Table 1. Sodium, potassium and magnesium in pasture (g/kg DM), plasma (mg/L) and faeces (g/kg DM).

Time	Pasture			Plasma			Faeces		
	HC[a]	NS[b]	AH[c]	HC	NS	AH	HC	NS	AH
Sodium									
Summer	0.09	0.38	0.02	2630	3810	3260	0.93	1.41	0.52
Autumn	0.06	1.66	0.04	2570	3990	3170	0.45	3.19	0.84
Winter	0.20	0.23	0.01	2910	4100	3330	1.65	2.74	1.72
Spring	0.21	0.76	0.01	2520	4160	3380	0.55	3.02	2.16
Potassium									
Summer	14.9	21.9	15.5	154	202	192	17.4	15.3	5.2
Autumn	8.1	11.6	5.6	159	214	194	12.1	5.9	4.1
Winter	5.1	4.2	12.4	175	211	193	8.1	5.0	3.9
Spring	2.3	11.8	3.2	140	189	195	8.6	9.0	4.0
Magnesium									
Summer	1.74	2.82	2.63	21.1	20.3	23.1	5.03	6.92	7.01
Autumn	1.80	3.38	1.93	22.2	25.3	22.7	3.34	6.73	5.30
Winter	1.28	2.58	4.82	22.9	22.0	27.0	2.97	3.04	5.20
Spring	1.38	1.63	1.55	16.3	19.9	23.3	4.16	3.99	5.42

[a]Huang Cheng farm; [b]Nanshan farm; [c]Aohan farm

Table 2. Concentration of minerals in feed supplements (g/kg DM).

	Concentrates			Hay			Silage		
	HC[a]	NS[b]	AH[c]	HC	NS	AH	HC	NS	AH
Sodium	0.06	3.6	0.03	0.17	3.20	5.80	1.30	–	0.46
Potassium	4.20	7.0	4.60	10.1	18.5	10.8	12.6	–	13.8
Magnesium	1.27	2.6	1.90	0.90	1.93	2.40	1.57	–	3.10
Phosphorus	2.80	7.0	3.70	0.97	3.30	1.30	1.48	–	1.21
Calcium	0.68	5.2	0.72	1.45	7.70	3.80	3.10	–	5.00
Sulfur	1.06 (oats)	–	1.20	1.10	–	2.00	1.80	–	1.10

[a]Huang Cheng farm; [b]Nanshan farm; [c]Aohan farm

potassium, usually excreted in urine, may be replacing sodium in saliva. Widespread habitual consumption of soil, a characteristic of sodium deficiency, was also observed at Huang Cheng. In most of the predominant pastures grown in northern China, sodium concentrations (Table 3) were usually below the level suggested by Morris and Peterson (1975). Therefore, sodium is a mineral element which must be given consideration in sheep farming in northern China.

Requirements of sheep for potassium are estimated at 5 to 7 g/kg DM (NRC 1985). During autumn and summer, pastures contained adequate potassium (6–22 g/kg, Table 1), with the highest concentrations on all farms in summer. Potassium concentrations fell as pastures matured at Huang Cheng and Nanshan, and the dead, dry pastures of winter and spring contained the least. This is consistent with reported changes in potassium concentrations in plants in other environments (White et al. 1992). While potassium levels in pastures were below 5 g/kg at all sites in either winter or spring, the feed supplements used during these periods provided significant additional potassium (Table 2) and a deficiency at any time of the year is unlikely. This is also supported by the values for potassium in plasma. The concentrations (140–214 mg/L) were normal compared with those reported by Telle et al. (1964) in deficient sheep (97–135 mg/L). Hou Xueyu (1982) reported that the range of potassium concentrations in the predominant pastures grown in northern China is 5–21 g/kg (see Table 3).

Magnesium concentrations in all pasture, hay, concentrate and silage samples were above the minimum levels needed for growth and reproduction (0.7–1.0 g/kg; Underwood 1981). The acute form of magnesium deficiency often occurs in lactating ewes and causes a hypomagnesemic tetany which may lead to death of the animal. Clinical signs have been described when plasma magnesium falls from the normal of 20–30 mg/L to less than 10 mg/L (Suttle and Field 1969; Grace 1972). In all seasons, at all farms, magnesium in plasma was above 15 mg/L. However, while no evidence of hypomagnesemia was found, susceptibility is increased when sodium intakes are low and potassium intakes high (SCA 1990), as occurs in northern China. This, together with the observation of lowest concentrations of magnesium in plasma in spring (during lactation) on both Huang Cheng and Nanshan, indicates that the occurrence of hypomagnesemia under such conditions may be possible.

Phosphorus and Calcium

It is estimated that 1.5 to 1.7 g P/kg DM are required by young growing sheep (Underwood 1981); slightly higher levels may be needed during pregnancy and lactation. While summer pastures at all farms contained sufficient phosphorus for growth, concentrations in winter and spring were usually below 0.5 g/kg. Phosphorus concentrations fall in plants as they mature (Underwood 1981) and the lowest levels are in the dead, dry plants found in pastures in northern China in winter and spring. The lowest concentrations measured would restrict animal growth if pastures were the only source of phosphorus and if no other nutrients were limiting. However, as with potassium, the supplements of concentrates, hay and silage, fed during winter and spring provide substantial amounts of phosphorus. More significant are the low or marginal levels of phosphorus observed in autumn pastures (0.31–1.08 g/kg). Autumn is a period of rapid animal growth as pasture is in excess and no additional feed is provided. During this period a lack of phosphorus may restrict growth.

Langlands (1987) indicated that responses to phosphorus supplementation were most likely when the N:P ratio was high and Little (1968) observed a response in intake following phosphorus supplementation of steers consuming a feed with a N:P ratio of 23:1. As estimated from the data collected from Aohan farm, the N:P ratios in pasture were 18:1, 71:1, 12:1 and 22:1 in summer, autumn, winter and spring, respectively. Therefore, further study on phosphorus nutrition is justified.

No clear evidence of a lack of phosphorus was indicated by analysis of faeces or bone at any farm, although at Aohan farm the concentration of phosphorus in bone was similar to that reported in the humerus and femur of phosphorus deficient sheep (Underwood 1981).

Table 3. Macromineral concentrations in the predominant pastures in northern China (g/kg DM).

Pasture species	Element				
	P	S	K	Na	Ca
Stipa baicalensis					
(Eastern part, Inner Mongolia)	0.60	1.5	5.10	0.22	5.30
Stipa grandis					
(Northern part, Inner Mongolia)	1.10	0.9	9.80	0.90	3.60
Stipa glaressa					
(Eastern part, Xinjiang)	1.40	1.1	13.2	3.10	7.20
(Western part, Inner Mongolia)	1.33	2.8	10.5	0.38	6.00
Agropyron mongolicum					
(Northern part, Inner Mongolia)	1.24	0.5	5.90	0.40	3.30
Aneurolepidum chinense					
(Northern part, Inner Mongolia)	1.90	1.2	21.1	1.60	2.80
(Eastern part, Inner Mongolia)	2.15	–	17.8	0.90	4.40
(Eastern part, Inner Mongolia)	1.27	0.9	12.7	0.60	3.43

Source: adapted from Hou Xueyu (1982).

The calcium content of pasture (Table 4) was above the requirement for growing (2.0–5.3 g/kg) or reproducing (3.2–3.9 g/kg, NRC, 1985) ewes at all times and at all sites. Although some concentrated feed supplements contained less than 2.0 g/kg, the composite diet including pasture, hay or silage and concentrates would provide sufficient calcium. The high calcium in feeds was reflected by the high concentrations in faeces.

Sulfur

The sulfur requirements for maintenance, growth, pregnancy and lactation in sheep and cattle have not been clearly defined but diets containing 1.3–1.8 g/kg DM should be adequate (ARC 1980). Langlands (1987) suggested that a dietary sulfur concentration of 1 g/kg DM should be regarded as low. In Table 5 most of the values in the pastures at Aohan and Huang Cheng farms were lower than 1 g/kg DM, while at Nanshan farm the values in the pasture were always higher than 1 g/kg. It is also shown in Table 3 that sulfur concentrations in the most predominant pasture are below or near 1 g/kg DM. It follows that sulfur may be one of limiting nutrients for sheep production in some areas of northern China. The sulfur and nitrogen requirements should also be considered together. The range of N:S ratio in the pastures at the three farms was 6.00–25.5 with some values above the optimum of 14:1.

Conclusions

There are clear seasonal changes in minerals available in pastures at all farms. This is caused by the growth pattern of pasture. As the rain falls almost exclusively in the warm seasons of summer and autumn, rapid pasture growth occurs at this time. In late autumn the annual native pastures die and only dead residues are available for grazing in winter and spring. As a consequence, potassium, magnesium and phosphorus are all lowest in winter and early spring. However, pasture at this

Table 4. Calcium and phosphorus in pasture (g/kg DM), bone (g/kg DM) and faeces (g/kg DM)

	Pasture			Bone			Faeces		
	HC[a]	NS[b]	AH[c]	HC	NS	AH	HC	NS	AH
Calcium									
Summer	6.5	11.7	22.3	273	215	237	19.1	30.1	38 .6
Autumn	8.0	13.9	18.8	268	244	246	16.8	37.3	32.7
Winter	5.0	10.2	12.7	277	226	247	8.8	15.6	22.2
Spring	4.4	7.2	14.8	275	240	248	10.8	15.3	17.1
Phosphorus									
Summer	1.55	2.12	1.57	121	99	85	5.29	3.49	1.68
Autumn	0.78	1.08	0.31	109	102	87	2.70	2.69	2.41
Winter	0.29	0.39	1.56	117	101	90	2.12	1.99	3.07
Spring	0.24	1.62	0.38	121	99	86	2.80	3.00	2.48

[a]Huang Cheng farm; [b]Nanshan farm; [c]Aohan farm

Table 5. Sulfur in pasture (g/kg DM)

	Sulfur			Nitrogen:Sulfur		
Time	HC[a]	NS[b]	AH[c]	HC	NS	AH
Summer	1.90	2.20	1.20	9.2	9.8	23.4
Autumn	1.47	3.50	0.86	4.4	6.0	25.5
Winter	0.93	1.30	0.81	6.0	9.2	10.5
Spring	0.83	1.40	0.72	4.8	6.4	11.9

[a]Huang Cheng farm; [b]Nanshan farm; [c]Aohan farm

time is also low in nitrogen (<1.0%), has a low digestibility (38–40%, Peter et al., this report) and contains little sodium. The lack of protein, energy or sodium is likely to be the primary limitation for production.

Importantly, responses to supplementation with macrominerals may be increased when energy supplies and protein are not limiting. In practice, salt fed in winter and spring, or grain-based supplements, partially offset the lack of protein and energy. Of these supplements, concentrates contain high levels of phosphorus, and both hay and silage high levels of potassium (Table 2), so that severe deficiency of these elements during winter or spring is not likely.

Summer and autumn may be when sheep are at most risk of a macromineral deficiency. Although pasture is plentiful and both protein and digestible energy are higher than at other times of the year, sodium, in both summer and autumn, and phosphorus in autumn, are below published requirements. A lack of sodium at this time would cause reduced growth and wool production (Joyce and Brunswick 1975), and inadequate phosphorus depressed intake, growth, bone development and reproduction (Underwood 1981).

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Consequences of Mineral Deficiencies in Sheep in Northern China

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PREVIOUS studies have shown that sheep grazing pastures in northern China may have inadequate intakes of selenium, copper and sodium, and possibly zinc, sulphur and phosphorus for optimal animal production (Yu et al. 1988 and this report; Lu et al., this report). As many of the sheep in China are dependent on unfertilized natural pastures for most of their nutritional requirements, loss of production due to deficiencies of essential elements may be widespread. Some responses to mineral supplements are presented in this paper, along with plans for future research.

Experimental Results

Huang Cheng farm

Weaners

Two flocks of 160 weaner ewes were selected. One flock was given a macromineral–urea supplement (Mm) containing gypsum (21%), dicalcium phosphate (26%), salt (32%) and urea (21%) at a rate of 19 g/day from April 1988 to June 1989. A second flock was given only a salt supplement, less regularly, as part of the normal farm practice. Within each flock, 40 weaners were given either no additional treatment (N), copper with selenium (CuSe), cobalt with iodine (CoI) or all four elements together (CuSeCoI). Selenium and cobalt were provided as intraruminal bullets (Tri-Sel selenium pellets, Arthur Webster Pty Ltd, Australia; 'Top' Brand cobalt pellets, Adelaide and Wallaroo Fertilizers Ltd, Australia) copper as copper oxide needles (Cuprax for lambs, Coopers Animal Health Pty Ltd, Australia) and iodine as an intramuscular long acting injection (Lipiodol, May and Baker, New Zealand). While the flocks were maintained separately during the experiment, they had the same initial live weight, grazed over common areas and were managed in the same way.

Four times during the year, blood was collected from 10–12 sheep in each treatment group and all sheep were weighed. In June 1989, all sheep were shorn, fleeces were weighed and a mid-side wool sample collected for determination of clean wool yield. Results were analysed by two-way analysis of variance.

The weaners receiving the macromineral–urea supplement were consistently heavier (1.1–2.03 kg, $P < 0.05$) throughout the year and had heavier greasy fleece weights (220 g, $P < 0.05$) with a trend towards heavier clean fleece weights (120 g, $P < 0.08$) than the weaners given only the farm salt supplement (Table 1).

The CoI treatment had no effect on live weight or wool growth, but when the pooled results from the CuSe and CuSeCoI treatments were compared with the treatments without copper or selenium (N and CoI), greasy fleece weight (216 g, $P<0.05$) and clean fleece weight (140 g, $P<0.05$) were both increased (Table 2).

Supplementation of sheep with copper and selenium resulted in significant increases in the concentration of these elements in plasma (Fig. 1).

Treatment with either macrominerals or copper and selenium supplements therefore resulted in significant increases in growth and/or wool production. To compare the extreme treatments, ewe weaners given the normal farm treatment (occasional salt with no trace elements) grew 4.5 kg of greasy wool (2.31 kg clean) and weighed 35.8 kg at the end of the experiment, whereas those given minerals (Mm) plus copper and selenium, grew 4.95 kg of greasy wool (2.48 kg clean) and

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Table 1. Effect of macrominerals (Mm) on live weight and wool production[a] (mean ± SEM).

	Live weight (kg)			Fleece weight (kg)	
Date	20.4.88	25.3.89	25.6.89	Greasy	Clean
Treatment					
No Mm	18.9 ± 0.47	31.3 ± 0.33	36.4 ± 0.35	4.65 ± 0.07	2.34 ± 0.04
+ Mm	19.4 ± 0.42	33.3 ± 0.36[b]	37.8 ± 0.40[b]	4.87 ± 0.08[b]	2.46 ± 0.05

[a] Trace element treatments pooled within macro-mineral treatments.
[b] Significantly different from untreated group ($P < 0.05$).

Table 2. Effect of copper and selenium on live weight and wool production[a] (mean ± SEM).

	Live weight (kg)			Fleece weight (kg)	
Date	20.4.88	25.3.89	25.6.89	Greasy	Clean
Treatment					
N and CoI	19.0 ± 0.4	31.9 ± 0.4	36.8 ± 0.4	4.65 ± 0.08	2.33 ± 0.05
CuSe and CuSeCoI	19.4 ± 0.4	32.7 ± 0.4	37.4 ± 0.4	4.87 ± 0.07[b]	2.47 ± 0.05[b]

[a] All sheep receiving copper and selenium (CuSe and CuSeCoI) were pooled and compared with sheep receiving no copper or selenium (N and CoI).
[b] Significantly different from sheep given no copper or selenium ($P < 0.05$).

weighed 38.9 kg at the end of the experiment. The difference then is 0.45 kg in greasy fleece weight and 3.1 kg in live weight. This result represents an immediate financial benefit from the increase in wool growth. The increase in live weight is also significant. The young ewes were due to be mated for the first time in the month following the end of the experiment. Increased live weight is associated with increases in ovulation rate (Morley et al. 1978) and potential increases in lambing percentages and will provide additional body reserves in winter and spring, during late pregnancy and lactation.

The individual macroelements involved cannot be identified from the responses to treatments in this experiment. However, previous research at the same site (Yu et al. 1988) showed that crude protein, sodium, phosphorus and sulphur are all low in pastures at some times of the year. In particular, sodium is low throughout the year, and is often less than 10% of estimated requirements. Although all sheep received some sodium, it is possible the irregular use of salt on the farm does not provide a sufficient amount of this element for optimal production. This suggestion is supported by the widespread incidence of soil licking and ingestion by grazing sheep on the farm and the low faecal sodium concentrations reported from previous years (Lu et al., this report).

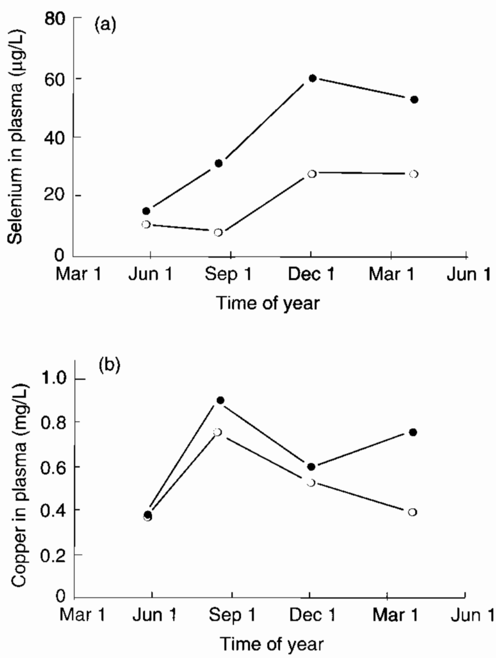

Figure 1. (a) Concentration of selenium in plasma with (●) and without (○) additional selenium; and (b) concentration of copper in plasma with (●) and without (○) additional copper.

Analysis of plasma clearly shows that both selenium and copper are low for part of the year: selenium during the flush growing season in late summer and copper during autumn when only dead pasture residues are available. The minimum concentrations of both elements (selenium 8 µg/L, copper 0.37 mg/L) are below normal [selenium >20 µg/L, copper >0.57 mg/L: Judson et al. (1987), Masters and Peter (1990)] and at such concentrations responses would be expected.

Breeding ewes

Two flocks of 800 breeding ewes were selected. One flock was given a macromineral–urea supplement (Mm), as described previously, at a rate of 25 g/day. A second flock was given only a salt supplement, less regularly, as part of the normal farm practice. Within each flock, 100 ewes were given either no additional treatment (N), copper with selenium (CuSe), cobalt with iodine (CoI) or all four elements together (CuSeCoI). The trace element treatments were provided in controlled-release devices (Peter and Ellis 1988). While the flocks were maintained separately during the experiment, they had the same initial live weight, grazed over common areas and were managed in the same way.

The flock receiving macrominerals produced more twins (P<0.05) than the control group, had fewer lamb deaths than the farm average (P<0.01) and weaned 4% more lambs than ewes given no minerals or than the farm average (Table 3). In the previous two years this flock had a lower lambing percentage than the farm average.

There were technical difficulties in obtaining reliable lambing data within flocks for the trace element treatments. Consequently these data were not evaluated.

Aohan farm

The mineral experiments at this farm were carried out in conjunction with the testing of protein and energy supplements. Two flocks of weaner ewes were used, one flock was provided with a protein and energy supplement and the other managed according to normal farm practice. The normal farm practice at Aohan includes some salt supplements to all sheep. Within each flock, sheep were given macromineral (Mm) or micromineral treatments as described in Table 4

Table 4. Treatments and sheep numbers used at Aohan farm.

	Flock 1 (+ protein/energy)		Flock 2 (– protein/energy)	
	+ Mm[a]	– Mm	+ Mm	– Mn
+ zinc[b]	25	25	25	25
+ all[b]	25	25	25	25
Control	25	25	25	25

[a] Macromineral (Mm) mixture contained: salt (40%), gypsum (27%) and dicalcium phosphate (33%) and was provided at 10-14 g/day.

[b] Ewes were given a controlled release device containing just zinc or zinc, cobalt, iodine, manganese, iron, molybdenum, selenium, copper and nickel.

The protein and energy supplement used resulted in significant (P<0.05) increases in both greasy fleece weight and live weight (Table 5). There were no significant effects of either macromineral or micromineral treatments in either flock, although there was a trend towards increased wool growth in ewes given macrominerals with either no trace elements or all trace elements, but not in those given zinc. Of the three farms, Aohan consistently had higher levels of most minerals in sheep and pastures during the first year of the project (Lu et al., Yu et al., this report), and was the least likely to have problems with mineral deficiencies. Although sodium in pasture was extremely low, of the other elements, only zinc and phosphorus in pasture were near deficient levels.

Table 3. Macromineral (Mm) supplements and reproductive performance at Huang Cheng.

	+ Mm		– Mm		Farm total	
	Number	%	Number	%	Number	%
Sheep	872		858		4499	
Ewes lambing	682	78.2	662	77.2	3557	79.1
Lambs born	728	83.5	682	79.1	3728	82.9
Twins	46	5.3	20	2.3	171	3.8
Lamb deaths	54	7.4	54	7.9	402	10.8
Lambs weaned	674	77.3	628	73.2	3327	73.9

The salt supplements used as part of normal farm practice supplied sufficient sodium to this flock of sheep to prevent any signs of deficiency.

Conclusion

This research indicates that responses to minerals do occur in northern China and may cause significant decreases in wool production growth and reproductive efficiency. These changes in production are consistent with those described for marginal deficiencies of one or a number of elements (Judson et al. 1987). As both macro and micromineral supplements can be provided to sheep without causing any major disruption to the traditional systems of animal management, there is potential for significantly increased production through their use.

Costs of Mineral Supplementation

The benefits reported from the use of mineral supplements need to be evaluated in conjunction with the costs of the supplements. The actual cost of the elements copper and selenium, if supplied as copper sulphate and sodium selenate, is approximately 2.5 cents (all costs and returns are expressed in Australian currency) per sheep each year. The additional wool produced was valued at 48 cents (1989 wool prices), and an additional benefit of increased live weight was also achieved. There are some extra costs associated with the incorporation of these elements into salt supplements, but very little extra cost incurred in their use on the farm when salt supplements are already in use. The potential return is significantly higher than the cost. The macromineral supplement used at Huang Cheng is more expensive, and the additional 220 g of greasy wool (valued at 50 cents) and 2 kg of live weight resulted from the use of supplements costing 101 cents. However, it is likely that future research will identify the most important minerals, cheaper sources of these minerals (e.g. bonemeal) and define the times of the year when they are required. The cost of the supplement will then be reduced and the length of time they are fed may be reduced from 365 days per year.

Efficiency of Forage Utilisation

Deficiencies of minerals may result in a decline in the efficiency of metabolism of ingested nutrients, a decrease in feed intake or a combination of both. Both selenium and copper deficiencies cause a reduction in production through reduced wool growth and live-weight gain without any conspicuous decline in feed intake (Underwood 1981). Severe sodium deficiency causes inappetence but also results in inefficiency of use of consumed feed (NRC 1985). In addition, the low sodium intakes cause excessive soil licking. This contributes to the erosion of waterways and results in iron consumption of up to 100 times requirement (due to

Table 5. Effect of supplement on greasy fleece weight and live weight at Aohan farm (group means)

	Flock 1 (+ protein/energy)			
	Greasy fleece weight (kg)		Live weight at end of expt (kg)	
	+ Mm	– Mm	+ Mm	– Mm
+ zinc	7.50[a]	7.72	32.3	30.7
+ all	7.59	7.40	30.1	33.5
control	7.70	7.42	32.2	30.7
	Flock 2 (– protein/energy)			
	Greasy fleece weight (kg)		Live weight at end of expt (kg)	
	+ Mm	– Mm	+ Mm	– Mm
+ zinc	7.19	7.29	27.2	26.6
+ all	7.27	6.95	27.4	27.5
control	7.22	6.90	27.5	27.2

[a] Significant effect ($P < 0.05$) of protein and energy only on wool growth and live weight.

the high iron concentration in soils) (Yu et al., this report). Wang (Wang and Masters 1990; Wang, unpublished data) has observed a 30% decrease in efficiency of conversion of nutrients in young sheep fed a diet containing 2000 mg Fe/kg diet (as Fe_2O_3) (Table 6). This is lower than the iron consumption reported by grazing sheep in China (Yu et al. 1988).

The consequences of mineral imbalances are therefore to decrease production from grazing sheep without any major decline in the intake of available forage. This will exacerbate the overgrazing characteristic of the Chinese grasslands. Provision of balanced mineral supplements, when mineral problems exist, will provide the opportunity to maintain levels of production with fewer sheep and contribute to more responsible grazing management.

Future Research Emphasis

The comprehensive examination of the mineral status of sheep at three sites in northern China has provided evidence on inadequate mineral intakes by grazing sheep. Because of the small number of sites used it is necessary to be cautious in generalising from the results. Nevertheless, the findings, together with the nature of the terrain, climate, fertilizer and animal husbandry practices, indicate that it is highly probable that clinical and/or subclinical deficiencies of minerals decrease animal growth and the quantity and quality of wool grown over a wide area in northern China. Research is therefore needed, directed at the identification of areas where minerals are deficient, the diagnosis of deficiencies and the provision of low cost, convenient forms of supplementation.

These will all be addressed in the research now planned. Collection of blood and tissue samples will be carried out on an increased number of farms, with particular emphasis on selection of sites representative of different soil types, management systems, climate and terrain. Sufficient information on the mineral status of the sheep, together with detailed information on the site, will permit some extrapolation of the results to identify other areas at risk from deficiencies.

Analytical facilities will be improved at a number of institutes, and diagnostic tests for iodine and cobalt, together with improved methods for determining sodium, phosphorus and sulphur status, will be introduced into the research program. Iodine deficiency is a serious health problem in the human population in China and is likely to contribute to the high mortality and poor growth of some grazing sheep. The recent identification of a biological interaction between iodine and selenium (Arthur et al. 1990) is also of relevance to China as both deficiencies occur in humans and animals and often in the same geographical regions. Any lack of selenium will exacerbate an iodine deficiency.

Experiments to date have shown some responses, but considerably more information is required on production responses to minerals. These types of experiments are not easy to perform in China as the care and management required for controlled experiments with grazing sheep is not well understood by herdsmen. In addition, the herdsmen have a financial interest in the return from their flocks so are reluctant to introduce changes for fear of decreased productivity. Only through demonstration of the potential benefits from research will cooperation on farms improve.

Development of supplements suitable for use in China is also a priority. Many farms in northern China currently use a salt supplement, and previous research indicates all sheep in northern China should be given salt regularly. This type of supplement offers a convenient vehicle for the provision of other minerals. The advantage is that the supplements are cheap and simple to use and require no change in the traditional methods of sheep management. Acceptance is therefore likely to be high. Minerals required can also be incorporated into salt supplements in a cheap compound form and no special processing or use of delivery devices is needed. At present there appears to be

Table 6. Effect of high iron intakes on growth and feed intake of young sheep (mean ± SEM).

Dietary Fe (mg/kg DM)	53	203	503	2003
Live-weight gain (g/day)	86 ± 9	92 ± 8	66 ± 16	42 ± 14
Feed intake (g/day)	883 ± 69	912 ± 51	851 ± 75	763 ± 76
Predicted live-weight gain[a] (g/day)	87	96	81	62
Actual/predicted gain	0.99	0.95	0.81	0.68

[a] Predicted gain estimated using MAFF (1976); energy content of the diet was estimated from the live-weight gain of the lowest iron group.

minimum scientific input into the formulation of salt-based mineral supplements. It is planned through direct contact with the producers of these supplements to provide a scientific input and to evaluate different formulations under grazing conditions.

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An Introduction to the Helminthological Studies in Project 8555

N. Anderson*

ENVIRONMENTS suitable for sheep grazing are also suitable for the transmission of their helminth parasites. Therefore, it is reasonable to assume that all grazing sheep are infected with helminths all of the time and that the pastures they graze are more or less continuously contaminated with infection. However, this assumption has been found to be incorrect.

The usual situation, under extensive grazing conditions, consists of periods of delay between the times of pasture contamination and infection, together with quite lengthy periods when transmission of infection is not possible. The end result of these effects is that helminths rarely complete more than two generations per year and frequently only one generation per year is possible.

Parasitologists have recorded over 300 species of helminth from sheep throughout northern China. Among the most common of these are the nematodes, or round worms, of the genera *Haemonchus, Ostertagia, Trichostrongylus, Nematodirus* and *Oesophogostomum*. These are the same parasites which cause disease in other parts of the world where sheep are grazed extensively.

The Life Cycle of the Common Nematodes of Sheep

The life cycle of the common nematode parasites of sheep is direct and has two phases: a parasitic phase in the sheep, and a free-living phase in the faeces and on the pasture (Fig. 1). Infective larvae ingested with the pasture usually develop to adult worms within a time span of 2–7 weeks, depending on the species. However, under certain conditions, development of newly ingested larvae is suspended or arrested for periods extending over several months. This reservoir of immature parasites is not, in itself, harmful to the host, but the subsequent resumption of development of these arrested larvae is often associated with severe pathological changes. Thus, the physiological effects or disease arising from nematode infections can occur long after the time when infective larvae were ingested. This new population of adult worms, through egg laying, also makes an important contribution to pasture contamination.

Development of eggs to the infective third-stage larvae takes place in the faeces before the larvae migrate onto the pasture in films of moisture. Their survival, both in faeces and on pasture, is largely determined by the prevailing weather conditions, principally temperature and availability of moisture. Under optimum conditions, development to the infective third stage can be completed within a week but it usually takes much longer under field conditions where temperatures fluctuate and are rarely at the optimum for long.

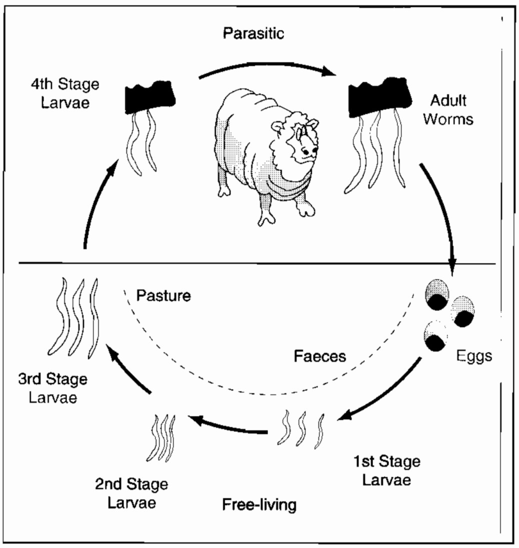

Figure 1. Simple direct life-cycle of a sheep nematode parasite

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The Effects of Nematode Infections on Sheep

The common parasites of sheep in China are located in the gastrointestinal tract. They each have a specific location within the gut, and each has a different affect upon the sheep. *Haemonchus contortus* is a blood-sucking parasite which inhabits the abomasum, or 4th stomach of the sheep, and in large numbers can produce a fatal anaemia without obvious signs of ill health. Also found in the abomasum are *Ostertagia* spp. which do not suck blood but cause a severe inflammation of the gastric mucosa. *Trichostrongylus* and *Nematodirus* spp. are found in the small intestine where they cause inflammation and destruction of the specialised secretory and absorptive cells within the mucosa. Finally, the home of *Oesophogostomum* is the large intestine where it gives rise to severe erosions or ulcers on the mucosal surface. These frequently haemorrhage, causing a progressive anaemia in sheep.

Despite the differences in site of infection along the gastrointestinal tract and the gross pathology caused by infections of the different nematode genera, there is a remarkable similarity in the functional change induced in the host. The principal effects of gastrointestinal parasitism in sheep can be listed under three headings:

- a reduction in food intake;
- a reduced retention of protein and fat in the body; and
- a reduced absorption or utilisation of minerals, notably calcium and phosphorus and, in the case of the genera causing haemorrhage, iron.

The reduction in food intake, often 20% or more, is generally directly related to the numbers of worms present in the animal. As yet, no satisfactory explanation of the mechanism can be given. Its occurrence following infection at different sites along the gastrointestinal tract tends to suggest a common physiological pathway, perhaps one mediated by neural receptors or hormones.

Measurements of some gastrointestinal hormones, notably gastrin, pancreatic polypeptide and cholecystokinin, have been made but neither the time relationships nor the size of the response is sufficiently well correlated with reduced food intake to indicate a causal relationship. Recent evidence from *Trichostrongylus* infections suggests that parasites either release substances themselves or cause the release of substances from the host's damaged tissues, possibly one or more of the cytokines, which act directly on the centres of food intake regulation within the brain.

Whatever the mechanism it is obvious that a reduction in food intake will reduce the supply of nutrients for maintenance, growth and production in the parasitised animal.

Furthermore, when comparisons are made between parasitised sheep and worm-free sheep, under conditions of 'pair feeding', it is found that nematode infections have effects additional to those resulting from reductions in food intake.

The inflammatory response, including the specific immunological components, and the tissue repair processes induced by helminth infections, give rise to a quite massive leakage of endogenous protein, principally the blood proteins, into the gastrointestinal tract. Estimates of up to 300 mL per day of plasma have been measured in moderate to heavy infections of the common species mentioned earlier. About 80% of this endogenous protein is reabsorbed lower down the tract and that which is lost is replaced by an increase in the synthesis of proteins in the liver. However, there comes a time when catabolism of protein exceeds synthesis and a progressive hypoproteinaemia develops.

Increased urinary excretion of nitrogen is a common sequel to gastrointestinal parasitism, arising partly from an increased breakdown of endogenous protein by intestinal microflora and partly from the mobilisation of protein from skeletal muscle and possibly skin sources. Thus, the lower nitrogen retention measured in parasitised animals is a composite of reduced nutrient supply, incomplete reabsorption of protein lost into the gastrointestinal tract and the inevitable metabolic losses associated with a high rate of protein turnover.

Infections of *Ostertagia* and *Trichostrongylus* spp. have been shown to impair skeletal growth in young sheep. The rates of increase in the length and volume of bone were decreased and the total weight of bone ash was reduced. This may be due either to a reduced absorption of calcium and phosphorus, particularly in infections causing change in the upper small intestine, or to the general effects of parasitism on the utilisation of energy and protein.

Similarly, in the case of species causing haemorrhage into the gastrointestinal tract, the haem part of the haemoglobin molecule cannot be reabsorbed once in the gut lumen. Consequently, large losses of haemoglobin from haemorrhage into the gastrointestinal tract give rise to a mobilisation of iron reserves and ultimately to an iron deficiency anaemia.

This general overview, gleaned from studies conducted in other parts of the world, clearly indicates that helminth infections can have profound effects on the well-being and productivity of grazing sheep. For example, in the high rainfall regions of Australia where pastures have a high legume content, losses in production from uncontrolled nematode infections can be substantial. Experiments have shown that mortality among weaners can range from 10 to 68% but is generally less than 10% for mature stock. Similarly, reductions in live-weight gain amount to between 14 and 79% for weaners and less than 10% for mature sheep, but wool production may be reduced by 9 to 30% in all classes of sheep.

Objectives of the Helminthological Component of Project 8555

It follows that the objectives of any study of helminth parasitism in a new environment should be aimed at:

- measuring the abundance of the helminth species present in the sheep population;
- measuring the seasonal changes in infection of the predominant helminth species; and
- determining the impact, or significance, of helminth infections on the productivity of sheep in the new environment.

Together, this information provides a logical basis upon which control measures, if needed, can be applied to achieve a cost-effective benefit for sheep producers, both in terms of controlling parasite numbers and of eliminating the losses in production due to helminth infections.

Experimental Design for Helminthological Studies

The experimental design for these studies was quite simple. Groups of 30 or more sheep, either weaners or two-year-old ewes, were chosen to form three treatment groups which grazed together and were subjected to the usual management practices on each of three farms in northern China, at Nan Shan in Xinjiang, Huang Cheng in Gansu and Aohan in Inner Mongolia (for details see Lindsay et al., this report).

The treatment groups were:

(a) sheep given no treatment for helminths;

(b) sheep given routine anthelmintic treatment to remove nematode infections; and

(c) sheep maintained free of nematode infections by the use of intraruminal controlled release capsules.

Intraruminal Controlled-Release Capsules

The general purpose, intraruminal, controlled-release capsule for ruminants was invested by CSIRO and developed for commercial release by Captec Pty Ltd. It was designed to release controlled amounts of various medicaments, including anthelmintics, for ruminants. The capsule consists of a polypropylene barrel with a pair of wings attached at one end. The wings are taped to the barrel for easy administration to the sheep and in the rumen the fluids soften the paper tape so that the wings open out and prevent regurgitation. The active ingredient is incorporated into a matrix of sucrose stearates which are compressed to form tablets and inserted into the barrel. The release rate is determined by the rate of dissolution of the matrix, which forms a gel on contact with water, and the diameter of the orifice at the other end of the capsule. The spring at the top end of the capsule keeps the tablets pressed against the orifice.

The anthelmintic used in these studies was either oxfendazole or albendazole, the rate of release ranged from 0.5 to 1 mg/kg/day, depending on the weight of the sheep, and continuous release was maintained for 106 days. Studies have shown that this rate of release will kill all of the worms present in the sheep and prevent the establishment of any new infection. Under field conditions in Australia, it has been shown that a single capsule, applied at an appropriate time determined by the epidemiology of nematode infections, can prevent the contamination of pastures with worm eggs for up to 5 months. Therefore, by giving each sheep three capsules at intervals of about 120 days, the sheep can be maintained free of nematode infections for the whole year.

In the experiments conducted within Project 8555, the helminth infections were monitored by measurements of worm egg counts in the faeces of sheep in each of the groups. In addition, five sheep from the untreated group were slaughtered at 4 times during the year for total worm counts. These counts provided a measure of the seasonal changes in helminth numbers.

Changes in live weight and the amount of wool grown, each season and for the whole year, from sheep in the three groups provided a measure of the significance of helminth infections and when the differences occurred.

The Effects of Helminth Infection on the Productivity of Sheep on the Grasslands of Northern China

Z. Runkuan*, S. Cheng*, N. Anderson† and D.A. Petch†

Helminth infections appear to be one of the major factors restricting sheep production in the grassland areas of northern China. Helminth infection results in losses due to reduced live-weight gain, reduced wool growth, poorer wool quality and, in severe cases, death of livestock. It was estimated that between 1977 and 1985 up to 20 million kg of wool and 3 million sheep were lost annually in Inner Mongolia alone as a direct result of helminth infection. At the present time, most farms in Inner Mongolia do not have a parasite control program and consequent losses in production are substantial. To combat these losses an effective control program needs to be implemented. The basis of such a program is knowledge of the timing and patterns of helminth infection.

Materials and Methods

Location

Observations were carried out at Aohan farm in Chifeng County, in the eastern part of the Inner Mongolia Autonomous Region (IMAR) (see Lindsay et al., this report).

Sheep on Aohan farm are grazed in flocks of about 120 which are reconstituted several times during the life of the sheep according to expected lambing dates. Flocks remain in one grazing area for about 10 months, moving to alternate areas during summer only. Sheep are housed for much of the time in winter and are given supplementary feeding (Fig. 1, Lindsay et al., this report). The cold, dry conditions of winter and spring leave little more than dead residues on the pasture which the sheep graze for part of each day during clement weather.

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Animals and experimental design

The experimental procedures used at Aohan farm during Project 8555 are described by Anderson (this report). Two classes of sheep were used in each year: newly weaned wethers (weaners) and one-year-old ewes. During the third year of the study, two separate flocks of sheep were used, each made up of only two groups of sheep. The two treatment groups represented in each flock were; for the weaners, untreated (no anthelmintic) and worm-free (capsules); and for the ewes, untreated (no anthelmintic) and routine treatment.

Because the flocks were grazed in different areas by different shepherds separate analyses were done for each flock.

Results

Helminths

The most common internal parasites encountered in sheep of both classes were the nematodes *Haemonchus contortus, Nematodirus* spp., and *Oesophagostomum columbianum.* In addition, very small numbers of *Monesia expansa, Taenia lani* and *Cysticercus tenuicollis* were also found. No hydatid cysts of *Echinococcus granulosus* were detected in any of the sheep killed for worm counts.

Worm egg counts

The pattern of worm egg counts from the untreated groups of both weaners and ewes was distinctly seasonal. Counts were high (6000 eggs per gram (epg) in September 1988 for both weaners and ewes) in the warmer months of all three years, but declined to almost zero during the colder months (November–March). A spring rise in egg counts was evident in all three years, particularly for the ewes in year two when egg counts rose to 10 000 epg in mid May (Fig. 1).

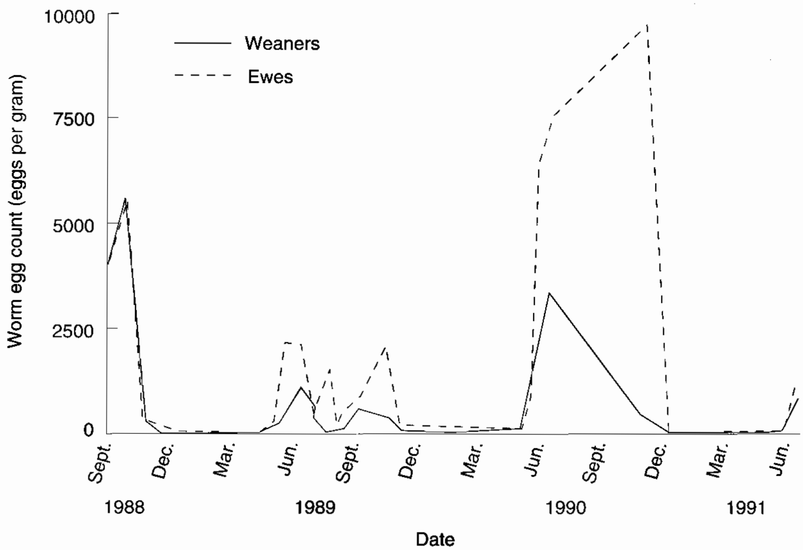

Figure 1. Mean counts of worm eggs in the faeces of untreated weaners (solid line) and ewes (dotted line) at Aohan farm over three years.

Worm egg counts of the routine treatment and capsule treatment groups of both classes of sheep were essentially zero for most of the experiment, although a small spring rise in egg counts was observed for the ewes in the routine treatment group for the first year. During this time the egg count was never higher than 75 epg. No post-parturient rise in worm egg counts was observed during the first two years, but the counts from ewes increased substantially after lambing in the third year. This rise in egg output occurred in ewes before the spring rise in egg output occurred in weaners (Fig. 1).

Worm counts

Adult *H. contortus* were most prevalent in weaners in late spring and early autumn (Fig. 2). In late autumn, adult *H. contortus* became rare and were replaced by large numbers of inhibited fourth-stage larvae. Almost 60 000 inhibited larvae per sheep were recorded during November 1988. Fewer *H. contortus* were present in the late autumn of year two than in year one (750 worms/sheep), but in spring 1992 the numbers of adult *H. contortus* were higher than the previous year (Fig. 2). A similar pattern was observed in the ewes, but numbers were very much lower than those found in weaners.

The numbers of *Nematodirus* spp. observed in weaners peaked in November of both years with between 1500 and 2000 worms per sheep present during this time (Fig. 2). The pattern was slightly different in ewes where the peak in *Nematodirus* spp. occurred in springtime of the first year and remained relatively constant at about 500 worms per sheep throughout the second year.

Numbers of *Oesophagostomum columbianum* in both classes of sheep were small and peaked during spring (Fig. 2).

Production

Live-weight gains

Weaners in all groups generally gained weight throughout the year. Starting at around 23 kg in August these sheep gradually progressed to about 40 kg a year later. This pattern was repeated in each of the three years (Fig. 3). Production losses, represented by lower growth rates compared with those of other two groups, were sustained by the untreated sheep in all years (Figs 3 and 4). The losses occurred mainly during autumn and winter, when the differences were significant, but growth rates of untreated sheep tended to be lower during spring and summer also (Fig. 4). In autumn of each year, the difference between untreated and treated groups in mean gain/day varied from 8.5 to 39 g/day and in winter from 9 to 12 g/day. No significant differences in growth rates were detected between weaners given the routine anthelmintic treatments and those maintained worm-free by the use of controlled-release capsules.

All ewes, whether lambing or not, went through an annual cycle of weight gain in summer and autumn followed by a loss in winter and spring (Fig. 3). At the start of each of the years, ewes weighed 48 kg and the weight of these sheep gradually increased to about 60 kg by early winter. By early summer the average weight of the ewes was again about 48 kg.

The dramatic loss of weight by ewes during winter was due to two factors: lambing and poor nutrition. Lambing did not account for the total loss because about 20% of ewes without lambs also lost weight. However, because it was difficult to distinguish ewes which had not lambed and ewes which had lost their lambs soon after birth, it was not possible to reliably partition the effects. Furthermore, ewes that were not rearing a lamb were fed different rations to those suckling a lamb.

The changes in live weight of ewes in the three treatment groups are shown in Figure 5. Significant differences between treatments occurred but were not as consistent as those for weaners. In the autumn of the first year, ewes treated with capsules gained more weight, 13.8 g/day, than ewes in the other treatment groups, which were not significantly different.

Lambs

The mean weights at birth and weaning of lambs born to sheep in the different treatment groups are shown in Table 1.

During all years of the study there was no significant difference between the weights of lambs born to ewes in any of the treatment groups. There was, however, a difference between groups in the growth of lambs to weaning. Weaning weights were not available for year one, but in subsequent years they revealed significant differences in weight between lambs in the untreated group and those in treated groups. In year two, weaned lambs in the untreated group were almost 4 kg lighter than those in the worm-free group. In year three, the comparison between the untreated group and the routine-treatment group resulted in a weight difference of 1.5 kg.

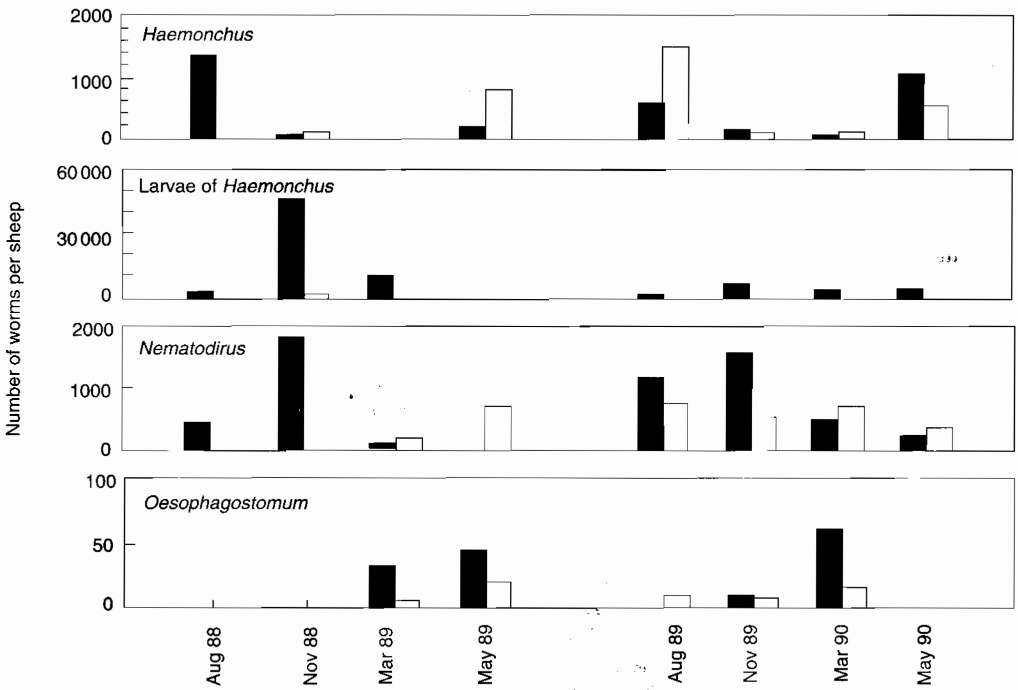

Figure 2. Mean worm counts from 4 weaners (solid bar) and 4 ewes (open bar) killed at Aohan farm over the first two years of the study.

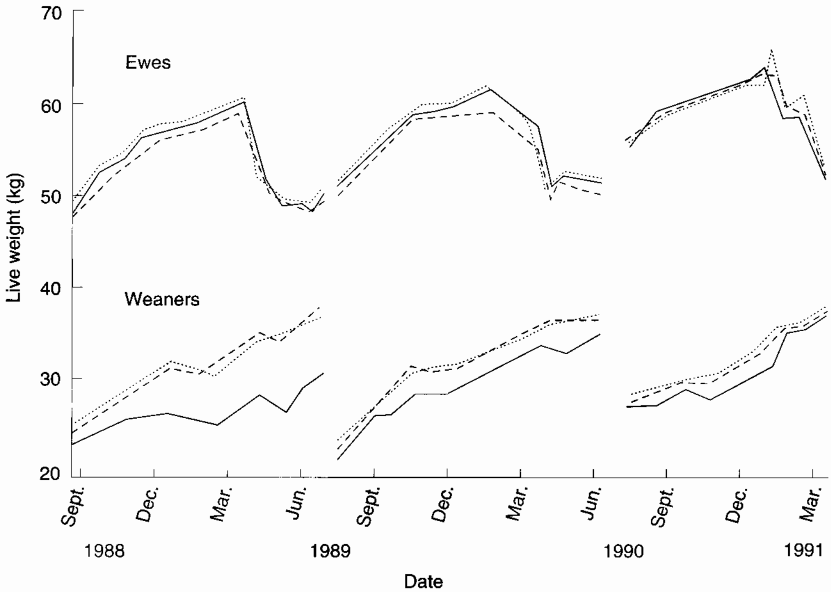

Figure 3. Live weights of weaners and ewes at Aohan Farm over the three years of the study. Groups shown are: untreated (solid line); routine treatment (dashed line); capsule treatment (dotted line).

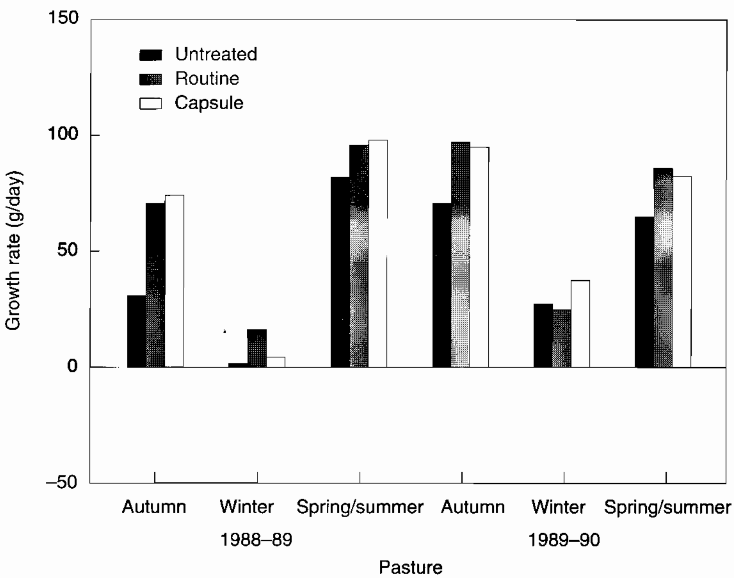

Figure 4. Weight gains of weaners over the first two years of the study. The year is divided into three periods related to the pasture grazed at the time.

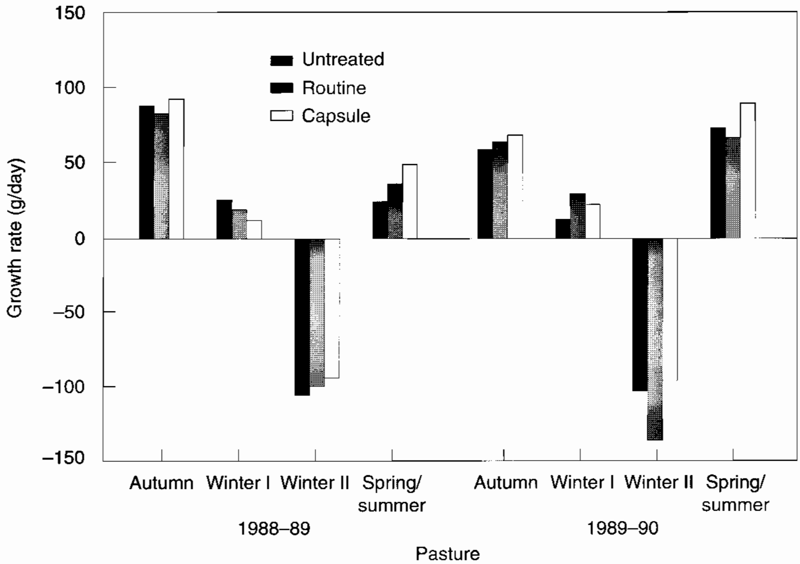

Figure 5. Weight gains of ewes for the first two years of the study. The year is divided into four periods based on the pasture grazed at the time. Winter I = winter pasture, before lambing; Winter II = winter pasture, after lambing.

Table 1. The mean weights (kg) at birth and weaning of lambs born to sheep in the different treatment groups.

Year	Group	Birth weight Mean	Birth weight s.d.	Weaning weight Mean	Weaning weight s.d.
1	1	3.76	0.73	n.a.	
2		3.60	0.68	n.a.	
3		3.85	0.84	n.a.	
2	1	4.26	0.73	25.0	3.2
2		4.32	0.69	26.6	4.7
3		4.47	0.78	28.9*	4.5
3a	1	4.28	1.18	23.5	3.7
	2	4.10	0.95	23.8	3.4
3b	1	4.52	1.17	23.7	3.8
	2	4.55	0.98	25.2*	3.1

* Significantly greater than untreated group, $P < 0.05$.

Table 2. The mean weight (kg) of greasy wool from weaners and ewes in each treatment group for each year.

Year	Group	Weaners Mean wool	s.d.	Ewes Mean wool	s.d.
1	1	5.6	0.9	7.6	1.4
	2	6.0	0.7	7.4	1.2
	3	6.2	1.0	7.9	1.4
2	1	5.2	0.7	6.9	1.3
	2	5.6	0.5	7.8	1.5
	3	5.6	0.7	7.9	1.1
3a	1	5.4	0.8	7.4	1.2
	2	5.7	0.7	7.3	1.1
3b	1	5.6	0.8	7.2	1.2
	2	5.9	0.8	7.5	1.6

Wool production

The mean weight of greasy wool produced from weaners and ewes in each treatment group for each year is shown in Table 2. Parasitism significantly reduced wool production by 0.3–0.4 kg when treated and untreated groups were compared. The difference was significant in the first two years but not in year three. A similar trend was observed for wool production from ewes, but the difference was significant only in year two in which treated groups produced 0.9–1 kg more wool than those in the untreated group. For both weaners and ewes there was no significant difference in wool production between the groups given routine treatment or capsules.

Discussion

Helminth infections caused significant losses in production from both ewes and weaners at Aohan farm. These losses comprised reduced gains in live weight, reduced wool growth and lower rates of lambs born to parasitised ewes. Such reductions in productivity probably amount to large financial losses for sheep producers in Inner Mongolia.

The most common parasites were nematodes of the genera *Haemonchus, Nematodirus* spp. and *Oesophagostomum.* Adults of the blood-sucking *Haemonchus contortus* were most prevalent in spring and early autumn at times when the growth rate of parasitised weaners was lowest. However, reductions in weight in both weaners and ewes occurred during winter when they were virtually no adult *H. contortus* present, although inhibited larvae of this species were numerous. Inhibited larvae are not considered to be pathogenic because of their small size, inactivity in a metabolic sense and their inability to suck blood. Therefore, the moderate numbers of *Nematrodirus* spp. together with 50 or so *Oesophagostomum columbianum* present in untreated sheep were apparently sufficient to reduce the growth of weaners on winter rations. Alternatively, the previously reduced period of growth predisposed the weaners to further reductions during the period of nutritional stress.

A rise in the output of worm eggs in the faeces of ewes was observed during and after lambing and during spring in weaners. This is indicative of a maturation of inhibited *H. contortus* larvae to the adult, blood-sucking stage, because results from the ecological studies (Cai et al., this report) show that no infective larvae of *H. contortus* are available on pasture until late April, well after the rise in worm egg output. Indeed, the absence of new infection during the harsh winter months implies that this species is dependent for its survival on the presence in sheep of either inhibited larvae or small numbers of adult worms.

This provides the basis for a preventative strategy of control. Anthelmintic treatment in late autumn or early winter would have substantial benefit. The removal of worm burdens in autumn would prevent losses of productivity in winter and would reduce the amount of pasture contamination in spring.

Strategic Control of Nematode Infections of Sheep in Inner Mongolia

Z. Rui, S. Cheng, and Z. Runkuan*

The Inner Mongolia Autonomous Region (IMAR), located in the north of the country, covers approximately one eighth of the total territory of China. Much of the area of Inner Mongolia, about 66 million ha, is grassland upon which graze about 36 million sheep. Over the past 20 years the increase in sheep numbers has led to a serious degradation of pastures, with a 20% decrease in the carrying capacity occurring from the 1960s to the 1980s. This decrease in the capacity of the pastures means that, for sustainable production in the long term, the numbers of sheep will have to be reduced progressively and the productivity of the remaining animals increased. Parasite control is one factor in which significant gains in efficiency can be made, resulting in less pressure on the grassland ecosystem for equivalent productivity.

It has been estimated that parasitic infections reduce the wool yield, over Inner Mongolia as a whole, by 20 000 t/year and that up to 3 million sheep are seriously affected by disease each year. Such losses, if measured in economic terms, cost the sheep industry in the IMAR several hundred million yuan per year. The currently-employed control strategy does not appear to be as effective as it might be in minimising these losses (Zheng et al., this report).

The pastures in Inner Mongolia are usually free from nematode larvae during the period December–April because most of the eggs and pre-infective larvae, except those of *Nematodirus*, are killed by low temperatures (Cai et al., this report). Therefore, virtually all of the parasites, other than *Nematodirus* spp., should be resident within the sheep. Thus, control of infections and perhaps even their eradication, should be straightforward. An anthelmintic treatment in early December, followed by one in mid to late March, should result in a very substantial decrease in parasite numbers.

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All sheep in the IMAR should be treated with albendazole at a dose rate of 10 mg/kg in late November or early December, to remove the worm burdens accumulated during summer and autumn. Removal of the parasite burden would significantly reduce the stress that is inevitable during winter (Lu et al., this report). A second treatment in March would remove the inhibited fourth-stage larvae of *H. contortus* acquired after the first treatment and thus prevent pasture contamination with worm eggs in spring.

Unfortunately, in most sheep-raising areas of IMAR, there are usually no anthelmintic treatments given before ewes are housed in winter, and removal of faeces from sheep pens is rarely practiced. Thus, it is possible that nematode eggs could develop, and that infective larvae could survive indoors when field temperatures are too low for eggs and larvae to survive. Therefore, parasitic infections may persist throughout the winter, even though conditions on pastures prevent transmission. This problem could be solved by treating sheep before they are put into the sheep sheds each winter. Regular cleaning of the pen floors should also help reduce the possibility of reinfection from parasite larvae which have developed there.

If an effective parasite control program is to be implemented in the IMAR then action must be taken in the following key areas:

- Increase the research effort, particularly in the area of fundamental studies of parasitology including epidemiology, immunology, ecology and resistance to anthelmintics.
- Establish a program of integrated grazing management and worm control and monitor its progress.
- Reduce stocking rates of sheep and improve sheep nutrition, particularly during the winter.
- Provide an effective extension service for the dissemination of research results and advice to all farmers.

If these actions are taken, it should be possible to significantly reduce the losses caused by parasitism in Inner Mongolia. This will mean that more productivity can be gained from fewer sheep, making it possible to lower stocking rates for the same returns. Such an action would help redress the problem of pasture degradation in the IMAR. There is also the possibility that a parasite such as *H. contortus* could be eradicated altogether. This would further increase the efficiency of sheep production by reducing or eliminating the costs of anthelmintics. The promise of an effective parasite control program thus carries with it many potential benefits for the sheep farmers of Inner Mongolia.

An Introduction to Ecological Studies of Sheep Parasites

D.A. Petch*

THE control of gastrointestinal parasites of sheep can often be an expensive and time-consuming activity. The most common method of parasite control is through the use of chemical agents known as anthelmintics, which are, in general, highly effective in controlling numbers of internal parasites. They do, however, present a number of problems to the sheep farmer.

Anthelmintics must be administered to every sheep and therefore the treatment of large numbers of stock can often be a costly and difficult exercise. There is also the problem that all anthelmintics may in time lose their effectiveness due to the development of resistance by the target parasite. It has been well documented that the higher the frequency of anthelmintic use the greater the rate of selection for resistance.

A third problem is the ecological damage that overuse of any pesticide may cause. Some anthelmintics are excreted unchanged and are thus deposited on the pasture with the sheep faeces. This can cause environmental problems by killing the organisms that help to decompose the faeces.

The aim of a well-designed chemical control program for parasites is to overcome these problems by minimising the use of the anthelmintics. This has to be accomplished without any substantial loss in effectiveness of the drug being used. This paper suggests the methods by which a strategic parasite control program can be designed utilising aspects of the ecology of the parasite.

Parasite–Environment Interactions

The reason for the importance of parasite ecology in the design of control strategies lies in the responses of the parasites to the environment in which they live. Most of the important gastrointestinal parasites of sheep have the same simple, direct life cycle, with a parasitic phase in which the parasite resides within the host and a free-living phase when the parasite lives independently. It is the behaviour of the parasite during the free-living phase that is of most interest when considering the design of a parasite control program.

The environment in which the adult worms live during the parasitic phase of the life cycle provides constant conditions and a plentiful food supply. The only threats to parasites in this phase are: an immune response of the sheep; competition from other parasites for attachment sites within the gut; and chemical attack from anthelmintics that may be administered to the sheep.

In contrast, in the free-living stage, parasites find themselves in constantly changing environments which are frequently hazardous. It is these hazards that we can use to our advantage in the design of parasite control programs.

The free-living stages of sheep nematodes experience wide fluctuations in microenvironmental conditions. For example, temperatures may range from the freezing conditions of severe frost to temperatures of around 65°C when exposed to direct midsummer sun. The parasites may also experience circumstances ranging from almost complete desiccation to being submerged in water. Other hazards include ultraviolet radiation and attack by organisms that prey on nematodes. Mortality rates under these conditions are very high with fewer than 0.02% of the eggs deposited on the pasture reaching adulthood in the gut of sheep.

Although very high, these mortality rates are not constant over time. Some periods of the year have been shown to be considerably more favourable to the survival of infective larvae than others. Southern Australia has a Mediterranean climate with a cool, moist winter and a hot, dry summer. These conditions can be considered analogous to those in northern China, in that there is a growing period for pastures in both countries from about April to October, and a period from October to April when

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there is little if any pasture growth. In the context of sheep nematode parasitism and control, the similarities between the two countries lie in the fact that part of the year is quite favourable, with moderate temperatures and adequate rainfall, and part of the year is hostile, with temperature extremes and little moisture. In China, the temperature extremes are represented by the extremely harsh winter, whereas in Australia the hot summer provides the hazardous environment. Because of the similarities between the two countries, the strategies for timing parasite control treatments in Australia and in China are likely to be similar.

The major gastrointestinal parasites of sheep in the southern Australian region are the nematodes of the genera *Ostertagia* and *Trichostrongylus*: *Nematodirus* spp. are generally not of any consequence.

In southern Australia there is a distinct seasonal pattern with respect to the presence on pasture of the infective larvae of gastrointestinal nematodes. This pattern follows the seasonal changes in weather, with peak numbers of larvae available to sheep occurring in late winter, a rapid decline in spring following the rise in temperatures, and low numbers present during the hot, dry months of summer. This pattern has been shown to be relatively stable and repeatable over many years. It can, however, be modified by variations in local weather conditions. For example, a particularly dry autumn may result in an extension to the period when parasite numbers on the pasture are low. Alternatively, an early appearance of the autumn rains may increase the time during which the numbers of larvae on pasture are high. The high numbers of larvae are considered to be derived from eggs deposited in winter. This results from the more favourable conditions for egg development in autumn and from the higher amounts of worm egg output by adult sheep in summer and autumn than in winter (Anderson et al. 1978).

The egg output from mature sheep is highest during summer and early autumn. As the sheep begin to encounter more parasite larvae, the egg output of the parasites falls because of the effects of the immune response of the sheep. There is thus a negative feedback relationship between the intake of infective larvae and the output of worm eggs. Thus, the number of new eggs deposited on pasture is inversely proportional to the rate of intake of new larvae. The pattern for weaners is more variable because these sheep, which are yet to become resistant to the parasites, continue to deposit high numbers of eggs on the pasture. As their exposure to new infection increases, so does the immune response of the sheep and the numbers of eggs that are deposited on the pasture decreases.

The control of parasite numbers in sheep is most effective if the supply of new infection can be reduced rather than controlling an already existing infection. With the knowledge that nematode infections in the sheep in southern Australia are derived from larvae ingested by the sheep during winter and that these larvae are, in general, derived from eggs deposited on the pasture in summer and autumn, the reduction of numbers of parasites is relatively simple.

The reduction in the contamination of pasture during the summer can be achieved by reducing the population of adult worms in the sheep. Only two treatments of anthelmintics are needed to reduce pasture contamination by a substantial margin. The first treatment is given in late spring or early summer and thus prevents further contamination of the pasture with worm eggs emanating from these sheep. The larvae and eggs which have remained on the pasture from previous contamination quickly succumb to the hazard of the hot, dry weather. Thus, the environment is used as an aid to the decontamination of the pasture.

There will still be some pickup of larvae from the pasture over the summer, particularly by newly weaned sheep. A second treatment some 4–6 weeks before the onset of the autumn rains will remove this infection and dramatically reduce further contamination with worm eggs deposited in autumn. Because there is a 4–6 week period when the weather remains dry and hot, any free-living stages remaining on the pasture will have a high mortality. Thus, with both the summer and autumn contamination periods severely reduced, the number of infective larvae appearing in the winter will be substantially lower.

By these means, it is possible to time the treatments to lower the total number of parasites by using the environment to help kill off the free-living stages. Such a strategy should, in many cases, be more effective in China than in Australia. The hostile season for parasites in China is the winter, when temperatures often fall below –25°C. No parasite development at all should be possible under these conditions and it is probable that the free-living stages of many parasites will not survive. If survival in the external environment is impossible then the parasite must survive the winter in the sheep. With a single treatment of anthelmintic it should be possible to effectively control the parasite. Examination of the worm egg count data from Aohan farm reveals that *H. contortus* may follow such a pattern, but the ecology of the free-living stages needs to be examined.

Field and Laboratory Studies in China

As part of ACIAR Project 8555, an examination of the ecology of the free-living stages of the main parasite at each site was undertaken. An area of typical pasture was selected and fenced off from stock. Within this area an automatic data recorder was set up to monitor the temperature in the air and the temperature in faecal pellets. Rainfall on the plot was also measured.

Deposits of sheep faeces containing a known number of parasite eggs were placed on the pasture at regular intervals. The faeces were obtained from sheep kept in pens and infected with pure strains of the parasite under investigation. About 50 deposits, weighing about 40 g each, were placed on the pasture every month. At intervals of between two days and one week, depending on the time of year and expected rates of development, random samples of these deposits were collected and examined for the presence of worm eggs and larvae. The grass and soil within a 25 cm radius of the deposit were also examined for the presence of third-stage infective larvae. The methods described by Young and Trajstman (1979), Young et al. (1980) and Young (1983) were used for the recovery of eggs and larvae from the field samples. Thus, measures of the rate of development of worm eggs and rate of appearance of infective larvae could be made and related to the weather data.

The survival of infective larvae on the pasture was also examined. The procedure was essentially the same as before, except that the faeces placed on the pasture contained infective larvae rather than eggs. The faeces had been cultured in the laboratory until third-stage larvae were present.

In addition to the field work, some detailed experiments were carried out in the laboratory. This work sought to gain a better understanding of the responses of the parasites to various environmental conditions and to developing more responsive control programs. A further extension of the ecology work is the development of predictive models which give the capability to determine, using a computer, the likely outcome of certain treatment strategies.

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The Transmission of Nematode Infections to Sheep in Northern China

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THE availability on pasture of the infective stages of common helminth parasites is a central part of the epidemiology of the diseases they cause. Before preventive control programs can be formulated it is necessary to know the times when transmission of infection is possible and the factors which limit these times.

A convenient means of obtaining information on transmission of helminth parasites is to undertake quantitative studies of the ecology of their free-living stages. Consequently, as part of ACIAR Project 8555, a series of experiments was carried out to measure the development and survival of the free-living stages of the common nematode parasites found at three different sites in northern China. The time to first appearance of worm eggs in the faeces of sheep treated with anthelmintic during winter was taken as a measure of the importance of the sheep shed as a source of infection for sheep during the cold, harsh conditions of winter. This study supplemented the ecological work.

Nematode Species and Experimental Procedure

Similar experiments were undertaken at Nan Shan, Huang Cheng and Aohan farms (see Lindsay et al., this report). The main difference between the experiments was the species of parasite examined. The most common parasite found on each of the farms was used. At Aohan farm this was *Haemonchus contortus*, at Huang Cheng farm *Ostertagia circumcincta* was studied, and at Nan Shan farm the studies were focused on *Nematodirus oiratianus*.

On each farm, the experiments were conducted on an area of land approximately 100 m^2 which had been fenced off from stock and was free of contamination by nematodes that parasitise sheep. At intervals of about one month, replicate deposits of about 40 g of faeces containing known numbers of eggs were placed on herbage which had been previously cut to a uniform height of 5–8 cm. The faecal deposits were uniformly spaced at a distance of 600 cm.

Every two days after deposition, collections of two randomly selected faecal deposits were made. The frequency of sampling depended on the time of year and expected rates of development. In January, for example, when the temperature was well below 0°C and when no development was found after the first few samples, the frequency of collection was changed to monthly until temperatures increased above freezing.

After collection, the faecal deposits were examined for the presence of worm eggs and larvae. In addition, all of the grass within a radius of 20 cm of the deposit was collected for the recovery of infective larvae. On occasions, the top 0.5 cm of soil within the same radius was also examined. Each time that a deposition was made, duplicate samples of the faeces were incubated at optimum temperatures to measure the viability of eggs in the deposition. The methods described by Young and Trajstman (1979) were used for the recovery of eggs and larvae from the field samples.

Development and Survival of *Ostertagia circumcincta* at Huang Cheng Farm

The proportion of *O. circumcincta* eggs which developed to the infective stage from each deposition of faeces at Huang Cheng farm is shown in Figure 1. The most favourable period for the sur-

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vival of eggs and development of infective larvae, in terms of the greatest proportion developing and for shortest time of development to the infective stage, was from June to October. During spring (March–May) only a few eggs developed to infective larvae, whereas in winter months there was no development at all. Survival of infective larvae ranged from 20 to 30 days during the moist, relatively warm conditions of summer and most of these larvae were found in the faecal deposits. The highest recovery from herbage, 10% of the eggs deposited, occurred in September, but at other times generally less than 1% of the eggs were recovered as larvae from the herbage.

Development and Survival of *Haemonchus contortus* at Aohan Farm

The results of the field studies conducted at Aohan farm are shown in Figure 2. The time when the eggs of *H. contortus* could develop to the infective third stage was limited to the warmer months of the year. In early June about 1% of the eggs completed their development, and this figure increased to a maximum of about 5% around the beginning of July. From November to May no larvae were recovered from faeces, herbage or soil. Eggs collected from the deposits during this time were incubated at 25°C in the laboratory, but no development was observed.

Development and Survival of *Nematodirus oiratianus* at Nan Shan Farm

Nematodirus spp. differ from other members of the family Trichostrongylidae in that development to the third or infective stage is completed within the egg and, for some species at least, a specific environmental stimulus is required for the eggs to hatch.

A series of deposits containing *Nematodirus oiratianus* eggs was put out onto pasture at the beginning of December and January, and samples were collected at intervals of about 2 weeks until May, when another series of deposits was established. The number of eggs in the samples was determined and part of each sample was incubated at 25°C in the laboratory to determine the proportion that developed to the infective stage.

The results for the winter deposits are shown in Tables 1 and 2, and for the spring deposits in Table 3. It was found that eggs deposited in early winter did not develop but, unlike those of *O. circumcincta* and *H. contortus*, they remained viable until spring, when the warmer temperatures allowed development to proceed and the eggs to hatch. In contrast, eggs deposited in spring developed quite rapidly to the infective stage, hatched and moved onto the pasture. Relatively large numbers were recovered from the soil, possibly washed there by the spring rains. The protection provided by the

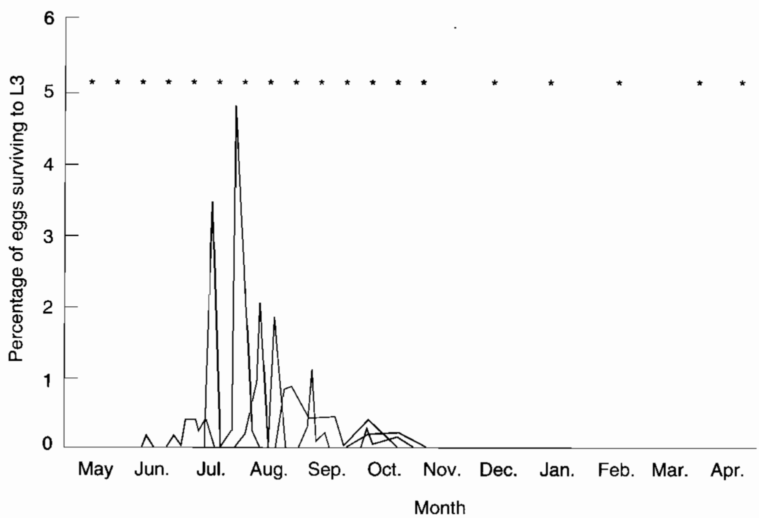

Figure 1. The proportion of *O. circumcincta* eggs which developed to infective larvae (L3) on the pasture at Huang Cheng farm from April 1990 to April 1991. Asterisks indicate the times of deposition of faeces.

egg resulted in a greater proportion of the *Nematodirus* eggs reaching the infective stage than was possible for the other trichostrongylid species.

Table 1. Viability of eggs of *Nematodirus* deposited on pasture in early winter at Nan Shan Farm.

Date	Stage of development	% viable
Dec. 1	Blastomere	89.2
Dec. 7	Blastomere	89.1
Dec. 14	Blastomere	89.6
Dec. 21	Blastomere	87.9
Jan. 6	Blastomere	88.8
Jan. 20	Blastomere	79.0
Feb. 3	Blastomere	88.1
Feb. 17	Blastomere	83.4
Mar. 10	Blastomere	86.9
Apr. 21	Blastomere 0.7% Prehatch 99.3%	99.3
May 5	L3 100%	n.a.

Transmission of *O. circumcincta* in Sheep Sheds

It was observed that worm egg counts of sheep treated with albendazole at the start of winter rise as winter progresses. The source of this new infection is not known. Because it was shown that eggs and infective larvae do not survive the intense cold and dryness of winter, pastures were considered an unlikely source of infection during winter. Consequently, the possibility of infection arising from within the sheep sheds or feeding yards was investigated.

Table 2. Development of eggs of *Nematodirus* placed on the pasture mid-winter.

Date	e.p.g.[a] faeces	L3.p.g.[b] faeces	L3.p.g. grass	L3.p.g. soil
Jan. 1	550	0	0	0
May 5	98	95	11	0
May 20	0	257	10	80
Jun. 3	0	356	31	64
Jun. 16	0	30	1	16
Aug. 18	0	0	11	0

[a] eggs per gram; [b] third-stage larvae per gram.

Within single flocks of weaners and ewes, separate groups of sheep were either treated or not treated with albendazole, at 10 mg/kg, each month from December to March. Other management practices were not changed. Samples of faeces were collected fortnightly from 10 sheep in each group and the numbers of worm eggs counted. The presence of eggs in the faeces of treated sheep provided a measure of when the sheep first became infected.

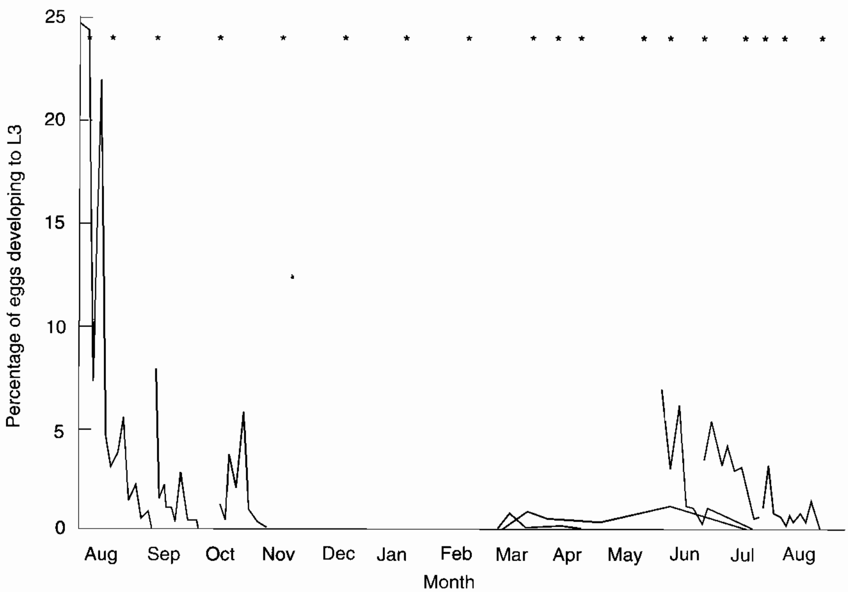

Figure 2. The proportion of *H. contortus* eggs which developed to infective larvae (L3) on the pasture at Aohan farm from August 1990 to August 1991. Asterisks indicate the times of deposition of faeces.

Results for the groups of treated and untreated ewes are shown in Figure 3. Worm eggs were detected in treated sheep 6–8 weeks after treatment in December to March inclusive. Results from the groups of weaners were not essentially different but showed more variation than those from the

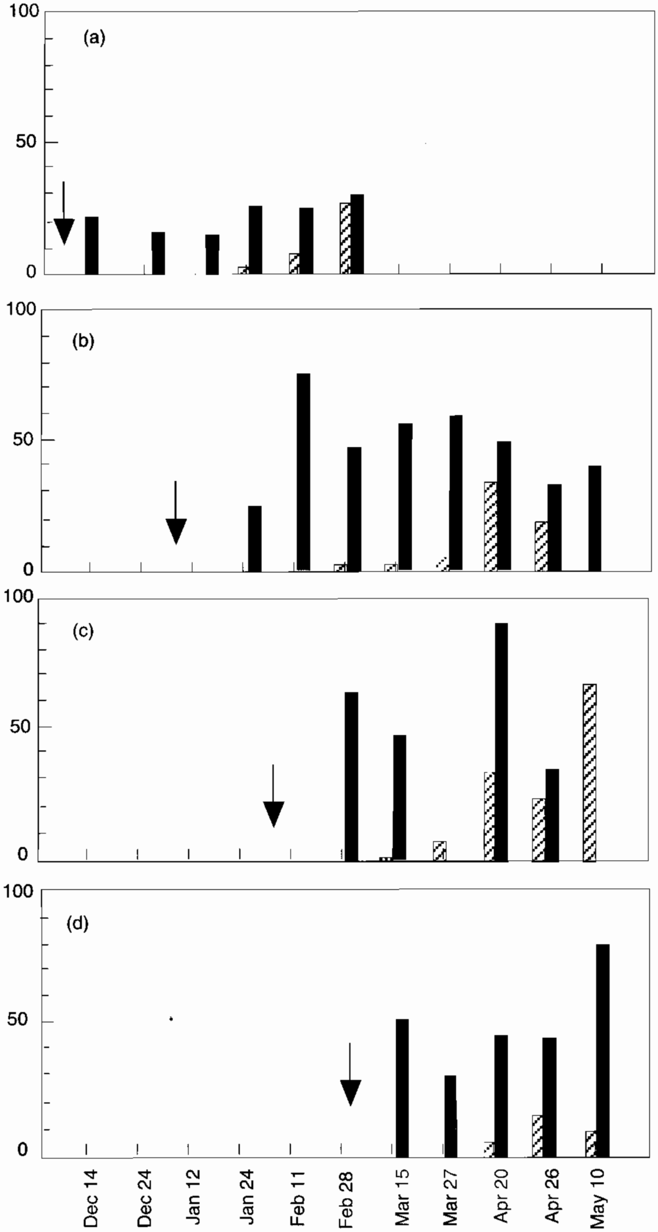

Figure 3. Mean worm egg counts from untreated ewes (hatched bars) and treated ewes (solid bars) at Huang Cheng farm during the winter of 1991. The letters a, b, c and d represent different groups, half of which were treated with albendazole (10 mg/kg) on the first day of December, January, February and March, respectively. Arrows indicate treatment times.

ewes. Allowing for a delay of at least three weeks to enable infective larvae to complete their development to the adult egg-laying stage, the results imply that sheep were re-infected shortly after treatment. In two of the four instances, worm egg outputs from treated and untreated sheep in April and May were not essentially different.

Table 3. Development of eggs of *Nematodirus* placed on the pasture mid-spring.

Date	e.p.g.[a] faeces		L3.p.g.[b] faeces	L3.p.g. grass	L3.p.g. soil
May 1	214		0	0	0
May 5	gastrula	73			
	tadpole	82	0	0	0
May 13	gastrula	6			
	L 1–2	40	0	0	0
May 20	L 1–2	80	0	0	0
May 27	L 1–2	175	0	0	0
Jun. 3	0		59	7	50
Jun. 9	0		22	1	5
Jun. 16	0		26	2	0
Aug. 20	0		0	3	16

[a] eggs per gram; [b] third-stage larvae per gram.

While this experiment demonstrated that infection is transmitted during winter, it did not resolve the source of this infection. Unfortunately, shepherds could not be convinced to retain some of the treated sheep in the shed over the experimental period, so all sheep had access to pastures during winter. However, the plot studies at Huang Cheng clearly show no development of eggs or survival of larvae occurred on pasture over the same period (see Fig. 1). Likely sources of infection therefore appear to be restricted to the hay fed in the sheep yards or to litter consumed from the floor of the sheep shed. Temperatures recorded from these sites are plotted in Figure 4 and show that conditions in the sheep yards are comparable to those on the pastures, whereas within the sheep shed temperatures are consistently above 5°C, which would enable the development of *O. circumcincta* eggs to proceed to the infective stage. Further studies are needed to determine the relative contribution made to infection of sheep in winter from (a) winter pastures, (b) dry forage fed in the sheep yards and (c) litter from the sheep shed.

Conclusions

The ecological studies provided some important insights into the transmission of the common nematode infections to sheep in northern China. As might be expected, there was no successful development of *H. contortus* or *O. circumcincta* eggs deposited on the pasture during the cold winter months (November–April) when temperatures were always below 0°C. It was also found that the larvae of these species did not survive these conditions when placed on the pasture. In contrast, the eggs of *N. oiratianus* were able to survive the cold winter conditions in the undeveloped state. They continued their development and hatched when warmer conditions prevailed in spring.

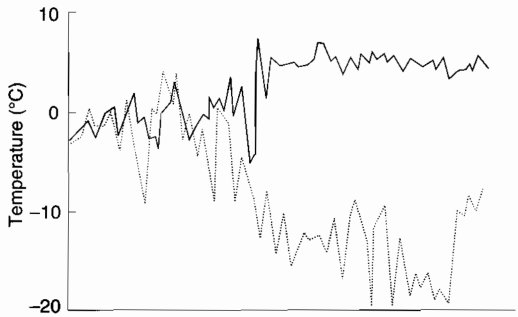

Figure 4. Mean daily temperatures recorded inside the sheep sheds (solid line) and in the sheep yards (dotted line) at Huang Cheng farm during winter 1992.

Temperatures recorded in the sheep yards were not different to those obtained on the pasture plots, but temperatures in the sheep sheds were consistently above 5°C, which may have been sufficient for the development of *O. circumcincta* eggs deposited there. Both ewes and weaners became infected after treatments given early in winter but no direct measurements were made to attribute this infection to winter pastures, to forage fed in the sheep shed or to the litter present in the sheep sheds. Judging from the mean egg counts of treated sheep in April and May, the infection acquired during winter would make a significant contribution to spring contamination. To reduce or eliminate this contamination another treatment with albendazole would be required when sheep leave the winter quarters.

Reference

Young, R.R. and Trajstman, A.C. 1979. A rapid technique for the recovery of strongyloid infective larvae from pasture and soil samples. Parasitology, 80, 425–431.

The Effects of Helminth Infections on the Productivity of Sheep in the Alpine Regions of Northern China

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THE alpine regions of northern China are important to the Chinese sheep industry, supporting over 50 million sheep (Copland 1987). Although there is an extensive body of work on the taxonomy of helminths of sheep in these regions (Qi et al. 1983), little is known about their effects on meat and wool production. This paper presents work undertaken as part of ACIAR Project 8555, investigating the effects of gastrointestinal helminth infections on sheep and wool production, the epidemiology of these infections and the reliability of current measures used to control them.

Materials and Methods

The study was undertaken at Nan Shan farm in the Xinjiang Uighur Autonomous Region and Huang Cheng farm in Gansu province. Details of the location, topography and sheep management practices on these two farms are given in Lindsay et al. (this report). The management cycle on each farm can be divided broadly into three periods: the time sheep graze on spring and summer pastures; the time the sheep spend on autumn pastures; and the time during which the sheep are on winter pastures and fed extra rations to supplement their diet. The timing, duration and location of sheep within each of these time periods and the amounts of supplementary feed given are shown in Figure 2 of Lindsay et al. (this report).

To measure the effects of helminths on the productivity of sheep, groups of either weaned lambs or 2-year-old ewes were established and given different treatments to vary the degree of parasitism. These groups grazed together in their respective flocks which were managed according to the regular practices on each farm. The details of the treatment and the subsequent observations made are given in the introduction by N. Anderson to this section of the report.

Results

Helminths

Nan Shan farm

The most common helminths found at Nan Shan farm were the strongyles *Nematodirus, Trichostrongylus, Ostertagia* and *Marshallagia.* High numbers of intestinal fluke, *Skrjabinotrema ovis,* were present in both weaners and ewes after their return from the summer pastures. Benzimidazole anthelmintics are not considered to be effective against this species so separate experiments were conducted in years two and three to assess the efficiency of some common flukicides.

Worm egg counts. Mean faecal counts of nematode eggs from the untreated weaners and ewes were higher in the first year than in the second, with counts averaging between 100 and 200 epg (Fig. 1). A rise in egg counts in spring was evident in both years, particularly for the ewes in year one, in which mean counts rose to 600 epg in mid April. This may represent a post-parturient rise in egg output because the pattern from weaners showed a less pronounced rise.

Worm egg counts in the faeces of sheep in the capsule-treated groups of both classes of sheep were essentially zero throughout the experiment. The routine treatment, although reducing egg output when compared to that observed in the untreated sheep, did not reduce egg output to zero. Nevertheless, mean counts were generally below 30 epg (Fig. 1).

Separate counts of the distinctive eggs of *Skrjabinotrema ovis* were not made.

Worm counts. Adults of the genus *Nematodirus* were the most prevalent worms found in weaners during the period from winter to early summer

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(Fig. 2). Mean numbers in the weaners reached 9500/sheep in January 1990. A similar pattern was observed for the other nematode species, with lower peak numbers occurring during the coldest time of the year. The numbers in the ewes were similar in pattern and magnitude to those in the weaners.

Infections of Skrjabinotrema ovis. *Skrjabinotrema ovis* is a small fluke, about 1 mm in length, which parasitises the small intestines of sheep and goats in the central Asian region. Apart from its life cycle, little is known of its seasonal prevalence or pathogenicity for sheep. Counts of up to 65 000 were found in individual weaners and ewes killed on Nan Shan farm. The flukes were most numerous in the second year, which was wetter than the first, and the highest mean counts were recorded in September 1989 when the sheep were grazing summer pastures at high altitudes.

Two anthelmintic efficacy experiments were undertaken in October–November of years two and three. Separate groups of weaners, with equivalent *S. ovis* egg counts, were treated with a number of anthelmintics, most of which had proven activity against the liver fluke, *Fasciola hepatica*. Faecal egg counts from treated and untreated groups, at 16 days after treatment, and worm counts from selected groups, were used to measure efficacy. Neither oxyclosanide nor triclabendazole was effective in reducing the mean egg counts of treated sheep, whereas closantel and praziquantel reduced mean counts by up to 98%. Praziquantel at 25 or 50 mg/kg reduced worm counts by 99%. Albendazole at 15 mg/kg reduced mean egg counts by 83% and worm counts by 91%, but at 7.5 mg/kg and 0.5 mg/kg/day (controlled-release capsule) albendazole was ineffective (Anderson et al. 1993).

Huang Cheng farm

Strongyle parasites of the genera *Ostertagia, Trichostrongylus* and *Nematodirus* were the most prevalent nematodes encountered in the sheep at Huang Cheng farm. Small numbers of *Skrjabinotrema ovis*, never more than 25 flukes per sheep, were also recorded.

Worm egg counts. Mean faecal counts of nematode eggs from sheep in the untreated groups were always low in both classes of sheep, and never

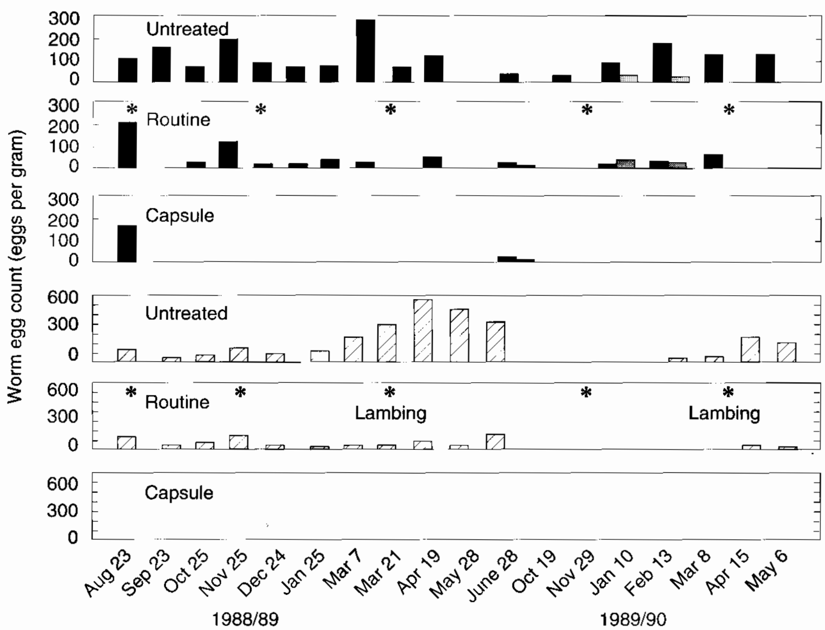

Figure 1. Mean worm egg counts in faeces from all treatment groups and classes of sheep at Nan Shan farm. Heavy shading = worm egg counts from weaners. Light shading = counts of *Nematodirus* spp. eggs from weaners. Cross hatch = worm egg counts from ewes. Asterisks indicate times of routine treatment.

exceeded 300 epg (Fig. 3). A spring rise in egg count was evident, as was a post-parturient rise in the counts from ewes. The routine treatment did reduce the worm egg output of both weaners and ewes, but was only partially successful (Fig. 3). Egg counts from the capsule-treated sheep were always zero.

Worm counts. Worm counts for weaners and ewes at Huang Cheng farm followed the same pattern during year one, with the highest numbers of all species occurring during the period from late winter to early spring. Numbers were higher in the second year in the weaners but, unfortunately, no ewes were slaughtered for worm counts in year 2.

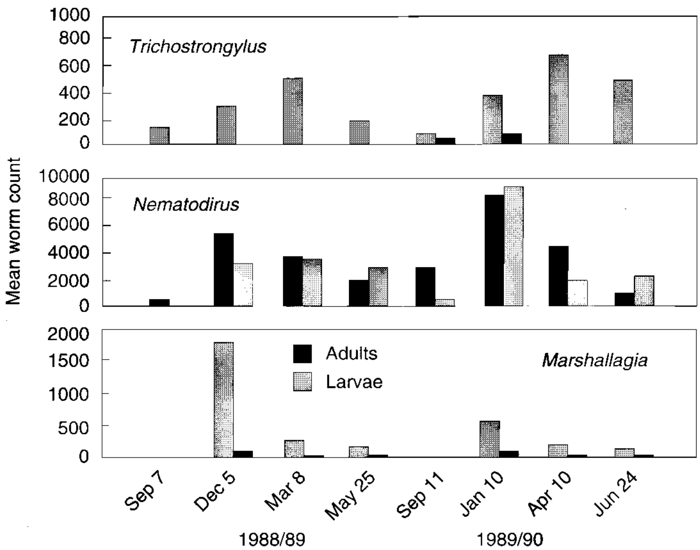

Figure 2. Worm counts from untreated weaners at Nan Shan farm.

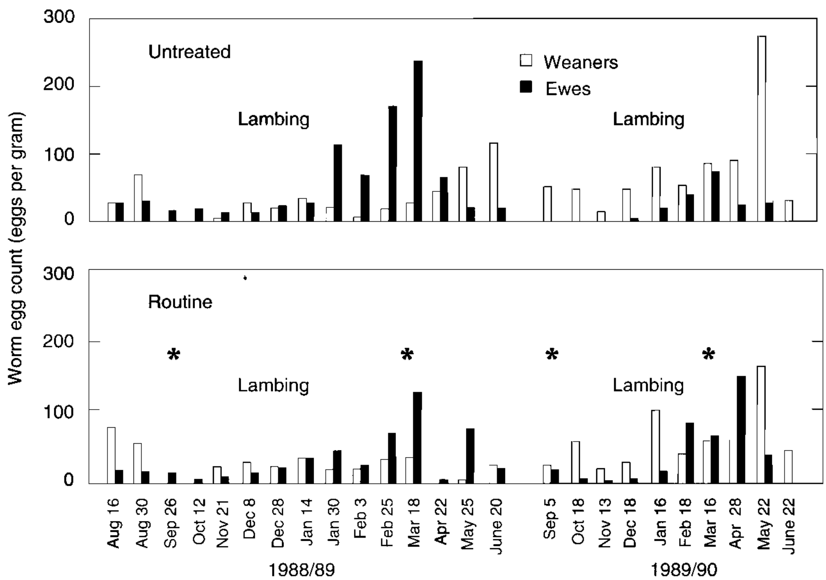

Figure 3. Mean egg counts from untreated and routine-treatment groups of weaners and ewes at Huang Cheng farm. Asterisks indicate times of routine treatment.

The pattern of infection varied between species, with moderate numbers of *Ostertagia* and *Marshallagia* present throughout the year and peaks of *Nematodirus* and *Trichostrongylus* in the spring.

Production

Nan Shan farm

Weaners generally gained weight throughout the year (Figs 4 and 5). Commencing at around 25 kg, these sheep progressively increased to 35 kg. Significant differences between treatment groups, in the mean gain in live weight, were limited to the winter period in each of the three years. Untreated weaners gained 12–13 g/day less than those given anthelmintic treatment and there was no difference in gain between the routine and capsule treatment groups.

Ewes from all groups, whether lambing or not, went through an annual cycle of weight gain in summer and autumn followed by a weight loss in winter and spring (Figs 4 and 6). At the start of each year, ewes weighed 45–50 kg and the weight gradually increased by about 5 kg until early winter. A subsequent decline in liveweight occurred during mid to late winter and throughout the spring. During this period the ewes lambed and were fed supplementary rations. By early summer the average weight of the ewes was once again 45–50 kg.

At Nan Shan farm the only significant effect of parasitism on the liveweight of ewes was observed before lambing in the winter of the second year. During this period, sheep in both the untreated and routine-treated groups gained weight at a rate of 15 g/day less than those in the capsule treated group.

Huang Cheng farm

Weaners at Huang Cheng farm were about 28 kg at the start of the year and grew steadily throughout the year to reach an average of about 38 kg by the start of summer (Figs 7 and 8). Parasitism caused significant losses in live-weight gain in both years of the study. During year one, sheep in the worm-free group gained at a rate of 9 g/day more than sheep in the untreated and routine-treated groups. In year two the differences in production were greater, with the worm-free sheep gaining an average 23 g/day more than the untreated and 9.4 g/day more than the routine-treated sheep.

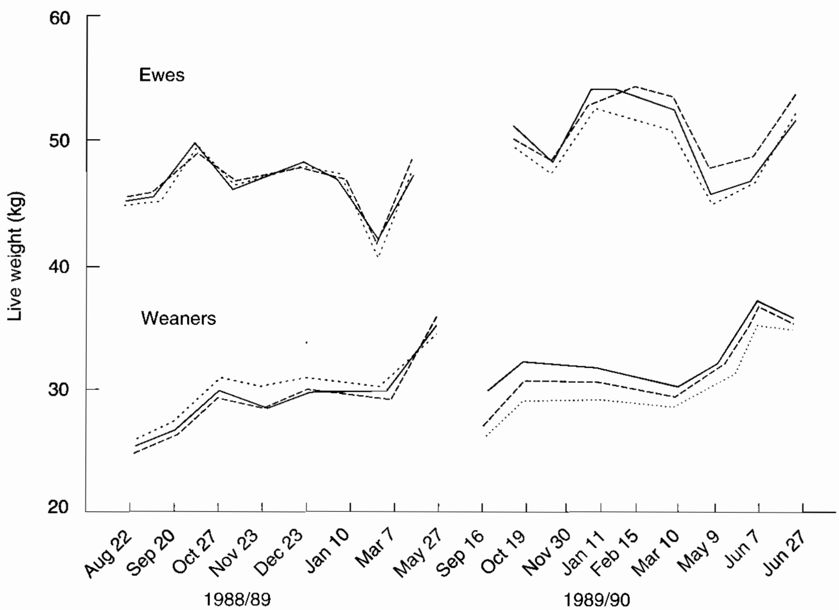

Figure 4. Mean live weights of weaners and ewes at Nan Shan farm over the first two years of the study. The groups of sheep are: solid line, untreated; dashed line, routine treatment; dotted line, capsule treatment.

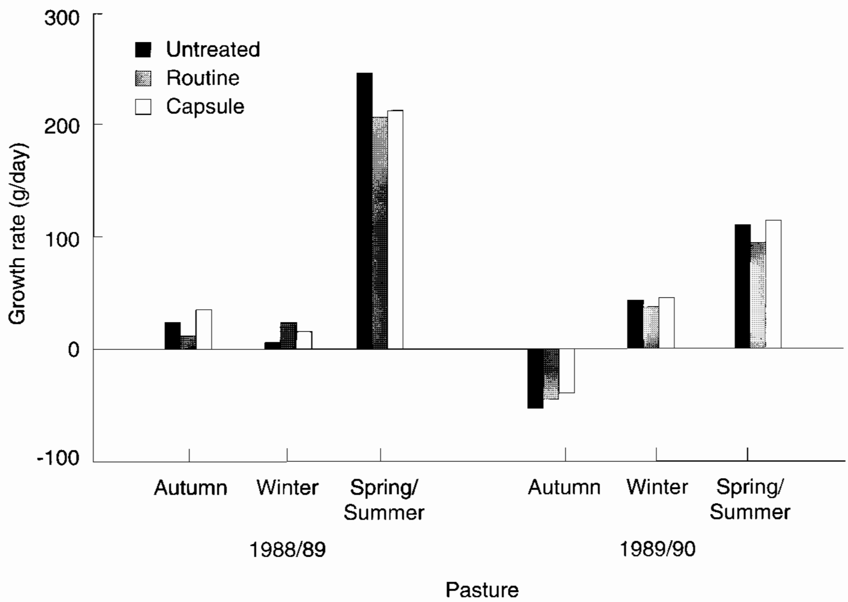

Figure 5. Weight gains of weaners at Nan Shan farm over the first two years of the study.

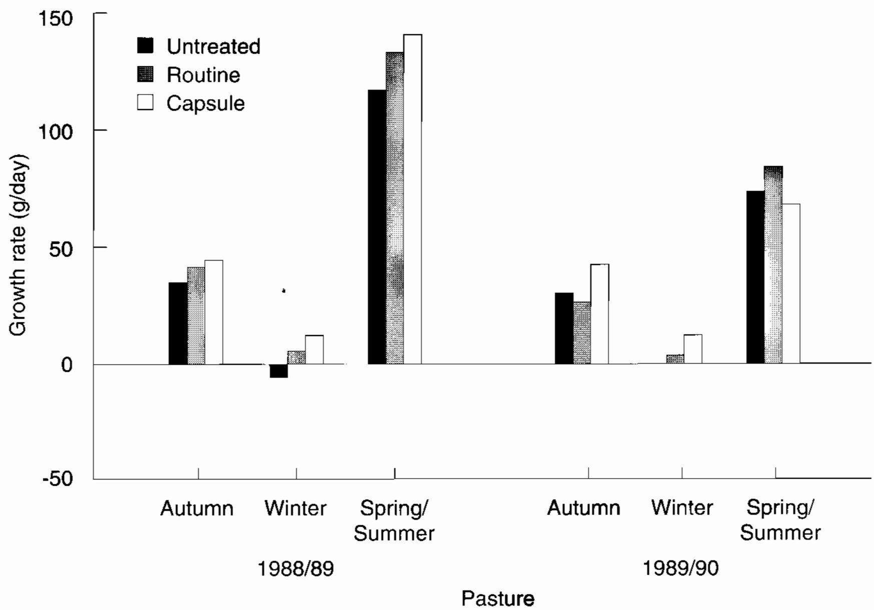

Figure 6. Weight gains of ewes at Nan Shan farm over the first two years of the study.

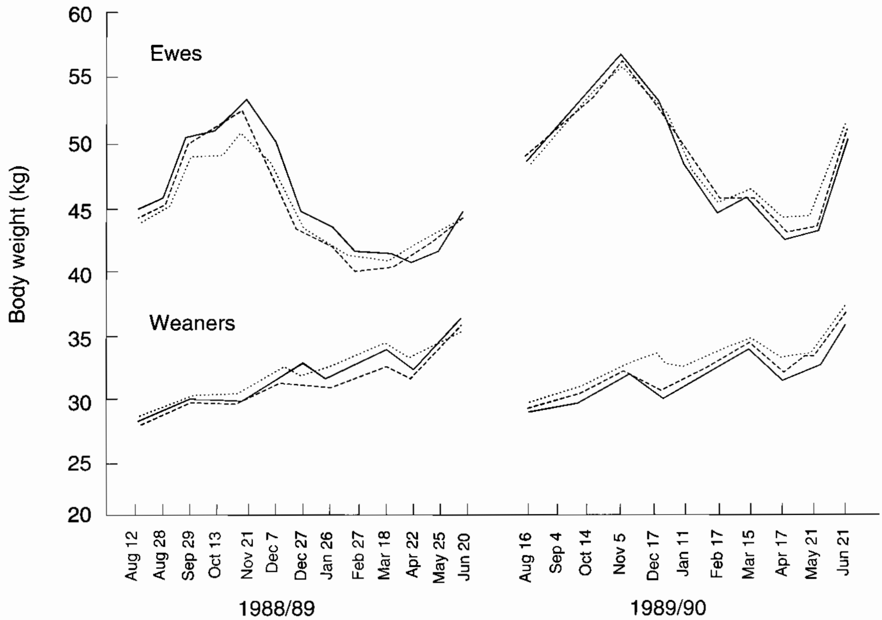

Figure 7. Liveweights of weaners and ewes at Huang Cheng farm. Groups of sheep are: solid line — control; dashed line — routine treatment and dotted line — capsule.

Sheep given the routine treatment gained 13.5 g/day more than the untreated sheep. Internal parasites also contributed to a production loss in the weaners during the late spring–early summer at the end of the second year when the worm-free sheep increased in weight by 14.5 g/day more than the untreated sheep.

There was no pattern to the effects of parasitism on liveweight gains of ewes (Figs 7 and 9) but reductions in gain occurred in the periods immediately before and after lambing in year 1 and during the spring of year 3. In all cases, sheep in the worm-free group performed better than sheep in the untreated and routine-treatment groups. Although infrequent in occurrence, the difference in gain between these groups was relatively large: 33 g/day and 84 g/day.

Lambing

On both farms the mean birth weight of lambs ranged from 3.7 to 4.2 kg. There was no significant difference between the weights of lambs born to ewes in different groups in either year on either farm.

Wool production

There was no significant difference between treatment groups for wool production from weaners or ewes on either farm in either year. The weights of greasy wool ranged from 4 to 4.8 kg/weaner and 4.6 to 5.2 kg/ewe on both farm (Tables 1 and 2).

Table 1. Greasy wool weights from weaners and ewes recorded at Nan Shan farm during the three years of the study. WWt = greasy wool weight.

Period	Treatment	Weaner WWt.	s.d.	Ewe WWt.	s.d.
Year 1	Untreated	4.7	0.8	4.4	0.5
	Routine	4.5	0.8	4.4	0.6
	Capsule	4.7	0.8	4.2	0.6
Year 2	Untreated	4.1	0.6	5.4	0.9
	Routine	4.4	0.5	4.7	0.7
	Capsule	4.3	0.5	5.6	0.8
Year 3a	Untreated	4.3	0.6	5.0	0.7
	Capsule	4.5	1.3	5.2	0.9
Year 3b	Untreated	3.9	0.8	5.4	0.9
	Capsule	3.8	0.5	5.3	0.8

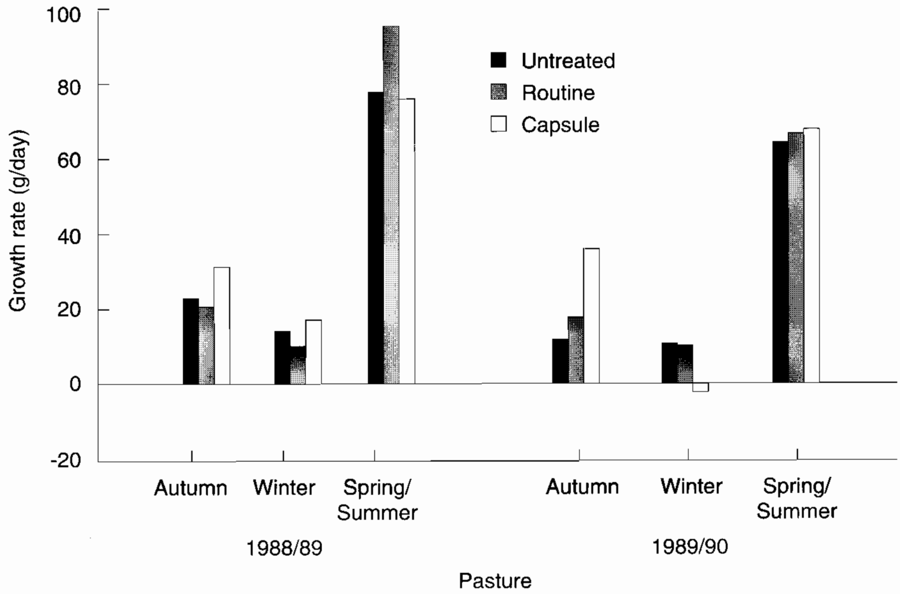

Figure 8. Weight gains of weaners at Huang Cheng farm over the first two years of the study.

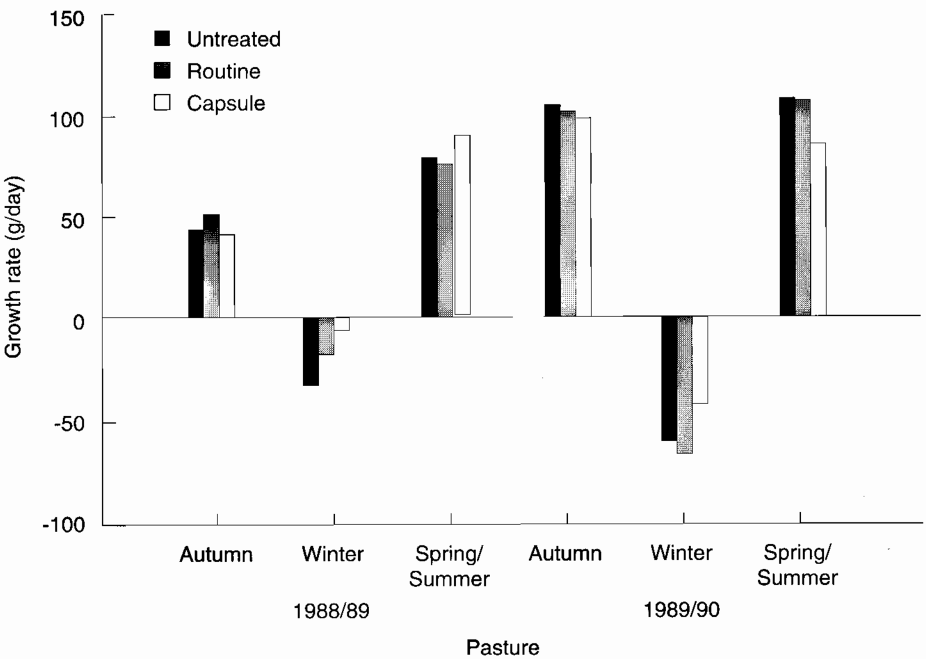

Figure 9. Weight gains of ewes at Huang Cheng farm over the first two years of the study.

Table 2. Weights of greasy wool shorn from weaners and ewes at Huang Cheng Farm over the three years of the study. WWt = wool weight.

Period	Treatment	Weaner WWt.	s.d.	Ewe WWt.	s.d.
Year 1	Untreated	4.8	0.8	3.9	0.6
	Routine	4.8	0.8	4.0	1.0
	Capsule	4.6	0.9	4.0	0.8
Year 2	Untreated	4.5	0.7	4.4	0.6
	Routine	4.4	0.5	4.6	0.9
	Capsule	4.4	0.9	4.2	0.6
Year 3a	Untreated	5.0	1.0	4.2	0.7
	Routine	4.5	0.9	3.9	0.6
	Capsule	4.1	0.6	4.6	1.0
Year 3b	Untreated	4.4	0.9	4.5	0.8
	Routine	4.3	0.9	4.3	0.7
	Capsule	4.4	0.8	4.6	0.7

Discussion

Internal parasitism resulted in significant losses in production in both weaners and ewes on both Huang Cheng and Nan Shan farms. These losses were restricted to particular times of the year, and contributed to the stress placed on sheep during the harsh winter and spring in northern China.

On Nan Shan farm, the time of greatest prevalence of parasites in the weaner flock was winter. The parasites *Nematodirus, Marshallagia, Trichostrongylus* and *Skrjabinotrema ovis* all reached greatest abundance during this time. Only *Ostertagia* was found in greater numbers in the warmer months.

At Nan Shan farm the effects of internal parasitism resulted in reduced weight gain in weaners in the winter of each year. The losses experienced in winter probably result from a mixed infection, with *Nematodirus* spp. likely the most important contributor to this production loss. There was no pattern to the weight losses observed in ewes, but they did occur and thus there is a need for parasite control in both classes of sheep.

At Huang Cheng farm the most significant parasites were *Ostertagia* and *Trichostrongylus*. The effects of these parasites on sheep production were sporadic and involved only small differences between groups. There was no pattern in either weaners or ewes with respect to reduced weight gains and there were no reductions in lambing performance or wool growth. There were, however, losses due to parasitism at various times and these losses were often quite severe. For example, during the winter of 1988–89 parasitised ewes lost 84 g/day more than non-parasitised ewes during their annual cycle of weight loss in early winter. Such a loss could have serious implications for the ability of the sheep to survive the harsh winter with its nutritional and cold stresses. Thus, there is a need for an effective parasite control strategy on Huang Cheng farm if substantial losses from an outbreak of parasitic disease are to be avoided. Such a strategy for both Huang Cheng and Nan Shan farms is presented by Anderson and Petch (this report).

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Conclusions Resulting from the Helminthological Studies in Northern China

N. Anderson and D.A. Petch*

THE helminthological studies in ACIAR Project 8555 were conducted in three environments typical of those throughout northern China. The broad epidemiological picture of the helminth infections in these environments therefore provides a basis for both the assessment of their economic importance for sheep and wool production and for strategies of control that can be formulated for evaluation throughout the region.

Common Helminths

Nematode parasites were the most common helminths and although a different spectrum of genera was found at each site, *Nematodirus oiratianus* was abundant at all sites. The smallest worm burdens, comprising the genera *Nematodirus, Ostertagia, Trichostrongylus* and *Marshallagia*, were found at Huang Cheng farm, which probably reflects the severe environmental conditions associated with its high elevation (2500–3000 m). At the other alpine site, Nan Shan farm, the small intestinal trematode, *Skrjabinotrema ovis*, was also abundant but its impact on sheep production could not be properly assessed because the controlled-release capsule containing albendazole used to maintain sheep free of nematodes was ineffective against this parasite. From efficacy studies on a number of flukicides, it was found that praziquantel was the drug of choice for treatment for *S. ovis* infections; efficacy at 25 mg/kg was 99%. The effectiveness of praziquantel now provides the opportunity to determine the impact of *S. ovis* infections on the productivity of sheep in the Xinjiang region.

At Aohan farm, on the Mongolian grasslands, *Haemonchus contortus* and *Nematodirus oiratianus* were the most abundant species, together with small numbers of *Oesophagostomum columbianum.*

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The Epidemiological Pattern of Nematode Infections

The seasonal prevalence of nematode infections was broadly similar at each of the three sites. In the alpine areas, contamination of pasture was greatest in the spring, and on the grasslands in summer. A rise in worm egg output in spring was seen in both young and mature sheep, with an additional contribution from the post-parturient rise in egg counts from ewes which lambed from February to April. On the grasslands, there was a maturation of inhibited *H. contortus* larvae in spring, although the highest output of worm eggs did not occur until summer, presumably due to the acquisition of new infection. Relative to other times, little contamination of pastures occurred during winter. The results clearly showed that all nematode eggs, except the *Nematodirus* spp., were killed by temperatures consistently below 0°C. There was no development of *Nematodirus* eggs during winter, but they remained viable until spring temperatures increased sufficiently to allow development to proceed and hatching to occur. Accumulation of eggs over winter and their synchronous development in spring could result in sheep being exposed to relatively high amounts of infection over a short period in, say, early summer.

In contrast to worm eggs deposited on pasture, or in the sheep yards, those deposited in the sheep sheds during winter were able to develop to the infective stage and therefore constitute a reservoir of infection to maintain the life cycle of these nematodes. The extent to which sheep become infected in the sheds, and the significance of this infection for contamination in spring, need to be examined in more detail than was possible in these studies.

The most successful development of eggs to the infective stage occurred during summer, and the survival of infectives on pasture persisted for several weeks. However, the highest worm burdens in sheep generally occurred in autumn, probably soon after the sheep returned to the spring/autumn pastures. Thus, it would appear that only one generation of these nematodes is possible each year in these environments.

Despite the very evident overgrazing at all sites, especially those designated for spring and autumn grazing, the total worm burdens of the sheep were modest in comparison with those reported from more temperate environments of the world. There are several reasons for this:

- the severe climate, with long, harsh winters, markedly reduces the time during which the free-living stages can develop and survive on pasture;
- the low stocking rates, relative to temperate environments elsewhere, result in a reduced probability that sheep will encounter infective larvae;
- current grazing management practices further limit both the place and period of effective transmission of nematode infections, because sheep are moved to different pastures throughout the year; and
- the regular use of routine treatments over the past years could have reduced the overall abundance of nematode larvae on the common grazing areas of these farms.

No measurements were made of the development and survival of the free-living stages of the common nematodes on the high-altitude summer pastures because of the difficulties of conducting studies at such remote sites. However, it seems likely that continuing cold conditions on these pastures would severely limit free-living development and the number of larvae available to sheep. In contrast, the spring and autumn pastures at lower altitudes would provide favourable conditions for free-living development from at least the end of spring until mid-autumn. There is usually considerable overlap in the areas designated for spring and autumn grazing because they tend to be readily accessible from the sheds used in winter. Consequently, more or less the same pastures are grazed, and contaminated, in spring before the sheep are moved to the higher altitudes and again in autumn on their return to winter quarters. Therefore, infective larvae on autumn pastures could be derived from eggs deposited in spring as well as from eggs deposited in autumn itself. This may account for the generally higher worm burdens of sheep killed in winter and early spring.

Effects of Nematode Infections on Production from Merino Sheep

Though worm burdens were only modest in size, they were sufficient to have a significant impact on sheep production. The losses were usually expressed as decreased gains in liveweight of both young and mature sheep, and decreased wool growth in weaners.

The greatest losses were observed on the grasslands where live weights of parasitised weaners at the end of autumn were 8–15% lower than worm-free sheep. A loss of 0.4–0.8 kg of wool was also noted from these sheep. Decreased weight gains among ewes occurred in some but not all years, and within the limitations of the present study no distinct pattern could be discerned. Bearing in mind that all ewes lost weight during late autumn, winter and spring, it was noted that losses in weight were often less in ewes treated for parasitism and, in some circumstances, would probably enhance the survival of ewes during winter. Over all groups and years, the range in difference between treated and untreated sheep was 9 to 84 g/day.

Generally, wool production from ewes at all sites and from weaners on the alpine farms was not significantly reduced because of the nematode infections present.

Economic Impact of Helminth Infections

Because of the limited data available on seasonal differences in productivity from treated and untreated sheep and the value given to higher body weights of worm-free sheep, estimates of the financial losses attributable to helminth infections must be regarded as indicative only. However, data from Aohan farm can be used to illustrate the benefits associated with the effective control of nematode infections in the Inner Mongolian Autonomous Region. In this calculation it is assumed that the small differences in productivity between untreated and worm-free sheep on Aohan farm represent a mean value for the whole region.

The total sheep population of Inner Mongolia is 20.7 million, of which 15%, or about 3.1 million, are weaners. If greasy wool production from each weaner were increased by 0.4 kg in the absence of helminth infections then, at a price of 7.5 Yuan per kg, the value of the increased production would be 9.3 million Yuan. Similarly, weaners treated for helminth infections were 8 kg heavier than untreated ones and, at 1.8 Yuan per kg, the extra production has a value of 44.7 million Yuan. The total value of effective parasite control in weaner sheep therefore amounts to 54 million Yuan.

The cost of two anthelmintic treatments a year (see recommendations to follow) has been put at 2 Yuan/weaner for labour and chemicals. Total cost is therefore 6 million Yuan and the net benefit of helminth control is 47.8 million Yuan, or a benefit–cost ratio of 8.7. For wool production alone the net benefit is 3.1 million Yuan and the ratio 1.5. The high cost of treatment is due to the policy which requires anthelmintics to be administered by veterinarians rather than by farmers.

Recommendations for the Control of Helminth Infections in Northern China

It could be argued that, because the effects of helminths on sheep in the alpine areas of northern China were both small and irregular in occurrence, routine treatments for their control would not be cost-effective. However, it should be borne in mind that the studies were limited to two years and an adequate measure of the year-to-year variation in helminth numbers and their effects on production has not yet been obtained. More importantly, the studies were conducted on farms where routine treatments for the control of nematode infections had been implemented for several years. Since it was demonstrated that these treatments did reduce contamination rates substantially, it is likely that the amount of infection on these farms was much less than on farms where parasite control was not used. Before recommendations can be made for general use, further work is needed to determine the amounts of infection on other farms in the region and the extent to which they affect the productivity of sheep.

The anthelmintic treatments used routinely on the farms were effective in reducing, but did not eliminate, the losses in production due to nematode infections. A change in the timing of these treatments may be all that is required to obtain the maximum benefit from them. In the light of the epidemiological pattern described above, it is recommended that all sheep, in both grassland and alpine environments, be treated with albendazole (10 mg/kg) in late November or early December to remove the worm burdens accumulated from summer onwards, before the onset of the inevitable nutritional stress which occurs during winter. This may be all that is necessary to reduce parasite numbers sufficiently to avoid losses in production from sheep in alpine areas. Though losses in production were small and erratic in occurrence, all classes of sheep, and of goats, which harbour the same helminths as sheep, should be treated because of their contribution to the contamination of the common grazing areas. A second treatment in early April could be considered, to prevent contamination of the important spring and autumn grazing areas, especially if it is subsequently found that significant re-infection of sheep occurs from material in the sheds during winter.

On the grasslands, a second treatment of albendazole, or levamisole, in March would remove the inhibited populations of *H. contortus* acquired after the first treatment. If closantel were used for the second treatment, a period of 4–6 weeks would follow when transmission of *H. contortus* infection was prevented and eradication of this species could perhaps be achieved. A process of monitoring helminth infections for a year or two after implementation of the two-treatment strategy may show that the second treatment in spring could be omitted. This would halve the cost of treatment.

A comparison of these preventive treatment strategies should be undertaken at various locations throughout northern China to establish the most effective one for general promotion to sheep producers. Some care will be needed in the design of these studies because of communal grazing practices which could negate strategies based on the prevention of pasture contamination. Boundaries between brigades are often better circumscribed than are the areas used by shepherds within brigades. Consequently, it may be better to utilise the brigade rather than the flock as the experimental unit.

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