ESTIMATING THE GAINS OF STRATEGIC INTERNAL PARASITE CONTROL IN SHEEP

R S McLeod*, D J Collins!, E H Barnes# and R J Dobson#

Contributed paper presented at the 36th Annual Conference of the
Australian Agricultural Economics Society
Australian National University, Canberra, 10-12 February 1992

* Final year Bachelor of Agricultural Economics student at Sydney University.

! Institute of Animal Production and Processing
CSIRO Corporate Centre
Limestone Avenue Campbell, 2601.

Division of Animal Health, CSIRO, McMaster Laboratory, Sydney

ESTIMATING THE GAINS OF STRATEGIC INTERNAL PARASITE CONTROL IN SHEEP

R S McLeod*, D J Collins!, E H Barnes# and R J Dobson#

ABSTRACT

Internal parasitism inflicts substantial costs on the Australian sheep industry, with gastro intestinal nematodes being a primary cause of production losses. With the evolution of resistance to chemical treatment strategic control programs have been devised to more efficiently manage gastro intestinal nematodes. Production losses are most acute in higher rainfall areas where the environment permits population development.

The winter high rainfall region was selected to estimate the benefits from increased adoption of strategic control. In this region the climate is favourable to pathogenic nematodes species and there is a relatively low adoption of strategic control. The cost of internal parasitism in this region was estimated at $89M in 1990.

An epidemiological model was used to estimate sheep parasite burdens and subsequent production losses when using traditional or strategic control practices over 20 years. The simulation model predicted weekly nematode burdens given daily weather data, genetic systems for anthelmintic resistance, regional sheep management practices and differing sheep susceptibility to infection with breed and age. Strategic control was shown to more efficiently manage nematodes and increase animal production.

Increased adoption of strategic control reduced the regional loss of internal parasitism and generated substantial national benefits as well as welfare gains to overseas consumers. Producers in the winter high rainfall regions were the major beneficiaries from increased adoption.

* Final year Bachelor of Agricultural Economics student at Sydney University.

! Institute of Animal Production and Processing
CSIRO Corporate Centre
Limestone Avenue Campbell, 2601.

Division of Animal Health, CSIRO, McMaster Laboratory, Sydney

ESTIMATING THE GAINS OF STRATEGIC INTERNAL PARASITE CONTROL IN SHEEP[1]

R S McLeod, D J Collins, E H Barnes and R J Dobson

Background

Gastro-intestinal parasites impose a substantial cost on the Australian sheep industry. The problem is by no means recent, as evident by a producer's submission to the Australian Pastoralist Review in 1892 which reads: *There are few or no subjects of more interest to the sheep owners of Australia than that of parasites of sheep* [and the investigation of their] *cause, proper treatment and if possible the prevention of worms in sheep* (quoted in Hall 1990).

Internal parasitism is a problem in the high rainfall and wheat/sheep zones where environmental conditions favour development of helminth populations. Internal parasites, or more specifically helminths, can be classified as either nematodes (roundworms), trematodes (flukes), or cestodes (tapeworms). Gastro-intestinal roundworms are the most important of these internal parasites. Of the 20 species found in Australia, the species Haemonchus contortus (Barbers pole worm), Ostertagia spp (medium stomach worm) and Trichostrongylus spp (black scour worm) exhibit a large range and potential to significantly impair animal productivity. Fasciola hepatica (live fluke) can also cause significant loss but, as an aquatic snail is required as an intermediate host its distribution throughout eastern states is limited (Anderson et al 1987).

Trichostrongylus spp and Ostertagia spp are the nematodes of primary importance in the southern winter rainfall areas of Australia due to their greater tolerance of colder conditions (Anderson et al 1978). Larval numbers peak in late winter and decline rapidly during the dry months of summer (Dash 1988). Where summer rainfall is above average H contortus and Trichostrongylus spp are likely to be endemic.

---

[1] This project was undertaken at the instigation of Dr John Steel, Head, McMaster Laboratory, CSIRO, Sydney and with the encouragement and collaboration of Dr Helen Scott Orr, Chief, Division of Animal Industries, Dr Ian Roth and other officers of NSW Department of Agriculture. The project was coordinated under the direction of Dr Jim Johnston, Manager, Institute of Animal Production and Processing, CSIRO, Sydney. Their assistance and comments along with other staff at CSIRO and other State Departments of Agriculture are much appreciated. Naturally however, all remaining errors in this paper are the responsibility of the authors.

To mitigate the potential loss from helminth infection control practices are employed at the farm level. Anderson et al (1978) identified two basic strategies which can be used to control helminth burdens in sheep. The first is a traditional method which relies predominantly on chemotherapy or anthelmintic drenches. The second method is a more strategic form of control whereby fewer but strategically timed anthelmintic treatments are used in conjunction with grazing management.

In this study the economic gains over a twenty year period from the greater adoption of strategic control in the winter high rainfall area of Australia are estimated. Expected gains were estimated using a two-step methodology. Firstly, the productivity gain of adopting strategic control in preference to traditional control was identified at the farm level using the Barnes and Dobson (1991) Trichostrongylus spp biological simulation and production loss models. The regional and national gain from greater adoption of strategic worm control was then estimated by adapting the Edwards and Freebairn (1981) model.

Production losses in sheep caused by internal parasites

The major nematodes affecting sheep are ingested when feeding on pasture as infective stage 3 larvae. The establishment of the parasite within the host is subject to the host's level of resistance. The level of immunity is both endogenous (age, previous experience of infection, physiological state and breed) and exogenous (the species of challenging nematode, the size of the stimulating dose and effects of nutrition) to the host (Cole 1986).

The disturbances helminth infection causes to the host's physiology and metabolism are identified by Symons and Steel (1978), Barger (1982) and Anderson et al (1987). The structural disturbances resulting from nematode infection primarily cause loss of appetite, protein loss and anaemia. These disturbances manifest themselves in increased mortality, impaired liveweight gain, reduced growth and quality of wool, poorer lactation, reduced fertility and increased susceptibility to fly strike as a result of scouring.

The magnitude of production losses that uncontrolled helminth infection can inflict on weaners in the winter high rainfall area of Australia has been reported by Anderson et al (1976), Anderson (1972, 1973, unpublished), Brown et al(1985) and Thompson and Callinan(1981). Production losses in adult stock were obtained from Morris et al (1977). Production losses associated with uncontrolled infections are reported in Tables 1 and 2.

Table 1 : Uncontrolled Production Loss in Weaners

	Wool loss	Meat loss	Mortality
	Kg	Kg	%
Mean value	0.73	5.89	28.78
Range	0 to 1.06	0 to 12.41	0 to 55.00

Table 2 : Uncontrolled Production Loss in Adults

	Wool loss	Meat loss	Mortality
	Kg	Kg	%
Mean value	0.80	6.9	0
Range	0.78 to 0.82	6.6 to 7.19	0

Note : No mortality was assumed to occur in adult stock as their natural immunity to infestations is higher than in weaners.

Because of the variation in reported production losses associated with uncontrolled worm infections, these losses were incorporated stochastically in the model with the use of the @RISK software program (1990 Palisade Corporation). Triangular probability distributions were specified for production losses in weaners, and for adult stock a uniform probability distribution was assumed. The @RISK program is an add-in to Lotus 123 which allows a series of random points to be drawn from the specified probability distributions.

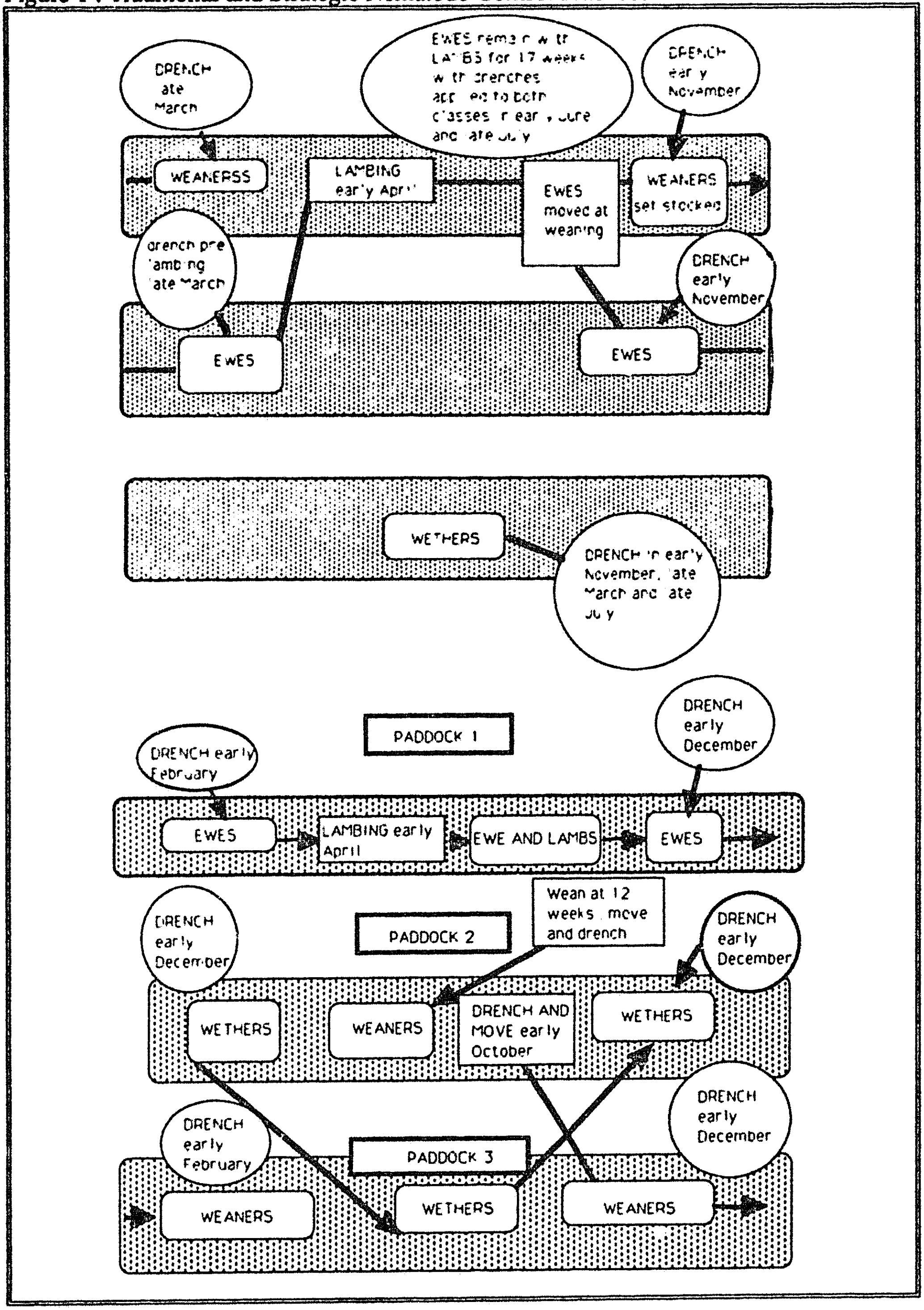
Production Loss Under Strategic and Traditional Control

Farmers were deemed to utilise either a strategic or traditional worm control programme as detailed in Figure 1. The cost associated with each control programme across all sheep types was estimated by McLeod (1991) and is summarised in Table 3.

Table 3 : Annual Cost of Strategic and Traditional Control : By sheep type : c\head\year.

Sheep type	Strategic control	Traditional control
Merino ewe	55	69
Crossbred ewe	70	80
Merino lamb	83	57
First cross lamb	117	71
Second cross lamb		15
Wether	59	54
Ram	77	65

Figure 1 : Traditional and Strategic Nematode Control Practices



To estimate the production loss under each control programme it was necessary to consider additional management practices (lambing date, stocking rate, lambing percentage, weaning date and time of marketing) in conjunction with those that are specific to each programme. Management parameters and daily weather variables were specified for the Barnes and Dobson (1990) Trichostrongylus spp simulation model. The structure of the simulation model is described in Barnes and Dobson (1990) and was used to predict weekly Trichostrongylus spp adult burdens in weaners, ewes and wethers; death of weaners and the resistance status of free living stages. Parameters such as the host immunity of lambs, wethers and ewes and differences in breed susceptibility were also specified in the model.

Daily meteorological data over the years 1965 to 1984 recorded at the Kybybolite Meteorological Station in the high rainfall zone of South Australia was used as a representative 20 year climatic period in the analysis. For computational ease, the switch from traditional to strategic control was only considered as a possibility in every fifth year. That is, it was assumed that a grazier would carry out strategic treatment for 20 years (S20), or traditional control for 5 years followed by strategic control for 15 years (T5S15), or traditional control for 10 years followed by strategic control for 10 years (T10S10), or traditional control for 15 years followed by strategic control for 5 years (T15S5), or traditional control for 20 years (T20).

To calculate annual meat and wool loss under each control programme, the maximum weekly Trichostrongylus spp burden in each year was extracted from the simulation output to first predict the expected Ostertagia spp adult burden that would occur. The assumption was made that the population dynamics of Ostertagia spp is strongly correlated with that of Trichostrongylus spp. Although the free living stage of Ostertagia spp follows the seasonal fluctuation in Trichostrongylus spp, the correlation is not perfect as Ostertagia spp is more strongly regulated by the host and the expulsion of adult parasitic stages occurs at an earlier stage of infection. Barger (1984) has noted that parasites of differing gastro-intestinal organs (Ostertagia spp - stomach, Trichostongylus spp - small intestine) are differentially regulated by the host. To reflect the difference in the adult establishment of each species a piecewise model was constructed from Dobson and Barnes unpublished data. Ostertagia spp adult burden was defined as a constant proportion of Trichostrongylus spp adult burden until a threshold was reached above which Ostertagia spp maintained a constant plateau (see McLeod 1991).

To approximate the total liveweight loss in all sheep types after 12 months of grazing, a regression equation was fitted to experimental data of Sykes et al (1988). This data recorded the difference in total weight gain weaners displayed subject to varying combinations of Ostertagia spp and Trichostrongylus spp adult parasite burdens. The data is based on observations of weaner stock 12 weeks after experimental infection. Nematode burdens were assumed to be at a maximum at this time because after 12 weeks of infection immunity response and parasite regulation occurs. The liveweight of sheep is likely to fall during the expulsion of the nematode burden but once the parasite burden is expelled compensatory growth usually occurs and liveweight parameters at 12 months are likely to be in the vicinity of those after 12 weeks of infection.

It should be noted however that the above method to approximate liveweight loss is an extremely crude measure of annual production loss due to worm parasitism. The regression equation was utilised in the absence of more appropriate experimental data and is given in equation 1. Experimental data indicates that uncontrolled infection causes similar production loss in lactating ewes and susceptible weaners. The resistance status of wethers and British adults to adult establishment was modelled in the simulation which prevents production losses in the vicinity of susceptible types.

$$(1) \qquad LW = \underset{(11.59)}{6.87} - \underset{(-3.82)}{0.00054}*Ost - \underset{(-3.59)}{0.000084}*Tri \qquad (R^2 = 0.81)$$

Where LW = Liveweight gain (kgs),
Ost = Ostertagia spp adult burden, and
Tri = Trichostrongylus spp adult burden (includes Nematodirus spp
recovered from sheep during the trials).

To estimate wool and meat loss the total liveweight loss regression predictors were scaled by the average percentage that wool and meat loss contributed individually to total liveweight loss. Grazing trails by Anderson et al (1976), Anderson (1972, 1973, unpublished data), Morris et al (1977), Brown et al (1985) and Thompson and Callinan (1981) were used. The total liveweight loss predictors derived from Sykes et al (1988) were separated into body and wool weight losses for young stock. Rescaling coefficients used in the study were, for adult stock 0.1 for wool and 0.9 and for young stock, 0.11 for wool and 0.89 for meat.

The productivity parameters estimated for strategic and traditional control over the evaluation period are reported in Table 4 for merino type sheep. Results of the simulation showed that strategic control was more effective in controlling the establishment of parasitic stages within a merino host. The movement of stock to pastures of low infectivity, use of effective anthelmintics and employment of strategically timed treatments reduces the exposure of susceptible lambs to parasites.

Under strategic control the development of resistance to Benzimidazoles (BZ) and Levamisole / Morantel (LEV) was slower over the twenty year period with the introduction of @Ivomec (IVM) in rotation. IVM resistance becomes apparent in the final years of the simulation. The continued use of IVM during the drought years could be responsible for the expression of resistance. During a drought a greater proportion of the entire population are within the host as environmental extremes suppress free-living stages. Drenching stock in these conditions can lead to a greater proportion of the population surviving anthelmintic treatment. Subsequent generations of parasites are offspring of the resistant stock which form the genetic background for the increase in %R allele frequency. (The %R allele frequency describes the portion of the free-living population which exhibits resistance to the drench chemicals used in each worm control programme.)

Table 4 : Controlled production loss in Merinos : Reduction compared to uncontrolled loss : By control strategy through time : %

Strategy	Ewes		Lambs			Wethers	
	Wool	Meat	Death	Wool	Meat	Wool	Meat
1990 to 1994							
S5	92	91	88	68	68	96	96
T5	85	84	-3	57	57	97	97
1995 to 1999							
S10	95	94	100	79	79	97	97
T5S5	95	95	77	67	67	96	96
T10	95	95	90	61	61	96	96
2000 TO 2004							
S15	95	95	100	72	72	96	96
T5S10	95	95	100	60	60	95	95
T10S5	94	94	100	72	72	96	96
T15	94	94	53	51	51	97	97
2005 TO 2009							
S20	95	95	100	75	74	96	96
T5S15	95	95	100	79	79	97	96
T10S10	95	95	54	74	74	92	92
T15S5	95	95	100	83	83	95	96
T20	94	94	70	52	52	97	96

Ewes and wethers were found to be much less sensitive to the effects of worm parasitism when compared to lambs. Despite lapses in immunity around lambing, ewes display a higher resistance to larval challenge, and the difference between traditional and strategic control was less pronounced than in lambs. Adult wethers display the highest resistance to nematode parasitism. The adoption of strategic control did not cause substantial production gain for this stock class.

British ewes have a higher immunity to larval challenge than Merino types. Consequently, the establishment of parasitic stages in British ewes is substantially lower. Throughout a year there is a lower availability of infective larvae on the lambing paddock and hence reduced pick-up by susceptible lambs during grazing. The short grazing season of 18 weeks for fat lambs also prevents a significant build-up of parasitic stages within lambs before marketing.

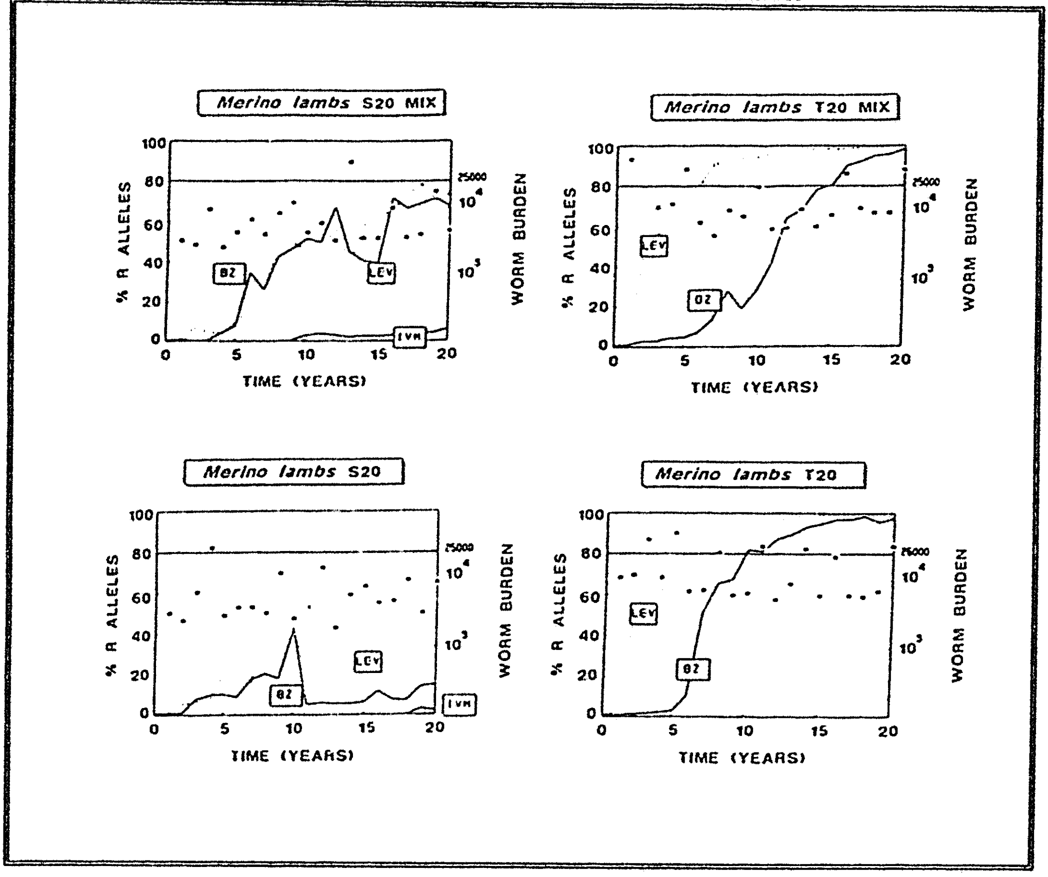
Production losses for British ewe and lamb classes were found to be very low irrespective of the control programme used. The administration of a pre-lambing drench did not appear to reduce the build up of parasites within lambs. This corresponds to the winter rainfall recommendations of Morley and Donald (1980, p116): *If summers are hot and dry, pastures may be relatively non-infective from mid-spring until the autumn rains* [] *Autumn lambing is common in such regions and a late summer drench would substitute for a pre-lambing drench.* The drenching of lambs just prior to marketing is usually performed to prevent scouring at the point of sale. Any benefit generated from reduced scouring in lambs has not been accounted for in the evaluation.

Because seasonal factors cannot be isolated, it is difficult to assess the impact of increased nematode resistance on animal productivity. It is not clear that the distribution of worm burdens trend upwards with the onset of resistance under both programmes to any significant degree. To illustrate the impact that climate can have on worm populations, a randomised weather sequence was used instead of the 1965-84 sequence (see McLeod 1991).

Under strategic management for 20 years (S20) both the worm burden and resistance status of parasites differed between the two climatic sequences considered. This difference is illustrated in Figure 2. Variation in nematode burden due to seasonal variation has been well documented in many of the field trials conducted in the area (see Barton and Brimblecombe 1983, Brown et al 1985 and Thompson and Callinan 1981).

Resistance develops more rapidly under the randomised weather pattern. This is perhaps due to the inclusion of the 1982 drought year earlier in the weather sequence. Drenching during periods which do not favour the survival and development of free-living stages increases the potential for the development of resistance. Despite the earlier development of IVM resistance, and more rapid BZ and LEV resistance, there does not appear to be a significant upward trend in the distribution of worm burden under strategic control. Under a traditional programme worm burdens in lambs were higher and there was a more rapid development of resistance.

Figure 2 Merino Productivity Parameters under Randomised Weather



Evaluation model

To determine the regional costs of parasitism and national welfare benefits from increased strategic control in the winter high rainfall region the Edwards and Freebairn (1981, 1982) model of a productivity gain in part of an industry was used. The model assumes a perfectly competitive industry, linear supply and demand specifications and a parallel shift in supply as a result of increased productivity.

The Australian industry can be disaggregated into Region A, the winter high rainfall region and Region B, the rest of Australia's sheep-growing areas. The total industry supply of sheep products (wool and meat) is represented by the summation of regional sheep product supplies. Total farm level demand is derived from the domestic and export demand for sheep products. The winter high rainfall zone was defined as all high rainfall zones in Victoria, South Australia, Tasmania and Western Australia. Within each State sheep numbers were broken down into ewe, wether, lamb, hogget and ram stock classes to account for differing losses of each stock class due to helminth infection. For the calculation of productivity parameters rams were included with wethers due to the absence of data pertaining to this class.

ABS statistics were used to define the number of sheep in each stock class on State basis (ABS 1990). To estimate the number of sheep carried across an entire grazing season a flock multiplier was estimated using Kingwell and Pannell (1987) flock dynamics. Under a steady state assumption, it was estimated that annual lamb sales comprised 33% of all lambs carried over a year and mutton sales accounted for 12% of all adult sheep carried. Total sheep carried over 1990 was estimated to be 19% higher than that estimated by the ABS (which is based on stock at hand on 31 March 1990). Sheep numbers are reported in Table 5.

Input data on liveweight, fleece weight and wool price are provided in Tables 6, 7 and 8. Lamb and mutton prices used in the study were 70 cents and 15 cents per kg liveweight respectively (AMLC 1991).

Table 5 : Sheep numbers : million head

Sheep type	Winter high rainfall zone	Rest of Australia	Australia
Ewes	19	75	94
Wethers	12	41	53
Lambs	9	36	45
Rams	0.5	1.5	2
% Merino	73	79	78

Table 6 : Liveweight of British and Merino Stock : kg per head.

Breed	Ewes	Rams	Wethers	Lambs
Merino	50	80	50	34 (a)
British	70	80	-	34 (b)

Notes: (a) The merino lamb weight category represents a composite of merino and first cross lambs. Under the flock dynamic assumptions, 19% of the merino ewe annual drop would be comprised of first cross lambs used to maintain a steady 26% British proportion of the national flock.

(b) The British lamb category represents second cross lambs targeted at the 34 kg prime lamb market.

Table 7 : Wool price

Micron class	Production	Greasy wool price
	%	c/kg
<21.5	38	1109
21.5 to 23.5	44	841
>23.5	18	680
	Average	914

Source AWC (1991)

Table 8 : Average wool cut per head : kg

Zone	Victoria	Western Australia	South Australia	Tasmania
High rainfall	4.54	4.41	4.75	3.8

Source: ABS (1991)

In the evaluation model, wool prices and sheep numbers were adjusted downwards from 1995 onwards to reflect the anticipated downturn in the Australian sheep industry (ABARE 1991). Based on ABARE (1991) forecasts, the average wool price was reduced by 46% and sheep numbers reduced by 25% from 1990 levels.

Supply elasticities used in the evaluation model were obtained from Dewbre et al (1985) and measure supply response after a five year adjustment period. It was assumed that the industry supply elasticity was the appropriate elasticity across all producing regions. Elasticity estimates are reported in Table 9.

Table 9 : Supply and Demand Elasticities for Sheep Products

Commodity	Supply elasticity	Export demand elasticity	Domestic demand elasticity
Wool	0.31	-1.10	-1.10
Lamb	0.47	-1.25	-0.62
Mutton	0.31	-0.50	-0.62

The regional cost reduction due to the increased adoption of strategic control was represented by a parallel shift in the supply curve and is measured by the cost saving (production loss plus cost of control) generated by using strategic instead of traditional control. During 1900 is was assumed that 30% of producers were practising strategic control as previously defined (McLeod 1991). This level of adoption was used as the base adoption across the 20 year period evaluated. The rate of switching from traditional to strategic control over the 20 year evaluation period was determined by first assuming that all producers in the region would adopt strategic control by year 20 and then secondly, expressing the rate of adoption between year 0 and year 20 as a logistic function. The two adoption profiles are given in Table 10, averaged over 5 year steps. The distribution of producers adopting each of the five strategies over the 20 year period is given in Table 11.

Table 10 : Average 5 year Cumulative Adoption (%) of strategic Control

Year	Current level of adoption	Projected rate of adoption
1990-94	30	51
1995-99	30	89
2000-04	30	99
2005-09	30	100

Table 11 : Distribution of producers adopting strategic control through time : %

Strategy	Current level of adoption	Projected rate of adoption
S20	30	51
T5S15	0	38
T10S10	0	10
T15S5	0	1
T20	70	0

Evaluation model results

Production loss data on uncontrolled and controlled worm infections in sheep were incorporated into a Lotus123 spreadsheet along with the physical and economic data detailed above. Simulation results for production loss and control costs over the 20 year evaluation period are reported in Table 12.

Table 12 : Production loss and control costs under base and projected adoption scenarios : By 5 year periods : $m

Period	Base adoption			Projected adoption		
	Production	Control	Total	Production	Control	Total
1990/94	62	27	89	54	27	81
1995(a)	31	27	59	29	26	55
1996/99	14	20	35	14	19	33
2000/04	22	20	42	13	19	32
2005/09	19	20	40	12	19	31

(a) 1995 is included separately because the adjustment in wool prices and sheep numbers was made in the following year.

The current cost of internal parasitism was estimated at $89m, falling to around $40m by 2009. Although the costs of parasite control remained constant from 1996, there was a substantial variation in the estimated production loss. Adoption of strategic control did not lead to any sizeable reduction in control cost, but did result in a marked reduction in production losses in all but one year over the 20 year evaluation period. The total cost of worms to producers in the winter high rainfall areas of Australia were lower across all years under the higher level of adoption of strategic control.

The cost of controlling internal parasites in ewes was reduced with the use of strategic control. In contrast, the cost of nematode control was greater for wethers, lambs and rams under strategic management. This higher cost is due to the use of IVM in rotation with other broad-spectrum anthelmintic chemicals. From the simulation results presented in Table 4 it is unlikely that any benefit from using strategic over traditional methods would be generated in the wether class However, wethers can be successfully used in grazing rotation to reduce worm populations on infective pastures in preparation for grazing by susceptible stock.

Economic gains from a greater adoption of strategic control, as measured by changes in producer and consumer surplus, are reported in Table 13. Over the 20 year period evaluated, the annual gain to Australia as a whole reached a high of $8.2m (see Figure 3). The lowest annual gain was estimated at $1.6m. In absolute terms, gains to the wool industry were greater than in the sheep meat industry. Not surprisingly, the price and flock reduction in 1996 reduced the benefit of switching from traditional to strategic control.

One of the major strengths of using the Edwards and Freebairn approach is that the distribution of gains across producers and consumers can be easily identified. Although the estimated price response flowing on from increased productivity in the winter high rainfall zone was small (<0.1%), the aggregated effect across producers outside this area resulted in annual losses of nearly $2m in some years. However, the gains to producers in the winter high rainfall area more than compensated for this loss. Because Australian agricultural production is geared towards export markets, especially for wool, overseas consumers would stand to gain from any on-farm productivity improvements in Australia. It was estimated that nearly 18% of the total gain from increased adoption of strategic control would be captured by overseas consumers.

Table 13 : Economic gains from greater adoption of strategic worm control : By average 5 year periods : $m

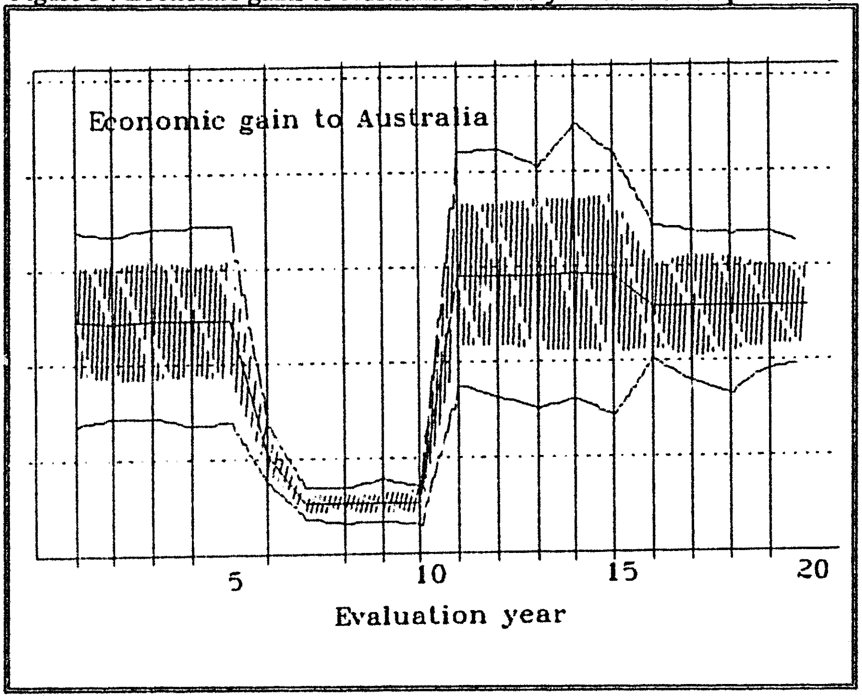
Period	WOOL				MEAT			
	REG A	REG B	AUST	OS	REG A	REG B	AUST	OS
1990/94	7.6	-1.4	6.4	1.6	0.5	-0.2	0.5	(b)
1995(a)	3.3	-0.6	2.8	0.7	0.2	-0.1	0.2	(b)
1996/99	1.7	-0.3	1.4	0.4	0.2	-0.1	0.2	(b)
2000/04	8.6	-1.6	7.2	1.8	1.0	-0.3	1.0	0.1
2005/09	7.6	-1.4	6.4	1.6	0.8	-0.3	0.9	(b)

(a) 1995 is included separately because the adjustment in wool prices and sheep numbers was made from the following year.

(b) Value is less than 0.05.

Note : REG A represents producers in winter high rainfall area ; REG B represents producers in the rest of Australia; AUST represents Australian producers and consumers; and OS represents overseas consumers.

Figure 3 : Economic gains to Australia over 20 year evaluation period : $m



Discussion

Simulation results indicated that internal parasitism is a significant constraint on sheep production in the winter high rainfall region of Australia. It was shown that strategic control was a more effective nematode control strategy than traditional nematode control practices. The increases in animal production under strategic control appeared to emanate from the use of strategically timed treatment and grazing management. The increase in anthelmintic resistance did not appear to result in reduced animal productivity under strategic or traditional treatment.

With the adoption of strategic control, annual Merino ewe, British ewe and prime lamb control costs could be reduced. In comparison, control costs for wethers, rams, first-cross and merino lamb classes would be higher. In total, winter high rainfall strategic recommendations do not, in general, generate substantial control cost savings over traditional methods.

Productivity increases as a result of switching to strategic control were negligible for wether, British ewe and prime lamb stock classes. This was due to high natural immunity in wether and British ewes, along with the short grazing season of prime lambs. Gains would be greater in Merino ewes because they are susceptible to infection during lambing and have a lower natural immunity than British ewes. Reduced production losses were most evident in merino lambs.

The increase in LEV, BZ and IVM resistance did not appear to cause an upward trend in the distribution of maximum predicted lamb worm burden under either traditional or strategic control. In experiments by Brown et al (1985), strategically timed treatments in Merino weaners generated gains in animal productivity that were *very similar to that of sheep which were drenched every three weeks*(ibid 1985 p.854). This apparent lack of observed sensitivity between nematode burden and increased resistance highlights the importance of correct grazing management practices. More recently, Hall (1990) has stated that although *the actual impact on animal production* [of] *worm control programmes has not been comprehensively defined*, [ ] .*it would appear to be far less than the impact of under nutrition and grazing practices* [,and therefore] *we should be putting greater emphasis on* [the] *integrated management of worms and putting less reliance on the anthelmintic used* (ibid 1990 p.272). Even with a 100% effective broadspectrum anthelmintic, sheep placed back on infective pastures are provided only limited protection from worms because of the non-persistance of the drug inside the animal (Dash 1988).

The effect of climate in regulating the development of nematode populations has been documented to some extent. Brown et al (1985) observed variations in greasy fleeceweight of up to 57% as a result of seasonal variation on nematode populations. The comparison of the 1965-84 climatic sequence against a randomised sequence showed that there could be a significant variation in the status of nematode populations, and development of resistance, due to climatic variation. Failure to separate other causes of increased parasitic burdens in sheep from climatic factors prevents a detailed commentary pertaining to the effects of nematode resistance on parasite populations through time.

Many of the parameters used to establish the production loss resulting from traditional and strategic control are not supported by experimental evidence. Barnes and Dobson (1990) note *conclusions based on genetic model predictions are difficult to validate because of the scant knowledge of parasite genetics and the lack of detailed observation on the evolution of resistance* (ibid 1990b, p.830). More sophisticated Ostertagia spp. population simulation models are needed to improve the linear regression model and the Ostertagia spp. piecewise approximation used in this study.

Also, it is well to recognise that farm nematode control decisions are part of a matrix of other complementary and conflicting farm management decisions. Morley and Donald (1980) stress that *management decisions aimed at helminth control cannot be considered in isolation from their effects on other parts of the enterprise mix, since they compete for labour, finance, skill and perhaps other resources* (ibid 1980, p.105). The integration of parasitological and economic models, similar to that carried out in this study, should be the norm in policy evaluation not the exception.

Results of the evaluation indicated that substantial benefits could be generated by increasing the level of adoption of strategic control above 30% of producers in the winter high rainfall areas of Australia. Despite a substantial leakage of benefits to overseas consumers through time, a significant benefit was captured by Australia as a whole. The estimation of annual gains to Australia was predicated on the assumption that producers' supply response was a medium term response, there were no second round price effects, inter-regional spillover of technology would not occur and the rate of adoption can explained by a logistic function with a 100% ceiling. However, it is unlikely that the relaxation of these assumptions would reduce to any significant degree the robustness of the evaluation model used in this study(McLeod 1991).

An area of future interest could possibly be in the financing of increased worm control extension. A strong case for the public financing of greater extension could be made if there existed externalities in the provision of accurate worm control information to producers. McLeod (1991) examines this case in some detail. As Tisdell (1974, p.73) notes *it may be nationally advantageous to finance research into and promotion of products produced principally for export by relying heavily on levies on production of the products concerned. If demand is not perfectly elastic, the tax falls to some extent on overseas purchasers. If, however, demand is perfectly elastic the tax falls entirely on local producers, but then they tend to be the main beneficiaries from any technical advance.*

Further study

The areas of further study identified as a result of this study are the refinement of simulated production loss estimates, development of a framework to determine production loss independently of seasonal variability, evaluation of other sheep-producing areas, screening of a wide range of worm control technologies and the potential use of computer simulation techniques to predict seasonal rises in nematode populations.

To more accurately gauge the welfare benefits of increased adoption, productivity parameters need to be expressed as a function of time rather than projected climatic conditions. To estimate productivity losses in a given year, weather sequences need to be randomised in a structured way and differences in worm burdens explained.

Many of the assumptions used in the derivation of production loss parameters are not currently supported by detailed experimental evidence. The determination of Ostertagia spp. population dynamics would be more accurately predicted with the development of a biological simulation model. The determination of meat and wool loss as a result of nematode parasitism across the grazing season could further be refined by mapping the trajectory of weekly nematode burdens in grazing trials and expressing annual losses as a function of worm burdens over the entire grazing season. The effects of nutrition were not explicitly incorporated in the simulation. There is currently a lack of experimental evidence to separate the effects of climate and nutrition. Hall (1990) makes the observation that: *The profound effects on wool production, growth rates, food intake and utilisation and host metabolism are reasonably well documented from pen trials.* [However,] *the majority of these trials ensured that good nutrition prevailed* (ibid 1990, p.272). Grazing trials by Beveridge et al (1985) observed that the effects of parasitism were exacerbated by reduced nutrition in the dry summer period in the winter high rainfall region. To more accurately describe production losses the impact of nutritional status on worm burdens needs to be better understood.

There has been little attention to the potential productivity gain that strategic control could generate in the wheat/sheep zone. This zone contains the majority of the Australian flock, and the potential for welfare gains are substantial. Most scientific research and economic evaluation has focused on the high rainfall areas where productivity losses per animal are high. However, the mere size of the flock in this zone could result in substantial welfare gains being generated from only modest gains in the productivity of individual animals.

The screening of other worm control technologies using a similar analytical framework should also be undertaken. Johnston (1983) noted most pest management evaluations only screened a narrow range of management technologies. There is currently considerable research into alternate nematode control technology and recent availability of novel anthelmintic delivery devices. Ex ante evaluation of the potential welfare benefits this technology could generate would be of assistance to policy makers. The use of vaccination, nematode resistant sheep and new anthelmintic delivery devices are all potentially valuable technologies to increase sheep productivity.

In many instances, nematodes cause problems because both free-living and parasitic stages are not readily apparent. The development of regional simulation models to predict rises in seasonal larval availability could take the "guesswork" out of nematode control. The provision of this information is likely to reduce anthelmintic treatment as much drenching is practised as an insurance policy against the problems of nematode infection in some areas. Much of the integrated pest management approach focuses on the benefits of gathering pest population information and the reduction of risks associated with pest control. Strategic control was developed to minimise parasite infection by strategically timing treatments defined by an average seasonal population rise. There is considerable seasonal variation in the dynamics of a parasite population. Simulation techniques could serve to predict periods of infectivity and further refine strategic timings of treatment. The value of such information could be treated in a Bayesian framework once the seasonal variability in production loss and grazier utility was defined.

In conclusion nematode parasites are a substantial burden on the Australian sheep industry. Strategic control was developed to reduce the costs nematodes impose and reduce the selection for anthelmintic resistance. In the winter high rainfall areas strategic control both increases short-run animal productivity and reduces the selection for resistance. Increased adoption of strategic control generates substantial national welfare benefits. The Barnes and Dobson (1990) simulation and the Edwards and Freebairn (1982) model provide an analytical framework useful in ex ante research and extension evaluation. These tools should be further used by policy makers to allocate funds efficiently in economic conditions which demand resource accountability.

References

ABARE (1991) Agricultural and Resource Quarterly, Vol (2) No. 1, June.

ABS (1991) "Livestock and livestock products : 1989-90"several issues, Cat Nos. 7221.(1-6).

AMLC, (1991) Statistical Review July 89- June 90, Sydney.

Anderson, N. (1972). "Trichostrongylid infections in sheep in a winter rainfall region. region. I. Epizootlogical studies in the western districts of Victoria, 1966-67", Australian Journal of Agricultural Research 23, 1113-1129.

Anderson, N. (1973). "Trichostrongylid infection of sheep in a winter rainfall region II. Epizootiological studies in the western district of Victoria, 1967- 68", Australian Journal of Agricultural Research 24, 599-611.

Anderson, N., Barger, I.A. and Waller P.J. (1987). Impact of gastrointestinal parasitism on pasture utilisation by grazing sheep. In Temperate Pastures their production, use and management, edited by J.L. Wheeler, C.J. Pearson and G.E. Robards, Australian Wool Corporation, CSIRO, Melbourne.

Anderson, N., Dash, K.M., Donald, A.D., Southcott, W.H. and Waller P.J. (1978). In The Epidemiology and Control of Gastrointestinal Parasites of Sheep in Australia, edited by A.D. Donald, W.H. Southcott and J.K. Dineen, CSIRO Division of Animal Health, Melbourne, pp. 23-51.

Anderson, N., Morris, R.S. and McTaggart, I.K. (1976). "An economic analysis of two schemes for the anthelmintic control of helminthiasis in weaned lambs" Australian Veterinary Journal 52, 174-180.

AWC (1990) Minimum Reserve Price Schedule 1990/1991, Australian Wool Corporation, Melbourne.

Barger, I.A. (1982). Helminth Parasites and Animal Production. In Biology and Control of Endoparasites, Ed I E. A. Symons, A. D. Donald and J. K. Dineen, CSIRO Division of Animal Health, Melbourne.

Barger, I.A. (1984), "Correlations between numbers of enteric nematode parasites in grazing lambs", International Journal for Parasitology 14(6), 587-589

Barnes, E.H. and Dobson, R.J. (1990), " Population dynamics of Trichostrongylus columbriformis in sheep: computer model to simulate grazing systems and the evolution of anthelmintic resistance " International Journal for Parasitology 20(7), 823-831

Barton, N.J. and Brimblecombe, C.J. (1983), "The effects of anthelmintic treatment and season on the quantity and quality of wool grown by merino sheep", Australian Journal of Agricultural Research, 34, 557-568

Beveridge, I., Brown, T.H., Fitzsimons, S.M., Ford, G.E., Judson, G.J., Martin, R.R., Miller, D.W. (1985), "Mortality of weaner sheep in South Australia under different regimes of anthelmintic treatment", Australian Journal of Agricultural Research, 36, 857-865

Brown, T.H., Ford, G.E., Miller, D.W. and Beveridge, I. (1985), "Effect of anthelmintic dosing on the productivity of weaner sheep in a Mediterranean climate environment", Australian Journal of Agricultural Research 36, 845-855

Cole V.G., (1986), In Animal Health in Australia Volume 8: Helminth Parasites of Sheep and Cattle" Australian Government Printing Service, Canberra.

Dash, K.M. (1988). Helminth control strategies and anthelmintic. In: Sheep Health and Production. The T.G. Hungerford Refresher Course for Veterinarians, Post-Graduate Committee in Veterinary Science, University of Sydney.

Dewbre, J., Shaw, I., Corra, G. and Harris, D. (1985), EMABA: Econometric Model of Australian Broadacre Agriculture, Australian Government Printing Service, Canberra.

Edwards, G.W. and Freebaim, J.W, (1981), Measuring a Country's Gains From Research : Theory and Application to Rural Research in Australia, Report to the Commonwealth Council for Rural Research and Extension, Australian Government Printing Service, Canberra.

Edwards, G.W. and Freebaim, J.W., (1982) "The social benefits from an increase in productivity in part of an industry", Review of Marketing and Agricultural Economics 50(2), 193-210.

Hall, E. (1990). Reasons for Breakdown in Worm Control Programmes The Sandy and Georgina Reid Memorial Refresher Course for Veterinarians, Post Graduate Committee in Veterinary Science, University of Sydney.

Johnston, J.H. (1983), " Public Policy, Pest Management and Stored Grain Insects" Phd. Dissertation, School of Economic and Financial Studies , Macquarie University, North Ryde, NSW.

Kingwell, R.S. and Pannell, D.J. (1987), MIDAS, A Bioeconomic Model of a Dryland Farm System, Pudoc Wageningen.

McLeod, R.S., (1991) " An Economic Evaluation of Internal Parasite Control in the Winter High Rainfall Region of Australia" Thesis submitted as a partial requirement for the Degree of Bachelor of Agricultural Economics, University of Sydney, Unpublished, December.

Morley, F.H.W. and Donald, A.D. (1980). Farm management and systems of helminth control. *Veterinary Parasitology*. 6, 105-134.

Morris, R.S., Anderson, N. and McTaggart, I.K. (1977). An economic analysis of two schemes for the control of helminthiasis in breeding ewes. *Veterinary Parasitology* 3, 349-363.

Skyes, A.R., Poppi D.P., and Elliot, D.C. (1988), "Effect of concurrent infection with *Ostertagia circumcincta* and *Trichostrongylus colubriformis* on the performance of growing lambing consuming fresh herbage" *Journal of Agricultural Science Cambridge*, 110 531-541

Symons, L.E.A. and Steel, J.W. (1978), In "*The Epidemiology and Control of Gastrointestinal Parasites of Sheep in Australia.*" edited by A.D. Donald, W.H. Southcott and J.K. Dineen, CSIRO, Division of Animal Health, Melbourne.

Thompson, R.L. and Callinan, A.P.L. (1981), "The effect of Nematodirus on weaner sheep in Western Victoria", *Australian Journal of Agricultural Research* 32, 975- 985

Tisdell, C.A. (1974), "Research and promotional levies for Australian rural products -a brief economic review emphasising wool", *Farm Policy* 14(2), 63-75.