minor health problems in all age classes on most farms. The incidence of the most pathogenic species, *Eimeria ninakohlyakimovae*, was generally low (Jalila et al. 1995).

Epidemiology

Epidemiological studies conducted in sheep have shown that in a smallholder (SH) system, animals were already shedding strongyle eggs at the age of 1–2 months (Dorny et al. 1995), in an open pasture

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(OP) management at four months of age and in an integrated production system (IPS) with rubber at five months of age. The time of egg shedding is dependent on the age at which the lambs are allowed to graze. The SH system allowed lambs to graze with the rest of the herd at about two weeks of age while in the OP and IPS managements lambs only begin to graze at three months of age. Lambs appeared more susceptible to ill thrift when they began to graze under one month of age. The highest egg shedding was shown in the 4–8 months age group with geometric mean eggs per gram (EPG) around 3000 (SH), in the 5–6 months age group with mean EPGs around 2200 (OP), in the 6–7 months age group with mean EPGs around 1750 (IPS). The mean EPG values partly reflect the varying degrees of pasture contamination, the highest being in the SH system and the lowest in the IPS system. The improved plane of nutrition found in the OP and IPS managements is also an important factor to consider when comparing egg loads between the different systems of management.

Evidence of immunity build-up against trichostrongyle infection in sheep was seen over 8 months of age (SH) and at 7.5 months of age (OP, IPS) while in goats (Dorny et al. 1995) this occurred from 12–18 months onwards. However, Daud-Ahmad (1991) did not find any evidence of immunity build-up against trichostrongyle infections in Kacang goats.

A marked periparturient rise in egg shedding was observed in ewes starting at ± two weeks before parturition for about three months (SH) (Dorny et al. 1995) and six weeks before and after parturition (OP) (Sani 1994). These observations on the epidemiology of gastrointestinal strongyles of sheep are useful in designing control measures. It is therefore recommended in deworming programs to direct attention towards sheep under eight months of age and ewes around lambing.

Studies on the bionomics of trichostrongyles in the field during wet and dry periods revealed that development of eggs to infective larvae happened between 3–4 days and that most larvae died by the fifth to sixth week (Sani et al. 1994; Sam-Mohan et al. 1995). This means that sheep can safely graze in a fenced area for 3–4 days and that a heavily contaminated area should be 'rested' for 5–6 weeks.

Anthelmintics

A postal survey of nine selected goat and sheep farms revealed that all farms practised rotational drenching with two or three types of drugs to delay worm resistance (Chandrawathani et al. 1994). It was, however, suspected that five of the farms had developed resistance to benzimidazoles.

A nationwide survey involving 96 randomly selected goat farms demonstrated the high incidence of resistance (34%) of *Haemonchus contortus* towards the benzimidazole group of anthelmintics (Dorny et al. 1994a). Levamisole resistance was detected on two of 10 farms investigated. Sivaraj and Pandey (1994) showed multiple resistance of *Haemonchus contortus* in an institution farm to ivermectin and benzimidazoles. Closantel through its sustained activity was a potential drug in the strategic control of haemonchosis, and as an alternative treatment for benzimidazoles and levamisole resistant *H. contortus*. It was shown that a single treatment with closantel resulted in a 72.5% to 86.8% reduction of strongyle egg deposition on pasture during a two month period (Dorny et al. 1994b). The problem of anthelmintic resistance was found to be particularly serious on institution farms. These farms allow their animals to graze on overstocked pastures and are consequently required to deworm the animals at 3–4 weekly intervals to avoid high mortality. The resistant strains of nematodes that developed on these farms may spread when these farms supply breeding stock to smallholder farmers. These findings clearly show that there is an urgent need to monitor for anthelmintic resistance on small ruminant farms using the simple Faecal Egg Count Reduction Test (FECRT).

Control Measures

Grazing management was tested as a control option to minimise the numbers of available infective larvae on pasture of two institution farms (Sani et al. 1996). Based on previous findings on bionomics of trichostrongylid larvae a pasture rotation of 3–4 days in each paddock was adopted. Depending on availability of paddocks pastures were 'spelled' for 30–35 days. The faecal egg counts (FEC) were significantly reduced in sheep that grazed rotationally compared to set stocked animals. Hence the FEC results did show the benefit of rotational grazing. However, in another situation where sheep were rotationally grazed under oil palm, FEC remained high despite frequent anthelmintic intervention. The probable reason for that failure was that the areas were spelled for only 25 days. Earlier findings also showed that larvae survived for slightly longer periods under tree canopy compared to open pastures (Sani et al. 1995). Rotational grazing may not be applicable to certain types of management, for example communal grazing or limited land. However, in farming situations where it can be applied it is another control option.

The introduction of medicated urea molasses mineral blocks to grazing sheep produced variable results. On permanent pastures where animals constantly grazed the use of these blocks coupled with conventional anthelmintic dosing failed to prevent worm establishment. In another group of sheep which rotationally graze the use of these blocks gave much lower FECs. These findings indicated that the benefits of treated blocks is enhanced by rotational grazing with the recommended spelling period.

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Prevalence of Parasites and Small Ruminant Production in Bangladesh

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Abstract

Gastrointestinal parasitism together with an inadequate husbandry system are the main constraints to small ruminant production. Animals suffer mostly from haemonchosis and fascioliasis and a higher incidence was observed during summer and the monsoon season. The efficacy of anthelmintics is high and the provision of drugs has improved animal health. Control of parasites by grazing management is limited by indiscriminate grazing of communal land, and chemical control is expensive. Selection of disease resistant animals and the use of anthelmintics, at strategic intervals, may contribute significantly to a reduction in the level of parasitic infestation. Detailed investigations on the prevalence of parasites, intensities of infection and effect on animals in the present farming system would provide data for the formulation of a strategy for control programs and a reduction in the dependency on drugs.

THERE are about 13 million goats and 1.5 million sheep in Bangladesh. About 98% are reared by the landless and marginal farmers in rural areas to provide income. The animals are penned at night in animal houses and allowed to graze and browse on vegetation found on roadsides and the inter rows of field crops. The present husbandry system is compounded by deficiencies in feeding and breeding, which further aggravate the effects of diseases and parasitism.

In Bangladesh, gastrointestinal parasitic infection is a common cause of goat mortality (Rahman et al. 1975). Information on production losses due to insidious losses in small ruminants is not available; only death rates are recorded. Assessment of economic losses may be based on the direct and indirect production losses, cost of control of parasites and the cost of the damage that the parasites would cause if they were not controlled.

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Prevalence of Parasites

The climate of Bangladesh is very conducive to multiplication and spreading of all types of parasites. Prevalence of these parasites in small ruminants is shown in Table 1. Infestation of internal and external parasites are caused by nematodes (Huq and Shaikh 1968; Qadir 1981; Mondal and Islam 1994), trematodes (Qadir 1976), cestodes (Islam 1980 and 1981), coccidia (Mondal and Qadir 1978; Karim et al. 1993) and different species of lice, ticks, and mange mites (Huq and Mollah 1972; Kader and Huq 1973 and Rahman et al. 1978). Of them, haemonchosis and fasciolosis are important endo-parasitic diseases that cause problems to sheep and goats. External parasites are not as pathogenic as the internal parasites and are easily detected. Incidence of almost all types of internal and external parasites occur during the summer and monsoon seasons, except lice which are more prevalent in winter. Their infestation varies greatly, being in the order of 50%–84% of the small ruminant population.

Use of Anthelmintics for Control of Parasites

The prevalence of animal parasites and strategies for their control in Bangladesh have not been investigated. The most favoured method of worm control is

Table 1. Prevalence of parasites in sheep and goats.

Parasites	Peak infection
Nematodes: *Haemonchus contortus, Oesophagostomum columbianum, Trichostrongylus axei, T. colubriformis, Strongyloides papillosus, Trichuris ovis, T. globulosa, Gongylonema pulchrum, Moniezia expansa, Paramphistomum cervi, Cotylophoron cotylophorum, Gastrothylax crumenifer.*	Summer-monsoon
Trematodes: *Fasciola gigantica.*	Summer
Cestodes: Hydatid cysts (Larval form of *Echinococcus granulosus*).	9.2–55% infestation
Cocciodosis: *Eimeria intricata, E. ovis, E. parva, E. faurfei, E. ninakohlyakimovae.*	37–42% young animals infected
Lice: *Linognathus africanus, Damalinia caprae, D. ovis.*	4–84% in winter
Ticks: *Haemaphysalis bispinosa, Boophilus microplus.*	62–84% in summer
Mange: *Psoroptic mange.*	

the use of various anthelmintics at regular intervals. There are many anthelmintics available for the treatment of parasitic gastroenteritis (Table 2). Information on their use and effectiveness at the farmer level is scanty. Most farmers are unaware of the extent of the loss caused by parasitism. The use of drugs is not practiced due to cost and the belief that small ruminants are resistant to parasites. Reports on effectiveness of some drugs suggest that their efficacy in reducing worm burden to the hosts varies between 86%–100% (Qadir 1966 and 1967; Sobhan et al. 1976; Pandit et al. 1981; Alam et al. 1994 and Mostafa et al. 1994).

Table 2. Use of anthelmintics for parasite control in sheep and goats.

Anthelmintics	Parasite	Effectiveness
Thiabendazole	*Trichostrongylids*	Highly effective
	Strongyloides	Slightly effective
	Trichuris	No effect
Franten®	*all parasites*	No effect
Phenothiazine	*all parasites*	Inhibitory effect
Nilverm®	*Haemonchus*	100% efficacy
	Oesophagostomum	
	Trichostronglylus	
Tetramisole	*Haemonchus and Trichuris sp.*	100% effective
	Strongyloides	80% effective
Rametin	*Haemonchus*	98% effective
	Strongyloides	No effect
Zanil®	*Fasciola gigantica*	Most efficient
Thiophanate	*nematodes*	Most efficient
Triclabendazole	*Fasciola gigantica*	100% efficacy
Fenbendazole	*H. contortus*	100% efficacy
Oxfendazole	*T. sp., Ostertagia*	86–96% efficacy
Thiophanate sodium 70%		
Morantel Tartrate		

Helminth resistance to anthelmintics in sheep and goats has not been evaluated, since anthelmintic use is not common on farms. Sporadic use of these drugs is difficult to ascertain. However, animals may develop resistance by the frequent use of drugs with the same mode of action. This resistance may also be overcome by using higher dosages (Urquhart et al. 1987). Parasite resistance to drugs can be determined by the faecal egg reduction test following treatment.

Effect of Parasites on Animal Productivity

Production losses due to parasite infection arise from animal mortality and reduced productivity of survivors. These reductions of live weight gains can exceed 50% in animals with mild helminth infections (Barger 1982). The total mortality from gastrointestinal parasitism is estimated at 20% of kids and 44% of adults in Bangladesh (Rahman et al. 1975). Various types of mites, ticks and lice in sheep and goats causes 15%–67% of skin diseases which accounted for 11% of monetary loss through leather defects (Dey and Nooruddin 1993). Animal productivity is reduced by the insidious effects on food intake and its utilisation which in turn affects live weight gain and reproductive efficiency. Parasitic infestation is shown to damage the gastrointestinal tract and affect feed utilisation. This may be evident in increased protein loss in the gastrointestinal tract and reduction of synthesis of skeletal muscle and mineralisation (Sykes and Coop 1976 and 1977).

Change in body weight is a common feature in infection. The live weight changes in does and kids of naturally parasite infested and anthelmintic drenched groups were monitored in a village situation (Alam 1993). All the animals in a drenched group were found to have higher growth rates. Worm eggs detected in the faeces of infected animals were below pathogenic levels and the animals appeared

Table 3. Effect of anthelmintics on the live weight change of does.

Treatment	Before parturition			After parturition		
	Initial wt. (kg)	Final wt. (kg)	Wt. gain (g/d)	Initial wt. (kg)	Final wt. (kg)	Wt. gain (g/d)
Grazing + leaves + 100 wheat bran + Anthelmintic	12.6	14.9*	38	14.1	15.5*	24
Grazing + leaves + 100 g wheat bran	12.6	13.8	20	13.3	14.2	15
SEM	2.08	2.97	1.86	3.27	2.52	1.63

*Significance level of comparable means, (P<0.05).

healthy. Provision of improved feeding and drenching during the late pregnancy and lactation periods resulted in 46% more live weight gain in does. Kids in this group had 39%, 42% and 24% higher birth weights, growth rates and suckling periods, respectively (Tables 3 and 4). It appears that provision of drenching with improved feeding increased the body condition of does and their kid-rearing ability. Strategic drenching combined with strategic supplementation would have similar effects on increasing productivity in subsistence farming systems.

Table 4. Effect of improved husbandry on performance of kids.

Parameters	Group		
	Treated	Untreated	SEM
Birth weight (kg)	1.150	0.827*	0.22
Growth rate (g/d)	57	40*	1.94
Kid mortality (%)	4	17	0.36
Weaning age (days)	67	54*	3.72

*Significance level of comparable means, (P<0.05).

Host Susceptibility

Many animals have a genetically acquired immunity to diseases. For instance, some sheep are more resistant to helminthosis than others (Altaif and Dargie 1978). Genetic resistance to disease is particularly important in the village situation due to cost of drugs. Resistance to endoparasites relates to the age, sex, genetic characteristics and immunological state of the host. Selection of animals that are highly resistant to parasites for breeding can help to establish a parasite-resistant flock.

Young animals are more susceptible to gastrointestinal helminths and coccidiosis and older goats much more resistant to worms (Lloyd 1987). The intestinal parasite burdens in animals are tools for estimation of immunity. A safe value for egg counts in the faeces of surviving small ruminants and a clear definition of the worm population is needed if the potential effect of EPG is to be given meaning. In a study with village goats (Alam 1993) all the animals had less than 1000 EPG, and none were suffering severely, suggesting that goats surviving to this age probably have some degree of tolerance to intestinal parasite infections. Determination of the level of urinary nitrogen excretion, plasma urea and serum pepsinogen would give a good assessment of the degree of infection. However, there is a need to study the incidence of parasite burdens in village systems to determine whether strategic treatment is needed until resistance is acquired.

Feasibility of Sustainable Parasite Control

Sheep and goats share most species of worms when they are grazed on communal land where there is little chance of controlling the infection in the pasture. Elimination of these parasites requires a regular program of prevention and control in the flock, and the pasture the animals consume. Production systems comprise numerous smallholder and subsistence units and cover extensive areas and effective control would incur considerable expense in terms of drugs and personnel. The magnitude of the problem involved in prevention and control is being exacerbated by increasing livestock numbers, without a corresponding increase in veterinary services. Control measures must be conceived and executed as an integral part of a balanced package of production practices that has had careful economic assessment.

Preventive control may be carried out in conjunction with control of grazing, i.e., keeping animals off pasture when the grass is wet, control of grazing land and the utilisation of the natural immunity of animals or the species to reduce the risk to susceptible animals. The use of anthelmintics at strategic intervals prior to maximum risk may reduce the faecal egg contamination of pasture. High cost and low availability of proper anthelmintics may likewise be a problem for farmers. This model for smallholders requires support of the national government. A program may be undertaken with the participation of individual owners to reduce the debilitating effects of parasitism. The program should aim to treat the infective parasite with highly specific drenches before the build-up of eggs or larvae occurs, and when environmental conditions are most favourable to build up on grass. The strategy would be to drench with a specific nematodcide, plus a broad spectrum drench prior to summer, and again with a broad spectrum plus specific drench in the monsoon season when infective levels are likely to be high. This requires detailed information on the prevalence of, and nature of, parasites, their effect on animals and the conditions under which they thrive. The intensities of infection in current farming systems should be investigated throughout the season before drugs are used. Control by medication is not long lasting. Nevertheless, there is a definite reduction in the egg concentration in faeces when anthelmintic drugs are given routinely to animals.

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Epidemiology of Gastrointestinal Helminth Parasites in Small Ruminants in Bangladesh and their Anthelmintic Therapy

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Abstract

Parasitism is a serious problem of the developing nations of the world, particularly, where nutrition and sanitation are poor. In Bangladesh, gastrointestinal nematodiasis and liver fluke infestation are encountered mostly among ruminants, causing a significant economic loss to the country as a result of animal diarrhoea, stunted growth, decreased milk production, emaciation, loss of working ability and even death. A total nine species of helminths have been identified in small ruminants of which seven are nematodes, with one cestode and two trematodes. The incidence of helminths ranged from 1%–24%, the highest relating to *Haemonchus contortus* (20%–24%) followed by *Fasciola gigantica* (12%–15%). Plasma pepsinogen values were determined to assess abomasal damage caused by *H. contortus* or *Ostertagia circumcincta*. Forms of pepsinogen were isolated from both parasite naive and from sheep or goats infected with *O. circumcincta*, and three sub-types of pepsinogen were identified. In Bangladesh, modern anthelmintics are imported and expensive, having an efficacy range between 80% and 100%. Thiophanate, a probenzimidazole, is reported to have reduced efficacy for nematodes, particularly *H. contortus*. Studies of the indigenous medicinal plant Neem (*Azadirachta indica*) seeds have shown anthelmintic action against naturally infected gastrointestinal nematodes and effectiveness was recorded at between 35% and 52.77%.

Incidence of Gastrointestinal Helminth Parasites

In Bangladesh, information on the prevalence of helminth parasites in small ruminants is limited, although goats play a major role in the economy. In 1995 (January to December) research work was conducted at the Bangladesh Agricultural University (BAU), Mymensingh, on gastrointestinal helminth parasites of sheep and goats. Results showed that out of a total of 100 Black Bengal goats and 50 local breed sheep examined, 60 goats (60%) and 25 sheep (50%) were found to be infected with one or more helminth parasites. The age of these animals was between 3–36 months of either sex. Faecal samples were examined by a flotation method, using a saturated solution of sodium chloride, and fluke ova were analysed by sedimentation. The worm egg counts were performed using the McMaster technique as described by Gordon and Whitlock (1939). Identification of various helminth parasites was based on the morphology of the eggs and the helminthological charts prepared by Cunliff and Crofton (1953). The identification of different species of helminths was also based on the detection of adult worms collected after autopsy. This survey recorded the presence of a total of seven nematodes, one cestode and two trematodes (Table 1).

Quadir (1967) reported that the incidence of *Oesphagostomum columbianum* and *Haemonchus contortus* was high throughout the year among ruminant animals at the East Pakistan Agricultural University Campus. Haq and Shaikh (1968) examined gastrointestinal tracts of goats and sheep in Mymensingh, finding the abomasam nematodes

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Table 1. Incidence and types of helminths isolated from sheep and goats in Bangladesh.

Sheep		Goats	
Parasite	Number (%) of sheep infected	Parasite	Number (%) of goats infected
Haemonchus contortus	12(24)	*Haemonchus contortus*	20(20)
Trichostrongylus axei	5(10)	*Trichostrongylus axei*	7(7)
Oesophagostomum columbianum	6(12)	*Oesophagostomum columbianum*	15(15)
Trichuris ovis	2(4)	*Trichuris ovis*	6(6)
Strongyloides papillosus	2(4)	*Mecistocirrus digitatus*	4(4)
Mecistocirrus digitatus	3(6)	*Gaigeria pachyscelis*	2(2)
Ostertagia circumcincta	1(2)	*Paramphistomum cervi*	4(4)
Moneizea expansa	4(8)	*Monizea expansa*	10(10)
Fasciola gigantica	6(12)	*Fasciola gigantica*	15(15)

Total numbers and total % of animals will exceed expected value due to multiple parasitism.

H. contortus and *Trichostrongylus* spp. Rahman (1969) in his study of the abomasal worm of 150 goats and 50 sheep recorded *H. contortus* (85.33%); *Trichostrongylus axei* (36.6%); *Trichostrongylus colubriformis* (28.3%) and immature Paramphistomum (8.0%) in goats. Romizur (1989) found *H. contortus* and *Trichostrongylus* spp in the abomasa of 250 Black Bengal goats. Infection with *H. contortus* and *Trichostrongylus* spp was very high among Black Bengal goats in Mymensingh district throughout the year at 70.4% for *H. contortus*, varying from 27.3% in February to 100% in September, and 64.0% for *Trichostrongylus* spp varying from 45.0% to 80.0%. The rate of infection was lowest at 45.0% in March and the maximum of 80.0% was observed in November. Of 250 goat abomasi, *H. contortus* was recorded in 176. On the other hand, 160 abomaso were infected with *Trichostrongylus* spp and the average mixed infection with both parasites was 84.0%, varying from 75.0% to 95.5%. The major differences in the percentage of mixed infection were not observed among different seasons. Mahfuja (1995) reported that *H. contortus* and *Trichostrongylus* spp were found in 100 abomasa of Black Bengal goats slaughtered between 12 and 16 months of age during March to April 1994. Out of 100 abomasa, 68 were infected either with *Haemonchus* spp or *Trichostrongylus* spp or with both, thus contributing 68% of average mixed infection.

In Bangladesh, the prevalence of gastrointestinal nematodes belonging to the genera *Haemonchus*, *Trichostrongylus*, *Toxocara*, *Strongyloides*, *Trichuris*, *Capillaria* and *Mecistocirrus* ranged from 1% to 89% in slaughtered cattle, sheep, goats and buffalo (Haq and Shaikh 1968; Quadir 1967, 1979; Rahman 1969; Rahman and Mondal 1983). However, in live animals the prevalence of these parasites is not well defined.

Mondal and Islam (1994) reported that the prevalence of *Trichuris* infection in 149 slaughtered Black Bengal goats was 42.28%. Two species of *Trichuris*, viz. *T. ovis* (37.58%) and *T. globulosa* (20.81%), were identified. They also found a positive association between *Trichuris* spp and *O. columbianum*.

It was reported by Alam et al. (1994) that faecal examination of 57 local breeds of sheep (7–36 months old) and 25 Black Bengal goats (2–36 months old) maintained in a mixed flock showed clinical *Fasciola gigantica* infection in 17 (29.82%) sheep and 15 (60.00%) goats, of which five (29.41%) sheep and three (20.00%) goats died.

The present study reveals that helminth infection of small ruminants in Bangladesh is a major threat to production performance and growth. The most pathogenic parasites are *H. contortus* and *F. gigantica*.

Pathophysiology of Abomasal Parasitism in Small Ruminants

During an *Ostertagia* infection, the larval stages enter the abomasal glands, settle in the mucosa, moult, grow and emerge again in the lumen causing damage and leakage of pepsinogen into the blood stream (Jennings et al. 1966). Pepsinogen concentration is also increased due to *H. contortus* (Mapes and Coop 1970). Plasma pepsinogen and pepsinogen types in worm-free sheep and sheep infected with *O. circumcincta* and *H. contortus* were identified (Mostofa and McKellar 1990) for disease diagnosis. Forms of pepsinogen in the abomasa of parasite naive and *O. circumcincta* infected goats were isolated to compare with serum pepsinogen for the diagnosis of goat abomasal damage (Mostofa 1991).

Anthelmintics Currently Used in Small Ruminants of Bangladesh

Anthelmintics of benzimidazole group such as thiophanate, fenbendazole, albendazole, mebendazole and oxfendazole are available in Bangladesh. The rate of their efficacy ranged from 80%–90%. Levamisole and morantal citrate are also available and prescribed by veterinarians. Ivermectin is not available in Bangladesh. For the treatment of fasciolioisis, triclabendazole is the drug of choice in Bangladesh. Although nitroxynil and oxyclozanide are also available, they are not favoured by veterinarians because of their efficacy only against adult fluke, and their toxicity. Triclabendazole has been reported 100% efficacious against *F. gigantica* in goats and sheep (Alam et al. 1994). Clinical trials against helminths in small ruminants with modern anthelmintics are not reported extensively. This study shows that fenbendazole has 99.66% and morantel citrate 87.50% efficacy against gastro-intestinal nematodiasis in sheep. Comparative efficacy of four anthelmintics against natural infection of gastrointestinal nematode in goats showed fenbandazole with 96.26% efficacy, followed by oxfendazole 94.44%, thiophanate 91.89% and morantel citrate 86.11%, respectively, as reported by Mostofa et al. (1994).

Anthelmintic Resistance

There are no reports available on anthelmintic resistance in Bangladesh because small ruminants are mainly kept by subsistence farmers. Because anthelmintics are imported and very expensive, they are not routinely used by subsistence farmers, but only by some government and a few small private farms. Anthelmintic resistance to abomasal parasites has been reported by field veterinarians for the benzimidazole compound thiophanate against abomasal parasites, mainly *H. contortus*.

Herbal Medicine as an Alternative Therapy or Substitute for Anthelmintics

Bangladesh is a developing country with a population of 120 million and a per capita income of about $US220. As stated, imported anthelmintics are beyond the resouces of subsistence farmers and it is thought that indiscriminate and repeated use of these anthelmintics might develop resistance problems in animals. A variety of medicinal preparations from indigenous herbs and plants are now being manufactured by some pharmaceutical companies in India, Indonesia and Thailand. Indigenous plants, pineapple, Bet, chirata and Haritaki have some degree of anthelmintic activity (Mostofa et al. 1983). *Azadarichta indica*, locally known as Neem tree and a member of Meliaceae family, is an important multipurpose medicinal tree in Bangladesh. The plant contains azadirachtin, vepaol, isovepaol, nimbin, nimbidin and vanillic acid. The oil from the seed is used in man and animals as an anthelmintic and as a parasiticide for ringworm, scabies and other skin conditions (Fernando, 1982, Katker and Katker 1984). Efficacy of neem seeds against natural infection of gastrointestinal nematodes in goats ranged from 40% to 52.77% (Mostofa et al. 1995) and in sheep from 35.29% to 40% (Ahmed et al. 1994).

Further extensive research on the indigenous medicinal plant (Neem) is needed before use in routine anthelmintic therapy. Research on the seeds' toxicological and pharmacokinectic parameters are particularly necessary.

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Gastrointestinal Parasites and Small Ruminant Production in India

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Abstract

Parasitic gastroenteritis, dominated by haemonchosis, is one of the major constraints to profitable sheep and goat production in India. The hot and humid tropical climate is very favourable for the development and survival of preparasitic stages of nematodes and it is likely that at all times of the year infective larvae are available on the pasture of grazing animals. Control of parasitic gastroenteritis is primarily based on the frequent use of anthelmintics at short intervals, particularly in intensive and semi-intensive management systems. Frequent suppressive dosing has been shown to result in the emergence of anthelmintic resistance. No efforts have been made so far to use environmentally friendly alternatives to chemotherapy, including genetic resistance of hosts, vaccines, biological control and mathematical model based decision support systems. However, there is now a growing awareness about the importance of parasitism and the need for sustainable parasite control. Efforts are now being made to utilise Geographical Information Systems (GIS) based decision support for developing sustainable parasite control in ruminants with integrated parasite management programs involving conventional and alternate strategies.

SHEEP (44.8 million) and goats (118.3 million) with a large genetic diversity (40 breeds of sheep and 20 of goats) account for 0.5% to 5% of the value of total output of the livestock sector in India (Singh 1995). Indian goats have been adapted to the variety of climatic and agroeconomic situations in different parts of the country and cost little to maintain as they feed on harvested or fallow fields, canal banks or overgrazed common lands. Sheep in India are primarily reared in the migratory system which depends on changes in season and availability of grazing. Flocks used in public research and development are primarily sedentary. The sheep breeding regions of India are classified as (1) the northern plains, (2) the semi-arid western region, (3) the southern humid region and (4) the temperate and subtemperate mountains.

Diseases are regarded as primary reasons for poor productivity of such a fairly large population of small ruminants in the country. Though gastrointestinal parasites are regarded as one of the most important economic species, much of the national animal disease control efforts during the past four decades have been devoted almost exclusively to bacterial and viral diseases responsible for major epizootics. Further, effective parasite control has not been possible due to paucity of information on parasite epidemiology, variability in infection rates depending on agroclimatic conditions, shortage of trained personnel and traditional patterns of ownership and animal management (Sanyal 1988).

Epidemiology of Parasitic Gastroenteritis (PGE) in Small Ruminants

The prevalence of PGE in a tropical country like India is largely determined by rainfall and production systems practiced. Most of the available information on parasite epidemiology comes from flocks maintained in intensive management systems. *Haemonchus contortus* is considered to be the most pathogenic nematode parasite of sheep and goats followed by *Trichostrongylus colubriformis*. Less economic *Bunostomum*, *Oesophagostomum*,

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Cooperia, and *Strongyloides* spp. are also common, particularly during rainy and post-rainy months (Sanyal 1988).

In the northern plains, limited surveys indicated a higher prevalence rate during monsoon and post-monsoon months (June to October) in the states of Bihar, Orissa, Punjab and Haryana. The adult parasites persisted in the host throughout the year due to favourable weather conditions for the development and survival of preparasitic stages. However, July to October were the months of highest parasitism (Gupta et al. 1987).

July to October were the months when parasites were found more in the host and on pasture in the semi-arid western region (Singh et al. in press). The observed equivalent average parasitism rates were 1.96%, 1.10% and 0.17% for adults, hoggets and weaners respectively (Swarnkar et al. in press).

Gupta and Mathur (1969) observed November to January were the months of peak parsitism in Madras, Tamil Nadu. This is associated with the rainfall pattern of the southern humid region which receives northeast monsoons during October–November.

In the temperate Himalayan region of Kashmir an increasing trend of infection during March–May (Spring), and June–November (Summer and Autumn) was recorded (Makhdoomi et al. 1995).

The bionomics of preparasitic stages in subtemperate Tamil Nadu indicated that June to November were best suited for rapid hatching of eggs followed by moulting. Seasonal availability of ovine strongyle larvae on pasture indicated *H. contortus* was active during June to November and rare during December to May, whereas *Trichostrongylus colubriformis* was found on pasture throughout the year. Periparturient rise with resultant higher worm burden in lambs and hypobiosis of *H. contortus* during September to February were also recorded in that agroclimate (Sanyal 1991).

Epidemiology of PGE in Large Ruminants

As the epidemiologic pattern in a tropical climate is likely to be similar in all grazing animals, it will be worthwhile to discuss epidemiology of PGE in cattle and buffalo conducted under National Dairy Development Board (NDDB)–Australian Centre for International Agricultural Research (ACIAR) projects 8523 and 9132 on medicated urea molasses blocks. The study was undertaken during 1990–1994 in eight different agroclimatic zones of India. Typical seasonal rise in worm burden in host and on pasture was observed in all agroclimates following monsoon rain (Sanyal and Singh 1995).

Epidemiology of Fasciolosis and Amphistomosis

Fasciola gigantica is a common parasite in bile ducts of sheep, goats, cattle and buffalo. A review of some of the recently conducted surveys indicated a high level of incidence in the endemic areas all over the country. Ruminants also harbour several species of amphistomes. Nationwide survey in dairy animals indicated two peak periods of liver fluke infection (July–September and February to March). Amphistomes were abundant during rainy and post-rainy months (Sanyal and Singh 1995).

Control Measures in Practice

In the majority of farmers' flocks, no anthelmintic treatment is given to control PGE unless clinical cases appear. In some flocks tactical anthelmintic treatment is practiced during the months of March–April, June–July, September–December. Based on the observations on parasite epidemiology in sedentary flocks in the subtemperate Tamil Nadu, a control strategy was formulated with the combination of rotational and clean grazing with anthelmintic dosing at strategic points, which is working satisfactorily (Sanyal 1991). Implementation of a control strategy formulated for sheep flocks in the semi-arid western region, involving two strategic dosings during March–April and June–July and one tactical drenching during October–November, resulted in drastic reduction in equivalent average morbidity per 1000 animal days at risk from 0.12 to 0 (Maru et al. 1993). Only tactical dosing with flukicides is given to control fluke diseases and no drenching strategy is implemented. However, FAO (1994) has recommended strategic dosing against fluke diseases in ruminants in India.

Anthelmintic Resistance

Varshney and Singh (1976) first reported resistance to phenothiazine and thiabendazole in *H. contortus* of sheep. From 1990 onward six reports of emerging benzimidazole resistance, two of imidothiazoles and one of rafoxanide resistance in farmbred ovine and caprine *H. contortus* appeared (Singh et al. 1995). In migratory farmers' flocks anthelminthic treatment against PGE tends to be ad hoc and hapazard, so the selection pressure for anthelmintic resistance may be considered to be low. However, distribution of farmbred flocks to the farmers under various extension programs has resulted in the spread of resistant strains generated on the farms to the farmers' flocks. Humar and Yadav (1994) surveyed 32 traditionally managed and 22 intensively managed flocks and found no fenbendazole resistance in tradionally managed rural flocks while, 15 and four of 22 intensively managed flocks had slight and severe resistance, respectively. Resistance against flukicides is yet to be reported. However, observing the poor uptake of triclabendazole in buffalo and its very poor efficacy against bubaline fasciolosis (Sanyal 1995; Sanyal and Gupta, in press), we may soon see triclabendazole resistant liver flukes generated in buffalo infecting other ruminant species.

Perceived Effect of Parasites on Production

Naturally acquired mixed trichostrongyle infection is believed to influence live weight gain and fibre production in small ruminants. In nomadic migratory flocks nematode parasitism is generally regarded as causing major losses in production, which is often exacerbated by severe and seasonal shortage of adequate nutrition. Suppressive anthelmintic drenchings resulted in marked increase in live weight gain and clean fleece yield with reduced morbidity and mortality rates. Anthelmintic-unresponsive diarrhoea and anthelmintic-unresponsive growth retardation has also been observed in flocks maintained in institutional farms (Sanyal 1988).

Host Genetic Resistance

Breeding of stocks genetically resistant to helminth parasites may provide a promising control strategy at the outset of emerging anthelmintic restance in gastrointestinal nematodes. However, in India no such efforts have been made. Very few studies have been conducted on the breed susceptibility to nematode parasitism. It was observed that following infection native breeds had significantly less changes in haematological values, body weight gains and abomasal pH, significantly less faecal egg and worm counts with distinctly less pathophysiological changes in the abomasum compared to purebred and their crosses (Yadav et al. 1993).

Feasibility of Initiating Sustainable Parasite Control

Small ruminants play a crucial role in the conversion of low quality plant material and crop residues to high quality human food, and in returning valuable plant nutrients to the soil. As sustainable development is a compromise between reducing environmental degradation and positive economic growth, sustainable parasite control should aim towards less intensive, lower input, less risk of parasite induced losses with greater opportunities for integration of chemotherapeutic control, grazing management, biological control, mathematical models and decision support systems. In most cases, resistance seems clearly to be associated with heavy reliance on chemical control, applied frequently and sometimes haphazardly. As resistance to newer anthelmintics are emerging, there is a need in India for undertaking a sustainable parasite control program. Because of the long-term, multidisciplinary nature of research, government and international agencies must acknowledge the crucial role of public research and development and the need for widespread dissemination of its results in the quest for sustainable development.

Acknowledgment

For brevity, the recent articles and reviews are cited. My sincere apologies to the primary authors.

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Importance of Parasites as a Constraint on Small Ruminant Production in Pakistan

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Abstract

Major parasitic diseases of small ruminants in Pakistan include fasciolosis, haemonchosis, trichostrongylosis, ostertagiosis, nematodirosis, trichurosis and coccidiosis. Incidence of these parasitic diseases has been reported from all parts of the country. Prevalence rates of different parasitic fauna differ with ecological conditions. Almost 100% of grazing sheep and goats harbour light to medium levels of parasitic infestation. Effects of parasitism on weight gain, wool/hair production, birth weight of lambs and blood characters have been documented in studies conducted in different parts of the country. Small ruminant farmers generally do not recognise low-to-moderate types of infestations until these precipitate into clinical cases. Deworming with anthelmintics is the only practice being followed by farmers for the control of these parasites. Studies on drug resistance and host parasite relationships are lacking.

PAKISTAN lies 24–30 ° north and 60–75 ° east. Its total area is 76.61 million hectares. The climate is arid with monthly rainfall ranging from 0 to 116 mm in winter and 2 to 236 mm in summer (Table 1). Temperature exceeds 40 °C and sometimes even touches 50 °C during summer months, especially in June. It falls to zero during the winter season. Two rainy seasons prevail, one during December–January and the other during July–August. The mainstay of Pakistan's economy is based upon agriculture with a contribution to GNP of 28%. Out of this, 8% is shared by the livestock sector. The total population of small ruminants is 72.7 million (29.0 million sheep and 43.7 million goats (Govt. of Pakistan 1994–95). These two species provide mutton, wool and hair at the local level, and are a good source of foreign exchange earnings through the export of skins. Besides, small ruminants also serve as a bank for smallholder farmers as they meet their emergent needs by selling sheep and goats.

Despite a fairly large population of small ruminants in the country, their per head productivity is low. This low productivity can be attributed to many factors, the heavy parasitic loads being the most important (Irfan 1984). According to a survey, about 100% of grazing small ruminants harbour more than one type of parasites (Durrani et al. 1981). Due to their insidious nature, the parasitic infestations often escape the attention of farmers until these precipitate into clinical cases.

Prevalence of Parasites

Internal parasites

Internal parasites are one of the major factors limiting small ruminant productivity in Pakistan. Various studies conducted across the country speak of a high prevalence of internal parasites in all the ecological zones of the country. Durrani et al. (1981) conducted a survey in Azad Jammu and Kashmir Valley and found 100% of sheep and goats infested with internal parasites (Table 2). Each animal was found parasitised with at least more than one species of parasites and as many as nine different types of ova were recorded in one animal's faecal sample. *Fasciola gigantica, Ostertagia ostertagi* and *Moniezia expensa* were the most common species recorded in the study (Table 2). Khan et al. (1988) studied the incidence of internal parasites of sheep in

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Table 1. Agro-ecological zones in Pakistan with annual temperature and rainfall.

	Name of zone	Average monthly temperature (° C)		Average monthly rainfall (mm)	
		Minimum	Maximum	Summer	Winter
1.	Indus Delta	5	40–45	75	5
2.	Southern irrigated plain	3–7	43–47	45–55	Dry
3.	Sandy desert				
	(i)	2.5	43–45	32–46	Dry
	(ii)	1.3	46.6	71	18
4.	Northern irrigated plain				
	(i)	2	45.0	75–108	14–22
	(ii)	1.4	43.5	31	29
5.	Barani lands	0.5	344	200	44
6.	Wet mountains	0.5	42	236	116
7.	Northern dry mountains	−2 to −13	30	10–20	25–75
8.	Western dry mountains	−9.6 to 4.0	33–44	5–15	30–35
9.	Dry western plateau	−1.5 to −4.0	38–44	2–4	9–36
10.	Sulemain Piedmont	−1.5 to 2.7	45.7–48	27–31	13

Source: Pakistan Agricultural Research Council 1980. Summer (April–September). Winter (October–March).

Table 2. Showing 1000 sheep/goats parasitised with different parasites on faecal sample examinations.

Species of parasites	No. of samples positive	Infection %
A) Nemathelminth		
Bunostomum trygonocephalum	330	33.0
Dictyocaulus filaria	535	53.5
Haemonchus contortus	662	66.2
Nematodirus Spp.	260	26.0
Ostertagia ostertagi	653	65.3
Oesophagostomum columbianum	590	59.0
Strongyloides papillousus	400	40.0
Trichostongylus axei	504	50.4
Trichostrongylus colubriformis	412	41.2
B) Platihelminth parasites		
Dicrocoelium dendriticum	430	43.0
Fasciola hepatica	350	35.0
Fasciola gigantica	732	73.2
Cotylophoron cotylophorum	160	16.0
Schistosoma indicum	130	13.0
Avitellina centripunctata	400	40.0
Moniezia expensa	662	66.2
Moniezia benedeni	110	11.0
C) Protozoan parasites		
Eimeria Spp.	530	53.0

Source: Durrani et al. (1981).

Table 3. Relative rate of incidence of nematodes of sheep under the arid environmental conditions of Baluchistan.

Name of parasite	No. of positive samples	Infestation %
Nematodes		
Nematodirus sp.	218	54.45
Marshallagia marshalli	100	25.00
Dictyocaulus filaria	84	21.00
Strongyloides papillosus	53	13.25
Trichostrongylus sp.	52	13.00
Oesophagostomum sp.	48	12.00
Haemonchus contortus	47	11.75
Trichuris globulosa	32	8.00
Chabertia ovina	27	6.75
Bunostomum trigonocephalum	25	6.25
Ostertagia ostertagi	15	3.75

Source: Khan et al. (1988).

Baluchistan province under arid environmental conditions. They found *Nematodirus* spp. *Marshallagia marshalli* (Table 3) and *Fasciola hepatica* (Table 4) to be the major parasitic species infesting sheep.

Chaudhry and Anwar (1984) conducted a survey from 1979 to 1982 and found 58.5% sheep and goats infested with *Fasciola* spp. in Faisalabad district (canal irrigated and heavily populated with livestock). Sheikh et al. (1984) reported 28.6% to 53.3% incidence of *Fasciola gigantica* in Sind province. Khan (1992–93) studied the incidence of internal parasites in small ruminants slaughtered at a local abattoir. He found 88.47% of the slaughtered sheep/goats positive for parasitic ova; *Haemonchus contortus* and *Trichostrongylus* spp. had the highest incidence rates, i.e., 50.76% and 43.2%, respectively (Table 5). In another study, Pal and Qayyum (1993) found 93.6% sheep and goats infested with helminth parasites in Rawalpindi-Islamabad areas.

Table 4. Relative rate of incidence of trematodes and cestodes of sheep under the arid environmental conditions of upland Baluchistan.

Name of parasite	No. of positive samples	Infestation %
Trematodes		
Fasciola hepatica	105	26.25
Cotylophoron cotylophorum	10	2.50
Paramphistomum cervi	3	0.75
Cestodes		
Avitellina centripunctata	52	13.00
Moniezia benedeni	50	12.50
Skrajabinema ovis	30	7.50
Moniezia expensa	6	1.50

Source: Khan et al. (1988).

Table 5. Prevalence of different species of parasites in sheep and goats slaughtered at Rawalpindi abattoir.

Species of parasites	No. of samples positive	Infestation %
Haemonchus contortus	140	50.76
Trichostrongylus spp.	105	43.2
Chabertia ovina	26	10.60
Ostertagia circumcincta	20	8.23
Oesphagostomum columbianum	7	2.88
Trichuris globulosa	1	0.41
Dictyocaulus filaria	1	0.41
Avitellina centripunctata	3	1.23
Moniezia expensa	22	9.05
Fasciola gigantica	4	1.64

Source: Khan (1992–93).

External parasites

The external parasites of small ruminants in Pakistan include ticks, manage mites, lice, sheep nasal flies and goat warbles. Their prevalence and intensity varies in different ecological zones and during the different seasons of the year. The infestation is at peak during the hot and humid months (June to August). The egg laying season of warble fly lasts from April to June. The warbles are seen on the back of the infested goats during November and December. Published information regarding the prevalence of these external parasites in small ruminants is scarce. Siddiqui and Jan (1986) studied the prevalence of ixodid ticks in sheep and goats of North Western Frontier Province (NWFP) and found 14.27% sheep and 24.42% goats infested with ticks. Khan et al. (1991, 1994) reported a high rate of warbles in goats of hilly and semi-arid areas of Pakistan. In another study Khan et al. (1993) reported *Boophilus* and *Hyalomma* species of ticks infesting 18.8% sheep and 12.3% goats of Faisalabad division.

Effects on Production

The effects of parasitism on the productivity of small ruminants have been documented all over the world. Its effects on productivity of small ruminants in Pakistan have been reported by a few workers. Hussain and Akram (1967) reported 3.8% and 40% reduction in meat and wool production, respectively, from sheep infested with *H. contortus*. Khan et al. (1988) reported a significant effect on weight loss of sheep experimentally infected with *H. contortus*. In another experiment, Khan et al. (1995) studied the effects of disease preventive measures (prophylactic vaccination and deworming) on the productivity of small ruminants. They reported that vaccination along with deworming had a significant effect on wool production and birth weight of lambs in sheep (Table 6) and goats (Table 7). Ahmad (1992) studied the effect of various anthelmintics on productive and reproductive performance of sheep. He concluded that statistical analysis of data pertaining to weight gain, birth weight, and wool production indicated a significant difference among the treated and control animals.

Table 6. Descriptive statistics of various productivity parameters of treated and control groups of sheep.

	Average wool production (g/shear)			Average birth weight of lambs (Kg)		
Group No.	Treated	Control	SE	Treated	Control	SE
Vac + Dew	399.27[a] (48)	349.71[b] (34)	10.69	2.80[a] (40)	2.54[b] (33)	0.049
Dew	473.10[a] (50)	383.53[b] (34)	16.75	2.88[a] (43)	2.68[b] (27)	0.0432
Vac				2.67[a] (20)	2.76[a] (13)	0.079

Means with different superscripts in same row for the same variable differ significantly ($P < 0.05$).

Vac + Dew = Group given prophylactic vaccination (against enterotoxaemia, pleuropneumonia sheep pox) and two dewormings during the study period.

Dew = Group given two dewormings during study period.

Vac = Group given prophylactic vaccination.

Source: Khan et al. (1995).

Table 7. Descriptive statistics of various productivity parameters of treated and control groups of goats.

	Average annual hair production (g)			Average birth weight of kids (Kg)		
Group No.	Treated	Control	SE	Treated	Control	SE
Vac + Dew	589.80[a] (50)	562.08[b] (36)	13.580	3.00[a] (35)	2.94[a] (29)	0.006
Dew	526.03[a] (34)	500.00[b] (40)	17.398	2.80[a] (30)	2.62[a] (23)	0.070
Vac				2.68[a] (14)	2.31[b] (18)	0.079

Means with different superscripts in same row for the same variable differ significantly ($P < 0.05$).

Vac + Dew = Group given prophylactic vaccination (against enterotoxaemia, pleuropneumonia goat pox) and two dewormings during the study period.

Dew = Group given two dewormings during study period.

Vac = Group given prophylactic vaccination.

Source: Khan et al. (1995).

Parasite Control

Small ruminants in Pakistan are generally owned either by smallholder farmers or by landless farmers. The socio-economic status of these farmers is low compared to other communities, and most of them have little education. Primarily, animals are raised for meat production and they supply almost as much red meat as that supplied by large ruminants (Ahmed 1995).

Four types of small ruminant flocks, i.e. nomadic, transhumant, sedentary and household, prevail in the country (Ishaque 1993). The frequencies of kinds of flocks vary in different parts of the country depending mainly upon the geo-ecological conditions.

The number of transhumant flocks is larger than the other three. Although parasitic fauna varies in different ecological zones yet, due to the movement of nomadic and transhumant flocks across the country, parasite ova/larvae are distributed along the routes and ultimate destinations of these flocks. These may cover several hundred kilometres annually.

Deworming of flocks for the control of parasites is not practised by private farmers until animals start becoming clinically sick and there are a few mortalities. Farmers try to check these mortalities by administering country medicines. Due to ignorance, sometimes superstitious practices are also observed. The help of professionals is sought at a very late stage and the diagnostic laboratories established at district level are rarely consulted. Hence, indiscriminate use of anthelmintics is common. The commonly used anthelmintics include albendazoles, morantel tartrate, oxfendazole, levamisole, oxyclozanide and niclosamide etc. Deworming of household flocks, especially those which are not sent out for grazing, is seldom done. At state-owned farms, the deworming of small ruminants is carried out twice a year: firstly, during spring (February–March), and secondly, before the onset of autumn (July–August). Studies on grazing management and other measures adopted for the control of parasites have not been undertaken.

Recommendations

The prevalence of parasites in Pakistan has mostly been studied by teaching/research institutions in the areas where they are located. There is a need to investigate the incidence of parasites in all ecological zones during the different seasons in order to develop control measures and deworming schedules.

Epidemiological studies on ecto and endoparasites of small ruminants should be undertaken.

There is a great need to educate farmers about the ill-effects of parasitism on small ruminants. Currently, the farmers deworm their flocks without determining the type of parasitic infestations. This results in indiscriminate use of anthelmintics which should be discouraged.

A systematic study of drug resistance, which is currently lacking in the country, should be undertaken.

Parasite control programs based on other than chemotherapy, such as grazing management, should be investigated.

There should be collaboration between the countries facing parasite control problems particularly those with the same ecological conditions to benefit from mutual experiences.

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Internal Parasites in Goats in Southern Thailand

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Abstract

Most of Thailand's goats are raised by smallholder farmers in villages of the southern region where the climate is humid and tropical. Gastrointestinal nematodes, particularly stomach round worm (*Haemonchus contortus*), are common parasites and a major constraint to goat production in this region. Due to favourable climatic conditions, the transmission of parasites occurs throughout most of the year. Current control practices rely heavily upon chemotherapy, which leads to the development of anthelmintic resistance in parasite populations. Strategic use of anthelmintics and grazing management to control of helminthiasis are discussed. Recently, considerable effort has been devoted to searching for an alternative or complementary method to chemotherapeutic control of nematodes. Breeding animals with higher genetic resistance is one such alternative. Preliminary results of the study at Prince of Songkla University (PSU) indicate that Thai native goats are more resistant to *H. contortus* than Anglo-Nubian crossbred goats.

THAILAND is an agriculture-based country located in Southeast Asia between the latitudes of 5° and 21° north. Most agricultural activities involve intensive crop production on predominantly small farms of 3 to 4 hectares. Livestock production, particularly of ruminants, is generally secondary and supports crop production. Buffalo, cattle, swine and poultry are numerically among the most important species found throughout the country, whereas goats and sheep are important only in the southern region, particularly in the southernmost provinces where Thai-Muslims are concentrated. Most of the southern region is in the equatorial monsoon zone with a humid tropical climate characterised by an annual rainfall of about 2000 mm, temperatures of 20–35 °C, relative humidity of 60–90% and less than 60 minutes difference in day length between solstices. There is a 3 to 4-month dry period commencing in early January with bimodal peaks in rainfall occurring in June and November. It is common for the region to have persistent rain for two to three days during both the short (June) and long (November) wet seasons.

The productivity of Thai native goats in villages is generally poor compared with growth achieved when raised under improved management conditions (Saithanoo et al. 1991). One of the likely constraints to production is the effects of internal parasites on growth of young kids and on the performance of adult goats (Kochapakdee et al. 1993a,b; Pralomkarn et al. 1994). Mortality in goats is markedly high in rural areas, particularly in young kids up to weaning (Saithanoo 1990; Saithanoo et al. 1992). Results of the studies in southern Thailand (Kochapakdee et al. 1993c; Saithanoo et al. 1992) indicate that disease incidence and mortality are expected to increase in goats of higher exotic gene proportion as a result of arising adaptability problems. Internal parasites, especially the gastrointestinal nematodes, are recognised as a major constraint in small ruminants in Southeast Asia (Daud-Ahmad et al. 1991; Pandey et al. 1994; Dorny et al. 1995). Due to the risk of development of anthelmintic resistance in nematodes, public concern about chemical residues and environmental protection, alternative methods of parasite control, such as breeding for genetic resistance with minimal strategic use of drugs are desirable.

This paper reviews the prevalence and effects of internal parasites in goats in southern Thailand. Strategic use of anthelmintics and grazing management to control of helminthiasis are discussed.

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Preliminary results on genetic resistance of goats to *Haemonchus contortus* will also be presented.

Prevalence of Internal Parasites

Studies in southern Thailand on the prevalence of internal parasites in village goats (Suttiyotin 1987; Kochapakdee et al. 1991) revealed that the most common parasites were stomach round worms (*H. contortus*) and coccidia (*Eimeria* spp.). More than 90% of faecal samples of goats were found positive for *H. contortus* eggs. However, there was a higher proportion (95%) of younger goats (<1 year old) infected with *Eimeria* spp. than the older goats (Kochapakdee et al. 1991), although the levels of infestation were similar in both groups (i.e., an average number of coccidian oocysts per gram of faeces (OPG) were 2371 and 2214 in young and mature goats, respectively). This may imply that goats gain some form of immunity to coccidiosis as they get older. Coccidia was also found to be the most common internal parasite of cattle in this region (Choldumrongkul and Suttiyotin 1986). The average eggs per gram of faeces (EPG) of stomach round worms in young goats was 1523 whereas that in mature goats was 1004. It was observed that the EPG levels of stomach round worms tended to increase with the levels of rainfall (Kochapakdee et al. 1993a). This indicates that animals may have to be drenched more often (every 4 to 6 weeks) during the wet season. Nevertheless, Kochapakdee et al. (1993a; 1995a) suggested that drenching alone would not result in increased weight gain unless the nutritional status was also improved. Under village environments where nutritional status is poor, gastro-intestinal nematodes have much greater effects on growth rates of Anglo-Nubian crossbred goats when compared to Thai native goats.

The internal parasites of lesser importance found in goats in southern Thailand were threadworm (*Strongyloides papillosus*), whipworm (*Trichuris ovis*) and tapeworm (*Moniezia expanza*). Threadworm infection was found in 60% of the goats surveyed (Kochapakdee et al. 1991), but an average EPG level was low (221). Whipworm and tapeworm were found in only 18% and 3% of goats, respectively (with average EPG levels of 66 and 50, respectively).

Strategic Management

The minimal strategic use of drugs for parasite control employed at the PSU Campus Farm was described by Milton et al. (1991). For technical drenching, internal parasite burdens are determined by faecal egg counts every 6 to 8 weeks for marker goats representing 10% of the goat flock. Goats are drenched only if the EPG level of the marker goats exceeds a specified threshold level, e.g. all adult goats will be treated when the burden of *H. contortus* of the adult marker goats exceeds 1000 EPG.

Coccidiosis is a serious disease of young goats, usually having its greatest effect on kids prior to and just after weaning. Apart from rational use of a coccidiostat, minimising stress of young animals, maintaining sanitary conditions and good nutrition along with sunlight and air movement to keep housing dry are essential for control of coccidiosis.

Rotational grazing among paddocks also aids control of helminthiasis. Faeces are removed and spread over the paddocks last grazed by goats when goats are removed. As faeces dry, helminth eggs and coccidia oocysts desiccate thus reducing potential parasite infection when goats return to graze. As infective parasite larvae are less likely to survive on the upper leaves in a tall pasture with an open canopy, grazing a relatively tall pasture (>30 cm) should help to reduce parasite infection. This also means that a paddock will be spelled if the pastures are grazed too low, and also suggests that pasture slashing should not be lower than 30 cm.

Anthelmintic Resistance

Anthelmintics to control gastrointestinal nematodes in goats are used extensively, especially on research/institutional farms. Studies at PSU demonstrated that the frequent use of anthelmintics for parasite control in goats has led to development of resistant nematodes against several groups of drugs (Kochapakdee et al. 1995b). Anthelmintics fenbendazole, albendazole, ivermectin and levamisole have sequentially been used at the PSU Campus Farm since 1985. From 1985 to 1990, the antheminthic fenbendazole was used at weaning, mating and when egg counts were higher than 1000 to 1500 eggs per gram of faeces. Between June 1991 and February 1994, albendazole was used five times, fenbendazole once and ivermectin three times. Between September 1992 and February 1994, seven treatments with levamisole were given. It was found that *H. contortus* isolated on the farm was highly resistant to fenbendazole and albendazole and suspected for resistance to levamisole whereas ivermectin was highly effective. Inappropriate dosage rates for goats may be one of the contributing factors in the development of resistance. Recommended drug dosage for goats are the same as for sheep. However, due to differences in pharmacokinetics of drugs between sheep and goats, the anthelmintics are less efficacious in goats and may lead to rapid selection of anthelmintic resistant worms (Sangster et al.

1991). Pandey et al. (1994) reported that *H. contortus* from sheep and goats in Malaysia has been found to be resistant to benzimidazoles, febantel, levamisole and ivermectin. Recently benzimidazole resistance has also been observed in goats in southern Thailand. Therefore, frequent use of anthelmintics would not be desirable even though farmers could afford it.

Genetic Resistance

There is evidence of genetic variation in resistance to helminths between and within breed (Gray et al. 1995). Therefore, breeding of animals resistant to internal parasites is an alternative method, complementary to other methods of control. Thai native goats, which are raised for meat, are small in size. The exotic Anglo-Nubian breed has been introduced for cross breeding with the aim of producing a new genotype with larger body size and higher productivity. Crossbred goats with different degrees of Anglo-Nubian infusion, have been produced. A study on genetic resistance of different genotypes of goats to gastrointestinal nematodes is being carried out at PSU. The preliminary results of the study on the effects of trickle infection with a sheep strain of *H. contortus* (Pralomkarn et al. 1996) suggested that Thai native goats are more resistant to *H. contortus* for parasitological and blood parameters as they had lower EPG, lower worm counts and low reduction in blood values (PVC, haemoglobin, total protein and albumin) compared to their Anglo-Nubian crosses. This may be due to the evolution of Thai native goats in an environment where *H. contortus* is an important parasite. In this study, a large variation among goats within and between genotypes in parasitological variables was observed. During the course of infection, Thai native goats exhibited less change in blood parameters than their crosses with Anglo-Nubian.

Acknowledgment

The author gratefully acknowledges the financial assistance of the Australian Centre for International Agricultural Research (ACIAR) for his participation in this workshop.

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Helminth Diseases of Small Ruminants in the Tropics: A Review of Epidemiology and Control Strategies

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Abstract

This paper briefly reviews the epidemiology and control of helminth parasites of small ruminants of economic importance in the tropics. Epidemiological factors influencing seasonal availability and acquisition of nematode larvae and metacercaria by sheep and goats on pasture are discussed. The pattern of faecal egg output with peaks most commonly observed during the wet season appeared to be well correlated with the adult worm burden within the hosts. The epidemiological consequences of periparturient rise in nematode faecal egg counts and arrested (hypobiotic) larvae as a manifestation of acquired immunity and/or as a result of prior exposure of climatic factors during the free-living stage and the implications for the control of nematode infections are reviewed. Alternative control methods under tropical climatic conditions are also addressed.

SMALL ruminants are widely distributed and are of great importance as a major source of economic security and income for small scale farmers and the landless in rural communities in developing countries. Approximatively one half of the sheep and three-quarters of the goat population in developing countries are found in the humid, sub-humid and semi-arid zones of the tropics (Coop 1985), where both species play an integral part of the production systems (i.e. mixed farming system, extensive production system).

In spite of the numerical and economic importance of small ruminants in tropical developing countries, productivity is generally low due to inadequate feeding resources, poor management and diseases. The recurrent loss in productivity and profit is often due to parasitic infections particularly helminth infections which are a common and major problem for small ruminant production in most parts of the tropics (Gall 1981).

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The most important and common helminthoses of small ruminants in the tropics are: (1) parasitic gastroenteritis (PEG) caused by a wide range of species of gastrointestinal nematodes, among which *Haemonchus contortus* is considered as the most single important nematode species of sheep and goats; (2) fasciolosis caused by *Fasciola gigantica* and *F. hepatica* transmitted by aquatic or amphibious snails whose distribution mostly depends on the availability of surface water.

The epidemiology of helminth diseases is determined by several factors governed by the environment-host-parasite interactions and this paper reviews available epidemiological data on helminth infections in small ruminants that could serve as a basis for recommendations of appropriate control strategies adapted to different geo-climatic zones within the tropics.

Epidemiology

Gastrointestinal nematodes

The nematodes species of economic importance which have been identified in sheep and goats in the tropics include *Haemonchus contortus* (Allonby and Urquhart 1975; Schillhorn van Veen 1978), *Trichostrongylus colubriformis* (Eysker and Ogunsusi, 1980), *Oesophagostomum columbianum* (Fabiyi 1970; Graber and Perrotin 1956) and *Gaigeria pachycelis* (Ortlepp 1937; Vassiliades 1981; Tembely 1986). In addition, sheep and goats are often infected with other species such as *Bunustomum* and *Cooperia*. In the cool tropical highlands, *Nematodirus* spp, *Pseudomarshallagia (Longistrongylus) elongata* and the lungworm *Dictyocaulus filaria* have also been frequently reported.

The development, survival and transmission of eggs and infective larvae are influenced by climatic and environmental factors such as temperature, humidity and precipitation. The effects of these factors often results in seasonal fluctuations in the availability of infective larvae and subsequently in the prevalence of infections and worm burdens of the hosts. This seasonal variation in parasite population dynamics has been demonstrated in a number of studies of the epidemiology of nematode parasites of sheep and goats in the tropics (Allonby and Urquhart 1975; Tongson 1985; Beriajaya and Stevenson 1986a; Tembely 1986; Cheijina et al. 1989). In general, active development occurred during most of the rainy season and grazing animals harbour a variable but significant number of worms. In areas with a distinct rainy and dry season the majority of third stage larvae (L_3) acquired undergo arrested development at the end of the rainy season, and faecal egg counts decline and remain consistently low during the dry season. At the onset of the rainy season when pasture larval challenge and intake of infective larvae are high there is a sharp increase in the egg output. While the pattern described is the most common there may be limited plots surrounding drinking places and permanent ponds which may be sufficiently humid to maintain optimum larval development and transmission all year around.

In the wet tropics of Africa, Latin America and Southeast Asia the climatic conditions permit development of eggs and larval stages throughout the year. However, the pattern of seasonal variation can also be found in these areas, though to a less degree, and the survival time for the infective larvae is reduced as a consequence of high temperatures and high humidity (Okon and Enyenihi 1977; Charles 1989; Aumont and Gruner 1989; Banks et al. 1990; Barger et al. 1994).

With regard to transmission, it is anticipated that a higher stocking rate may cause higher infection rates in the animals (Nansen 1991). In extensive grazing areas with high temperatures and low humidity, there may be little or variable association between sheep density and worm burdens.

As indicated above, the larvae of some genera of nematode are able to delay the maturation to adult stages (a phenomenon known as hypobiosis). Resumption of their development usually coincides with the onset of the rainy season, the most favorable period for larval development and transmission. This may occur as a manifestation of acquired immunity (Urquhart et al. 1962) and/or as a result of prior exposure to adverse climatic conditions during the stages as free-living larvae. While the onset of arrested development has been linked to falling temperatures in some temperate zones, the stimulus in tropical areas is clearly different. The arrested larvae accumulate in the abomasal and intestinal mucosa at the end of the rainy season, persist in this form over the dry season and complete the development at the start of the next rainy season (Vercruysse 1985; Tembely 1986; Chiejina et al. 1987).

The phenomenon of periparturient rise in faecal egg count is of great importance in the epidemiology of gastrointestinal nematodes of sheep and has been extensively reported under tropical conditions. A periparturient rise in nematode egg counts was observed in some instances as early as two weeks before lambing and persisted up to eight weeks post-partum when lambing took place at the end of the wet season (van Geldorp and Schillhorn 1976; Agyei et al. 1991; Zajac et al. 1988; Tembely et al. 1995). Thus, pregnant/lactating ewes become the major source of infection for new born lambs.

Although the same helminth parasites species were found to infect both sheep and goats, the former usually suffer heavier worm burdens because of the difference in their grazing habits. While sheep will rely almost entirely on grazing, goats prefer to browse trees and shrubs if given the choice, often reducing the intake of infective larvae considerably. An additional factor which may increase the worm burden of sheep is their ability to graze very close to the roots of the grasses during times of feed shortage, inevitably ingesting higher numbers of infective larvae.

Liver flukes

Disease caused by liver fluke results in major economic losses in sheep and goats. It is estimated that more than 250 million small ruminants are exposed to these parasites worldwide with losses estimated to be several hundred million dollars. Although both *Fasciola gigantica* and *F. hepatica* may be present, the former has a wider distribution and is the most common species found in the tropics. The disease is widespread and the building of dams and new irrigation schemes have further increased their distribution creating suitable environments for the propagation of the snail intermediate hosts.

Thus, the geographical distribution of trematode species of sheep and goats depends on the presence of suitable aquatic lymnaeid snail to serve as an intermediate host (extensively reviewed by Boray 1985). However, the establishment and maintenance of liver fluke infestation in any area does not only depend on the presence of the snails but also on favourable climatic and ecological conditions for both the parasite and the snails. While the temperature is generally favourable for the development of both the flukes and the intermediate host in most developing countries in the tropics, the variation in the precipitation and humidity creates big fluctuations in snail and free-living stages of the parasites. During the rainy season there is a marked increase in the reproduction of snails leading to a peak in the snail population towards the end of the wet season. This trend slows down or completly ceases during the dry or cold periods resulting in decreasing snail numbers in the dry season.

Herbage infestation by and survival of metacercaria also fluctuate considerably and the infective stage may survive up to 10 months in the wet tropics (Oven 1989) while the longevity of metacercaria have been reported to vary from a few weeks to 3–4 months in relatively hot and dry locations (Njau and Scholtens 1991). The egg production of adult flukes ultimately determines the degrees of pasture contamination, which subsequently influences the epidemiology of the disease. Flukes survive in the livers of sheep for many years (in chronic infection) and high egg production may continue for a long time.

The grazing habits of animals and the management may greatly influence the epidemiology of liver fluke infections. If pasture are available away from wet and marshy areas, sheep and goats prefer to graze these and only if forced by feed shortage will they enter the high risk areas. Although long wet seasons are usually associated with a higher infection rate, the disease causes most losses when the rainy season is followed by drought since the animals will be concentrated in contaminated areas and therefore inevitably will ingest higher numbers of metacercaria.

Control Strategies

In most traditional systems of small ruminant production in the tropics, helminth control is hardly practiced due to either the lack of awareness on the part of livestock owners or the relatively high cost and scarcity of modern anthelmintics. However, if control programs are implemented they are usually based only on chemicals and often the treatments are not given at the right time.

The lack of epidemiological data for strategic control programs in most of the regions in the tropics is a major handicap in the efficient use of available anthelmintics. Salvage treatment is of common practice and treated animals return to the communal contaminated grazing lands. The concept of 'clean' and 'safe' pasture has been advocated in several studies in developing countries but is not feasible under traditional management systems.

Although the risk of anthelmintic resistance is believed to be low in most of the developing countries of the tropics, there are increasing reports of its occurrence from Africa (van Wyk 1990; Bjorn et al. 1991; Maingi 1991; Mwamachi et al. 1995) and Asia (Pandey and Sivaraj 1993; Sivaraj et al. 1994; Dorny et al. 1993).

As a consequence of the growing concern regarding the global anthelmintic resistance problem, the need for introducing alternative control methods has been increasing during the past 5–10 years including the utilisation of genetic resistance to endoparasites. It is now established that indigenous breeds in the tropics have developed a range of unique adaptive traits which enable them to survive and be productive in a diverse and harsh environment. In the tropics, there have been some reports in sheep breeds resistant to gastrointestinal nematodes in Africa (Baker 1995), in the Carribean (Batubara et al. 1993) and to *Fasciola gigantica* in Asia (Wiedosari and Copeman 1990; Roberts et al. 1995), whereas there is less evidence for resistance among goats.

Conclusion

Improvement in the control of helminth infections in sheep and goats offers an opportunity to increase small ruminant productivity in the tropics. Livestock owners will continue to rely on the use of anthelmintics for quite some time before effective vaccines against helminth infections become available. Therefore, sustainable control measures should combine strategic anthelmintic treatments based on sound epidemiological data with other means of control such as exploitation of resistant breeds, pasture management and biological control methods. High variability in susceptibility or resistance to helminth parasites and genetic improvement of small ruminants leading to disease resistance may therefore contribute considerably to reducing the cost of anthelmintics and slow down the risk of development of anthelmintic resistance in small ruminants in the tropics. The development of new approaches to the control of helminth parasites of sheep, using simulation models which include grazing management may be a potentially useful tool in the management of the risk of helminth infections in sheep and goats in the tropics (Barnes and Dobson 1990).

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Gastrointestinal Helminths of Small Ruminants in the Philippines

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Abstract

This paper presents the gastrointestinal helminth of sheep and goats reported to be present in the Philippines. The humid tropical environment of the country favors the development of parasites. Attempts to break the life cycle of the parasites through management procedures to control their spread met limited success in smallholder farms. The most essential part of parasite control programs is the use of anthelmintics.

Filipino workers have relied on imported drugs for control. These dewormers proved effective, but the current status is unknown in terms of drug resistance, which is very possible. Researchers have also looked into the anthelmintic value of indigenous medicinal herbs.

SMALL ruminant (SR) production in many countries in the Asia-Pacific region has reached commercial proportions. In the Philippines, however, sheep and goat raising is mainly confined to smallholder farming systems. Compared to large ruminant animals, the management of sheep and goats is not as developed. Although it was only in recent years that efforts were made to uplift the industry, many researchers have already studied its prospects for the Filipino community. Several authors have recommended that smallholder SR raising be integrated with crop production systems. Many problems were still encountered. One of the major constraints was the presence of gastrointestinal helminths.

This paper aims to review studies undertaken about gastrointestinal parasites of small ruminants. It also seeks to describe the control measures against these parasites in the Philippines. Particular attention is given to the experience in the Small Ruminant–Coconut Systems Project (SRCSP). This project lasted for six years and both authors were directly involved in its implementation.

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Gastrointestinal Parasites of Sheep and Goats

Available literature shows that there are many reported species of gastrointestinal parasites present in the Philippines. Table 1 presents the results of early surveys in naturally infected animals. The morphological description of said parasites may be found in standard textbooks of parasitology (Soulsby 1982) and in selected references in this Table.

In an extensive study, Eduardo (1986), writing on helminths of ruminants in the Philippines (which included descriptions and illustrations based on actual examinations of specimen), reported the presence of 18 families, representing 34 genera and 68 species of parasites (Table 2). Specifically identified among the SR, were 10 families, with 13 genera and 14 species of helminth parasites (Tables 3 and 4). Most studies used eggs per gram (EPG) of faeces in demonstrating the presence of parasites. It should be noted that there is no correlation between EPG counts and intensity of host infection (Tongson et al. 1981).

Aside from the parasites identified in Tables 1 and 2, the presence of more species cannot be discounted. This is because there are many more parasites of cattle described in the Philippines. It is a known fact that cattle (and buffalo) share many common parasites with sheep and goats. This

Table 1. Early reports on helminth parasites of small ruminants in the Philippines.

Scientific name	Organ involved	Host	Early reports
1. Trematodes (Flukes)			
Carmyerius synethes	Rumen	Goat	Tongson et al. 1981
Cotylophoron cotylophorum (amphistome)	Rumen	Goat, Sheep	Manuel and Madriaga 1966
Eurytrema pancreaticum	Pancreas, duodenum	Goat	Manuel and Madiraga 1966
Fishoederius cobboldi	Rumen	Goat	Tongson et al. 1981
Fishoederius elongatus	Rumen	Goat	Javellana 1986
2. Cestodes (Tapeworms)			
Moniezia expansa	Small intestine	Sheep	Schwartz 1922, cited by Schwartz 1926
Monieza trigonophora	Small intestine	Sheep	Schwartz 1922, cited by Tubangui 1925
3. Nematodes (Roundworms)			
Bunostomum sp. (hookworm)	Jejunum and ileum	Sheep	Lazo 1963; Sanar 1963
Cooperia curticei	Small intestine	Goat	Tongson et al. 1981
Haemonchus placei	Abomasum	Goat	Tongson et al. 1981
Oesophagostmum venulosum	Colon	Goat	Tongson et al. 1981
Strongyloides papillosus	Small intestine	Goat	Tongson et al. 1981
Strongyloides sp.		Sheep	Lazo 1963; Sana 1963
Trichostrongylus axei	Abomasum	Goat	Tongson et al. 1981
Trichostrongylus capricola	Small intestine	Goat	Reyes 1967
Trichostrongylus colubriformis	Small intestine	Goat	Reyes 1967

Table 2. Helminth parasites of ruminant animals in the Philippines (1986).

	Number		
Helminths	Families	Genera	Species
1. Trematodes (flukes)	5	13	32
2. Cestodes (tapeworms)	1	1	2
3. Nematodes (roundworms)	12	20	34
Total	18	34	68

Source: Eduardo 1986.

Table 3. Helminth parasites of small ruminants in the Philippines.

	Number		
Helminths	Families	Genera	Species
1. Trematodes (flukes)	2	3	4
2. Cestodes (tapeworms)	1	1	1
3. Nematodes (roundworms)	7	9	10
Total	10	13	15

Source: Eduardo 1986.

perpetuates the cycle of parasitic infection. In addition, the tropical climate of the Philippines is conducive for the development and proliferation of internal parasites. Sana (1963) demonstrated that in sheep, nematode and trematode ova production was directly related to the amount of rainfall. The EPG counts are expected to be highest during the rainy season. Other predisposing factors to parasitism are the close grazing habits of the animals, limited range that favors faecal concentration, and in goats, the tendency to nibble at practically anything (Tongson et al. 1981).

While many of the parasites listed in the Tables are considered nonpathogenic (e.g., amphistomes), some cause diarrhoea, anaemia, emaciation, and death. The most important parasites (both in degree of infection and pathogenic effects) are *Haemonchus* sp., *Fasciola* sp., and *Trichostrongylus* sp. In most cases, an animal does not harbor only one species of parasite. Rather, mixed infections are common. For the average smallholder farmer, such manifestations of parasites are economically devastating.

Control of Gastrointestinal Parasites

In general, nematodes have a direct life cycle while trematodes and cestodes require intermediate hosts to complete their life cycles (Soulsby 1982). Examples of intermediate hosts are snails in the case of

Table 4. Helminth parasites of small ruminants in the Philippines.

Helminths	Host	Reports
Trematodes		
1. Family Fasciolidae	Goat	Marbella 1991
1.1 Genus *Fasciola* Linn.		
a. *Fasciola gigantica* Cobb		
b. *F. hepatica* Linn		
2. Family Gastrothylacidae	Goat	Eduardo 1986
2.1 Genus *Fischoederius*		
a. *Fischoederius cobboldi*		
2.2 Genus *Carmyerius*		
a. *Carmyerius synethes*		
Cestodes		
1. Family Anoplocephalidae	Sheep and Goat	Reyes et al. 1993; Tongson et al. 1981; Marbella 1991; Eduardo 1986
1.1 Genus *Moniezia*		
a. *Monieza expansa*		
Nematodes		
1. Family Cyathostomidae	Sheep and Goat	Faylon et al. 1995; Tongson et al. 1981; Marbella 1991; Eduardo 1986
1.1 Genus *Oesophogostomum*		
a. *Oesophagostomum* spp.		
2. Family Trichostongylidae	Sheep and Goat	Faylon et al. 1994; Tongson et al. 1981; Marbella 1991; Eduardo 1986
2.1 Genus *Trichostongylus*		
a. *Trichostonylus* spp.		
2.2 Genus Haemonchus	Sheep and Goat	Faylon et al. 1994; Reyes et al. 1993; Tongson et al 1981; Marbella 1991; Eduardo 1986
a. *Haemonchus contortus*		
b. *H. similis*		
2.3 Genus Cooperia	Sheep and Goat	Faylon et al. 1994; Reyes et al. 1993; Tongson et al 1981; Marbella 1991; Eduardo 1986
a. *Cooperia* spp.		
3. Family Ancylostomatidae	Sheep and Goat	Faylon et al. 1994; Tongson et al. 1981; Marbella 1991
3.1 Genus *Bunostomum*		
a. *Bunostomum* spp.		
4. Family Protostrongylidae	Goat	Marbella 1991; Eduardo 1986
4.1 Genus *Dicocaulus*		
a. *Dictyocaulus viviparus*		
5. Family Trichuridae	Sheep and Goat	Reyes et al. 1993; Tongson et al. 1981; Marbella 1991; Eduardo 1986
5.1 Genus *Trichuris*		
a. *Trichuris ovis*		
6. Family Capillariidae	Goat	Eduardo 1986
6.1 Genus *Capillaria*		
a. *Capillaria bilobata*		
7. Family Strongylidae		Reyes et al. 1993; Tongson et al. 1981; Marbella 1991; Eduardo 1986
7.1 Genus *Strongyloides*		
a. *Strongyloides papillosus*		

Fasciola sp., and oribatid mites in *Moniezia* sp. The control of parasites may, therefore, be approached from several stages of the life cycle: egg, larvae, intermediate hosts and adult.

Silvestre (1983) reported that raising goats in pasture gives rise to a more severe parasitic infection than when goats are kept in confinement. In general, there is less incidence of worm infection in animals during the dry season. Environmental temperature is observed to have no detrimental effects on the development of infective parasitic stages (Sana 1963). Therefore, pasture remains infective throughout the year.

Probably the first methods employed to reduce parasitic load is by simple management. An example is transferring the infected herd to a higher ground. Management of the grazing flock like rotational grazing is not being done as a parasite control measure but rather for the benefit of pasture grasses (and indirectly for the nutritional status of animals). In smallhold farms, sheep and goats are usually tethered rather than grazed. The separation of age groups as a management procedure to reduce spread of parasites is not practical under smallhold farming. Avoidance of the intermediate hosts (e.g., snails which carry *Fasciola* sp.) seems the only practical management procedure to break the life cycle of the parasites.

Medicinal plants are popular in the Philippines. One reason is the high cost of commercial drugs (which are usually imported) and often not available in remote villages. There are 150 documented medicinal plants claimed to be effective for human intestinal parasites (Quisumbing 1978). Farmers use herbal medicines for the symptomatic relief of early clinical signs of disease, e.g., diarrhoea (Mateo 1992). Several researchers attempted to study these plants for use in ruminants. Plants which have been used by farmers to control parasites in goats (Fernandez 1995) include *Quisqualis indica* (Niyog-niyogan), *Momordica charantia* (Paliya), *Clitorea ternatea* (Balog-balog), *Bixa orellana* (Asuite), *Lansium domesticum* (Lansones), *Karicia papaya* (Papaya), *Leucaena leucocephala* (Ipil-ipil), *Cajanus cajan* (Kadios), *Cassia alata* (Sunting), *Ananas comosus* (Piña), *Mangifera indica* (Paho), *Manihot esculenta* (Balanghoy), *Tamarindus indica* (Sambag), *Moringa oleifera* (Malunggay), *Artemisia vulgaris* (Hilbas), *Mimosa pudica* (Makahiya), *Chrysohyllum caimito* (Kaimito), and *Tinospora rumphii* (Panyawan). All of these plants above showed an efficacy of >50% against *H. contortus*. *T. rumphii*, with an efficacy of 85.6%, was the most promising in that it was comparable to a commercial anthelminthic.

The use of chemotherapeutics to control parasites has also been explored. Most studies involving drug efficacy are done abroad. When a new drug is introduced, it is usually used for cattle parasites. In actual practice, therefore, veterinary practitioners and farmers use the preparations for cattle to control parasites among SR. Table 5 shows a list of some local drug efficacy testing done specifically in small ruminants. The effectiveness of the drugs has been measured by EPG and post-mortem examination. All the drugs tested were considered effective.

The most popular anthelmintics used in the Philippines are the benzimidazole derivatives. These include albendazole, mebendazole, oxfendazole, parbendazole, and thiabendazole. Albendazole, the most readily available drug, is also preferred because of its wide spectrum of activity, that is, it is active against nematodes, cestodes, and trematodes. Other anthelmintics for ruminants commercially available are the avermectins (ivermectin), probenzimidazoles (febantel), imidazothiazoles (tetramisole, levamisole), organophosphates (trichlorfon), piperazine, substituted phenols (bithionol, niclofolan), and salicylanilides (closantel, oxyclozanide, rafoxanide). Except for ivermectin, there are no recent studies about the current efficacy of these drugs in small ruminants (Landicho 1989).

Table 5. Some anthelmintic efficacy testing in small ruminants conducted in the Philippines.

Drug	Species	Sensitive	Researcher(s)
Albendazole	Goat	Roundworms	Dajime 1981
Bithelmin (tetramisole + bithionol)	Goat	Flukes Roundworms	Peralta 1977
Fenarsenate (microfine purified phenothiazine with lead arsenate)	Goat	Roundworms Tapeworms	Montenegro 1974
Ivermectin	Goat and Sheep	Roundworms	Divina et al. 1994
Neguvon (0, 0-dimethyl 2,2,2-trichlorohydroxy ethyl-phosphoric acid esters	Goat	Roundworms	Ramirez and Dumlao 1964

In many foreign countries, researchers have reported anthelmintic resistance. In the Asian region, a serious problem in sheep is the resistance of *H. contortus* to albendazole, oxfendazole, fenbendazole, and febantel (Pandey and Sivaraj 1994). Ivermectin, a relatively new drug, is gaining wide acceptance as it has a wide spectrum of activity (ecto- and endoparasites). It is probable then that anthelmintic resistance is widespread. In the Philippines, there are still no indications of development of resistance to ivermectin (Divina et al. 1994). For six years, the SRCSP has alternately used three anthelmintics: albendazole, oxfendazole, and ivermectin. With a regular deworming interval of six months, the incidence of clinical intestinal parasitism was only 1.2%–1.5% but with a high case fatality rate of 33%–50% (Molina et al. 1993; Ducusin et al. 1994). No untoward effects were observed. One researcher suspected teratogenic effects of albendazole (Cabrera 1992).

There were claims that indigenous SR were more resistant to parasites than exotic breeds. Specifically, a local strain of goat known as "Dadiangas goat" was reported to be more resistant to gastrointestinal parasites than Anglo-nubian. However, a specific study is needed to support this claim.

Conclusion

Based on the above information about parasites in the Philippines, it is evident that the most essential part of the control program is the use of anthelmintics. The Small Ruminant-Coconut Production System Committee (PCARRD 1994) recommends, among others, that ewes/does which are expected to lamb/kid in three weeks should be dewormed. This prevents the transmission of parasites from the dams to their offsprings. The lambs/kids should be dewormed at three weeks of age. Deworming should be repeated after three weeks to break the life cycle of the parasites. Deworming every three months, thereafter, is also recommended. The above deworming schedule helped control the number of infective stages of intestinal parasites in the pasture.

Because anthelmintic resistance is an emerging problem for every drug introduced, it is necessary to monitor the efficacy of existing anthelmintics. There is a continuing effort for the development of new drugs against parasites for use in commercial farms in anticipation of the boost in small ruminant production. Another trend is the continued research on active compounds of medicinal plants to establish their anthelmintic values, with the smallholder farmers as target beneficiaries.

Ultimately, the raising of resistant animals along with the development of a planned animal health program which includes, among others, good husbandry practices and strategic deworming using combined commercial and herbal medicines proved to be the most appropriate practices to address parasite problems among small ruminants.

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Breeding for Gastrointestinal Nematode Resistance of Sheep in North Sumatra

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Abstract

Parasitic gastroenteritis is the most important factor causing production losses, disease and mortality in small ruminants in Southeast Asia. Among the gastrointestinal parasites *Haemonchus contortus* is the most common and also the most pathogenic nematode encountered in the region. Other important nematodes occurring in sheep in Indonesia are *Trichostrongylus colubriformis, T. axei, Strongyloides papillosus* and *Oesophagostomum* spp. Additionally the pancreatic fluke *Eurytrema pancreaticum* and tapeworm *Moniezia* spp. have also been shown to be common in North Sumatra. Parasite control can increase small ruminant production dramatically in the humid tropics. Control of the parasite is usually based on suppresive anthelmintic treatment; however, there are alternative strategies such as pasture rotation and breeding for resistance to parasites. Helminth parasite control using anthelmintics is still effective in this region, as there was no anthelmintic resistance apparent in several studies. Grazing management by spelling the pasture for more than 12 weeks showed that only a small proportion of infective larvae of gastrointestinal nematodes survive. This indicates that a combination of grazing management and utilisation of anthelmintics is effective. Studies on genotype differences of Local Sumatra sheep and its crosses with Javanese fat-tail, and imported tropical hair sheep (St. Croix and Barbados Blackbelly) as well as the new synthetic breed (25% Barbados, 25% St. Croix and 50% Sumatra thin-tail) by natural and artificial infection of *Haemonchus contortus* show a variation among genotypes, and the cross between Javanese fat-tail and Sumatra thin-tail are susceptible to nematode parasites. There was also high variation within genotypes. A series of studies has shown that breeding for gastrointestinal nematode resistance is an alternative for controlling helminth parasites that lower sheep production.

SHEEP production in Indonesia is generally carried out by smallholder farmers. The population of sheep is approximately 6.5 million (Direktorat Jenderal Peternakan 1995) and of these approximately 89% are found in Java. In Aceh and North Sumatra, the sheep populations are approximately 1.7% and 2.7% of the total. Smallholder farmers usually raise the sheep because land is available and the sheep are used as a source of meat, manure and cash (Direktorat Jenderal Peternakan 1995).

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Sheep production under hot, humid tropic conditions is constrained by several factors that are difficult to control. Fluctuations in temperature and high humidity are related to poor quality forages and high rates of parasite infestation which cause annual losses of approximately $US2 million (Temaja 1980). In North Sumatra, where sheep are mostly raised in semi-intensive management in which they are allowed to graze under rubber or oil palm plantations during the day and housed in the barn during the night, internal parasites seriously impair the performance of lambs.

Parasitic gastroenteritis is the most important factor causing production losses, disease and mortality in small ruminants in Southeast Asia. Among the gastrointestinal parasites *Haemonchus contortus* is the most common and also the most pathogenic nematode encountered in the region. In

Aceh province, a study from 1981 to 1982 showed that about 40% of sheep were infected with *H. contortus* (Temaja 1980). Other important nematodes occurring in sheep in Indonesia are *Trichostrongylus colubriformis, T. axei, Strongyloides papillosus* and *Oesophagostomum* spp. Additionally the pancreatic fluke *Eurytrema pancreaticum* and tapeworm *Moniezia* spp. have also been shown to be common in North Sumatra (Dorny et al. 1996; Mirza et al. 1994; Wilson et al. 1993; Carmichael 1990; Beriajaya and Stevenson 1985). Parasite control can increase small ruminant production dramatically in the humid tropics (Handayani and Gatenby 1988). Control of the parasite is usually based on suppresive anthelmintic treatments; however, there are alternative strategies such as pasture rotation and breeding for resistance to parasites (Carmichael 1993; Pandey et al. 1994).

This paper reviews work done in Sungai Putih, North Sumatra, for controlling gastrointestinal parasites by using anthelmintic treatment, pasture rotation and breeding for resistance to parasites.

Parasite Control using Anthelmintic Treatments and Pasture Rotation

Studies of helminth parasitism have shown that nematode and trematode parasitism were serious constraints to successful grazing of sheep in the rubber plantations of North Sumatra. Carmichael et al. (1992) reported that throughout the 13-month study period, faecal egg counts confirmed that substantial pathogenic burdens of helminths were rapidly acquired by sheep throughout the year. The rate at which the faecal egg counts increased from zero (after treatments) to high levels was similar at different times of the year. These findings confirm that in the rubber plantations helminthiasis is a perennial and not a seasonal problem. The most important parasite under these conditions was *H. contortus*. Other nematode species encountered were *Trichostrongylus colubriformis, Cooperia curticei, Oesophagostomum asperum* and *Trichuris globulosa*. Two peaks of larval recovery occurred, the first roughly from February to May, the second from August to November for *Haemonchus*. The faecal egg counts of all animals were reduced to zero following treatment. This shows that benzimidazole anthelmintic administered at the recommended dose was highly effective. Resistance to this anthelmintic is therefore not a problem under the present conditions.

Similar results were reported by Dorny et al. (1995) in studies on anthelmintic efficacy in sheep on a large sheep breeding farm and on seven smallholder farms in North Sumatra. By using the faecal egg count reduction test (FECRT) following the guidelines of the World Association for the Advancement of Veterinary Parasitology, albendazole, febantel, ivermectin and levamisole were tested. Results of the study showed that efficacies on the large breeding farm of albendazole, febantel and ivermectin were 99%, 100% and 99%, respectively, while for the levamisole the efficacy was 95%. On the seven smallholder traditional farms the efficacy was 100%. This indicates that there was no anthelmintic resistance on eight farms of North Sumatra.

Results of this study, in contrast with the study in Malaysia reported by Pandey and Sivaraj (1996), amply indicate the danger of development of resistance in gastrointestinal nematodes to most anthelmintics currently available on the market. This absence of resistance in North Sumatra is probably due to the fact that anthelmintics are not used as extensively as in Malaysia, primarily because they are not affordable to the farmers. Additionally, the advantage of grazing management in North Sumatra is that it can reduce the frequency of anthelmintic treatments (Dorny et al. 1995). In these studies, sheep grazing under rubber plantations were treated once every three months, followed by movements to pastures which had been spelled (not grazed) for three months. It was shown that there were dramatic reductions in faecal egg counts of sheep which grazed 12–14 weeks after pasture contaminations, compared to those of the 4–6 and 8–10 weeks group. Total worm burdens of sheep allowed to graze 8–10 and 12–14 weeks after pasture contamination were reduced by 83% and 96% respectively, compared with the 4–6 weeks group (Carmichael et al. 1992). Similar results were reported by Batubara et al. (1995a) on the study of infectivity of pasture contaminated with *H. contortus*, in which the lowest number of worms in abomasa were found in animals grazing pastures which were spelled for 12 weeks (29.3 worms) compared to animals grazing pastures which were spelled for 9 weeks (37 worms) and for 6 weeks (80 worms). This indicates that pasture rotation can effectively break the cycle of continuous infection between host and pasture. It was found that in hot humid tropical conditions infective stages develop within a few days from eggs, but their longevity is reduced due to exhaustion of stored energy (Carmichael 1993). These observations indicate that wherever possible, pasture rotation should be practiced in order to reduce anthelmintic resistance.

Genetic Variations in Resistance to Nematode Parasites

Resistance can be defined as the ability to suppress establishment and/or subsequent development of worm infection (Albers and Gray 1986). The body has a large number of defense mechanisms to protect it against pathogenic organisms. Resistance to infections with parasitic organisms operates at several different levels.

Resistance of vertebrate hosts to infection is comprised of innate and acquired components. Innate resistance reflects the exposure of a parasite to the fixed behavioral structural, biochemical and physiological characteristics of the potential host. Acquired resistance consists of those immune and immunologically mediated responses which adaptively protect an animal once it has experienced an infection (Wakelin 1992). Both humoral and cell mediated immune responses are involved. However, efforts to develop effective vaccines have been largely unsuccessful, because responses are variable and short-lived (Woolaston 1991). Another strategy currently being investigated involves manipulation of the host genotype to increase levels of resistance.

Resistance of sheep to gastrointestinal nematodes is known to be genetically variable in its characteristics. Variation among breeds of sheep in resistance to internal parasites, particularly to *H. contortus*, *Ostertagia circumcincta* and *Trichostrongylus* spp. have been documented in tropical and temperate breeds by many workers (e.g. Preston and Allonby 1978, 1979; Stear and Murray 1994; Courtney et al. 1984, 1985; Gamble and Zajac 1992).

Variation among genotypes of Local Sumatra thin-tail sheep (S), Pure St. Croix Hair Sheep (H), the first generation (F1) crossbred between St. Croix Hair Sheep × Sumatra thin-tail (50% H, 50% S, H1), the first generation (F1) crossbred between Javanese fat-tail (E) and Sumatra thin-tail (50% S, 50% E, E1), the first generation (F1) crossbred between Barbados Blackbelly (B) introduced by frozen semen × Sumatra thin-tail (50% B, 50% S, B1), and the second generation (F2) of H1 x H1 (HC) have been studied in Sungai Putih, North Sumatra, from 1991 to 1993 (Romjali et al. 1994; Romjali 1995). In this study ewes and suckling lambs were grazed under rubber plantations from 08.00 to 16.00 h daily, and housed in the barn with a raised slatted floor at night. Faecal egg counts on natural infection on weaning lambs (at 3 months) that were born in February through March 1992 showed that the highest egg counts (egg per gram of faeces, EPG) were found in E1 followed by H1, HC, H, S and B1 (Table 1). These results indicated that the genotypes susceptible to gastrointestinal nematodes were E1 (the cross between Javanese fat-tail with Sumatra thin-tail sheep) and H1 (the cross between St. Croix and Sumatra thin-tail sheep), while the most resistant genotype was the B1 (the cross between Barbados Blackbelly and Sumatra thin-tail sheep). Sumatra thin-tail sheep, Pure St. Croix, and HC had similar resistance to gastrointestinal parasites at the medium level. Similar results were also indicated when all data from 1991 to 1993 were analysed (Table 2). Group genotypes that had highest egg count and were not significantly different were H1 and E1, followed by S, HC and H. However, there were no genotype differences on the intensity of peri-parturient rise on the faecal egg counts (Dorny et al. 1994; Romjali 1995) (Table 3).

Differences in the genotype for parasitic resistance are probably due to the differences of environment and origin of the breed. The St. Croix, Barbados Blackbelly, and Sumatra thin-tail sheep are from the hot and humid tropics. Therefore, the animals have adapted to the constant challenge of gastrointestinal parasites which may lead to the development of some degree of genetic resistance. The Javanese fat-tail sheep come from Eastern Indonesia where the climate is drier. Therefore, the

Table 1. Faecal egg counts (EPG) of lambs of six genotypes at weaning at 3 months of age (Romjali et al. 1994; Romjali, 1995).

Genotypes	Number of lambs	Least square means of log (EPG+1) ± SE[1]	Geometric mean
Sumatra thin-tail (S)	90	3.01 ± 0.13^{ab}	1023
St. Croix (H)	22	3.06 ± 0.34^{ab}	1148
F1 cross St. Croix × Sumatra (H1)	106	3.47 ± 0.16^{b}	2951
F1 cross Javanese fat-tail × Sumatra (E1)	117	3.51 ± 0.20^{b}	3236
F1 cross Barbados Blackbelly × Sumatra (B1)	65	3.48 ± 0.15^{a}	302
F2 cross St. Croix × Sumatra (HC)	26	3.29 ± 0.30^{ab}	1950

[1]Means with different superscript within a column are significantly different (P<0.05).

Table 2. Least square means (LSM) for weaning weight (WWT), faecal egg counts (eggs/g of faeces, EPG), geometric means (GM) and regression coefficients of EPG on WWT (b) for five genotypes at 3 months of age (Romjali 1995).

Genotypes[1]	Number of lambs	WWT + SE[2] (kg)	LSM[2] log (EPG+1) + SE	GM	b (kg/log (EPG+1))
E1	221	8.7 ± 0.3^{a}	3.68 ± 0.11^{a}	4800	-0.553 ± 0.182
H	154	10.6 ± 0.3^{b}	3.18 ± 0.13^{b}	1500	-0.467 ± 0.186
H1	191	9.1 ± 0.4^{a}	3.79 ± 0.15^{a}	6200	-0.209 ± 0.171
HC	454	11.1 ± 0.2^{b}	3.40 ± 0.09^{ab}	2500	-0.281 ± 0.127
S	551	8.2 ± 0.2^{a}	3.46 ± 0.10^{ab}	2900	-0.235 ± 0.109

[1]E1 = F1 cross of Javanese fat-tail × Sumatra; H = St. Croix; H1 = F1 cross of St. Croix × Sumatra; HC = F2 (F1 × F1) cross of St. Croix × Sumatra; S = Sumatra thin-tail.
[2]Means with different superscript within a column are significantly different (P<0.05).

Table 3. Geometric mean faecal egg counts (eggs/g faeces, EPG) of lambing ewes of four genotypes according to the stage of pregnancy and lactation (Dorny et al. 1994; Romjali, 1995).

Genotype[1]	Number	Weeks relative to lambing −2	−1	0	+1	+2	+3	ANOVA
S	10	242	539	1064	2441	2465	8519	P<0.05
H1	8	78	189	145	1075	1086	ND[2]	P<0.01
E1	7	550	757	788	2165	907	ND	P<0.05
B1	10	1130	567	561	1012	1978	1604	N.S.[3]
All genotype	35	334	459	528	1588	1525	4188	P<0.005
Control	9	420	159	652	213	265	302	N.S.

[1]S = Sumatra thin-tail; H1 = F1 cross of St. Croix × Sumatra; E1 = F1 cross of Javanese fat-tail × Sumatra; B1 = F1 cross of Barbados Blackbelly × Sumatra.
[2]ND = no data.
[3]N.S. = not significant.

selection pressure for increased resistance to worms is expected to be low (Gatenby et al. 1995). Therefore in the E1 (F1 cross Javanese fat-tail × Sumatra thin-tail) more severely affected their weaning weight (Table 2). The weaning weight of E1 lambs was almost halved when the faecal egg counts (log EPG) increased in one unit as compared to the resistant genotypes, such as Sumatra thin-tail, F1 and F2 cross St. Croix × Sumatra.

No genotype differences in the intensity of periparturient rise indicates that the non-genetic effect was more important in ewes. This is supported by the important effect of litter size and the fact that periparturient ewes are much more susceptible to the effects of gastrointestinal nematodes (Dorny et al. 1994; Romjali 1995). The significant effect of the litter size on peri-parturient faecal egg counts indicated that the higher physiological stress imposed on ewes feeding for ewes that carried twin or multiple birth lambs could cause greater depression of the immune response. No differences among genotypes in the intensity of periparturient rise is probably due to the fact that all genotypes were of tropical origin. In contrast, other work has shown that breeds of sheep that originally came from the tropical region showed only a little or no periparturient rise, while breeds from temperate regions showed a pronounced rise (Courtney 1986).

Non-genetic effects were also found in the resistance to nematodes in lambs; however, genetic effects were expressed by genotype differences. Romjali (1995) reported that sex of lambs, type of birth and rearing and lambing season, and age of lambs influenced susceptibility to parasite infection. A study based on faecal egg counts and Packed Cell Volume (PCV) showed that ram lambs, twin lambs raised as twins and triplet rams raised as twins were more susceptible to parasites. Additionally, younger lambs were also more susceptible to parasites.

Variation in resistance to parasites within a flock or breed of sheep has been observed in Indonesia and other countries. Gatenby et al. (1991) found that some ewes in Sungai Putih, North Sumatra maintain low faecal egg counts, whereas others in the same flock are heavily infected. Carmichael et al. (1992) in the same place also identified three Javanese thin-tail ewes with consistently lower faecal egg counts than other animals in the flock in most of the 16 observations over one year.

Genetic variation in resistance to *H. contortus* within the sheep flocks has been demonstrated and used in breeding schemes in Australia (Albers and Gray 1987, Woolaston 1991). Genetic selection for resistance in parasites has been quite spectacular, compared to selection for other traits. A Merino flock selected for increased resistance to *H. contortus* since 1978 had faecal egg counts only 20%–30% as high as unselected controls and should rarely need drenching in temperate Australia (Woolaston 1991). This is probably due to high heritability of faecal egg counts of *H. contortus* that range from 0.3 to 0.5 (Gray et al. 1987; Woolaston 1991).

Evaluation of repeatability of faecal egg counts and PCV in three genotypes (Sumatra thin-tail, St. Croix and F1 cross of St. Croix × Sumatra) indicated that by using faecal egg counts the repeatability was 0.08, while using PCV it was 0.28 (Romjali et al. 1994). If the repeatability could be used as the indication of upper limit heritability of gastrointestinal resistance, using the faecal egg count genetic variation in this study was low, while using the PCV, genetic variation was medium. The inconsistent results compared to the previous study are probably due to limited available data. Therefore, genetic variation in gastrointestinal parasites for certain genotypes merits further studies.

Variation of resistance within genotypes have been observed in several artificial infection studies in Sungai Putih, North Sumatra. Romjali (1995) in a study of experimental infections with *H. contortus* on 4 genotypes (F1 cross Barbados × Sumatra, B1; F1 cross Javanese fat-tail × Sumatra, E1; F1 cross St. Croix × Sumatra, H1; and Sumatra thin-tail, S) to rams aged between 18–24 months showed there was no significant difference among breeds, but there were high variations among individuals within breeds. The geometric means of EPG for individual rams within B1, E1, H1 and S were 3 — 1028; 4 — 261; 7 — 3119 and 9 — 506, respectively. However, in another study reported by Batubara et al. (1995b) on similar experiments on weaning lambs (Sumatra thin-tail, S; cross of St. Croix × Sumatra, HC; cross of Barbados × Sumatra, BC; and composite cross of 25% Barbados, 25% St. Croix and 50% Sumatra) differences among genotypes were identified. Among genotypes, S, HC and BC there were no significant difference in their egg counts. The M genotypes had the highest egg counts, but statistically there was no significant difference to HC and BC. The difference of these to those of the previous experiment are probably due to differences in the ages of the rams that were used for the experiments.

Results of these studies show that genetic and non-genetic factors influence susceptibility to parasite infections, and show that in introduced breeds, the origin of the breed is important. In this case, it indicates that introducing a breed from a dry area to the hot, humid tropics is not suitable, because that breed has adapted naturally to the parasites in its original environment. Variation among individuals within genotypes indicated that genetic variation is quite high. Therefore, selection for resistance is possible as shown by studies with temperate breeds.

Conclusions

Results of the studies conducted at Sungai Putih, North Sumatra, have shown that gastrointestinal parasites are constraints to productivity for sheep that graze under rubber plantations. A combination of pasture rotation by 12 weeks spelling, and anthelmintic treatments, showed effective results without causing anthelmintic resistance. Breeding for gastrointestinal nematode resistance is another alternative, as indicated by variation within and between individual genotypes, and could be carried out by crossing of breeds adaptive to the hot humid tropics and by selection within breeds or strain.

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Integrated Control Programs Using Medicated Blocks

M.R. Knox[1]

Abstract

Small ruminants provide an important source of food protein and other benefits to the nations of tropical and sub-tropical Asia and the Pacific Islands. Demand for small ruminant products is increasing but limited land resources prohibit substantial industry expansion unless previously underutilised feed resources are exploited. The productivity of small ruminants in this region is severely constrained by inadequate nutrition and gastrointestinal parasitism which interact to restrict growth and reproduction rates and contribute to high mortality in some flocks. By reducing these constraints considerable productivity gains can be made without increasing overall flock sizes.

Where nutritional deficiencies are likely to exacerbate the detrimental effects of parasitic infection, the use of low cost supplements such as urea-molasses blocks (UMB) can enhance the animal's ability to utilise the available diet and assist the animal to withstand infection. Such supplements should therefore be considered an integral part of husbandry practice in these areas, in order to reduce the debilitating effects of parasitism and minimise the requirement for anthelmintic chemotherapy. Substitution of medicated UMB (MUMB) for UMB can then occur for short periods during times when parasite challenge is high or during periods of low host immuno-competence caused by immaturity or physiological stresses such as reproduction. For these reasons it is likely that MUMB will form an important part of strategic parasite control programs in developing nations where UMB have been shown to offer substantial nutritional benefits.

SMALL ruminants provide an important source of food protein, other commodities and social and cultural benefits to the people in the developing countries of tropical and sub-tropical Asia and the Pacific Islands. During the next 50 years this role is expected to increase in importance as the human population grows in this region and the demand for animal products also increases. Small ruminants can make a major contribution to meeting this demand if appropriate technologies are applied which maximise production potential from the low quality feed resources of this region. Land resources for livestock production are limited and except for integration of small ruminants into tree cropping systems there is little scope for flock expansion based on grazing. Therefore, it is essential that the production of existing animals be maximised through reducing current constraints to production.

Two factors which severely limit the productivity of small ruminants in developing countries are inadequate nutrition and gastrointestinal nematode parasitism. Available feed resources are often low in quality, fibrous and deficient in components which promote efficent rumen function. Supplementation, particularly with high quality protein, is often necessary to maintain adequate productivity but high cost limits their widespread use. Nematode parasites can cause high mortality in small ruminant livestock and losses to clinical and subclinical infections probably equal the value of present output in some areas. Up to the present time, control of nematode parasites has either relied on frequent anthelmintic treatment or has not been undertaken due to the high cost or unavailability of anthelmintics. Where anthelmintics have been frequently used, anthelmintic resistance is emerging as a major problem and the small ruminant industries must seek alternative control methods.

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The following paper describes low cost technologies based on use of urea-molasses blocks (UMB) which have been developed to enable small ruminant production in areas where parasitism is a problem and low quality forages are the primary feed resource. The nutritional benefits of these supplements are briefly discussed followed by a summary of recent research investigating the effects of such supplements in parasitised sheep. A section on development and application of medicated UMBs (MUMB) then precedes a summary of results of three field experiments which use MUMB in strategies for controlling nematode parasites in Fiji and Malaysia.

Low Cost Nutritional Supplements

Improved growth rates and increased reproductive performance of small ruminants in tropical areas can be achieved through supplementation with protein rich feeds but the use of such supplements is not often practised due to their high cost or low availability (Sanchez 1991). Low quality fibrous feeds, which small ruminants can readily use, are often a neglected feed resource and approaches which assist in optimising their use can lead to increased production without considerable increases in cost. Mineral and/or non-protein-nitrogen supplements can dramatically change rumen function by optimising the rumen environment (Leng 1991). Where deficiencies occur such supplementation leads to increased digestibility and utilisation of the feed resource which promotes greater intake of the available diet, increased microbial protein production and thereby increased protein for digestion and absorption in the small intestine (Kanjanapruthipong and Leng 1995). UMB have been successfully used to provide the necessary supplementation at low cost to producers in the production systems targeted by this workshop.

Interaction of Parasitism and Nutrition

Several extensive reviews have established that well fed hosts are better able to cope with the deleterious effects of nematode parasitism than those which are undernourished (Coop and Holmes 1995; Parkins and Holmes 1989). The bulk of evidence to support this argument is derived from experimentation which shows that the provision of high quality protein in the diet of infected animals enables them to compensate for production losses due to infection, often through an enhanced ability to resist infection. Unfortunately the provision of high quality protein is usually not an economic proposition for small ruminant producers due to high cost and is therefore not often practised.

Recent research has indicated that provision of low cost supplements enhances the ability of infected hosts to overcome the detrimental effects of nematode parasitism. In controlled pen studies with young Merino sheep, Knox and Steel (1996) showed supplementation of a low quality roughage diet of oaten chaff and essential minerals with urea reduced the effects of parasitic infection by reducing faecal egg output and parasite burden and increasing weight gain and wool production (see Table 1). Further studies (M.R. Knox and J.W. Steel, pers. comm.) using a UMB supplement with a similar basal diet showed similar production responses to supplementation in parasitised young Merino sheep but not when feed intake was restricted to that of the unsupplemented group (Table 2).

Table 1. Mean live weight and wool production over 18 weeks of Merino weaner sheep on a basal oaten chaff diet or supplemented with 3% urea and infected with nematode parasites.

Dietary treatment	Parasite treatment	Live weight gain (g/day)	Wool production (g/day)
No urea	Nil	30	4.2
No urea	*H. contortus* [1]	29	4.2
No urea	*T. colubriformis* [2]	32	4.4
No urea	Mixed [3]	22	3.8
3% urea	Nil	50	5.3
3% urea	*H. contortus*	40	5.7
3% urea	*T. colubriformis*	37	5.2
3% urea	Mixed	39	5.3

[1] 200 L_3 thrice weekly.
[2] 1000 L_3 thrice weekly.
[3] 200 *H. contortus* L_3 and 1000 *T. colubriformis* L_3 thrice weekly.

Table 2. Mean live weight and wool production over 20 weeks of Merino weaner sheep on a basal oaten chaff diet or supplemented with a urea-molasses block and infected with nematode parasites.

Group	Chaff	Block	Parasite	Live weight gain (g/day)	Wool production (g/day)
1	*Ad libitum*	No	Nil	69	6.4
2	*Pair* fed to 1	Yes	Nil	69	6.4
3	*Ad libitum*	Yes	Nil	90	8.6
4	*Ad libitum*	No	Mixed[1]	41	6.2
5	*Pair* fed to 4	Yes	Mixed	39	6.0
6	*Ad libitum*	Yes	Mixed	59	7.5

[1] 200 *H. contortus* L_3 and 1000 *T. colubriformis* L_3 thrice weekly.

In both these studies, supplemented animals with mixed species infections of nematode parasites showed similar or greater weight gains and wool production than their respective unsupplemented uninfected control groups. Such supplements can, therefore, assist sheep to overcome the detrimental effects of nematode parasite infection. This response is attributed to a greater intake of the basal diet, presumably due to increased digestibility arising from enhanced rumen NH_3-N levels and their effect on microbial fermentation, which results in increased post-ruminal microbial protein availability.

Medicated Blocks

The concept of using feed supplements to deliver anthelmintics and other antibiotics has existed for some time and has been applied with varying degrees of success. Initial attempts at delivery of benzimidazole (BZ) anthelmintics presented the drug in high concentrations and the target animal consumed sufficient supplement on one occasion to achieve the recommended therapeutic dose. Such treatment showed variable levels of success (McBeath et al. 1979; Bogan and Marriner 1983) and has not been widely adopted.

Prichard et al. (1978) showed that prolonged low level presence of BZ chemicals can efficiently control nematode parasites. This principle has been successfully applied through the development of intra-ruminal controlled release devices (CRD) which enable prolonged low level administration of BZ anthelmintics (Anderson et al. 1980). Studies by Barton et al. (1990) and Barger et al. (1993) have demonstrated the effectiveness of this technology even in areas where BZ resistant parasite strains have been identified. This increased efficacy is thought to be due to the continued presence of the anthelmintic preventing the establishment of incoming larvae, decreasing the viability and fecundity of mature worms and having an ovicidal effect on any worm eggs which are produced.

This research has followed similar pharmacokinetic principles to those applied in CRD applications to develop a UMB containing fenbendazole (FBZ) for use in livestock production systems where regular consumption of the block occurs. Through the animals consuming their daily low-level dose of FBZ via the feed block, control of parasites can be achieved. Early studies determined that the bioavailability of FBZ was not affected by incorporation into the block formulation, but that dose rates differed between target host species (Knox et al. 1994; Knox et al. 1995). Field testing has confirmed the prophylactic and therapeutic efficacy of the block in both large and small ruminants as reviewed by Knox (1995).

Control Programs using Medicated Blocks

In production systems where UMB, or alternative low cost supplements, are regularly used, anthelmintic treatment may continue to be necessary from time to time. Young animals, periparturient females and animals exposed to high levels of larval challenge need special attention in this regard, as do goats, since their ability to resist infection is limited. During these times the substitution of medicated blocks for UMB can provide the necessary prophylactic anthelmintic therapy to avoid drastic production losses which normally occur. The following three experiments demonstrate how MUMB can be used.

Young Fiji sheep — 1993-94

Manueli et al. (1995) investigated the effects of parasites and nutrition in young Fiji sheep at pasture. Six groups of 30 11-month-old ewes were each placed into 2 ha paddocks. Two groups were allowed unlimited access to MUMB (0.75 g FBZ/kg), two groups had unlimited access to UMB and two groups received no supplementation (NB). Animals whose faecal egg count exceeded 3000 EPG were treated with anthelmintic to avoid unnecessary mortality. Faecal egg counts during the experiment were lowest for the MUMB group, highest for the NB group while the UMB group was intermediate. During the experiment it was necessary to salvage treat MUMB, UMB and NB ewes 13, 55 and 92 times, respectively. Larval cultures indicated that *Haemonchus* spp. and *Trichostrongylus* spp. were predominant and *Oesophagostomum* spp. was also present but in low numbers. At mating after seven months of experimentation the MUMB (10.5 kg) and UMB (10.0 kg) group ewes had gained more weight than the NB (5.8 kg) group. Ewe conception rates, lambing percentages and total weight of lambs weaned were increased by MUMB and UMB with the former providing the greatest increase (Table 3).

Table 3. Reproductive performance of young Fiji sheep offered MUMB, UMB or no block.

	MUMB	UMB	No block
Ewes lambing	40	34	22
Lambs born	44	40	24
Total weight born (kg)	144	126	66
Lambs weaned	40	39	20
Total weight weaned (kg)	528	405	222
Average lamb weight (kg)	13.2	10.4	11.1

These benefits in reproductive performance are believed to be attributable to the higher liveweight at mating in sheep receiving UMB. Some additional benefits were gained by reducing parasite numbers to very low levels through inclusion of anthelmintic in the UMB.

Young Fiji sheep — 1995.

The previous experiment showed the benefits of UMB and MUMB when used continuously. However, MUMB is more expensive than UMB and its continual long-term use is not desirable due to concerns over the development of resistant strains of parasites. With this in mind P.R. Manueli, M.R. Knox and F. Mohammed (pers. comm.) tested a program of short term use of MUMB in conjunction with UMB to determine the optimal time for their prophylactic use. One hundred and fifty 11-month-old Fiji ewes were divided in to six even groups, on the basis of bodyweight, and allocated to 2 ha paddocks. Two groups were allowed unlimited access to UMB for eight weeks when MUMB (0.75g FBZ/kg) were substituted for UMB for four weeks prior to and seven weeks during mating. These groups were then returned to UMB until four weeks prior to parturition when MUMB were again introduced and remained available up to the weaning of the lambs produced. Two groups had unlimited access to UMB throughout the experiment and the remaining two groups received no supplementation (NB). Animals whose faecal egg counts exceeded 3000 EPG were treated with anthelmintic to avoid unnecessary mortality. Faecal egg counts during the experiment were lowest for the MUMB group, highest for the NB group while the UMB group was intermediate. It was necessary to salvage treat MUMB, UMB and NB ewes 4, 14 and 32 times, respectively, during the experiment. Treatment did not affect liveweights during the experiment but had a substantial effect on reproductive performance with MUMB producing more lambs and total weight of lambs weaned than UMB while NB produced the least of all (Table 4). The nutritional benefits of UMB were again demonstrated in young ewes and the restricted use of MUMB gave similar benefits to those derived in the earlier experiment. Further refinement of the program of use of MUMB in this system is now required to determine if further reductions in MUMB use can occur without compromising productivity.

Table 4. Reproductive performance of young Fiji sheep offered MUMB at mating and parturition, UMB or no block.

	MUMB	UMB	No block
Lambs born	46	43	41
Total weight born (kg)	173	146	134
Lambs weaned	36	31	19
Total weight weaned (kg)	537	382	206

MUMB and Rotational Grazing Systems

Rapid rotational grazing systems (RRGS) similar to that employed to control parasite infections in goats in Tonga (Barger et al. 1994) have been used with some success in Malaysia (Chandrawathani et al. 1995). Unfortunately control offered by RRGS sometimes breaks down due to seasonal changes or physiological stresses on the animal such as reproduction. When infection increases to levels where animal productivity may be affected it is necessary to intervene with anthelmintics to re-establish 'clean pastures' within the RRGS. Limited experimental work in Fiji established that this could be effectively done by conventional anthelmintic treatment followed by introduction of MUMB to goats for one or two rotation cycles (M. R. Knox and R. Singh, pers. comm.).

This approach has been further tested in sheep in the field in Malaysia by Chandrawathani P., Jamnah O. and C. Rajamanickam (pers. comm.). In their experiment RRGS animals were compared to those grazed under set stocked conditions over a six month period. Regular faecal egg counts led to four treatments with conventional anthelmintic for the set stocked group during this time (mean EPG > 5000). The RRGS group were treated with conventional anthelmintic two months after commencement of the experiment (mean EPG <1300) and a further two months later MUMB were introduced since faecal egg counts were beginning to increase. After introduction of the MUMB faecal egg counts stayed at very low levels (EPG <700) until the end of the experiment.

The use of MUMB in conjunction with RRGS has been shown to assist in the maintenance of nematode parasite control. Further work will assist in the identification of problem times/seasons for parasite control in RRGS and MUMB can then be used prophylactically to prevent control breakdown.

Conclusions

It is anticipated that small ruminant production systems in developing countries of Southeast Asia and the Pacific Islands will benefit from the introduction of programs which enable the sustainable control of gastrointestinal nematode parasites. The routine use of low cost supplements such as UMB can enhance the ability of small ruminants to withstand parasitic infection in areas where nutritional insufficiency occurs. In grazing sheep in Fiji use of UMB has been shown to give substantial benefits in young ewes with further benefits being derived from strategic use of MUMB at times when parasitism is normally a problem. Integration of MUMB into RRGS has assisted in the prevention of control breakdowns which can occur. Further work is aimed at refining the recommendations for the integration of MUMB into systems where UMB are nutritionally beneficial. This will yield control programs which optimise the animal's own ability to withstand infection and provide the means for minimal prophylactic chemotherapy when necessary to avoid production loss.

Acknowledgement

The author acknowledges the support provided by the Australian Centre for International Agricultural Research (Projects 8523 & 9132) which enabled these studies to be undertaken.

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Grazing Management for the Control of Nematode Parasites

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Abstract

It is currently possible to reduce significantly the number of anthelmintic treatments required by grazing ruminants by employing some relatively simple management procedures, enlightened by knowledge of the epidemiology of the parasites in the climatic region and production system in question. Some examples of these procedures, such as the Michel dose and move system for nematode control in cattle, strategic treatments at times of low larval availability for sheep, and alternate grazing of sheep and cattle, will be considered.

While such procedures can have a major impact on frequency of anthelmintic treatment, they rarely have a commensurate effect on reducing selection for anthelmintic-resistant worms. Only in control systems that avoid the use of anthelmintics altogether is there any certainty of avoiding selection for resistance. The nearest approaches to this ideal goal are some alternate grazing schemes and rotational grazing systems currently being tested in tropical environments. Even if these anthelmintic-free production systems are successful, the worms are still being selected for attributes that may ultimately render these control procedures ineffective. Examples of this are the propensity for alternate grazing systems to select for reduced host specificity, or increased numbers of parasite species able to infect both host species. Similarly, rotational grazing systems could be subverted by selection for enhanced larval survival or faster development from egg to infective larva. Nevertheless, it is hoped that selection for such fundamental changes as those presumably required to affect survival, development or host specificity will be slower than selection for anthelmintic resistance.

ALTHOUGH there is widespread agreement that grazing management techniques can offer relatively simple and rapid solutions for improving helminth control and reducing anthelmintic usage (Barger, in press), it remains a salutary fact that there are literally no examples of helminth control in highly productive grazing systems where the need for anthelmintics has been entirely obviated. In a future where the very real possibility exists that resistance will have rendered all chemical families of anthelmintics ineffective, this is cause for serious concern and for escalation of efforts to develop sustainable helminth control technologies. In this paper, the role of grazing management in reducing anthelmintic use and improving helminth control will be considered.

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Types of Procedures

The simplest and often most effective forms of management to limit obstacles to animal production raised by helminth parasitism are those that, by geographic location and/or choice of production system, successfully avoid specific helminthoses. Examples are the use of relatively insusceptible wethers for wool production in semi-arid grazing systems, the reservation of pastures infested with the liver fluke (*Fasciola hepatica*) for grazing by cattle rather than the more susceptible sheep on what are predominantly sheep farms, and in the location of sheep and goat industries in drier inland regions of continents rather than in the wetter coastal fringes. Even though successful, there is little geographic scope remaining for further exploitation of these strategies, and for the purposes of the present paper, such procedures avoid rather than control helminth parasites.

At the other extreme, virtually all practices associated with the management of grazing livestock have some influence on parasite epidemiology; effects of variables such as stocking rate, timing of parturition and weaning, use of fodder crops, fodder conservation and choice of pasture species have been reviewed by Morley and Donald (1980). All of these factors can influence the timing or severity of parasitic disease, but rarely to an extent sufficient to outweigh more important considerations, primarily nutritional and economic, regarding their deployment. That is, any parasitological benefits or penalties associated with these variables are almost always relatively minor side-effects, rather than compelling reasons for changes in their implementation. All further discussion in this paper of management to control parasitism will therefore focus on strategies specifically designed to reduce the numbers of, or effects of, helminth parasites on animal production systems in environments where their economic viability would otherwise be threatened by parasitism.

Michel (1985) classified such strategies as being *preventive, evasive* or *diluting*. *Preventive* strategies are those that rely on putting worm-free animals on a clean pasture, or by suppressing egg output by anthelmintic treatment in the early part of the grazing season until the initial population of infective larvae on pasture has declined to safe levels. *Evasive* strategies do not attempt to restrict contamination of the pasture by worm eggs, but rely on movement of livestock to another pasture just before the larvae resulting from these eggs are likely to appear in significant numbers on the original pasture. *Diluting* strategies exploit the concurrent grazing of susceptible animals with a greater population of helminthologically inert animals, of the same or different species, in order to reduce the herbage infestation resulting from their combined faecal output of worm eggs. Use of anthelmintics in all of these strategies is intended specifically to prevent contamination of clean pastures with worm eggs.

Because such treatment is characteristically given in conjunction with a move to a clean pasture, reinfection rates are extremely low and the suppressive effect of anthelmintic treatment on egg output is prolonged for several months rather than the three or four weeks seen on contaminated pastures. This is the basis of the substantial reduction in anthelmintic use achievable through grazing management.

Preventive strategies

The most common examples of preventive management strategies for control of helminth parasites are the short, intensive treatment regimes using controlled-release devices or carefully timed sequences of conventional anthelmintic treatments in the first half of the grazing season for calves in their first year. Controlled-release devices are given at turnout, and conventional treatments are commonly given at turnout, at eight weeks, and again at 13 weeks (e.g. Taylor et al. 1985; Armour et al. 1987; Vercruysse et al. 1987 and 1995).

A similar strategy is used by Australian sheep producers to control nematode infections in lambs following weaning. At weaning, lambs are usually carrying a moderate burden of worms picked up from the contaminated lambing paddocks. If lambs are kept on the same paddocks after weaning, eggs passed as a result of these infections rapidly develop into a disease-producing population of larvae on pasture. An anthelmintic treatment at weaning, in conjunction with a move to a safe pasture prepared by spelling or by grazing with non-susceptible hosts, with a further two or three anthelmintic treatments at 8-week intervals now forms the basis of recommended worm control programs in all sheep-raising areas (Barger 1995).

An extreme form of preventive strategy is the alternation of different host species, usually sheep and cattle, over the same pasture. Here the prevention of contamination is achieved not so much by anthelmintic treatment as by exploiting host specificity. In general, parasite species that are pathogenic in one host species either do not infect the alternate host, or are less pathogenic and prolific. Typical procedures involve alternation of the separate host species at intervals from two to six months (Barger and Southcott 1978; Donald et al. 1987), with anthelmintic treatment usually, but not always (Donald et al. 1987), given at times of alternation. In both studies, parasitism and production in young sheep given only one or two drenches annually was equivalent to that of suppressively treated sheep over a three-year period.

Evasive strategies

Devised by Michel (1969) for the control of gastrointestinal nematodes in calves, and by R.J. Thomas and B. Boag for ewes and lambs, (Boag and Thomas 1973; Michel 1976; Thomas 1982), this strategy relies on removal of a moderate existing infection by anthelmintic treatment, allied with a movement of the treated animals to a safe pasture, just before the population of infective larvae on the original pasture rose to dangerously high concentrations. The anthelmintic treatment removed an important population of worms in the calves or lambs that might otherwise have contaminated the safe pasture. The move, in these studies in mid-summer, enabled the young animals to escape exposure to a seasonal peak of larval availability on the original pasture resulting from the virtually synchronised development of eggs passed over several months in the earlier part of the grazing season. Later variations of the dose and move system extended its effectiveness to the control of lungworm (*Dictyocaulus viviparus*) in cattle (Jorgenson 1981; Eysker et al. 1995), and to the control of *Ostertagia* and *Cooperia* in young cattle under very different epidemiological circumstances in Australia (Smeal 1978; Smeal et al. 1980). Here, it was not spring and early summer contamination that resulted in a midsummer peak in larval availability as in Europe and the northern parts of North America, but autumn and winter contamination producing a late winter-early spring peak of larval availablity.

A further development in evasive strategies was described by Barger et al. (1994), and involved a rotational grazing system for goats in a wet tropical environment. Rotational grazing systems in temperate climates have generally been found to be ineffective for control of parasitic nematodes, because of the long survival times of infective larvae on pastures (Gibson 1973). In wet tropical climates, however, the warm, wet conditions that favour rapid and continuous egg hatching and larval development also result in extremely high death rates of infective larvae on pasture (Banks et al. 1990; Barger et al. 1994). These studies found that larvae survived in detectable concentrations on heavily contaminated tropical pastures for no more than a month or two following peak concentrations occurring about a week after contamination. Larvae were first detected on pasture as early as four days after eggs were deposited, and this was true for all of the major nematode species encountered (*Haemonchus contortus*, *Trichostrongylus colubriformis* and *Oesophagostomum columbianum*). All species also had similar survival times on pasture.

The grazing system developed to exploit these findings consisted of 10 paddocks, each grazed in sequence for 3.5 days, then spelled for 31.5 days. A grazing period of 3.5 rather than four days was chosen so that stock movements were made at the same times on the same days of each week (Barger et al. 1994). Egg counts of the rotationally grazed goats were less than half those of similar set-stocked goats on an adjacent paddock, which also required nearly three and a half times as many anthelmintic treatments over the course of a year as were given to the rotationally grazed goats. There were also indications that it might have been possible to dispense with anthelmintic treatment entirely in the rotational grazing system.

Diluting strategies

There have been fewer formal investigations of diluting strategies as a means of worm control than for the other two, but they are widely used in practice, often, but not always, aimed at giving younger animals a greater choice in diet selection. If susceptible animals graze with a greater number of non-susceptible animals, then the average rate of contamination of the pasture with worm eggs will be substantially reduced over what it would have been had the pasture been fully stocked with susceptible animals alone. This reduction in contamination should ultimately be reflected in a reduced intake of larvae by the susceptible stock. The empirical fact that clinical helminthoses are rare in calves before weaning can probably be explained by a dilution effect. Assuming that there is a cow accompanying each calf, and that each cow has a faecal egg count of 5 eggs/gram, but produces four times the faecal output of the calf, which has a faecal egg count of 500 eggs/gram, it can readily be calculated that the number of worm eggs reaching the pasture will be about one fifth of that had the pasture been grazed as heavily, but only by calves.

Mixed grazing of cattle and sheep has been extensively studied in relation to productivity and to effects on pasture composition, but rarely has its effect on worm burdens been documented. Arundel and Hamilton (1975) reported that when lambs grazed with steers, there was a decrease in numbers of sheep parasites such as *Ostertagia circumcincta* and *Nematodirus spathiger*, offset to some extent by an increase in burdens of species normally associated with cattle, such as *Trichostrongylus axei* and *Cooperia oncophora*. Jordan et al. (1988) examined the effects of grazing ewes and lambs or cows and calves, either alone, or mixed with the other species. They found that mixed grazing resulted in reduced sheep parasitism and increased productivity of lambs, but also in increased cattle parasitism allied with reduced productivity of the calves.

Grazing Management and Sustainability of Worm Control

The warning given by Michel (1985) that selection pressure on worms to develop anthelmintic resistance is not simply proportional to frequency of treatment, but depends on how anthelmintics are used in relation to grazing management, has been largely ignored. As Michel (1985) points out, selection pressure is measured by the contribution that resistant survivors of anthelmintic treatment make to subsequent generations of worms (see also Martin 1990). This contribution, and hence selection pressure, is obviously large when animals are treated frequently, but may be equally large in animals treated only once and immediately moved to a clean pasture. Similarly, highly effective anthelmintics, or combinations of anthelmintics, because they leave very few survivors, select less strongly for resistance than less effective drugs that leave many (Barnes et al. 1995).

Exhortations by well-meaning parasitologists to reduce the frequency of treatment by adopting one or more of the management strategies described above may well result in better worm control at less cost, but may not reduce significantly the selection pressure for development of resistance. An example of this has been seen in the Australian sheep industry, where for the past decade, farmers have decreased their frequency of treatment by adopting epidemiologically-based worm control programs that exploit grazing management (Waller et al. 1995). Far from decreasing the apparent rate of selection of resistant worms, these practices have at best had no effect, and may well have intensified selection. It has been argued that in any control strategy involving anthelmintic use, selection for resistance will be more closely related to the degree of success of the control strategy than to the frequency of treatment it entails (Barger 1995). Under this view, reductions in the rate of selection for anthelmintic resistance must be paid for in terms of reduced effectiveness of parasite control and ultimately in reduced production. Only where control technologies require no anthelmintic treatment at all, or where there are literally no survivors of anthelmintic treatment, can it be confidently predicted that there is no selection for anthelmintic resistance.

This does not mean that such technologies do not also contain the seeds of their own eventual destruction. Despite the initial successes of alternate grazing of sheep with cattle to control nematodes in both host species, there are reports of *Trichostrongylus axei* as a cause of deaths and weight loss in sheep grazing on cattle pastures (Abbott and McFarland 1991), an indication that this species may respond to alternation of sheep and cattle by evolving an increased ability to infect sheep. Of even more concern is the report by O'Callaghan et al. (1992) of the hitherto purely cattle parasite *Ostertagia ostertagi* causing clinical disease in sheep. More recently Bairden et al. (1995) have documented the initial success, but eventual failure, of a sheep/cattle alternate grazing system over a four-year period in Scotland, possibly through selection of strains of *Ostertagia ostertagi* and *Cooperia oncophora* that were capable of extended survival times on pasture. Selection for similar attributes, or for faster development from eggs to infective larvae could also reduce the effectiveness of rotational grazing systems for nematode control in tropical environments.

It should not be forgotten, however, that all control technologies that leave survivors are subject to evolutionary erosion of their effectiveness. Control mediated through the host immune response, for example, may select strains of worms that can avoid, endure or subvert that response, thereby jeopardising the long-term sustainability of control through vaccination or resistant hosts. The important point, however, is not that any specific control method may be unsustainable when considered in isolation, but that the more choices there are, and the more that different controls are used in combination rather than relying almost solely on anthelmintics, the longer researchers can eke out the continued effectiveness of all of them.

Acknowledgments

This paper was originally presented at the Fourth *Ostertagia* Workshop, March 5–8, 1996 at the University of Maryland, College Park, MD, USA, and will be published by the workshop organisers as part of a special issue of *Veterinary Parasitology*.

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Anthelmintics and Preserving their Effectiveness

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Abstract

Parasite control for the past thirty years has depended on anthelmintics. Now, however, anthelmintic resistance to the benzimidazole and the levamisole group of chemicals has reached a critical stage in much of the pastoral regions of the world. The introduction of the avermectin-milbemycin group of anthelmintics has provided some opportunity for continued reliance on chemical control but already avermectin resistance has been reported from many regions. It is agreed by parasitologists that anthelmintics will remain a part of parasite control strategies in the foreseeable future but that they should be integrated with other control measures such as selective breeding and grazing management. Consequently, it is vital that the present arsenal of anthelmintics remain effective. Important tools in combating the spread of anthelmintic resistance are methods of detecting anthelmintic resistance while the genes that cause it are still at a low frequency in the parasite population. At present, monitoring anthelmintic resistance relies almost entirely on the Faecal Egg Count Reductions Test (FECRT). The FECRT has a number of short-comings including the need to visit a farm on at least two occasions, and the requirement for a relatively large number of animals. Furthermore, the technique is relatively insensitive. A larval development assay (LDA), developed by CSIRO, is being marketed by Horizon Technology. The LDA requires only one farm visit and a simple microscope scanning of the proportion of nematode eggs developing in a range of anthelmintics to provide a direct correlation between in vitro and in vivo drug efficacy. This technique will be of great benefit to those responsible for managing anthelmintic resistance in the field.

PARASITE control for the past thirty years has rested firmly on the shoulders of anthelmintics. Now, however, this modern day Atlas is showing distinct signs of weariness. Anthelmintic resistance to benzimidazole and levamisole chemicals has reached serious proportions in much of the pastoral regions of the world. The introduction of the avermectin-milbemycin group of anthelmintics has prolonged the reign of anthelmintic control but already avermectin resistance has been reported from many regions. Studies indicate that the frequency of resistance genes in unselected parasite populations is high and that this group too will succumb unless immediate action is taken to delay the development of resistance.

There are several reasons why it is imprudent to rely on new anthelmintics to replace those whose effectiveness has been lost due to resistance. First is the escalating increase in the already high cost of development. The growing sophistication of analytical techniques for the detection of drug residues along with the use of new techniques for monitoring toxicity, teratogenic effects and extension of testing to a wide range of species to assess environmental safety all add to an increasing cost of development. To illustrate this point, the cost of development of a new drug was estimated to be US$30 million in 1985 (Hotson 1985) while today the cost is in the vicinity of US$230 million (McKellar 1994).

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There is a second, less obvious reason that could slow the development of new anthelmintics which relates to identifying market need. Anthelmintics make up only 3% of world-wide sales of animal health products (Hotson 1985) but their relative importance in the mix of products is greater in the Southern Hemisphere which has the majority of pastoral regions. Head offices of the pharmaceutical companies are in the Northern Hemisphere where intensive animal production systems predominate. Therefore, what may seem of great importance from our perspective is not quite as important from another.

Shifting to intensive production systems similar to those in the Northern Hemisphere is not the answer as ruminants will remain an important means of converting low quality forages to meat and fibre. Therefore, to ensure that parasite control remains effective, it will be necessary to develop an integrated approach in which anthelmintics play an important but not exclusive role.

Anthelmintics

There are a limited number of highly efficient anthelmintics available for the control of round worm parasites although, looking at the vast array of commercial formulations available, one would be excused for thinking otherwise. This is not the case. Most of the apparent variety is related to the fact that there are different chemicals within a group that have a similar mode of action. Thus, it is important to be aware that there is side resistance within similar mode-of-action anthelmintics, so that once resistance has developed to one chemical, resistance can be expected to others within the same mode-of-action group. For this reason it is of benefit to describe briefly the major mode-of-action groups of anthelmintics currently available.

Benzimidazoles

Thiabendazole (TBZ) was introduced in the early 1960s and ushered in a new era in anthelmintics, being much more efficient and less toxic than previous compounds. TBZ quickly became accepted as the market leader for treatment of parasitic disease in sheep, cattle and horses. Through the use of TBZ to suppress parasitic infections it became possible for the first time to see clearly the effects of parasites on production under field conditions.

It was known that TBZ was rapidly absorbed, hydroxylated to the 5-hydroxy compound, conjugated as the glucuronide or sulphate and excreted mainly in the urine (Tocco et al. 1964). Consequently, pharmaceutical companies expended considerable effort to find chemical groupings that would block the 5-position, preventing hydroxylation and excretion, in order to prolong the time the drug remained in the body, thereby increasing efficiency. This research led to a range of substituted benzimidazoles (BZs) being discovered with the 2-thiazolyl of TBZ replaced by 2-methyl carbamate and a range of aliphatic and aromatic side chains at the 5-position. The nature of the side chain in the 5-position greatly influences the rate of excretion and the efficiency and spectrum of activity.

Prichard et al. (1978) reported that the tertiary BZs (fenbendazole, albendazole and oxfendazole) reach maximum blood levels in sheep 15 to 24 hours after dosing compared to the 4 to 6 hours taken by thiabendazole, oxibendazole and parbendazole. The BZs act by attaching to tubulin dimers, preventing their polymerisation to microtubles and also by causing the disassembly of existing cytoplasmic microtuble structures (Borgers et al. 1975). These actions reduce the absorption of nutrient and must be maintained for some time to allow irreversible metabolic changes to occur, otherwise the parasite can survive by reducing its energy demands (Le Jambre 1985). Thus the tertiary BZs which remain in the host's body for longer periods have a broader spectrum of activity and include lung worms and tapeworms in their therapeutic range.

Levamisole and morantel

Levamisole (LVS) and morantel affect the nematode's nervous system. They are absorbed by the host almost immediately and causes a rapid paralysis in those parasites which are exposed. Once paralysed, the nematodes are swept out of the host along with the ingesta. Both compounds are active against the major intestinal parasites of sheep and cattle with the exception of inhibited *Ostertagia ostertagi.* It is possible that the larvae in the gastric crypts may be paralysed but not removed by the host. Thus when the drug is excreted, the worms are still present in their normal habitat and recover. Levamisole is also active against lung worms.

Avermectins

The avermectins (AVMs) are a family of 16-membered macrocylic lactones isolated from *Streptomyces avermitilis* and are potent nematocides and insecticides (Campbell et al. 1983). Structurally, the AVMs belong to the milbemycin class of macrocylic (Takiguchi et al. 1980). Within the AVM/milbemycin class, five analogues are commercially available for the treatment of parasitic nematodes in animals: ivermectin (IVM), avermectin

B1, doramectin, moxidectin and milbemycin A4-5-oxime. Ivermectin is also used for the treatment of infections of the filarial parasite, *Onchocerca volvulus* in humans (Campbell 1991). A number of potential sites of action for the AVMs have been identified in studies undertaken in a variety of species and test systems. Today, it is thought that AVM interacts with glutamate gated chloride channels (Arena et al. 1992). IVM is a potent inhibitor of the motility and development of the free-living stages of trichostrongylid nematode parasites.

Substituted salicylanilides and phenols

These compounds are either trematocidal or cestocidal and at normal dose rates some are highly effective against *Haemonchus contortus* in sheep. These compounds act by uncoupling oxidative phosphorylation resulting in energy depletion. They are all relatively toxic and are detoxified by the host binding the absorbed drug to plasma protein where it is available to blood sucking parasites such as *H. contortus* and *Fasciola hepatica*. Closantel, one of the substituted salicylanilides, as a single oral dose exerts a suppressive anthelmintic effect against *H. contortus* for 30 days after treatment and a significant effect at 60 days (Hall et al. 1981). If used at the commencement of a period when *H. contortus* eggs have a high probability of developing to infective larvae, closantel can reduce the contamination of pastures for long periods. Closantel is used in this fashion in the 'Wormkill' program on the Northern Tablelands of NSW.

Organophosphates

The organophosphates act by inhibiting acetyl cholinesterase, thus allowing a build-up of acetylcholine and continual stimulation of the nerve ending which results in a spastic paralysis. The worms are then removed by the normal peristaltic action of the intestines. The main anthelmintic in this group is naftalofos (napthalophos) and was first introduced as a broad spectrum compound in sheep. At a dose rate of 50 mg/kg, it has a high efficacy against *H. contortus*, moderate efficacy against *O. circumcincta* and *Trichostrongylus* spp., but little efficacy against the large bowel parasites. Naftalofos also lacks activity against immature stages. The moderate broad spectrum activity of this anthelmintic often leads to a revival of interest in it as an anthelmintic of last resort when resistance to the other broad spectrum anthelmintics has rendered them ineffective.

Anthelmintic Treatment of Sheep and Goats

Sheep and goats share the same species of gastrointestinal parasites and the same mode-of-action groups of anthelmintics are used to treat both hosts. However, the pharmacokinetic disposition of these anthelmintics are not the same in sheep and goats. Following single oral dose therapy of BZ, there was a lower sytemic availability of the drug in goats than in sheep, possibly owing to a more rapid hepatic clearance in goats (Bogan et al. 1987; Short et al. 1987; Hennessy et al. 1993a,b). Knox et al. (1995) found a similar difference between sheep and goats with fenbendazole (FBZ) administered either as an intraruminal infusion or formulated into a urea-molasses feed supplement block (UMB). These authors concluded that if FBZ were to be formulated into a UMB as a means of controlling parasites then the target dose rates for goats should be 0.75 mg/kg compared with 0.5 mg/kg in sheep. Hennessy et al. (1993c) reported that closantel was also less effective in goats than in sheep. These workers reported that the half-life of the expulsion phase of closantel was 4 days in goats compared with 14 days in sheep. It appeared that the sustained action of closantel would be greatly reduced in goats due to their more rapid clearance of the drug.

It is apparent from these studies that due to the rapid clearance of anthelmintics by goats, it is necessary to increase the dose rate in this species in order to obtain a similar efficacy as the same chemical in sheep. Thus, the cost of parasite control by anthelmintics in goats is greater than in sheep. The pharmacokinetic difference between sheep and goats presents manufacturers with a conundrum: if they follow the sheep dose, the efficacy that they can claim in goats is low, but if they aim at achieving the same efficacy level as in sheep, the cost of treatment is higher. Consequently, pharmaceutical companies often do not claim an efficacy for their drug in goats. This strategy relieves them of the cost of registering their chemical for goats.

However, goats still require anthelminthic treatment to control internal parasites and when pharmaceutical companies do not provide a dose rate, farmers are likely to use the same dose to treat both sheep and goats. The consequence is that the lower efficacy will result in the heterozygote resistant parasites being selected. It is clear that dosing goats with the sheep dose of anthelmintics is similar in consequence to underdosing with the effect of allowing the heterozygote resistant worms to survive. There appears to be some truth in the derisive claim by some sheep farmers that resistance develops first in goats and then spreads into the sheep flocks.

Current Status of Anthelmintic Resistance

There are many recent reviews of the present status of resistance throughout the world (e.g. Waller, 1996). Table 1 provides a breakdown of resistance by countries within continents. It becomes clear from Table 1 that there is no area where there are small ruminants entirely free of reports of resistance. Also apparent is a Hemisphere bias with the Southern Hemisphere containing the world's hot spots of resistance. As noted above, it is the Southern Hemisphere that accounts for most of the anthelmintic sales. Consequently, the rest of the world would be wise not to become complacent as the obvious conclusion is: where anthelmintics are used most, then that is where resistance is likely to develop first.

Resistance monitoring

Aims of monitoring

Effective resistance monitoring is a key requirement in managing anthelmintic resistance and needs to be sensitive to small changes in gene frequencies. Effective monitoring enables agricultural advisers to detect resistance at an early stage when it is still possible to limit its development. The aims of resistance monitoring are:

- confirm cause of control failure;
- measure and identify resistance genotypes;
- determine changes in distribution and severity of resistance;
- provide early warning of resistance problems;
- make recommendations for pesticides least affected by resistance;
- measure biological characteristics of genotypes under field conditions;
- test effectiveness of resistance management tactics.

Table 1. Prevalence of anthelmintic resistance in sheep nematodes.

Continent Country	No. of flocks tested	Prevalence (%) of resistance to:			
		BZ	LVS	COM	IVM
Africa					
Kenya			reported[1]		reported[1]
South Africa	60[2]	90			
Asia					
Malaysia	96[3]	36	reported[4]		reported[4]
Thailand		reported[5]			
Australia	Many[6]	81–95	40–95	26–59	reported
Europe					
Netherlands	70[7]	80			
UK	347[7]	15–47			
North America		reported			reported
Pacific					
Fiji	39[8]	44	38	nt	nt
South America					
Argentina[9]	65	40	22	11	6
Brazil[9]	182	90	84	73	13
Paraguay[9]	37	73	68 .	nt	73
Uruguay[9]	252	86	70	nt	1.2

References cited in Table 1.

[1]Mwamachi et al. 1995
[2]Van Wyk 1990
[3]Dorny et al. 1994
[4]Sivaraj et al. 1994
[5]Kochapakdee et al., 1995
[6]Overend et al. 1994
[7]Coles et al. 1994
[8]Le Jambre 1994
[9]Waller et al. 1996

BZ = benzimadazoles LVS = levamisole COM = IVM = ivermectin

Techniques for monitoring anthelmintic effectiveness

Anthelmintic resistance can be detected by a variety of in vivo and in vitro techniques. The in vivo techniques can be characterised as time-consuming and expensive, producing data that reflect the high degree of between-animal variation and the pharmacodynamics of the anthelmintic in the host. Nevertheless, the drench efficacy test where animals are first treated with anthelmintic, subsequently slaughtered and their worm burdens counted, is the standard against which all assays must be validated.

The most common means of detecting resistance is the Faecal Egg Count Reduction Test (FECRT). This technique requires that egg counts be made on sheep with infections of the parasites in question, then the animals be drenched with the anthelmintics to be tested. Ten days following the drench, faecal egg counts are done on the animals again. Based on the reduction in egg counts an estimate of the anthelmintics effectiveness is determined. Larval differentiations made from the eggs collected ten days after drenching determine which species of parasites are resistant.

In vitro assays have the advantage of being less time-consuming and by removal of the host variation from the calculations of anthelmintic effect have greatly improved precision of resistance estimates. In vitro techniques can either employ the intact parasite or preparations of parasite tissue. Whole organism assays monitor the effects of an anthelmintic on a normal physiological process such as egg hatch, larval development or motility.

In vitro assays employing whole worms, or worm eggs, were previously restricted to a narrow field of application within specific anthelmintic classes since these methods require the use of a technique in which the drugs show discernible action. Thus, the action of levamisole on motility constitutes the basis of a paralysis assay but as BZs and other classes do not exhibit such a strong action on motility, they cannot be assayed in this way. The dependence of the current in vitro techniques on the pharmacodynamics of specific anthelmintic classes has limited their widespread adoption for the diagnosis of resistance. The necessity of using three or four separate in vitro techniques to examine anthelmintic resistance in unknown isolates is far more daunting than either of the in vivo techniques where no assumptions regarding how the drug acts on parasites are necessary and trends can be established despite the poor quality of in vivo experimental data.

DrenchRite™

This lack of practical in vitro assays prompted consideration of the development processes in free-living stages for assay development. Lacey et al. (1990) developed a larval development assay (LDA) in which nematode eggs are added to an agar matrix containing the drug and developed through to infective L_3 larvae. Standardisation of the LDA demonstrated that currently used anthelmintic classes gave excellent dose-response data for the inhibition of egg to L_3 larval development in *Trichostrongylus colubriformis*, *H. contortus* and *O. circumcincta*.

A commerical in vitro assay called DrenchRite was developed from Lacey's LDA for the detection of resistance to BZ, LVS, BZ/ LVS combinations and IVM in the gastrointestinal nematode parasites of sheep and goats, *H. contortus*, *T. colubriformis* and *O. circumcincta*. In the DrenchRite assay, the nematode eggs are placed into the wells of a microtitre plate and hatched larvae develop to the L_3 stage in the presence of anthelmintic. The concentration of anthelmintic required to block development is related to an anticipated in vivo efficacy. The DrenchRite assay plate contains a single lane for the control and eleven lanes which contain increasing concentrations of a drug from each drench class. The plate is colour coded: green for susceptible, orange for weak to intermediate resistance and red for highly resistant. Parasite eggs isolated from faecal samples submitted by producers are applied to wells of the assay plate. After hatching, the first stage larvae are fed to sustain development through to the infective L_3 stage over the next five days. In the presence of the drenches, development of susceptible larvae is blocked. By scanning the plate under the microscope the number of the well in which development is blocked in half the larvae present is determined for each drench.

If the larvae are resistant to a drench, the well in which development in half the larvae is blocked will move from the green to the orange and subsequently to the red region of the plate for that drench, depending on the level of resistance. The well numbers so determined for each drench class are then used to estimate drench efficacy from a supplied table. For the avermectin/milbemycins where resistance in the field is very rare at present, the well number is used in a slightly different way. Rather than estimating efficacy, the presence of L_3 in wells containing avermectin are an indicator that a small number of worms in the population are resistant to the drug. This assay provides a repeatable method of detecting resistance and estimating anthelmintic efficacy. Incorporating the DrenchRite assay into a monitoring program would allow comparisions of resistance levels between regions and would provide a sensitive method of detecting changes in those levels.

Resistance Management Tactics

Models

Models are especially useful in comparing the impact of management tactics on the development of resistance. A good introduction to the use of models to simulate gastrointestinal nematode control systems can be obtained from Barnes et al. (1995). However, at least a general idea of how each resistance management tactic works and where it can be most effective can be obtained from the simple principle of discrimination between genotypes. In the least complicated case, that of a single gene encoding resistance, the genotypes would be: RR, RS and SS. Selection can only occur at concentrations that kill at least some susceptible homozygotes but allow at least some resistant homozygotes to survive. Tactics that reduce this discrimination, particularly the discrimination between susceptible homozygotes and resistant heterozygotes (the most common carriers for resistance genes early in a resistance episode), will generally slow the rate of resistance evolution. Once the genetic nature of resistance is recognised, it is easy to see the benefits of a sensitive assay. It is obvious that resistance management tactics are most effective when implemented at low resistance gene frequencies. For example, it may be possible to increase the dose rate of an anthelmintic or to increase the persistence of an anthelmintic to a level that renders the heterozygote recessive. This would tend to slow the development of resistance as homozygous resistant individuals are very rare when a new chemical is first introduced. Once the frequency of the resistance gene increases, heterozygotes become more common and the increased selection applied by increased dose rate will then tend to increase the rate at which the resistance spreads in the population.

Refuges

Allowing refuges for escape of susceptibles has often been proposed for conserving susceptible genotypes in insect populations. Recently, it has been proposed for nematode parasites by Barnes et al. (1995). Basically, this would entail not drenching a portion of the flock, perhaps 20% of the flock that appeared the most fit. Such a strategy would allow the unselected worms in these sheep to continue to produce offspring and dilute the effects of offspring of resistant worms from the treated 80% of the flock. Needless to say, this strategy would work best while the proportion of resistant worms was low.

Changing anthelmintic groups

Switching to anthelmintics from a group with a different mode of action when resistance has been discovered is another tactic. This could include consideration of more expensive or even less effective anthelmintics. These disadvantages could be offset by the possibility of salvaging a more desirable anthelmintic for future use. In Australia, a switch to organophosphates has been recommended, based on this principal.

Aim to make heterozygote recessive

One means of making the heterozygote recessive is to increase the dose rate. The disadvantages of this simple approach are that cost of treatment increases and host toxicity problems may be encountered. There are other means which include switching to anthelmintics with the same mode of action but with increased persistency, if available. These anthelmintics are often second and third generation chemicals such as the substituted BZs among the BZs and the milbemycins among the macrocylic lactones. There are other methods of increasing the persistence of anthelmintics. Prichard et al. (1978) infused BZ into the animals and their results indicated that persistence was an important determinant of the efficacy and spectrum of BZ anthelmintics. These authors speculated that increased persistency may also improve the efficiency of other anthelmintics. An increased efficacy through increased persistence was also achieved against BZ resistant strains of parasites by Le Jambre et al. (1981) by incorporating the BZ into a sustained release device and these authors suggested that by incorporating earlier, less-persistent anthelmintics into sustained release devices their useful life could be extended. Anthelmintics also can be incorporated into feed-supplement blocks to allow self-medication over extended periods of time. The self-medication technique works especially well when used in tethered husbandry systems. Ali and Hennessy (1993) demonstrated that the persistence of anthelmintics could be increased by slowing down the flow of digesta through the host and that this resulted in a significant increase in efficacy. A practical means of slowing down the flow of digesta is to temporarily restrict feed intake of the animals before treatment with the anthelmintic.

When reports of ivermectin resistance in goat and sheep parasites started to appear, a dispute developed around the apparent susceptibility of these parasites to moxidectin (Shoop et al. 1993; Kieran 1994; Rothwell and Rolfe 1994). Kieran (1994) attributed these findings to either a greater potency of moxidectin or to a different mode of action compared with ivermectin. Now that many strains have been described with resistance to both ivermectin and moxidectin (Leathwick 1995; Rolfe et al. 1994; Le Jambre et al. 1995) it appears that the greater potency of moxidectin can be attributed to its greater persistency in the host (Afzal et al. 1994). The situation is analogous to the introduction of the second generation BZs which had a greater persistency in the host and a greater efficacy against TBZ resistant nematodes. Unfortunately, this benefit of the second generation BZs was transitory and it is likely to be the same with the macrocylic lactones.

Once it became clear that moxidectin's greater efficacy was likely to be due to its greater persistency another debate developed over whether the selection for resistance in parasites exposed to the gradual decline in efficacy in a persistent anthelmintic was more effective in selecting for resistance than that of a short-acting anthelmintic. This debate was given further emphasis when Le Jambre et al. (1995) reported that avermectin resistance in *H. contorus* was inherited as a dominant trait. Dominant traits respond to selection faster at low gene frequencies than do incomplete dominants or recessives such as BZ resistance. Furthermore, increasing the dose to make the heterozygote recessive is not an option when dealing with dominant resistance genes.

The response of a dominant resistance gene under selection by a persistent anthelmintic was investigated using a simulation model (Dobson et al. 1996). In this model efficacy against incoming infective larvae (L_3) was assumed to decline or remain high over the period of drug persistence (3 days to 4 weeks) thus allowing the estimation of the relative importance of selecting resistant L_3s on the development of resistance in the worm population. These factors were also examined against a background of initial efficacy levels, against adults, and mode of inheritance. The outcome of the simulations was that persistence and initial efficacy were found to be far more important in determining the rate of selection for resistance on adults and larvae in the host at the time of treatment than was selection of incoming resistant L_3 as drug efficacy declined.

Combinations

Using formulations that contain two anthelmintics, each with a different mode of action has also proved successful in extending the life of the combined chemicals. The genetic principle behind this strategy is that resistant genes are rare in the population so that the odds of a single worm having both rare genes is the product of the frequency of each gene in the population. The two anthelmintic groups that are prime candidates for combining are the BZ and LVS groups (Anderson et al. 1988). Both of these groups have compounds which are no longer covered by patent and could be purchased as generic drugs which would reduce the cost of the combination. Again, this strategy highlights the need for good resistance monitoring techniques. Instituting combinations of chemicals is going to be much less effective if the resistance gene frequencies are high.

Non-chemical control

Of course, the most effective means of managing resistance and of conserving susceptibility genes in the parasite population is to use methods of parasite control that do not rely on chemicals. The three most promising techniques in this area are described in the papers by Woolaston, Barger and Waller in these Proceedings.

Resistance in Cattle Parasites

Previously, cattle producers could be excused for thinking that anthelmintic resistance was exclusively a problem for sheep and goat farmers and that one of the tangible benefits of specialising in large ruminants was freedom from worry about which drench to use to control parasites. How can this be so, with cattle and buffalo sharing many of genera of parasites with small ruminants? Le Jambre (1979) has shown that the cattle parasite *H. placei* can express the BZ resistance gene from *H. contortus*. Likewise, *H. placei* can also express the ivermectin resistance gene from *H. contortus* (Le Jambre, unpublished). This evidence indicates that there is no antagonism between resistance and the essential features in a cattle parasite's genome. There are two likely explanations for the sparse reports of anthelmintic resistance in the gastrointestinal parasites of large ruminants. First, in many temperate regions of the world drenching cattle is an infrequent activity and consequently there is little selection for resistance. However, suppression of parasites, particularly in young cattle, has increased, coinciding with the development of the controlled release devices (CRDs). Following the lead of CRDs, manufacturers of injectable and oral formulations have begun to recommend that their products be used with increased frequency to emulate the same control levels. The result, sales promotions aimed at total suppression, may have resulted in the few cases of resistance in cattle parasites reported in Europe and Australasia, for example, the first reports of resistance to ivermectin in bovine *Cooperia* spp. (Vermunt et al. 1995).

The second reason, as pointed out by Waller (1996), is that there have been no surveys of resistance in those regions of the world were intensive treatment of young cattle is commonplace. For example, anthelmintic resistance has been recorded in cattle parasites in southern Brazil (Pinheiro and Echevarria, 1990) but there has been no survey to estimate the proportion of properties where resistance occurs. It may be in the cattle producing regions of South America that resistance in cattle parasites will be first recognized as a serious problem. If there is a benefit to early detection of anthelmintic resistance in small ruminant parasites, then it is of even greater benefit for cattle. Because there is little anthelmintic resistance in cattle parasites at present, the option to change anthelmintics or combine anthelmintics with different modes of action has a greater chance of success.

Conclusion

The problem of anthelmintic resistance should be recognised thoughout the world as the greatest threat to the grazing industry. The solutions will not be found in any single approach. Farmers in countries where resistance is rare should realise that the cause of this rarity is most likely to be infrequent use of anthelmintics rather than some intrinsic lack of resistance genes in the parasites. It is fortunate that a large proportion of susceptible genes are in the indigenous parasites. These susceptible genes should be seen as a most valuable resource and a strenuous effort should be made to conserve them (Wood and Bishop 1981). One of the most valuable weapons in the battle to conserve susceptibility in nematode populations is the ability to detect resistance while it is still at a low level.

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Worm Control of Livestock — the Biological Alternative

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Abstract

Biological control, by the use of nematophagous fungi, is now emerging as the most promising non-chemotherapeutic control option of nematode parasites of livestock. Practical methods of fungal deployment are now being developed, such as feed supplements, feed blocks and controlled release devices. Biological control has many obvious advantages. For example, it is applicable to the range of nematode parasite species for all classes of livestock. It will provide the opportunity for livestock producers to capitalise on the increasing demands by consumers for chemical-free livestock products. Also, it is difficult to envisage the development of resistance mechanisms by nematodes to biological control, which now is an enormous threat to the future of chemotherapy.

LIVESTOCK in the tropical/subtropical regions of the world experience much greater ravages from internal parasitic disease than those in the more temperate climes. Here, the limiting ecological factor influencing the severity of parasitism is rainfall, as temperatures are almost always favourable for the development and survival of the free-living stages. Therefore, apart from the arid areas in the tropics/subtropics, where animals are typically allowed to browse or graze over extensive areas and worms are rarely a problem, rainfall, both total amount and seasonal distribution, determines the severity and occurrence of clinical parasitic disease in livestock.

Farmers have by experience come to recognise when problems are likely to occur, and if they can afford it, treat their animals with anthelmintics. In many instances lengthy periods of high rainfall require regular and frequent treatment. This has resulted in the widespread emergence and rapid escalation in the problem of anthelmintic resistance. There are now large areas in the tropical/subtropical regions of the world where grazing of sheep and goats is becoming unsustainable because of the existence of high levels of resistance to virtually all available anthelmintic groups (Waller et al. 1995).

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Immediate and drastic measures are needed in an effort to contain this problem. The search for alternatives to chemotherapy for the control of ruminant parasites has been directed towards developing worm vaccines, selection of livestock with natural resistance to parasites and, relatively recently, at the biological control of the free-living stages of parasites on pasture.

Biological Control

Biological control is not assumed to be a substitute for chemotherapy, where the expectation, if not the reality, is that parasites may be virtually eradicated by the frequent use of drugs with efficacies approaching 100%. The ultimate aim of any biological control scheme is to prevent clinical disease and production loss by reducing the exposure of susceptible hosts to pathogenic levels of infection.

Separating hosts from their faeces is the simplest, cheapest and most effective form of biological control of parasitic diseases. The classic example of success by these means is in human helminth control whereby the simple expedient of using pit toilets has led to dramatic reductions in trematode and nematode infections of people in the developing world. In the same respect, the practice of dung collection for use as fuel could, in the broadest sense, be regarded as a form of biological control. However, in areas where this is a common practice, it is restricted to bovine dung, and severe undernutrition or malnutrition rather than parasites are generally the major causes of losses in animal productivity.

Dung dispersal, or destruction, can occur in other ways and in regions of the world where parasites are of greater significance. A variety of birds rely heavily on coprophagous invertebrates as a food source and to seek these, they tear dung pats apart (McCracken 1993). But it is their invertebrate prey, notably dung beetles and earthworms, that are capable of rapid and often complete dung removal and thus are indirectly responsible for significant reductions in the number of free-living stages of parasites (Waller and Faedo 1996). However, such dung dispersal activity is notoriously labile, being dependent on ideal weather conditions, therefore little opportunity exists to exploit these organisms in attempts to achieve cost-effective and reliable biological control of nematode parasites.

Another example of indirect biological control applies to trematodes. In contrast to nematodes, trematodes and cestodes require intermediate hosts to complete their life cycle. Control of the snail intermediate hosts by foraging flocks of ducks has been shown to be of practical value in the control of *Fasciola gigantica* infections of ruminants raised in rice producing areas of Southeast Asia. Here the benefit is twofold: not only do the ducks seek the snails as a food source, but the free living stages of *Echinostoma revolutum,* which is a common trematode parasite of ducks, compete with *F. gigantica* to utilise snails as intermediate hosts (Partoutomo et al. 1995).

A number of organisms have been identified that exploit the free-living stages of parasites as a food source. These include microarthropods, protozoa, predacious nematodes, viruses, bacteria and fungi (Waller and Faedo 1996). Although all are of intrinsic interest, it is from the latter two groups of organisms that breakthroughs in biological control are likely to emerge.

Bacteria

Many species of bacteria are associated with the cuticle, body cavity and gut of nematodes and some of these are pathogenic. *Bacillus penetrans* has been shown to be a promising candidate for the control of parasitic nematodes of plants. It produces highly resistant spores which attach to the cuticle and then invade the nematode host. This bacterium is highly host-specific, which is both a good and a bad thing. It is good from the standpoint that only the target nematode pest will be affected, but bad insofar as the search for the specific *B. penetrans* pathogen for each of the whole range of nematode pests would be most laborious, expensive and fruitless in many cases. Another factor that is hampering the exploitation of this organism is the difficulty in synthetic culturing of large quantities of *B. penetrans,* which is an absolute pre-requisite for commercialisation.

Many bacteria and closely related organisms, the Actinomycetes, produce important secondary metabolites, which include antibiotics, insecticides and anthelmintics. As such they should be regarded as microbial control agents rather than true biological control agents.

Fungi

Fungi that exhibit anti-nematode properties have been known for a long time. They consist of a great variety of species which include nematode-trapping (predacious) fungi, endoparasitic fungi, fungi that parasitise nematode eggs, and fungi that produce metabolites that are toxic to nematodes (Barron 1977). The most important groups of nematophagous fungi are the first two, namely:

Nematode-trapping fungi.

These fungi produce specialised hyphal trapping devices, such as adhesive networks, knobs, and constricting or non-constricting rings. Fungi in this class may also produce nematode chemoattractant and/or chemotoxic substances (Waller and Faedo 1993). Within a short period of time following capture of the nematode, the fungus penetrates the worm and destroys it.

Endoparasitic fungi.

These fungi invade the nematode from adhesive spores that stick on the cuticle, from spores that are ingested by the nematode, or from motile spores in water.

Fungi from these two classes are found in all environments throughout the world, but are particularly abundant in rich agricultural soils. Under laboratory conditions, where fungi are grown as a monoculture on standardised, generally nutrient-poor media and are provided with a nematode prey that cannot escape, results can be spectacularly successful. Total capture and destruction of nematodes can occur within a matter of hours. However, this type of work provides little relevant information as to how these fungi would perform as practical biological control agents against animal parasitic nematodes. Testing needs to be done to determine the limitations and opportunities for parasite control associated with the livestock production systems being considered.

Methods for Selecting Fungi as Biological Control Agents

The most important principle for selecting candidate fungi as putative biological control agents is to obtain isolates from the field in the region, or country, where this work is to be performed. This is important for several reasons.

Firstly, it has been observed that laboratory stocks of fungal isolates lose various attributes, which may include nematophagous capacity, following repeated passage.

Secondly, most countries have stringent requirements regarding the importation and field release of exotic living organisms. These two drawbacks would apply if strains of fungi with known nematophagous activity were obtained from the major fungal collections or repositories in Europe or North America.

Thirdly, most of the current research on biological control is with *Arthrobotrys oligospora* and particularly, *Duddingtonia flagrans* conducted in Denmark and Australia. Local isolates are being used in these studies (Denmark, see Larsen et al. 1991; Australia, see Larsen et al. 1994) which represent the cold to cool temperate regions of the world. These fungal species could well prove to be inappropriate in the humid tropics/subtropics. However, in the broader sense it is possible that fungal species would have evolved to be more suited to any given region, or locality, than those derived from centralised fungal collections, or from laboratories in Denmark or Australia.

The most relevent sites for sampling would be the environments where the fungi are expected to exert their effects, notably fresh faecal deposits, but in intensive animal production systems, animal bedding may also be appropriate.

The reason for restricting the sampling to these sources is simply to save unnecessary labour at a later stage, because in almost all circumstances, fungal deployment will be in ways which require it to survive passage through the gastro-intestinal tract of animals and then to trap nematodes in freshly deposited faeces. Almost certainly, a plethora of nematophagous fungi would be isolated from other sources such as soil, pasture etc. However almost all would fail the most important test of gut survival and thus their isolation (and any other testing) would be a wasted effort.

The use of animals as a stringent screening procedure means that the number of occasions on which isolations can be expected is very few. Therefore if a serious attempt is to be made, a large number of small samples should be collected *per rectum*, from livestock found on a comprehensive range of farms in the region. Suitable procedures have been described by Larsen et al (1994). Following isolation by these means, pen trials should be carried out to confirm the gut survival and nematophagous capabilities of the fungal strains

Means of Fungal Deployment

Direct application

This could only be considered in the most intensive forms of animal production where animals are closely confined, and of course, where internal parasitism is a problem. Such an example would be the intensive calf-rearing units in the southern islands of Japan where *Strongyloides papillosus* can cause sudden death in massively infected animals in the hot summer months (Taira and Ura 1991). A practical solution to this problem may be the direct application of fungal elements to the bedding. Therefore, the requirement for fungi to survive gut passage is not relevent in this circumstance. All that would be required is for the fungi rapidly to colonise the bedding and to reduce the overwhelming number of *S. papillosus* larvae responsible for the sudden death syndrome, but to allow sufficient numbers to survive to provoke the normal, rapid acquisition of immunity which characteristically occurs against this parasite.

However, apart from similar forms of highly intensive livestock production, it is beyond the bounds of reality to conceive of a practical means of applying fungal material, especially to the grazing environment, to produce reliable and substantial reduction in the free-living stages of parasites.

Supplementary feeding

Danish workers have demonstrated that a daily supplement of barley grains supporting the growth of *D. flagrans* will reduce parasitism and increase productivity in grazing cattle (Gronvold et al. 1993), pigs (Larsen et al. 1995), horses (Nansen et al. 1995) and sheep (Larsen et al. 1996). These results are particularly exciting as they demonstrate that the principle of biological control of nematode parasites using nematophagous fungi is particularly robust, being applicable across the whole spectrum of grazing livestock species. Clearly then, the transfer of this technology to those industries where long-term daily supplementary feeding is a common management procedure would be relatively straightforward. The major impediment would be the need to scale-up production to satisfy the commercial requirements for the fungal grain supplementary feed option for biological control of nematode parasites.

Feed blocks

Block administration, developed mainly for mineral supplementation and to a lesser extent for anthelmintic medication, is now undergoing a resurgence of interest as a means of low-cost nutrient supplementation of livestock in the developing world. These blocks can be manufactured using simple, low-cost technology and generally incorporate surplus plant by-products as the nutrient source. These by-products may well prove to be suitable growing substrates for locally isolated strains of nematophagous fungi. A range of block formulations containing *D. flagrans* chlamydospores have been tested and the results are very encouraging (Waller and Knox, unpublished data). These blocks have also been shown to have a shelf life of at least six months. Fungal blocks could prove to be an important control option in the humid tropics and sub-tropics where tethered husbandry and night housing with stall feeding are common animal management practices and where anthelmintic resistance is a serious problem.

Controlled release devices

Intra-ruminal sustained or controlled release devices are a modern advance in anthelmintic medication. Although the unit costs of these devices are high, they allow great flexibility in animal management insofar as they provide protection against parasite infection for an extended period of time. Rather than using anthelmintic compounds, devices containing fungal spores could provide this extended prophylactic effect. The objective would be to develop a device which would release sufficient spores for an extended period (60 days or more) to result in a substantial reduction in the number of infective larvae which succeed in migrating to pasture over the same time period. These devices could be administered at epidemiologically critical times to reduce seasonal peaks in larval numbers but would allow sufficient larvae to escape and thus provoke the development of naturally acquired immunity in grazing livestock.

Investigations have shown that chlamydospores of *D. flagrans* can withstand tabletting pressures required for manufacture of these devices. The devices have a good shelf life and can release optimum concentrations of spores for effective parasite control in vivo (Waller and Ellis, unpublished data). Further work is required to test the time/release profiles of fungal chlamydospores in these prototype devices and to verify the long-term in situ viability of spores in devices administered to livestock. Although it is premature to speculate as to whether commercially attractive, fungal controlled release devices will be developed, they have an enormous potential market as a non-chemotherapeutic, environmentally benign form of parasite control to all the grazing livestock industries throughout the world.

Conclusion

Significant recent advances in the development of practical means of deploying nematophagous fungi as biocontrol agents of nematode parasites for a range of livestock species, clearly indicate that this may be the first non-chemical alternative to parasite control, other than selective breeding. This will not be before time. Resistance to anthelmintics is now rampant in nematode parasites of small ruminants in many countries in the tropical/sub-tropical zone. As more countries reach this chemotherapeutic end-point, abandonment or complete restructuring of their small ruminant industries will be the inevitable and tragic consequence. Biological control may be one way of delaying this doomsday scenario.

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Increasing Resistance by Selection

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Abstract

Resistance to nematode parasites can be improved by selection, but only recently have efforts been made to include resistance as a trait in commercial livestock breeding programs such as those currently operating in Australia and New Zealand. The steps required parallel those used for improving other traits. Three approaches have been used: breeding for resistance (reduced parasite numbers, as determined by faecal worm egg count), resilience (production during parasitism), or number of treatments required during parasitism. It is necessary, but difficult, to assess the economic benefits of improving resistance relative to other traits, because the impact of parasites varies widely depending on the production environment and on the availability, effectiveness and sustainability of alternative control measures. Selection for resistance usually requires that animals are exposed to parasites so that the effect of the host on parasite numbers can be assessed. In the longer term, it is desirable that selection criteria for all major diseases be developed that will be informative in healthy animals. Molecular genetic markers offer promise, but simple genetic markers have so far been as elusive as physiological traits to predict resistance in undiseased animals. Useful genetic markers should eventually be found and techniques for combining these with phenotypic information need to be developed.

RESISTANCE of small ruminants to nematode parasites can be improved by selection, but only recently have efforts been made to include the trait in commercial livestock breeding programs such as those currently operating in Australia (*Nemesis*, Anon. 1994) and New Zealand (*WormFEC*™, McEwan 1994). Southern and Southeast Asia encompasses a wide range of ecological zones in which there are numerous indigenous breeds of goats and sheep. Many of these have evolved in areas with high levels of nematode parasite challenge. As production systems intensify, it is likely that between-breed variation will be a useful resource to be exploited in genetic improvement programs designed to enhance resistance. Aspects of between-breed variation have been discussed by Baker (these Proceedings) and this author will concentrate mainly on matters related to within-breed selection for worm resistance in sheep. Discussion will be mainly based on a large body of data collected from the Australian Merino, augmented with data collected from tropical sheep and goats in Fiji, and with research conducted in New Zealand.

Within-breed Genetic Variation in Resistance

Host resistance is heritable and so it is possible to make genetic progress in a breeding program. One of the most-widely used measures of resistance, faecal worm egg count (FEC), has a heritability of 0.2 to 0.3 (Gray et al. 1995). Comparable heritabilities for other traits in the Australian Merino are 0.40 for fleece weight, 0.5 for average fibre diameter, 0.4 for body weight and 0.1 for reproductive rate (Ponzoni 1987). Heritability, however, is not the sole determinant of genetic progress. Variability, as described by variance or coefficient of variation (CV), is equally important. The response to selection, in percentage units, is given by the formula:

$$\% \text{ Response} = \text{heritability} \times \text{selection intensity} \times \text{CV}\%,$$

so it is clear that for any given selection intensity, the percentage response in a trait is proportional to the product of that trait's heritability and its variability.

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Coefficients of variation in FEC in excess of 100% are common, compared with about 60% in reproductive rate, and 7–15% in other traits of economic importance. Thus FEC is an extremely variable trait and for this reason, relatively rapid genetic progress should be possible when selecting for resistance. This prediction has been born out in single-character selection lines, such as the CSIRO Merino lines selected for divergent response to challenge with *Trichostrongylus colubriformis* (Windon et al. 1987) or those selected for increased or decreased resistance to *Haemonchus contortus* (Woolaston and Piper 1996, Fig. 1).

In another experimental flock run at the University of New England, 60 rams were progeny tested for resistance to *H. contortus* and the distribution of their estimated breeding values for FEC is shown in Figure 2.

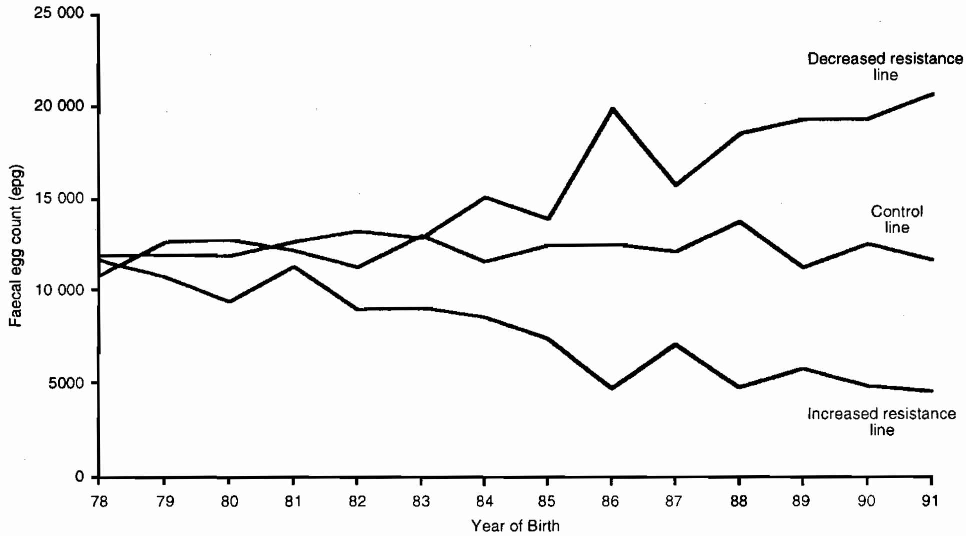

Figure 1. Estimated breeding values for *Haemonchus contortus* faecal egg count (back-transformed) in a long-term selection flock (after Woolastron and Baker 1996).

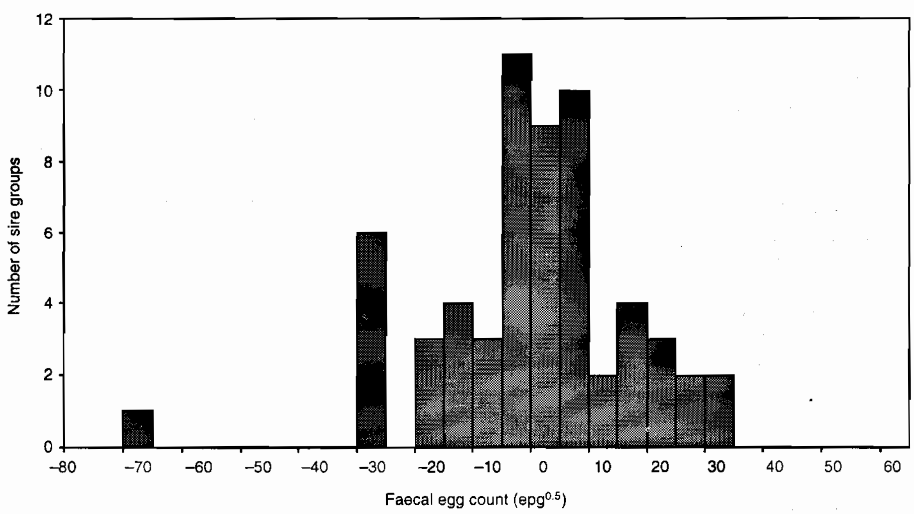

Figure 2. Frequency distribution of deviations of sire group means from the overall mean for four week egg counts, square root transformed (after Albers et al. 1987).

In the University of New England flock, the progeny means for most sires were clustered together (Fig. 2), reflecting a normal distribution, but one sire had extremely resistant progeny. This ram, dubbed the 'Golden Ram', was originally thought to be the carrier of a major gene for resistance to *H. contortus*, but exhaustive investigations have failed to prove this hypothesis (Woolaston et al. 1990, Woolaston, Gray and Piper, unpublished). Another possibility was that the sire came from a separate Merino sub-population to the other sires under test, and that the difference was merely a manifestation of between-flock variation. Extensive tests of a large number of Merino genotypes in experimental resource flocks (Eady et al. 1996) have shown that this is also an unlikely explanation. The total variation in FEC following challenge of weaner sheep with *H. contortus* or *T. colubriformis* can be partitioned into the component sources of variation. Table 1 shows that most of the genetic variation in FEC can actually be found within-flock and that by comparison, variation between major (strains) and minor (between flocks within strains) genetic classifications of the breed is very much smaller. This contrasts with the sources of variation in production traits such as fleece weight, average fibre diameter and body weight, where systematic strain and flock effects are far greater.

Genetic Comparisons

During collection of the data summarised in Table 1, care was taken to ensure that comparisons were made on animals born and managed together as a single group. This is particularly important when testing for resistance, so that age-acquired resistance is not a confounding effect in between-animal comparisons and so that management history is standardised, as this can have profound and lasting effects on expressions of resistance (Gray et al. 1990). An important inference to be drawn from Table 1 is that within-flock genetic variation in resistance can be much greater than between-flock or between-strain variation, and so adequate sampling is essential in any breed comparison. The simplest way to ensure adequate representation of a breed would therefore be to maximise the number of unrelated sire groups represented.

Approaches to Selection

Three main approaches have been advocated for improving the host's ability to deal with parasites. The first, selecting for resistance, focuses on maximising the effect of a host on its parasites. The other two approaches, viz. breeding for resilience or reduced number of treatments, aim to minimise the effect of parasites on the host. Each of these three methods has advantages and disadvantages and these have been discussed at some length by Woolaston and Baker (1996). Breeding for resistance is arguably the most practical method, because resistance, as measured by FEC, is more highly heritable than the other two traits and there are fewer practical problems encountered when incorporating the trait into commercial breeding programs.

Some New Zealand workers have suggested that breeding for lower FEC will not necessarily reduce the level of scouring or dag formation in a flock, nor will it necessarily reduce the number of anthelmintic treatments required (Bisset et al. 1994, 1996). These authors advocated using a selection procedure which includes some assessment of the need to treat individual animals for protection against parasites, whether measured by the number of drenches required in a given period or by the age at first treatment. This should have the dual advantages of reducing the need for anthelmintic treatment and also of reducing the prevalence of scouring and dag formation. Both of these measures, however, were quite poorly inherited (estimated heritabilities of 0.06 and 0.03, respectively) but strongly correlated with liveweight gain and dag score. Furthermore, the procedure used to measure the need for treatment appeared to adversely affect the heritability of production traits. Together, these results suggest that selecting for production plus some measure of resilience may be less efficient than selecting for

Table 1. Sources of variation in faecal egg count (average of *H. contortus* and *T. colubriformis* challenges, from Eady et al. 1996) and production traits (from Mortimer and Atkins 1989).

Source of variation	Proportion of total variance			
	Faecal egg count	Clean fleece weight	Av. fibre diameter	Body weight
Between strain	1%	29%	25%	21%
Between-flock (within strain)	3%	13%	12%	13%
Within-flock genetic	24%	16%	31%	23%
Within-flock non-genetic	72%	42%	32%	43%

production in animals that are essentially non-parasitised, except during a brief period when resistance is tested with a FEC. Given the parameters published by Bisset et al. (1994, 1996), it seems likely that a procedure which places selection pressure simultaneously on increasing production while decreasing FEC, will lead to direct gains in productivity and resistance. This should give favourable progress in reducing the need for anthelmintic treatments, while at the same time reducing scouring and dag score. Where it is considered necessary, further reductions in the level of scouring and dag formation should be obtainable by including dag score as an additional selection criterion, or perhaps by placing more selection emphasis on body weight.

Selection Criteria for Resistance

Various indicator traits have been investigated as an alternative to FEC:

- Packed cell volume. This trait is particularly useful where the main parasite under investigation is *H. contortus,* and the trait is used widely in tropical Africa as a measure of *H. contortus* infection (R.L. Baker, pers. comm.). It appears to be about as heritable as FEC and is highly correlated with it under *H. contortus* challenge (Woolaston and Piper 1996). The trait, however, is of little use in predicting the level of infection of other important parasites such as *Trichostrongylus* spp. or *Ostertagia circumcincta.*
- Lymphocyte responsiveness. An in vitro assay for determining lymphocyte responsiveness to nematode antigens was used to select sheep in lines developed for resistance to *O. circumcincta* (Cummins et al. 1991) but has since been found to be less suitable than FEC in that breeding program.
- Circulating eosinophils. Woolaston et al. (1995) investigated this trait in several sheep populations and concluded that although it was informative in some situations, the trait was not as suitable as FEC as a selection criterion for a breeding program.
- Ovine lymphocyte antigen type. Recent studies have indicated that this trait is of little use for indicating resistance to *H. contortus* and its usefulness for indicating resistance to *T. colubriformis* also appears to be limited (Woolaston, Gray, Eady and Outteridge, unpublished data).
- Faecal antigens. Workers in Western Australia are currently developing a test which uses worm antigens in faecal samples to estimate the worm species present in the gastrointestinal tract (R.B. Besier, pers. comm.). The test also shows promise as an indicator of comparative numbers of parasite species present in a sheep's gastrointestinal tract. It is unknown at this stage whether the trait will be suitable for routine use in breeding programs, but appropriate investigations are in progress.
- Circulating antibodies. Douch et al. (1995) evaluated a test to quantify worm antibodies circulating in sheep blood, and genetic correlations suggest that the trait can add useful information to a breeding program. The *WormFEC*™ program in New Zealand (McEwan 1994) can accommodate information from circulating antibodies, when it is available.
- Molecular genetic markers. In the longer term, these offer considerable promise as criteria for identifying animals with genetically superior disease resistance. Once a sufficient number of markers are known, it should be possible to identify resistant animals without the need to expose hosts to the disease under a standard testing protocol. However, it will be some years before markers are able to supplement phenotypic data, and it is not clear at this stage how such markers might best be used in commercial breeding programs.

Incorporating Resistance into Breeding Programs

Procedures currently used in Australia and New Zealand rely on infecting animals with third stage roundworm larvae, either artificially or naturally, then allowing a period to elapse (at least four weeks) so that FECs are sufficiently high to allow discrimination between animals in their resistance status. At this time, faecal samples are obtained and submitted to a laboratory for FEC determination. After FEC data are known, they are transformed statistically (usually using a cube root or logarithmic transformation) and combined in a conventional selection index with data from other traits. Genetic theory predicts that adding another trait to a breeding objective will reduce expected genetic progress in the existing traits. It is therefore wise to provide the breeder with information on the extent to which they are compromising gain in other traits by including resistance in their breeding objective and this is routine practice in both the Australian *Nemesis* program and the New Zealand *WormFEC*™ program. Figure 3 demonstrates graphically the effect of diverting some selection pressure to improving resistance, using data from a typical Merino flock.

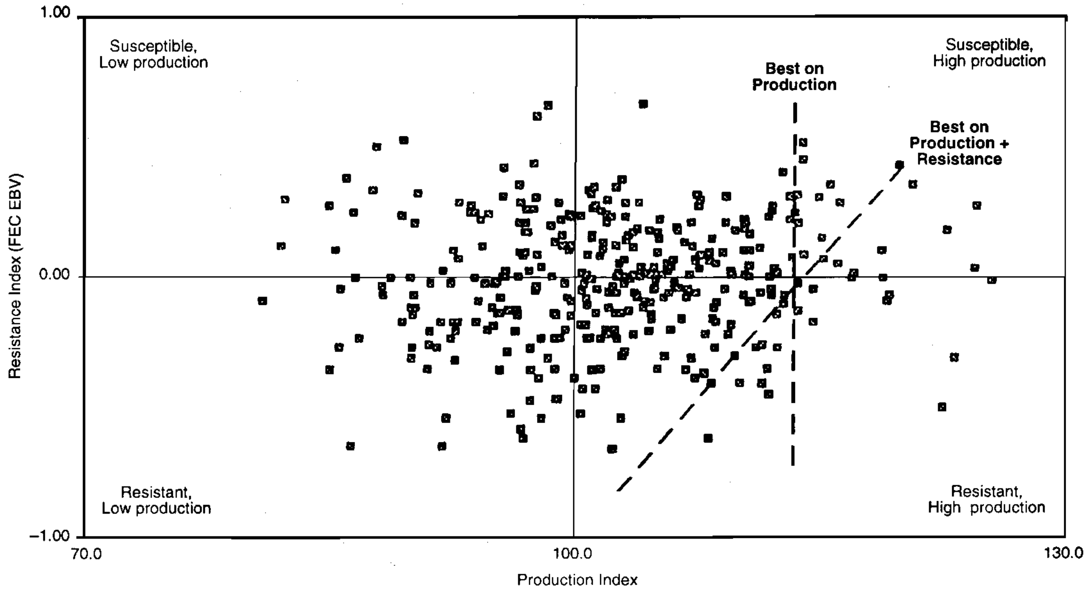

Figure 3. Scatter plot showing worm resistance and productivity in a typical Australian Merino flock. The broken lines delineate the best 30 animals either on production alone, or on a combination of production and resistance.

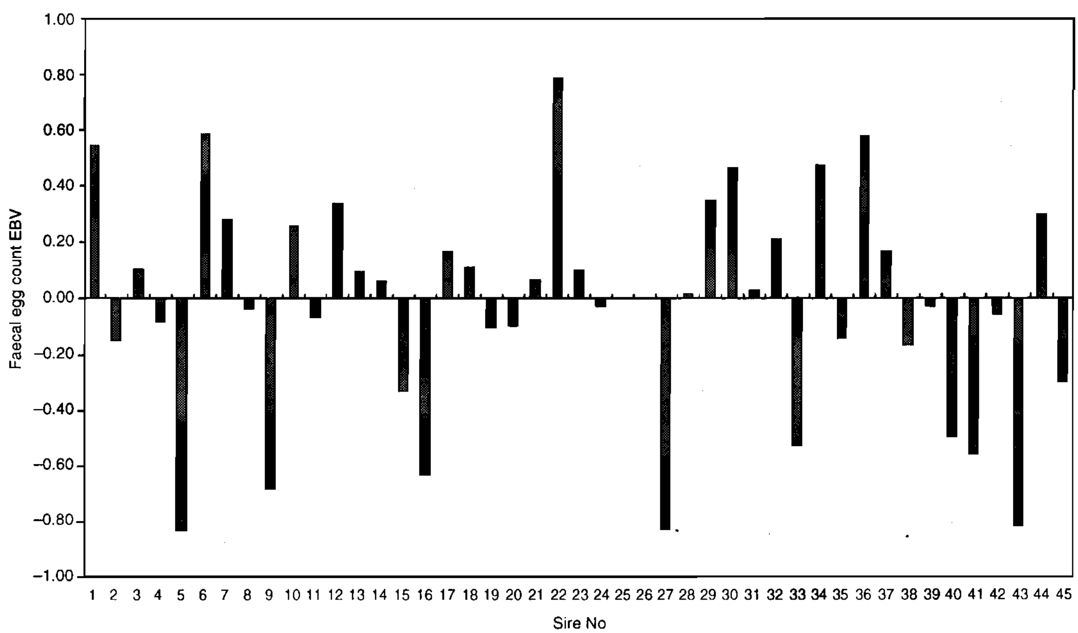

Figure 4. Estimated breeding values (EBV) for resistance, expressed in standard deviations of cube root transformed faecal egg count (epg). Data are derived from a centralised Merino sire progeny test in Australia. (After Eady 1995).

The extent to which gain in other traits should be compromised in order to improve resistance can only really be determined when the relative economic value of resistance is known. Reliable objective information on the benefits of improving traits such as fleece weight, average fibre diameter, body weight or reproductive rate in specific sheep production systems is readily available (Morris et al. 1982, Ponzoni 1987). However, insufficient information is available at present to quantify accurately the value of a unit change in resistance relative to gains in production traits and there is an urgent need to quantify the economic benefits of improving resistance. Such data are obtainable from suitably designed field studies of resistant and susceptible genotypes.

Other relevant information available to Australian Merino breeders is provided by central test sire evaluation schemes, where a number of sires are progeny-tested over a common group of ewes. Information from several testing programs can be combined, as can information collected over time, by ensuring that sufficient genetic links exist. A wide range of traits are recorded in these schemes and a recent innovation has been to also record FEC. Findings thus far illustrate the wide genetic variation that exists between sires in the Australian Merino population (Fig. 4).

Conclusion

Breeding for resistance is possible and several selection lines have demonstrated the progress that is possible in sheep (Baker et al. 1991, Karlsson et al. 1991, Cummins et al. 1991, Windon et al. 1993). In the context of sustainable parasite control systems, the benefits attainable from manipulating host genotype include a reduction in pasture contamination and parasite numbers, a reduction in scouring and associated problems of dag formation and reduced use of anthelmintic chemicals. Genetic theory predicts that these improvements should be attainable while simultaneously improving productivity.

If so desired, relatively rapid genetic improvement can be made in resistance, but maximum gains can only be made by compromising the rates of improvement in other traits. The optimal way of using the available selection pressure to change the individual components of a breeding objective will depend heavily on the relative economic values of those components. Aspects that require further study include the epidemiological value of reducing FEC in a production system, the relative importance of scouring and dag formation particularly in breeds maintained for fibre production, and the physiological cost, if any, associated with maintaining resistance in the presence of various levels of parasite challenge. In assigning a relative economic weight to improved resistance in their own breeding programs, breeders should also consider the importance of parasitism as a production constraint in the target population and also uncertainty surrounding the availability of chemotherapeutic control measures at some future time.

Acknowledgements

Much of the research work discussed in this paper has been supported by Australian woolgrowers, most recently through the International Wool Secretariat.

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Characterisation and Utilisation of Sheep and Goat Breeds that are Resistant to Helminths

R.L. Baker

Abstract

There is a large and diverse range of sheep and goat breeds in the world and some of these, particularly the indigenous tropical breeds, appear to have some unique genetic ability to resist or tolerate diseases. This paper reviews the information available on between-breed genetic variation for resistance to helminthiasis (mainly the gastrointestinal (GI) nematodes) and discusses how this genetic variation can be used in breeding programs.

The experimental design used in nearly all the breed comparisons reviewed is inadequate. In particular, the number of animals of each breed evaluated is too small, very few studies take account of variation among sires within breeds, and how the animals are sampled is not stated. However, there are a number of sheep breeds that have been identified as resistant in a number of independent studies and these include the East Africa Red Maasai, the Florida Native, the Barbados Blackbelly and the St. Croix. There is much less evidence for breeds of goats that are resistant to GI nematodes but the indigenous tropical breeds such as the Small East African and West African Dwarf may be somewhat resistant.

HELMINTHS constitute one of the most important animal health constraints to small ruminant production in both the temperate (McLeod 1995) and tropical (Fabiyi 1987) regions. The widespread occurrence of infection with endoparasites, the associated loss of production, the cost of anthelmintics and in some cases high mortality rates of infected animals (particularly in the tropics) are some of the major concerns. There is also growing public concern about environmental issues, particularly the regular and often excessive anthelmintic usage leading to chemical residues in animal products and pastures.

In nearly all regions of the world control of endoparasites in ruminant livestock is currently largely achieved by the use of anthelmintics, although pasture management also plays a role in some temperate regions. In many tropical regions of the world these control methods are limited by the high cost of anthelmintics, their uncertain availability, increasing frequency of drug resistance (in both tropical and temperate regions), and limited scope in many communal pastoral systems for controlled grazing to reduce parasite contamination of pastures. In this situation an attractive, sustainable solution is identification and utilisation of host genetic variation for resistance or tolerance to endoparasites.

Much of the recent research on genetic resistance to endoparasites in sheep has concentrated on quantifying within-breed genetic variation and selection of resistant (high responder) and susceptible (low responder) lines of sheep as reviewed by Gray (1991), Gray and Woolaston (1991), Gray et al. (1995) and Woolaston and Gray (1996, these Proceedings). There is a large and diverse range of sheep and goat breeds in the world and some of these, particularly the indigenous tropical breeds, appear to have some unique genetic ability to resist or tolerate diseases. This paper reviews the information available on between-breed genetic variation for resistance to helminthiasis (mainly gastrointestinal nematodes) in small ruminants and discusses how this genetic variation can be used in practical breeding programs.

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Evidence for Breed Variation in Resistance to Endoparasites

There have been many reports since the mid-1930s of variation among breeds of sheep in resistance to GI nematodes, particularly to *Haemonchus contortus, Trichostrongylus* spp and *Ostertagia (Teladorsagia)* spp. Gray (1991) reviewed and summarised 23 publications on this subject and this was expanded to 34 publications in a review by Baker et al. (1992). Space does not permit tabulating a summary of these publications in this paper, but this information is available from the author on request. Some of the important conclusions which arise on reviewing these publications are the following:

- Host resistance to *H. contortus* has been most commonly found but there is also evidence for resistance to *Ostertagia* sp and *Trichostrongylus* sp.
- Resistance has been demonstrated both with artificial infection and natural pasture challenge. Usually with natural challenge this involves a number of parasite genera with one or two predominating.
- In nearly every case faecal egg counts (FEC) have been used to measure resistance, but packed cell volume (PCV) and worm counts following necropsy have also been commonly measured. Production traits and mortality rates have been recorded less commonly.
- Resistance has been demonstrated in both lambs and mature animals (ewes, rams and wethers).
- The experimental design used in nearly all these breed comparisons was poor. In particular the number of animals of each breed evaluated (commonly about 5–10) was too small, very few studies took account of variation among sires within breeds, and how the animals were sampled was not stated. Requirements for adequate experimental designs for breed evaluation have been comprehensively reviewed and discussed by Dickerson (1969). How animals are sampled and the family structure (i.e. number of sires and progeny per sire) are critical factors.
- While many of the publications on breed variation for resistance to endoparasites can be criticised in terms of experimental design, it is reassuring to note that some breeds have been identified as resistant in a number of independent studies. This applies particularly to the East African Red Maasai (Preston and Allonby 1978 and 1979; Bain et al. 1993; Baker et al. 1993, 1994a, 1994b), the Florida Native (Loggins et al. 1965; Bradley et al. 1973; Zajac et al. 1988), the Barbados Blackbelly (Yazwinski et al. 1979 and 1981) and the St. Croix (Courtney et al. 1984, 1985a, 1985b; Zajac et al. 1990; Gamble and Zajac 1992; Zajac 1995) and for these breeds it can be concluded that they are relatively resistant to GI nematodes.
- Most of the breeds identified as being relatively resistant are indigenous or 'unimproved' breeds. This presumably reflects the fact that these breeds have been under natural selection for resistance for many centuries with no anthelmintic treatment. In addition to the breeds mentioned above that have been reasonably comprehensively characterised as resistant to GI nematodes there are other interesting breeds which may be resistant. These include the West African Djallonke sheep which may be resistant to endoparasites and trypanosomiasis (Baker 1995); the Sabi sheep in Zimbabwe (McKenzie 1986) and the Garole sheep in India (Ghalsasi et al. 1994). It is worthy of note that the Carribean St. Croix sheep originated from West Africa and are probably related to the Djallonke sheep (Bradford and Fitzhugh 1983).

The evidence for genetic variation for resistance to endoparasites among goat breeds is limited (Baker et al. 1992; Baker 1995) and all of these studies suffer from the same shortcomings in experimental design noted for sheep. As for sheep, it is usually the indigenous goat breeds (e.g. the Small East African and the West African Dwarf) that are more resistant than the imported exotic breeds. It is possible that the mechanisms or level of resistance may be different in sheep and goats, since, as goats are predominantly browsers, they are likely to have been under less intense natural selection for resistance. Indeed, it is usually reported that goats are innately more susceptible to nematode parasites than sheep, but the degree of susceptibility can differ for different parasite species (Gruner 1991). In those areas where browse is freely available it is often observed that the prevalence of endoparasites is higher in sheep than goats. This may not tell us anything about the relative resistance of sheep and goats to endoparasites, but could just reflect different grazing habits. More research on resistance of goats to internal parasites is needed, especially in view of their numbers and importance in many tropical regions.

In an effort to rectify the shortcomings in experimental design observed in most previous breed comparisons, in 1991 the International Livestock Centre for Africa (ILCA — now ILRI) initiated a pan-African research project to investigate more comprehensively both between- and within-breed genetic resistance to GI nematodes in some of the indigenous small ruminant breeds. Currently this research is evaluating the Menz and Horro sheep breeds in Ethiopia; Red Maasai and Dorper sheep and Small East African and Galla goats in Kenya;

Table 1. Least squares means by breed group for weaning weight (WWT, kg) PCV%, GFEC[a] (EPG) and mortality (MORT%).

Lamb breed (Sire Bd × Dam Bd)	Number born	Weaning (1991–95 data)				Yearlings (1991–94 data)		
		WWT	PCV	GFEC	MORT (Brth-Wng)	PCV	GFEC	MORT (Wng-Ylg)
D×D	288	11.1	23.1	1445	26.1	24.5	1653	51.7
D×(RM×D)	392	10.9	24.7	1259	21.3	24.0	1746	42.1
D×RM	97	10.5	25.5	1318	19.4	24.0	2041	33.6
RM×D	229	10.7	25.2	1071	18.1	25.7	1340	26.4
RM×(RM×D)	404	10.7	26.1	1175	15.4	25.6	1355	19.0
RM×RM	154	10.0	27.1	1230	9.5	26.1	1236	18.0
Total Number	1564	1267	1258	1004	1564	762	762	1086
Overall Mean		10.7	25.3	1230	18.3	25.0	1538	31.8

[a]FEC logarithm transformed for analysis and then the anti-log (i.e. the geometric mean-GFEC) presented in this Table.

Djallonke and Peul Peul sheep and West African Dwarf and Sahel goats in Senegal; and Sabi and Dorper sheep in Zimbabwe (ILCA 1991; Baker et al. 1992).

The sheep research in Kenya is now almost completed with the sixth and last lamb crop having been born in 1996. Some of the results from the first five lamb crops (1991–95) will be presented to illustrate what can be achieved in a more comprehensive breed evaluation experiment.

The study is being carried out at Diani Estate of Baobab Farms, 20 km south of Mombasa in the subhumid coastal region of Kenya. In 1991 Dorper and Red Maasai × Dorper (F_1) ewes, and in 1992 and subsequently Dorper, F_1 and Red Maasai ewes, were single-sire mated to 12 Dorper and 12 Red Maasai rams each year in a complete diallel to produce the six lamb genotypes shown in Table 1. At least half of both the Dorper and Red Maasai rams used each year were replaced by new rams the next year. Over the period reported here (1991–95) a total of 41 Dorper and 34 Red Maasai rams have been used. The rams were obtained from a wide range of sources and districts to ensure representative samples of each breed.

The ewes were weighed six times during the reproductive cycle: at mating, three months after mating, two weeks before lambing and one, two and three months after lambing. Blood and faeces samples were collected from all ewes at each weighing. Blood was taken to determine packed cell volume (PCV) — a measure of anaemia — and was examined for trypanosomes. Faecal egg counts (FEC) — a measure of endoparasite infestation — were taken and faecal samples, bulked by breed, were cultured and parasite larvae present were identified. Ewes found to have a FEC greater than 4000 eggs per gram (EPG) or a PCV less than 15% at any sampling time were treated with an anthelmintic drug.

Lambs were weighed as close to birth as possible, usually within 24 hours, and then every two weeks up to weaning at three months old. PCV and FEC were recorded on all lambs at one and two months of age. Individual lambs were treated with anthelmintic drugs at these times if they had a FEC greater than 2000 EPG or a PCV less than 20%. All the lambs were treated with an anthelmintic at weaning (90 days of age). They were then grazed on pasture until a monitor group of about 50 lambs, from which samples were taken every week, reached a FEC averaging between 1500 and 2000 EPG. All the lambs were then weighed and faeces and blood samples were taken on two consecutive days. All lambs were then treated with an anthelmintic. This procedure was repeated until the lambs reached one year of age, which usually involved four or five sampling times.

Differences among the breeds and crosses for weaning weight, PCV, FEC and mortality for lambs at weaning (1991–95 data) and at one year of age (1991–94 data) are shown in Table 1. Faecal cultures at these times showed that 66% of the larvae were *Haemonchus contortus*, 30% *Trichostrongylus* spp and 4% *Oesophagostomum* spp. The results in Table 1 show that Red Maasai (RM) lambs are more resistant to endoparasites than Dorpers (D) in the subhumid zone of coastal Kenya. Red Maasai lambs have significantly lower FEC, higher PCV and lower lamb mortality than Dorper lambs. There is also an additive genetic breed effect in the crossbred lambs for resistance (i.e. for FEC, PCV or lamb mortality), but no evidence for heterosis for any of these traits.

The difference among breed groups in mortality is dramatic and post-mortem results show that about 50–60% of the post-weaning mortality is due to haemonchosis. The relative resistance of the Red Maasai lambs confirms earlier reports from research conducted in the Kenya Highlands (Preston and Allonby 1978 and 1979; Bain et al. 1993). In addition, Red Maasai ewes have lower FEC and higher PCV over the lambing-lactation period (the periparturient rise) than Dorper ewes (Baker et al. 1994b).

Based on these results an initial assessment has been made of the flock productivity of Dorper and Red Maasai sheep in this coastal Kenyan site (Table 2). The combined effect of higher lambing rate, lower lamb mortality and similar yearling live weights results in approximately a three-fold increase in the number of yearling sheep for sale and the weight of yearling sheep for sale in a Red Maasai vs a Dorper flock. There is therefore a clear economic advantage for farming the more resistant Red Maasai breed in the sub-humid regions of Kenya.

Table 2. Productivity of flocks of Dorper and Red Maasai sheep at Diani Estate, Mombasa, Kenya.

Trait	Dorper	Red Maasai
Number of ewes mated	464	219
Ewes lambing/ewes mated (%)	62	74
Prolificacy (%)	102	103
Lamb mortality (Bth-Ylng, %)	63	27
Yearling live weight (kg)	22	21
Offtake (1 yr)[a]		
Number of sheep	12	36
Live weight (kg)	264	745

[a]Offtake based on a 100 ewe flock with a 20% replacement rate.

The Dorper Flock is not sustainable at this replacement rate.

In addition to confirming genetic variation in resistance to GI nematodes among breeds and crosses, this study is also providing some reliable evidence of genetic variation within breeds because of the reasonably large number of sires used in the experiment. Heritabilities of both PCV and FEC were small (0.01–0.04) and non-significant in lambs at weaning but were significant at the yearling stage, strongly suggesting that this is an acquired immune response. The heritability of logarithm transformed FEC in 10–12 month old lambs was 0.22±0.07, but higher in Dorper-sired lambs (0.32±.13) than Red Maasai-sired lambs (0.11±0.07). This suggests that after many centuries under endoparasite challenge that the Red Maasai sheep have become fixed for some of the important genes for resistance.

Virtually all the research on genetic variation to endoparasites in small ruminants has concentrated on the nematode parasites. In many areas of the tropics and temperate regions of the world liver fluke (trematode) infections (*Fasciola hepatica* and *Fasciola gigantica*) are also an important constraint to small ruminant production (FAO 1992). While it is well documented that sheep can mount an effective immune response (self-cure) to nematode parasites, it has been amply demonstrated that sheep are unable to acquire resistance to liver flukes (e.g. Haroun and Hillyer 1986; Boyce et al. 1987). Possibly for this reason very little research has been undertaken on genetic resistance to liver fluke infections and few studies have been published. Boyce et al. (1987) found significant breed differences in faecal egg counts and fluke counts following experimental infection of five breeds of sheep with *F. hepatica*. Barbados Blackbelly sheep were the most susceptible to infection while St. Croix and Florida Naive sheep were the most resistant. While none of the breeds demonstrated an ability to resist reinfection with *F. hepatica,* clear breed differences were detected in response to infection. Wiedosari and Copeman (1990) reported relatively high resistance to *F. gigantica* in Javanese thin-tailed sheep, although there was no contemporaneous breed comparison. Roberts et al. (1995) compared the resistance to *F. gigantica* of Javanese thin-tailed sheep with St. Croix sheep and F2 and F3 crosses between these breeds. They concluded that the Javanese thin-tailed sheep were more resistant than St. Croix sheep and that resistance may be controlled by a major gene with incomplete dominance.

Breeding Programs

The main pathways of genetic improvement are choices among breeds or populations, selection within breeds and crossbreeding designed to exploit heterosis and/or combine the merits of different breeds. These genetic improvement options are not incompatible, but once a particular crossbreeding system is chosen and it has stabilised, then any further genetic progress can only be achieved through selection.

In many sheep or goat production systems in the temperate regions of the world within-breed selection is the only genetic improvement option which can be considered because breed substitution or crossbreeding would have unacceptable effects on the primary breeding goal (e.g. wool production in Merino sheep or mohair production in Angora goats). It has been clearly demonstrated that single-trait selection for resistance to GI nematodes is feasible in sheep and the important issue of how to combine selection for endoparasite resistance and production traits in multi-trait selection indexes is being addressed (Woolaston 1994; Gray et al. 1995; Sivarajasingam 1995).

In many tropical small ruminant production systems there is more flexibility to utilise both between- and within-breed genetic variation for endoparasite resistance in breeding programs (Baker et al. 1992; Baker 1995). A large amount of indiscriminate crossing with exotic breeds has occurred in the tropics. This is often done without any attempt to compare the exotic breeds or their crosses with the indigenous breeds, even though in some cases it has been extremely difficult to keep the exotic breeds alive and reproducing. It is now becoming increasingly clear that indigenous livestock that have evolved over centuries in the diverse, often stressful tropical environments, have a range of unique adaptive traits (e.g. disease resistance, heat resistance, ability to cope with poor quality feeds) which enable them to survive and be productive in these environments (Baker and Rege 1994).

Because of the many constraints to developing breeding programs in the tropics (e.g small flock sizes, communal grazing, year-round breeding, poor market structure) there are clear advantages to creation of nuclei or elite flocks of indigenous small ruminant breeds to facilitate the efficient implementation of genetic improvement programs (Ponzoni 1992) and conservation and utilisation of these unique breeds and populations.

In general, crossing with exotic breeds should be avoided, although planned crossbreeding among indigenous breeds with complementary attributes could have a place in a well-structured industry (e.g. Gatenby et al. 1995; Romjali 1995).

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Genetic Markers as Selection Criteria

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Abstract

The abundance of microsatellite sequences available for exploitation as genetic markers will lead eventually to dense genetic maps for a number of livestock species. Evenly spaced markers covering the entire genome selected from these maps can be used in linkage studies to detect markers associated with economically important traits and ultimately to track down the genes responsible. While such approaches are most readily applied to traits influenced by a single major gene, linkage analysis techniques have been applied to discover chromosome segments carrying genes with an effect on quantitative traits such as parasite resistance. However, given the relative sparsity of the sheep genetic map, discovery of the precise genes responsible will require supplementation of linkage methods with more direct approaches. These approaches will involve pinpointing genes by differential analysis of DNA or mRNA. This paper therefore provides a review of current strategies available for detection of genetic markers associated with important traits, with particular emphasis on approaches for detection of suitable candidate genes that can be tested for their effect on parasite resistance by linkage analysis. Genetic marker technology promises significant increases in accuracy when selecting livestock for breeding resulting in increased rates of genetic progress.

PARASITIC helminths cause considerable morbidity and mortality in livestock populations. The nematodes or roundworms are the most numerous, widespread and economically important group of internal parasites affecting sheep in Australia and are estimated to cost the industry $370 million annually (Collins 1992). Included in this estimate are the costs of administration of anthelmintics, the effectiveness of which continues to decrease with time, thus necessitating continual development of new, more expensive compounds.

In addition there is increasing public awareness of the effects of such treatments on the environment. This situation is driving development of alternative strategies for parasite control and in this respect genetic manipulation is seen as a promising option for sustainable control of parasites in livestock. Studies have shown that resistance to nematode infestation in ruminants is at least partly under genetic control with heritability estimates for *Haemonchus contortus* and *Trichostrongylus colubriformis* resistance of h^2=.34 and h^2=.41 respectively (Kloosterman et al. 1992).

It is therefore feasible to select genetically superior animals for parasite resistance using traditional selective breeding methods that have been used for a variety of other characteristics over the past several decades (Haley 1995). The use of genetic marker technology will enable streamlining of the selection process while increasing accuracy and minimising intrusive and time-consuming methods for assessing the resistant phenotype. Genetic marker technology will allow selection of animals for breeding at any age and may ultimately lead to identification of the actual genes responsible for a trait, elucidating their biological role in the phenotype.

Major Genes for Parasite Resistance

Reverse genetics approaches lend themselves most readily to the detection of markers for monogenic traits (i.e., those controlled primarily by the effects of a single locus), especially when the animals under

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study come from outbred, half-sibling families commonly found in livestock populations. Unfortunately, like many other traits of economic importance such as growth rate, body composition and wool characteristics, resistance to parasites appears to be controlled by the combined action of many genes modified by various environmental factors, which means that associations will be difficult to detect even with the most powerful methods. However, for many economic traits there may be a few genes that account for a large proportion of the variation observed.

While most current genetic models assume input from an infinite number of genes, there is some evidence for the existence of genes having a major effect on parasite resistance in sheep. This evidence comes from the observations of Whitlock and Madsen (1958) that a Suffolk ram (named Violet) gave rise to offspring more resistant to the anemia associated with *H. contortus* infestation, and of Albers et al. (1987) that the offspring of one Merino sire (the so-called Golden ram) displayed a high level of resistance to *H. contortus* infection. In the latter example, segregation analysis of descendants from the resistant sire failed to reveal the existence of a major gene affecting *H. contortus* resistance in this flock. However, segregation analysis methods lack statistical power since even single gene effects are often confounded by the actions of other genes and by environmental influences.

A more powerful approach to detect major genes is to narrow the search to regions of the chromosome where suspected candidate genes loci reside. Parasite resistance appears to have an immunological basis, since vaccination-challenge experiments (Windon 1990) show that parasite resistance is an acquired response. The central role of the immune system is further shown by additional experiments where removal of the ability to mount an immune response removes the difference between resistant and susceptible animals (Presson et al. 1988). However the plethora of genes encoding immune system components are located at diverse regions of many chromosomes and while some studies have been performed to test some individual obvious candidates such as MHC, IgH and L chain and T-cell receptor genes (Blattman et al. 1993; Blattman and Beh 1994), no associations have yet been found. New methods to detect major genes will be discussed later in this review but currently most searches for genes affecting parasite resistance in sheep are based on whole genome scans using genetic markers and applying linkage analysis to detect co-segregation of markers and parasite resistance in resource families.

Molecular Basis of Genetic Markers

Genetic markers arise from the polymorphic differences in DNA segments at a particular genomic location between two individuals. The earliest genetic markers were derived from mutations in restriction enzyme sites at a particular locus. On digestion of genomic DNA followed by Southern blotting and hybridisation to a cloned probe, size differences are detectable between individuals (Southern 1975), hence these markers are referred to as restriction fragment length polymorphisms (RFLPs). However because the polymorphisms observed are based on the presence or absence of a restriction site, they are usually diallelic. As mapping tools RFLPs were superseded by the considerably more polymorphic minisatellite probes first described by Wong et al. (1986) which detect variable numbers of tandem repeats (VNTRs) at multiple loci in digested DNA. These polymorphisms manifest also as size variations on a gel but show much greater variation due to the presence of hypervariable repeat sequences. When converted to single locus probes, VNTR motifs show a high level of polymorphism but they are generally restricted to telomeric regions of chromosomes (Royle et al. 1988).

The markers of choice for detecting associations with traits of economic importance are microsatellites which are composed of 1–4 base-pair motifs reiterated up to a hundred times. These simple tandem repeats have been found interspersed throughout the genomes of many eukaryotes (Hamada et al. 1982) and polymorphisms in repeat number are detected following PCR amplification of a short (100–300 base-pairs) region of DNA using specific primers that flank the repeat sequence. Products are radioactively labelled and are sized on polyacrylamide sequencing gels. Beckmann and Soller (1990) estimated that microsatellite repeats occur on average once every 50–100 kb in mammalian genomes which make them ideal markers to use when total genome coverage is important. Moreover, candidate loci showing little or no polymorphism as RFLPs are likely to be located near a microsatellite that could be characterised and used as a polymorphic marker for that gene. With such a high degree of polymorphism, the availability of microsatellite markers means that the extended families common in livestock populations should still be useful for linkage studies without necessarily having been designed for maximum heterozygosity.

In the absence of a restriction site mutation or microsatellite, another source of genetic markers can be derived from the presence of single base changes between alleles that are detectable by numerous methods. One approach of particular utility, provided that sequence information is available, is to reveal these changes as differences in single stranded conformation (SSC) of PCR-amplified DNA (Hayashi 1991). PCR primers are designed to flank a gene region of several hundred base-pairs that would be expected to show variation between individuals, such as 5' or 3' untranslated sequences or introns. Longer fragments are digested with a suitable restriction enzyme before electrophoresis. Following amplification, the denatured DNA product migrates as single strands through a nondenaturing polyacrylamide gel in a manner dependent on fragment size and on the conformation assumed by the DNA strands, thus enabling detection of a single base mutation by differences in migration.

Recently, a method was developed that enables detection of SSCPs for fragments larger than 1 kb in agarose gels (Monckton and Jeffreys 1994). Mutations may be detected in double stranded DNA by following movement of PCR products through temperature or buffer gradients (Fischer and Lerman 1983). Another source of DNA polymorphisms employs the technique of RAPD (random amplified polymorphic DNA) analysis (Williams et al. 1990). Arbitrary 10-mer primers at low annealing temperatures during PCR yield DNA fingerprints that differ between individuals. Polymorphic bands can be converted to single locus probes if desired. To date, RAPD markers have been of limited use in genome analysis in animal populations.

Discovering Markers Associated with Resistance Genes

Population association studies

Some studies aim to detect linkage disequilibrium between a marker and the gene or trait of interest. The degree of linkage disequilibrium in a population depends on effective population size and the recombination fraction between pairs of loci and may arise not only by chance in small populations but also when two populations are crossed, when a population encounters a bottleneck or through selection that favours particular combinations of alleles at different loci. An obvious prerequisite for such methods is a candidate gene locus or an associated marker. Thus population association studies will not lead to the discovery of new genes and lack statistical power.

Linkage methods

With the potential availability of unlimited genetic markers there has been an upsurge in the use of more powerful linkage methods which make use of genetic and physical maps. Family data for which phenotypic data for the trait of interest and family member genotypes at marker loci are known are used to search for linkage between the gene and typed marker loci.

This technology presents the opportunity to scan the entire genome for marker loci associated with the trait of interest, eventually allowing identification of the actual genes involved. Indeed such studies have led to the isolation of genes responsible for important human genetic diseases such as Duchenne muscular distrophy (Monaco et al. 1986), cystic fibrosis (Kerem et al. 1989) and familial breast cancer (Miki et al. 1994). With the number of mapped genetic markers on the ovine map at over 240 (Crawford et al. 1994), the use of evenly spaced ovine markers to detect major genes for parasite resistance is now feasible.

The more advanced cattle map has already yielded important linkage information on genes responsible increased milk production (Georges et al. 1993a) and for polledness (Georges et al. 1993b). However, although the road to detection of chromosomal segments containing genes affecting quantitative traits is now open, precise targeting of the gene will be difficult without densely mapped markers in the region of interest. Comparative maps can provide some assistance with generating such markers or even in suggesting possible gene candidates but the process of moving from linked marker to gene is a long and involved one.

In the next section, new techniques are presented that have the potential to assist with identifying key candidate genes from which to develop polymorphic markers thus increasing the chances of developing useful markers, without the need for a dense genetic map. Since they directly identify the genes involved it is possible that these methods will displace linkage studies in future as the method of choice for finding selective genetic markers.

Analysis of differences in expressed genes

Several recently developed techniques making use of the polymerase chain reaction show considerable potential towards enabling more direct isolation of genes responsible for a trait. The best possible selective genetic markers are those most closely linked to the genes responsible for the observed trait or ideally the genes themselves. While mapping experiments provide a good chance of locating the general chromosomal regions containing these genes, identification of the actual gene within this region requires that the region be densely mapped and also requires pedigrees suited to fine scale mapping of the trait in question. Methods for directly identifying genetic differences between two phenotypes are variations of two distinct procedures: representational difference analysis (RDA), and differential display.

Representational difference analysis

RDA was developed to determine and isolate the differences between two genomes (Lisitsyn et al. 1993). It employs the use of a tester genome sample that contains unique sequences to be cloned and a driver sample in excess designed to remove all sequences common to both genomes (Lisitsyn 1995; Figure 1). The technique is performed in two stages, one referred to as representation and the other as enrichment. The purpose of the representation stage is to reduce complexity of the DNA species in the tester and driver samples and this is achieved firstly by a restriction enzyme digest of each sample followed by ligation of an oligonucleotide to the 5' ends of the fragments in each population. PCR is then carried out using the oligonucleotide as primer under conditions favouring amplification of short (0.6 kb) fragments. The resulting modified tester and driver samples are used as the input to the next stage, referred to as enrichment. The first step in this part of the protocol involves ligation of another oligonucleotide adaptor only to the ends of the tester DNA fragments. Tester and driver samples are then mixed, the driver sample being in excess. Denaturation and reassociation causes tester sequences that are present in the driver sample to form heteroduplexes with driver fragments. Subsequent PCR amplification using the oligonucleotide as primer allows enrichment only of reannealed tester homoduplexes. These products represent the differences between tester and driver samples and following digestion with the original restriction enzyme are usually used as the input for further rounds of enrichment using a different oligonucleotide adaptor.

Genetically directed RDA (GDRDA) is a slight modification of RDA designed to isolate markers in a region of interest that differs between two lines or strains (Lisitsyn et al. 1994). It will detect deleted genes, amplified gene copy number and additional genes and works best for monogenic traits. While near-isogenic lines are ideally suited to such an approach, it may be adapted for use with 2-generation crosses which are more realistic for experiments involving livestock. This is achieved by obtaining a driver by pooling DNAs of several F2 individuals from an F1 intercross where the F2 individuals selected are homozygous for the recessive allele at the locus of interest. In the case of a dominant or co-dominant trait, the tester DNA comes from the parental 'mutant' strain and the driver from pooled F2 DNAs from 'normal' homozygous recessive individuals. When applied to a recessively determined trait, the tester DNA comes from wild-type individuals and the driver from pooled F2 DNAs from individuals showing a mutant phenotype, i.e. homozygous recessive. The pooling of driver DNAs ensures that variation at other loci is randomised, selecting only at the locus of interest. While best suited to monogenic traits and therefore not very useful in detecting markers for genes determining complex traits such as parasite resistance, such a technique could possibly be applied to fine mapping of a disease locus once flanking markers are identified.

Hubank and Schatz (1994) described cDNA RDA as an adaption of RDA to monitor gene expression. The representation stage is replaced by using mRNA to synthesise cDNA as this reduces genomic complexity to 1–2%. Further, digestion with a restriction enzyme having a 4-base recognition sequence ensures that tester and driver samples will contain short sequences easily amplified by PCR. Studying differences in mRNA populations means studying differences in gene expression thus allowing detection not only of mutant versus normal phenotypes but differences between activated cells from those in a resting state.

Differential display analysis of mRNA

The major factor that distinguishes differential display (DD) (Liang and Pardee, 1992) from RDA approaches is that difference products are detected by concurrent gel electrophoresis of products from two samples rather than by a subtractive process. Like cDNA RDA, differential display was developed to analyse differences in gene expression between different tissues, treatments or developmental stages, but has the added advantage of allowing comparison of more than two mRNA populations.

The differential display methodology evolved from another similar technique referred to as RNA arbitrarily primed PCR (RAP-PCR) which employs either one or a pair of arbitrary primers of approximately 20 bases in length to amplify all mRNAs by reverse transcription and second strand synthesis at low stringency (Welsh et al. 1992). PCR at higher stringency follows using the same primer or primer pair. DD-PCR was designed as a more systematic approach to detecting differentially transcribed mRNAs (Liang and Pardee 1992; Figure 2). The first step employs a series of anchored oligo-dT primers ($T_{11}M$ or $T_{11}MN$, M; A,G,C; N, any base) to separately reverse transcribe mRNA species (Liang et al. 1994). The resulting cDNA populations are

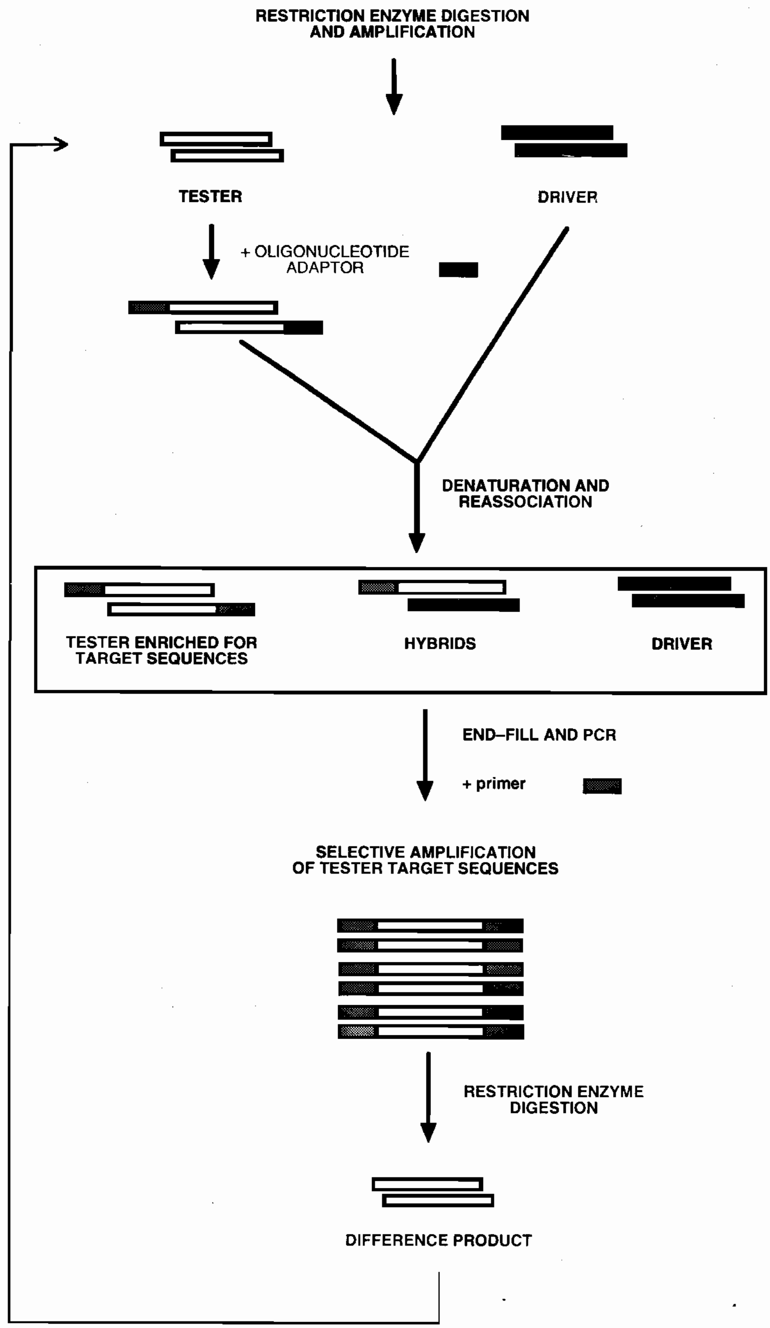

Figure 1. Diagram outlining the steps involved in representational difference analysis of DNA. Following restriction endonuclease digestion of both tester and driver DNA samples, only the tester sample is ligated to oligonucleotide adaptors. After mixing tester and driver DNAs, denaturation and reassociation yield three types of duplexes but only tester target sequences are amplifiable by subsequent PCR. Another round of the process can be carried out with ligation of a new adaptor sequence to the amplified fragments. (Adapted from Lisitsyn, 1995.)

amplified by further PCR using the anchored primer coupled with a range of random 10-mer primers (which may incorporate a restriction enzyme site) as well as radioactively labelled nucleotides. The products from each pair of identically primed PCR reactions, using different mRNA starting samples, are compared by polyacrylamide gel electrophoresis and the difference products excised from the gel and amplified further by PCR for cloning, sequencing and identification.

Knowledge of the immunological basis of parasite resistance can be used in the design of differential display experiments that aim to determine differences in gene expression. In the search for genes conferring parasite resistance, cloning and sequencing of the difference products between responding and non-responding tissues or individuals for example may lead to identification of novel candidate genes for marker development. These markers can then be tested for association with resistance phenotype in appropriate families.

Application of Genetic Markers

For any genetic marker to be useful it must be cheap and give the sheep breeder a reliable measure of the relative genetic merit of his breeding stock. Breeders must able to provide a sample from each animal for the preparation of genetic material and this is currently in the form of a small amount of blood but could in the future be satisfied by a single wool follicle. Presumably this will impact on cost as will the time and manipulations required for genotyping which is currently being minimised by implementation of semi-automated genotyping using fluorescently labelled nucleotides or primers in the PCR reaction, allowing typing of multiple marker loci per gel lane.

Incorporating Markers into Breeding Programs

Markers may be used within a breed or commercial line in a marker assisted selection program. The most important aspect of markers is the increased accuracy of selection obtained using genotypic as opposed to phenotypic information (Schested and Mao 1992; Smith 1967). In addition, several constraints exist when developing breeding programs that include genetic markers as selection criteria. The genetic markers used to select animals for a particular trait must be close enough to the gene responsible (1–2 cM) so that associations are not eroded by genetic recombination. Some native breeds such as

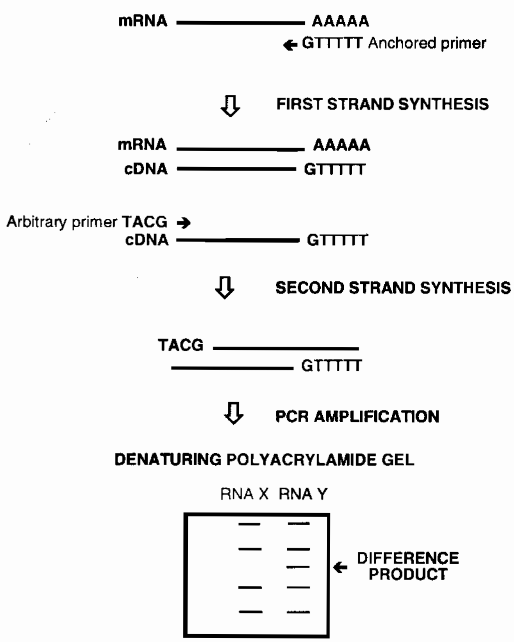

Figure 2. Outline of the process of differential display PCR analysis of messenger RNA using single-base anchored oligo-dT primers for first strand synthesis. Each oligo-dT primer leads to amplification of a subset of mRNAs when coupled with a 10-mer of arbitrary sequence for second strand synthesis and subsequent PCR amplification. Difference products between the mRNAs of two tissues or treatments, X and Y, are visualised by concurrent polyacrylamide gel electrophoresis.

Red Masai, Florida native and Scottish Blackface show superior resistance to nematodes, a range of breeds must be tested for linkage between relevant marker loci and the corresponding genes responsible for the desirable traits. Before markers are used it is important to check for adverse correlations with other production characteristics. For example, a negative correlation was detected between cow fertility and resistance to worms (Mackinnon et al. 1990). Other studies suggested that selection of cattle (Mackinnon et al. 1991) or sheep (Riffkin and Dobson, 1979) for production characters has been at the expense of resistance to worms. However the converse is not necessarily true in that in sheep, for example, no differences in production potential were found between genetically resistant and unselected or susceptible sheep (Windon and Dineen 1984; Albers and Burgess 1988). Moreover selection for resistance to one species of nematode generally leads to greater resistance against other nematodes (Windon 1990; Barger 1989). In most selection indices designed to achieve practical breeding objectives, it is likely that production traits will be given most economic weight thus reducing the intensity of selection for worm resistance. In this case it has been suggested that selection against susceptibilty may be easier to integrate into a selection index than intense selection for resistance (Kloosterman et al. 1992).

Another use of marker technology is introgression of genes from native breeds into more productive breeds. The combining of alleles from different breeds of pigs using marker assisted introgression where the aim is to fix the favourable allele in commercial populations with as little as possible of the remainder of the genome of the inferior breed has been discussed by Visscher and Haley (1995). Introgression of one or a few major resistance genes from one breed to another is costly, time consuming and causes disruption to normal breeding programs and therefore would probably only be carried out if the effects of a major gene were large enough to make it worthwhile.

Marker technology can be used to follow the fate of transgenes introduced into a population. Once particular genes are identified, transgenesis becomes an option but at this stage this option carries with it the burdens of being intrusive and somewhat unpredictable in terms of acceptance and effectiveness. Where between-breed crosses are uncommon, selection within a single breed for naturally occurring variation should be implemented with relative ease.

In conclusion, within the next few years genetic markers will become available and will enable more efficient methods for incorporation of traits such as parasite resistance into practical breeding programs. Markers will be identified as a result of linkage analysis or special resource families. Increasing use will be made of candidate gene approach based on genes identified by differential analysis of mRNA expression to identify functional markers within actual genes responsible for the trait.

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OTHER CONTRIBUTIONS

The Anthelmintic Effects of Bithionol Sulfoxide against Sheep Experimentally Infected with *Fasciola gigantica*

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Abstract

The treatment of *Fasciola gigantica* infection with bithionol sulfoxide was investigated in sheep that had been experimentally infected with 500 metacercariae. Ten sheep were divided into three groups: Group 1 (4 sheep) were given a single dose of bithionol sulfoxide 80 mg/kg orally at week 22 after infection; Group 2 (3 sheep) were untreated positive controls; and Group 3 (3 sheep) were untreated negative controls. All animals were examined for fasciola eggs per gram (EPG) of faeces at weekly intervals for a period of 28 weeks. The EPG during weeks 22–23 were examined daily. The results revealed that no eggs were found in the faeces of all treated sheep within one week of treatment. Hence, bithionol sulfoxide was highly effective against mature *F. gigantica* in sheep. Alterations in serum SGPT, SGOT, copper, iron, total white cell count, total red cell count, MCV, MCHC and live weight were noted.

FASCIOLOSIS is a particularly important parasitic disease affecting cattle, buffalo, sheep and occasionally goats (Loehr 1982; Reid et al. 1973; Suksaithaichana et al. 1993). In Thailand, it is caused by the tropical large liver fluke, *Fasciola gigantica* whose life cycle involves a fresh water intermediate host snail, *Lymnea rubiginosa* (Chompoochan et al. 1976). *Fasciola* infection in livestock is responsible for considerable economic losses in the country because of reduced growth rates, decreased performance, susceptibility to other infections and an increased percentage of liver condemnations in slaughter animals. The prevalence of liver fluke infections varies considerably between the different animal species and different geographic locations with a range of 0% to 85% (Srikitjakarn et al. 1988). To minimise such infections, an optimum treatment and appropriate fasciolosis control program is necessary.

Levacid® (Lek Ljublijana, Yugoslavia), a bolus preparation of bithionol sulfoxide, has been recently introduced by the Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand. As a country project (The Farmer Self-help Program), this drug has been offered as the drug of choice against fasciolosis in ruminants. Prior to the start of the control program, the study was designed to assess the effectiveness and safety of bithionol sulfoxide against *F. gigantica* experimentally infected sheep.

Materials and Methods

Experimental animals

The 10 one-year-old merino sheep used in this study were reared and maintained in parasite-free concrete pens throughout the experiment. The animals were divided into three groups.

- group 1 (4 sheep) *F. gigantica* infected animals treated with 80 mg/kg bithionol sulfoxide (Levacid®);
- group 2 (3 sheep) *F. gigantica* infected, untreated animals;
- group 3 (3 sheep) non-infected control animals.

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Animals in Group 1 and Group 2, were orally infected with 500 *F. gigantica* metacercariae in a gellatin capsule. Group 3, animals were not infected and served as controls for the experiment.

Matacercariae

Metacercariae of *F. gigantica* were obtained from laboratory reared *Lymnea ollula* intermediate host snails which had been exposed to miracidia of bovine origin.

Anthelmintic treatment

Levacid® was administered orally during week 22 post-infection, to animals in Group 1, at a dose of 80 mg/kg body weight. Animals in Groups 2 and 3 did not receive any anthelmintic treatment.

Faecal examinations

Throughout the experiment, faecal samples were collected from all sheep and examined by the beads technique (Taira et al. 1985, Chompoochan et al. 1990) in order to count *F. gigantica* eggs, before and after treatment, at 1–2 week intervals, for 28 weeks. During days 0–14 post treatment, EPG counts were carried out daily.

Blood and serum determinations

Blood samples were collected biweekly from the jugular vein of each animal and divided into two parts, one with EDTA added was used to determine haematological changes (Wbc, Rbc, Hb and PCV). Total Wbc, Rbc, MCV and MCHC determinations were done by a standard laboratory procedures using an automatic cell counter. Haemoglobin was quantified by a haemoglobinometer and PCV by the use of a microcapillary tube technique.

The second sample was placed into vials without anticoagulant for the preparation of sera. These were used to determine total protein, albumin, iron, copper and serum enzymes (SGOT, SGPT). Total serum protein was determined by a hand refractometer; albumin by the Bromocresol Green method; iron and copper by an Atomic Absorption Spectrophotometer and SGOT and SGPT by the Reitman Frankel's method.

Results and Discussion

All sheep in Groups 1 and 2 which were experimentally infected with 500 metacercariae (MC) of *F. gigantica* showed egg outputs in their faeces 11–13 weeks post infection. The peak EPG in Group 1 was found during week 22, with a mean EPG of 494 and in Group 2 during week 22 (1244 EPG). At week 22, each sheep in Group 1 was treated with Levacid® and faecal samples were examined daily for 2 weeks afterwards. The results (Fig. 1) showed that fluke eggs were absent on day 7, post treatment, whereas in the infected control animals the EPG still appeared up to the end of the experiment. Two infected control sheep (Group 2) died during weeks 20 and 22. Numerous flukes (131 and 111 adult flukes) were found in the bile ducts and gall bladder. In all treated animals, no clinical side-effects were observed.

Figure 2 shows that sheep in the Levacid-treated group had an antibody titre throughout the experiment which was similar to the non-medicated infected control group. This result was in contrast to studies by other investigators who found that sheep and cattle showed a rapid decrease in antibody titres after treatment with anthelmintics (Bruijning 1978; Kendal et al. 1978).

In this study serum enzyme levels of SGPT and SGOT were highly variable across samplings and no difference between treatment groups was observed. Other studies have found that SGOT level increased slightly eight weeks post infection and then returned to pre-infection levels (Reid et al. 1973).

Mean values of serum protein and serum albumin are shown in Figures 3 and 4 with a slight increase and fall. These alterations may be due to an increase in the serum gamma globulins of the animals (Reid, et al. 1973). Serum copper levels of all three groups of animals were similar throughout the experiment. Serum iron in the Levacid-treated group (Fig. 5) showed a declining value during week 18, post-infection and a return to normal soon after treatment. In the animals in the *Fasciola gigantica* infected control group, the serum iron level began to decline rapidly 15 weeks after infection and remained low until the end of the experiment. The effect of *F. gigantica* on the iron level in the infected animals was presummably due to three basic disturbances to the red blood cell metabolism (Reid et al. 1973) i.e. an increased rate of red cell destruction, a compensatory increase in red cell products and a continuous drain on iron stores, resulting from the blood sucking activities of the liver flukes. The total red cell count, MCV, MCHC and total white cell count results revealed that all values were in the normal range, and that no marked differences of any values were demonstrated in the three groups of animals.

In Figure 6, the live weight gain of animals was evaluated between weeks 0, weeks 22 and weeks 32 post-infection. Weight reductions were found in Group 2 animals. Sheep in Group 1 treated animals showed a slight weight gain from week 32 but this was significantly less than the control group.

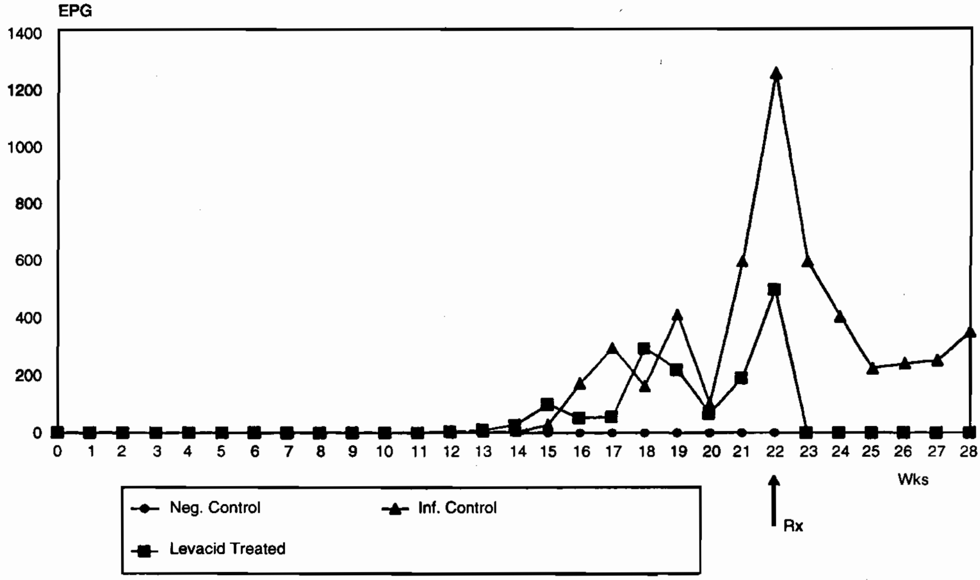

Figure 1. Mean EPG of *F. gigantica* in sheep after treatment with Levacid^R.

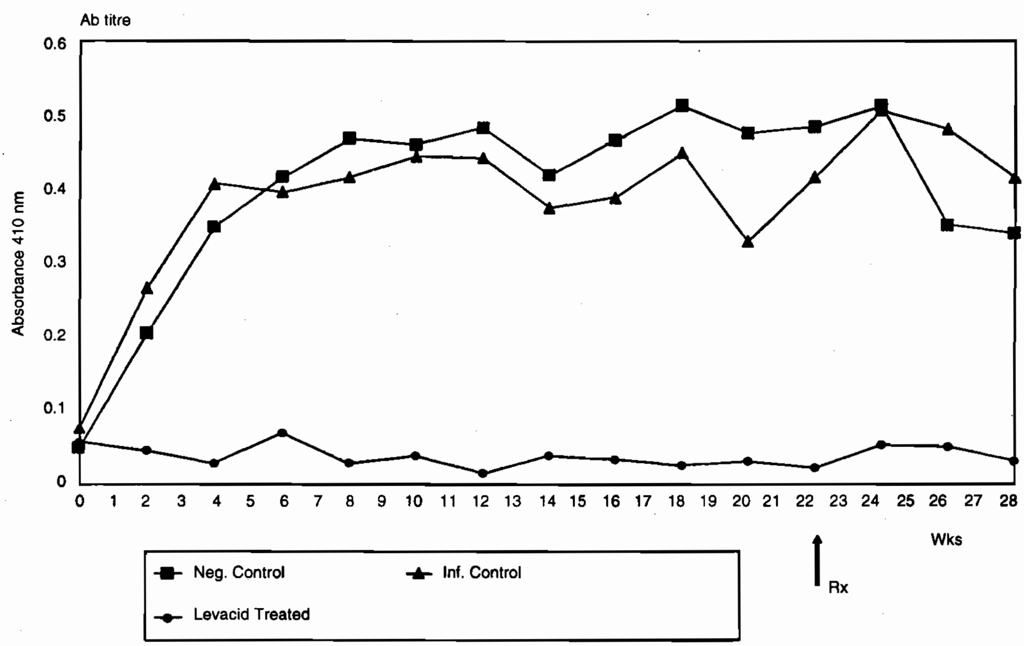

Figure 2. Mean Ab titre of *F. gigantica* in sheep after treatment with Levacid^R.

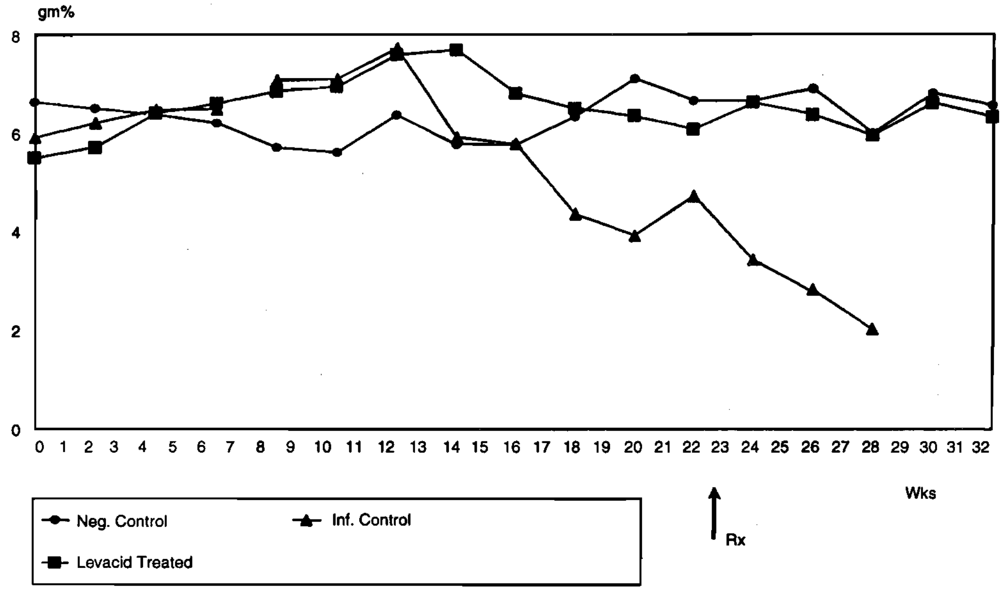

Figure 3. Mean serum total protein of *F. gigantica* in sheep after treatment with Levacid[R].

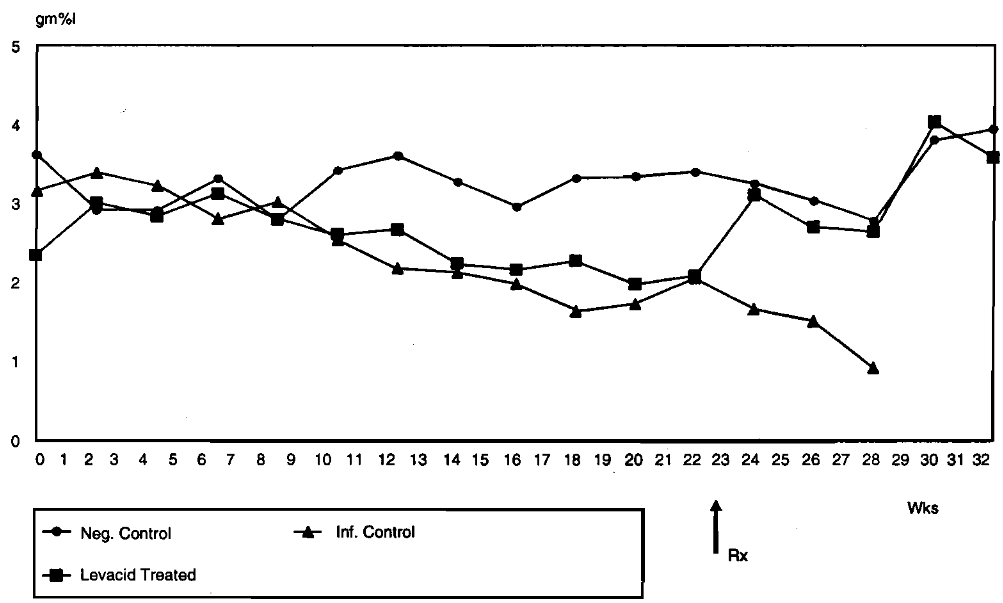

Figure 4. Mean serum albumin of *F. gigantica* in sheep after treatment with Levacid[R].

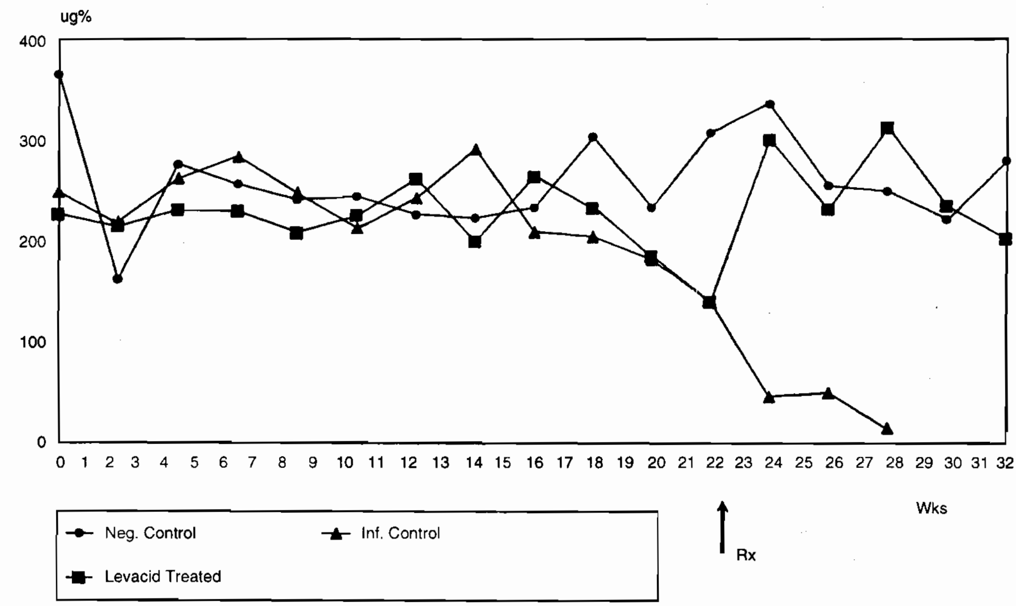

Figure 5. Mean serum iron of *F. gigantica* in sheep after treatment with Levacid[R].

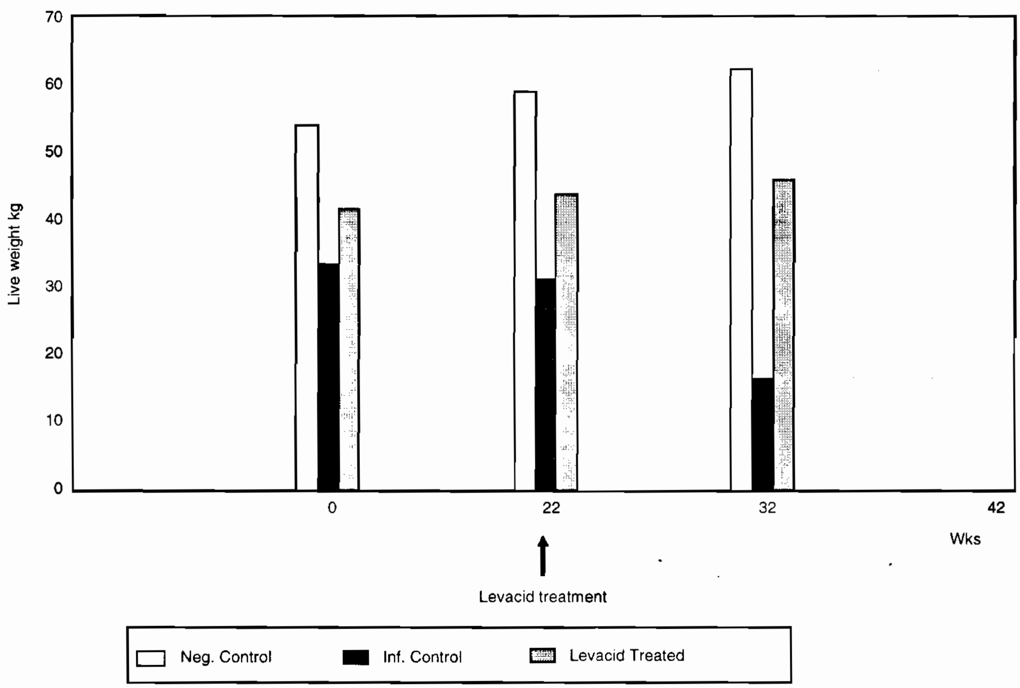

Figure 6. Live weight of sheep after treatment with Levacid[R].

Acknowledgments

The authors gratefully thank Dr. K. Nontapatamadul, F.E. Zuellig Co. Ltd. for partial support of this project.

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DISCUSSIONS AND OUTCOMES

Sustainable Parasite Control Workshop

FOLLOWING the presentation of papers, workshop sessions were held. The rationale was to generate a sound analysis of the main constraints in small ruminant production systems and then to determine what inputs in research, extension and training were required to change the existing parasite control programs into *sustainable parasite control programs*.

The format of the workshop sessions was for delegates to separate into groups of between seven and nine members and to discuss a topic for up to one hour. Then the groups reassembled for a general session where each group's deliberations were presented to the general session.

Although the group discussions were informal, each group had a 'Leader' and a 'Scribe'. The Leaders' duties were to generate and moderate the discussion and, together with the Scribe, ensure that the views of the group were expressed during the general discussion. The Scribes' duties were to make notes of the discussion and list the major points which arose.

The two topics to be considered in the first round of discussions were:

(1) for sheep and goats separately, describe the important production systems within Asia;

(2) what are the constraints on these systems? Rank parasitism as an animal health constraint.

The results of this discussion are summarised in Table 1. The general agreement was that for the purpose of describing productions systems, sheep and goats were equivalent.

In the second session, the groups were asked to consider what inputs (research/extension/training) were needed to turn parasite control into sustainable parasite control. The results of their deliberations are summarised in Tables 2 and 3. It was assumed that adequate funding for research and extension would be provided by national and international agencies and that control options being researched were economically viable.

Table 1. Major animal production systems and constraints on production within those systems.

Production system	Major constraints	Parasitism as an animal health priority
Smallholder		
Cut and carry	1. Nutrition/health	HIGH
	2. Information, education and extension	
Tethered grazing	3. Inappropriate genotype and infectious disease	
Landless		
Integrated systems		
Plantation	As for the smallholder system	HIGH
Other crops	Input costs have greater relative importance	
Transhumance (inc. omadic)	1. Nutrition and epidemic disease	LOW

Critique of Research Priorities

Table 2. Research priorities identified by workshop groups

Research priorities	
Identification of resistant genotypes	+ + +
Nutrition/parasite interactions	+ + +
Anthelmintic use and resistance monitoring	+ +
Epidemiology	+ +
Integrated strategies for control	+ +
Grazing management	+
Biological control	+

1. The need to rapidly develop parasite resistant strains of sheep and goats through selective breeding using recent developments in quantitative and molecular genetics was identified as the top research priority. Before selective breeding of goats for increased resistance was undertaken, it was recognised that further research would be required on the extent of within and between breed genetic variation of resistance to parasites in goats. It was suggested that a scheme be developed to enable genetic comparisons across breeds and between countries. This may involve the establishment of a 'reference flock' in one of the collaborating countries.

2. Determine the effects of improved nutrition on the small ruminant's ability to resist parasitic infection. Research would concentrate on the nutritional approaches to increasing productivity which are technologically appropriate for the target livestock production systems (i.e., low cost supplements, use of agricultural residues). The importance of adequate nutrition in the phenotypic expression of improved resistance genotypes also needs to be assessed.

3. Two types of monitoring were seen by the participants as beneficial. The first was monitoring anthelmintic resistance levels in nematode parasites so that management decisions could be made to prevent control failures. The larval development assay could be a useful means of providing a standard resistance monitoring system. The second type of monitoring was in regard to reports that have indicated that in some countries anthelmintics were found to be diluted before being sold to farmers or veterinarians. As a further step in ensuring that animals are treated with the correct anthelmintic dosage, a national government centre should be nominated to test commercial anthelmintic formulations at the point of sale for accurate labelling.

4. Ensure that adequate knowledge is gathered on the epidemiology of internal parasites of small ruminants in the participating countries. This information would enable the design of integrated control programs (ICP) for testing in each of the target production systems. Such programs would aim to minimise anthelmintic use while taking full advantage of benefits obtainable from grazing management and nutritional strategies designed to reduce the parasite burden. As alternative control options are advanced these could also be included into ICP when available.

Critique of Education and Training Priorities

Table 3. Extension training priorities identified by workshop groups.

Extension training priorities	
Regional short course training programs for scientists, administrators and extension staff	+ + +
Improved extension/farmer/researcher linkages through improved networks	+ +
Integration of Animal Health and Production Extension	+
Farmer training	+

Workshop participants recognised the importance of increasing the capability of national staff through training. This could be brought about by a series of initiatives aimed at scientists, extension workers and technicians. These measures included:

(1) Short courses

Technical and extension staff employed by each participating country should receive short-term training in the principles of parasite control, anthelmintic resistance diagnoses and genetic selection. This could be achieved by giving selected staff the opportunity to attend in-country training courses conducted by local and overseas experts. Training of technical staff was identified by all workshop groups as a priority need.

(2) Scientific staff

The majority of scientists involved in parasite control research have been trained in a specific discipline and experience some difficulties in coping with the multidisciplinary nature of SPC research. It was recommended that greater training opportunities in broad-based programs be made available to country scientists.

Critique of Communication/Networking Recommendation

The need to improve the effectiveness of regional research and development activities through networking was seen as the first priority in communication. It was envisaged that initially the network should function on two levels.

The first level would be a moderated newsgroup to link institutions and researchers involved in helminth control in ruminants in the tropics. This newsgroup should be established immediately and would serve to keep scientists involved in the 'Sustainable Parasite Control Workshop' in contact, and to facilitate the development of a project to implement sustainable parasite control. It was recommended that the newsgroup would be open to all with an interest in sustainable parasite control in ruminants in the tropics. In order to keep all workshop delegates informed, those without email links would receive paper transcripts of the newsgroup discussions.

The second level would be a paper-based system responsible for distributing reports of regional meetings to participants and relevant authorities, for production of information circulars for each country and distribution to other sectors and development agencies, and for publishing a regional newsletter twice each year and distributed to all animal health and production research and extension workers in the region. As the computer links improved in the region, it was envisaged that the newsgroup and paper-based newsletter would evolve into a single information system contactable through the worldwide web.

The group and general discussions on the final day centred on methods of implementing SPC in countries of South and Southeast Asia. Delegates agreed that SPC should be urgently implemented. It was recognised that not all countries represented at the workshop could contribute at the same level for implementing a multidisciplinary strategy of sustainable parasite control. Identifying the strengths and weaknesses of country institutions in their ability to contribute was not possible in the time allocated for the workshop. It was therefore the specific recommendation that a consortium be established with national representation, representatives from international agencies with interest in collaborative research and development in the region and with CSIRO and UNE representatives.

Initially, the consortium will consist of one member from each country and the institutional representatives. The initial task of the country representatives will be either to obtain approval to speak on behalf of their country's priorities or to enlist an alternative representative from their country who can. The delegates decided on the following terms of reference.

Consortium — terms of reference

Identify group strengths and weaknesses.
Identify research needs.
Identify training needs.
Consider new proposals.
Identify resources.

Specific recommendations arising from the workshop and to be acted on immediately

Disseminate workshop outcomes.
Establish a network.
Establish a consortium.

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