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Production of Fine Wool in Northern China: Effect of Nutrition and Helminth Infections

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Contents

An Introduction to ACIAR-Supported Studies of Sheep Production in Northern China

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APPROXIMATELY 100 million sheep are found in the northern provinces of China, which have extensive areas of marginal agricultural land suitable only for grazing livestock (Zhang 1990). About 30% of wool production is derived from 'fine' woolled sheep (medium to strong by Australian standards), based upon Merino types originally introduced from Russia and Australia (Zhang 1990). Increased productivity, especially of 'fine' wool, from sheep in the less populated, mountainous and grassland areas of northern China has been nominated by the Chinese Ministry of Agriculture, Animal Husbandry and Fisheries as a national priority. As a consequence of this decision, the Chinese Academy of Agricultural Science sought, through ACIAR, the collaboration of Australian scientists in joint studies on the limitations placed on sheep production by helminth infections and poor nutrition. This paper gives the background to ACIAR Projects 8555 and 8454.

The cold arid environment in the northern Provinces of China is harsh by any standards. Seasonal temperatures range from –40 to +40°C, rainfall from 100 to 350 mm annually and with only 80–120 frost-free days, pasture production is severely limited. Green feed is usually plentiful for 5 months but dry residues and crop stubbles are the main sources of fodder for the remaining 7 months of each year. During the dry, cold winters, sheep are housed, but graze during daylight hours. In winter and spring they are fed supplements of hay (lucerne or meadow), maize-based concentrates and silage, depending on availability. The pastures consist mainly of native grasses, with shrubs and forbs. The legume content of the pasture is typically very low.

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The marked seasonal effects of pasture quality and availability upon wool production in northern China have parallels in the Mediterranean regions of southern Australia, except that the 'poor' season occurs in winter in China and in summer in Australia. However, it was expected that similar principles of husbandry and nutrition would apply and it was considered that improvements could be made. Of particular interest was the occurrence of reduced tensile strength in wool fibres, manifested as tender or broken wool, during the 'poor' season in both countries. Measurement of nutrient supply in relation to available forage and nematode infections was needed to characterise their effects on the quantity and quality of wool produced and subsequently to formulate better management practices.

The grazing system is semi-nomadic in character, with shepherds accompanying the flocks of 120–200 sheep to different pastures throughout the year. In the mountainous areas of Xinjiang and Gansu, animals spend the winters in the sheltered valleys, moving upwards through the spring/autumn pastures on the alpine slopes, to the summer pastures above the snowline, then return at the end of summer. This regimen presents logistic difficulties to providing supplements throughout the year, and supplementation tends to be restricted to the winter and spring months. On the Inner Mongolian grasslands the patterns of movement are less pronounced but alternate pastures are often used for summer grazing. Ewes are shorn in early summer, artificially inseminated in late summer, lamb indoors during winter and are weaned in April before the next journey to summer pastures.

Location of the Studies

ACIAR Projects 8454 (mineral nutrition of sheep) and 8555 (effects of helminths and nutrition on sheep production) were undertaken at three farms in northern China (Fig. 1). Details of each of the locations follow.

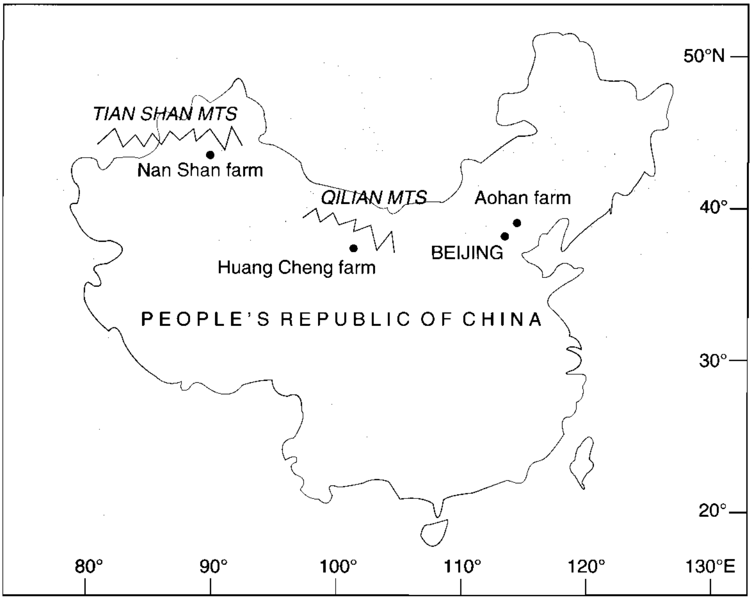

Figure 1. Locations of the three farms in the study.

Nan Shan farm, Xinjiang Uighur Autonomous Region

Nan Shan farm is located on the foothills of the Tian Shan Mountains in the Xinjiang Uighur Autonomous Region (43°31'N, 87°00'E). Nan Shan farm comprises 21 000 ha (320 000 mu) of which 11 000 ha (170 000 mu) is available for grazing purposes. There are, on average, 10 500 sheep and 3000 cattle, horses, goats, camels, and donkeys on Nan Shan farm. The farm ranges in elevation from 900 to 2600 m, with a temperature range from –15°C in winter to 30°C in summer. Average annual rainfall over the farm ranges from 300 to 600 mm and is concentrated in the warmer months of the year. Sheep are moved between pastures depending on the time of year. Details of sheep managements and movements are shown in Figure 2(a) and Table 1.

Sheep breeding using artificial insemination is carried out for a period of 35 days (2 ovulation cycles) beginning in mid-October, then the ewes and rams are run together for a further 18–20 days. Lambing occurs in sheds from mid-March to the end of April and the lambs are kept indoors for 20 days. Suckling is restricted to 30 minutes in the morning and 30 minutes in the afternoon. After 20 days the lambs are kept in open pens and allowed to graze. Weaning takes place on the summer pastures in August and lambs are then separated into flocks of males and females. The average weight at weaning is around 25 kg.

Feed supplements are provided to the ewes from mid-October until the following March, as indicated in Figure 2(a). The concentrate used is a mixture of maize (55%), wheat bran (20%), sunflower meal (20%) and bone meal + salt (5%).

Table 1. Characteristics of the seasonal pastures at Nan Shan farm, Xinjiang Uighur Autonomous Region

Pasture	Type	Grazing period	Altitude (m)	Rainfall (mm)	Area (ha)
Summer	Alpine	Jul–Sep	2500–3000	600	2500
Autumn Spring	Hilly-meadow	Oct–Nov May–Jun	1900–2500	400	3100
Winter	Arid, semi-desert	Dec-Apr	1100–1900	300	5800

Huang Cheng farm, Gansu Province

Huang Cheng farm is situated on the northern side of the southeastern section of the Qilian Mountains in Gansu Province (37°55'N, 101°52'E) (Fig. 1). It ranges in elevation from 2400 to 3500 m. Average daily temperatures range from –30°C in winter to 25°C in summer. Average annual rainfall is 375 mm concentrated in the warmer months. The farm has an area of 12000 ha (185 000 mu) and supports 14–16000 sheep, 300–400 horses and 1300 yaks and goats.

Sheep are grazed on different pastures depending on the time of year. The movements of sheep at Huang Cheng farm are shown in Table 2. Details of other aspects of sheep management are shown in Figure 2(b).

Table 2. Characteristics of seasonal pastures at Huang Cheng farm, Gansu Province

Pasture	Grazing period	Location	Altitude (m)
Summer	Jul–Sep	mid-level slopes	2800–3500
Autumn	Oct–Nov	lower slopes	2600–2800
Winter	Nov–Apr	valley floor	2500–2600
Spring	May–Jun	valley floor/ lower slopes	2500–2700

Ewes lamb in sheds between November and January. The lambs remain in the sheds until 2 weeks after weaning in April. Ewes graze at pasture during the day, but stay with the lambs overnight.

Hay is fed to ewes with lambs from early December at a rate of 250 g/head/day for 3 weeks, then continued for a further 2 months at 100 g/head/day. Barley:peas (67:33) are fed at 100 g/head/day from early December for 2 weeks, then 2 types of barley (50:50) are fed for a further 4 months at 200 g/head/day. Feeding of silage begins around mid-December and continues for 3 months. The amount of silage fed increases during lactation to a peak intake of 3 kg/head/day, decreasing to 250 g/head/day by the end of lactation.

Lambs receive hay supplements, ad lib, from 20 days of age. A mixture of barley (35%), peas (30%) and bran (35%) is also fed until weaning. At weaning, consumption is about 250 g/head/day.

Aohan farm, Inner Mongolia Autonomous Region

Aohan farm is located on the eastern grasslands of Inner Mongolia at latitude 42°18'N and longitude 119°49'E. The farmland is 400–500 m above sea level. The annual temperature range is –29°C to 37°C, with 130 frost-free days each year. The annual rainfall is 300–350 mm. The farm is 15000 ha (225 000 mu) in area and supports 16000 sheep together with 1000 horses, cattle and donkeys. Of the total area, 900 ha are used for grain production and 2800 ha for hay. Some 2000 ha have improved pasture and 6300 ha are native pasture. The majority of the farm is divided into 500 × 500 m blocks bounded by trees. Sheep are not generally moved between pastures at Aohan farm, although during summer months they graze what are called 'summer pastures'. Details of the management of sheep throughout the year at Aohan farm are given in Figure 2(c).

Supplements consisting of hays and concentrates are fed to all classes of sheep during winter. The hays used on the farm usually contain around 10% legume with the grass. The usual composition of concentrate is maize (75%), oilseed meal (20%), bran (3%) and millet (2%).

Silage is also used as a supplementary feed for the ewes (including ewe hoggets) during February and March.

Background to the Parasitology and Nutrition Project (Project 8555)

Parasitology

Parasitologists at several institutes in the northern provinces have classified over 300 species of helminths from domestic livestock, and parasitic infections are regarded as an important cause of loss in sheep production throughout the region. In common with Australia, nematodes of the genera *Ostertagia, Trichostrongylus, Haemonchus, Nematodirus* and *Oesophagostomum* are seen as the most important helminth infections in China.

The seasonal changes in helminth numbers have been recorded in the Ili and Aksu districts in Xinjiang in 1977–78 and from southern Gansu in 1962–63. These studies showed that sheep were readily infected when grazing on summer and spring/autumn pastures, and were clinically affected during winter and spring. Routine treatments of anthelmintics, principally neguvon, thiabendazole, and copper sulphate, are given once before going to summer pastures and once before housing in winter. Responses to the treatments ranged from 2–10% for liveweight, 1–41% for wool production and 1–15% for survival of lambs. However, the effects of the treatments on the epidemiology of nematode infections had not been evaluated. Neither had the importance of subclinical infections been recognised. In Australia, it is well known that inapparent infections of nematodes cause substantial losses in sheep production, and that strategically timed treatments have profound effects on nematode populations and result in greater productivity and financial benefits (Berger 1982).

The major effects on sheep of infection with common gastrointestinal nematodes are a reduction in food intake and changes in protein and mineral metabolism. The implications for productivity from sheep on diets of poor nutritive value are therefore obvious. Furthermore, pen studies have shown that poor nutrition favours the establishment of nematode infections and reduces the sheep's ability to mount an effective immunological response. Comparable studies have not been undertaken anywhere, so the extent of the lost productivity resulting from the interaction between parasites and poor nutrition remains undefined for grazing conditions.

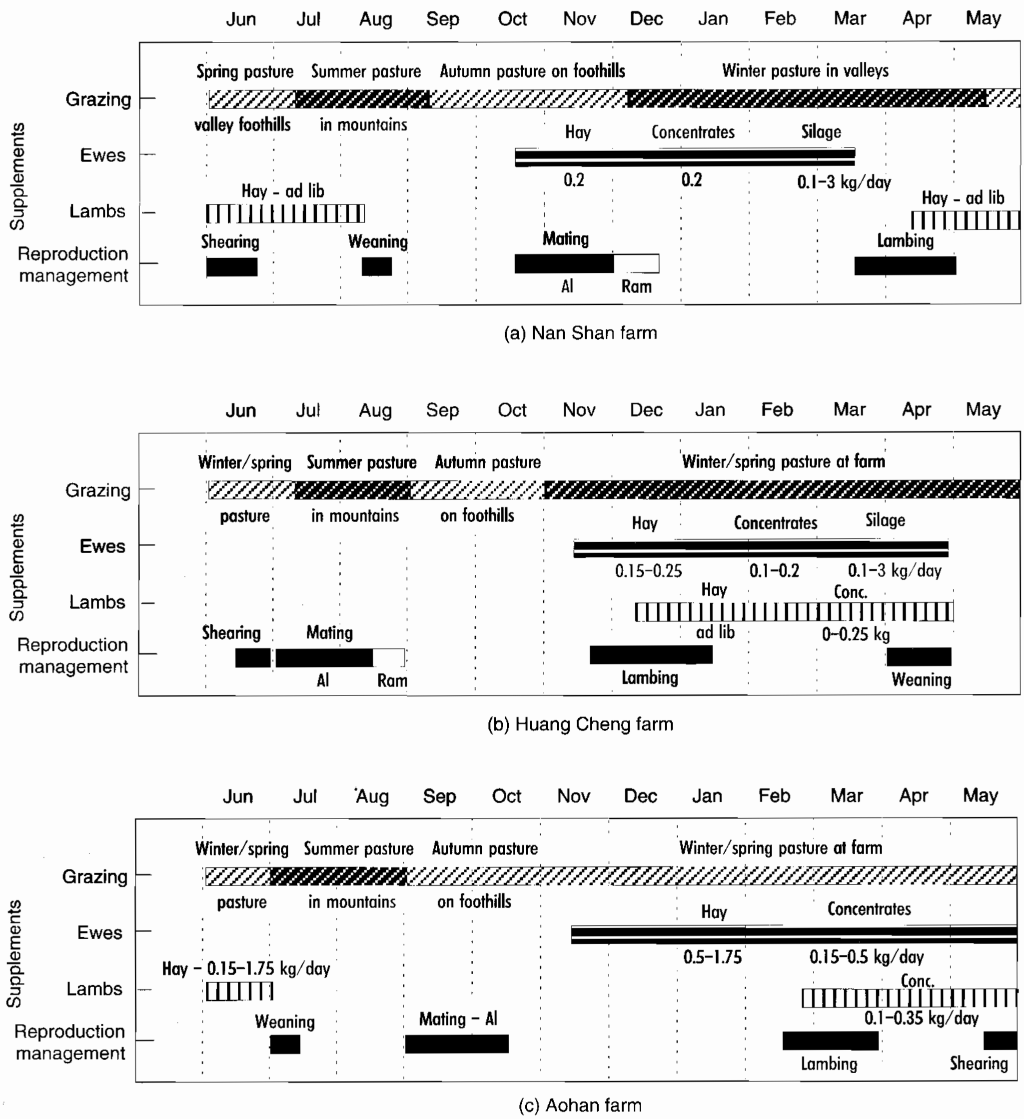

Figure 2. Sheep management and movements at three farms in northern China.

Nutrition

Data describing the nutritional value of herbage grazed throughout the year are virtually nonexistent for this region of the world and even data describing the nutritional value of hays and concentrate supplements are extremely limited.

Objectives of ACIAR Project 8555 'The effects of helminths and nutrition on sheep production in northern China'

The major aims of the helminth and nutrition project (8555) were as follows.

i) To measure the extent and effects of naturally acquired infections of gastrointestinal nematodes, and to evaluate current nematode control programs used in northern China.

ii) To determine the natural history of sheep nematode populations in this region as the basis for formulating and subsequent testing of an appropriate nematode control program.

iii) To measure and compare the nutritional status of nematode-infected and nematode-free sheep grazing pastures in northern China and to measure the seasonal production of wool from them.

iv) To determine the chemical composition and nutritive value of forages and supplements fed to sheep in northern China.

v) To relate the compositional and nutritional data to the production data, using computer models, for the purpose of improving feed use and for modifying sheep management systems.

vi) To assess the modified management systems under field conditions in northern China.

Experimental design used in Project 8555

On each of the three farms, three groups of weaner sheep and three groups of young ewes were used to assess the significance of helminth infections upon productivity. These groups received either no helminthic treatment (control group), were dosed with benzimadazoles according to routine practice (farm treatment group), or were given, in succession, three constant-release devices intraruminally to maintain these animals in a worm-free status throughout the year (worm-free group).

New groups of animals of the same age classifications were established each year to obtain a measure of the seasonal variation in productivity under defined conditions. Management procedures at the farms were modified during the second year so as to minimise production variations (rates of body weight change and wool growth) throughout the year. Changes during the third year involved refinements to modifications made in the second year.

Modifications involved addition of urea to concentrates to provide additional nitrogen, with the aim of improving rumen digestion of the low quality hay and silage and to increase microbial protein synthesis. They also involved changing the quantities and times of feeding supplements in an attempt to minimise liveweight variations throughout the year.

Objectives of ACIAR Project 8454 'Mineral nutrition studies of small ruminants in north-western and north-eastern China'

The two major aims of the project were:

i) to identify minerals limiting sheep and wool production in north-western and north-eastern China; and

ii) to determine the magnitude of the response in production when limiting minerals are provided.

Specifically, the levels of macro and microminerals in blood and tissues, and the annual growth and production patterns of sheep grazing pastures at three representative farms in northern China, were measured. Limiting elements at each of the locations were identified using conventional techniques or multivariate analysis. Responses in production (growth, reproduction or wool production) were then assessed after supplying limiting elements.

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Variations in Wool Growth with Nutrient Supply in Northern China

D.X. Lu*, Z.C. Feng*, H.R. Wang*, R.Z. Yang†, C.T. Ma§, D.B. Purser¶, J.R. Lindsay¶ and D.W. Peter¶

FIELD studies for ACIAR project 8555 were carried out in each of the three major grassland regions in northern China. These grassland regions, the north-eastern grassland (eastern Inner Mongolia and beyond), the Inner Mongolia–Ningxia–Gansu grassland and the Xinjiang grassland are located between latitudes 35 and 50°N and range in elevation from 200 to 3000 m. The grasslands cover approximately 160 million ha or some 45% of the total grassland area of China. They are characterised by the dominance of a wide range of genera and species of grass, although many other herbs and shrubs are present, especially in grazed areas.

Rainfall is predominantly in summer and generally low (<400 mm). There are wide extremes of temperature, ranging from above 30°C in summer to below –20°C in winter. The low winter temperatures are often accompanied by strong winds, which together pose serious problems for sheep production.

More than 56% of the sheep population of China is in these northern grassland regions, producing approximately 78% of the nation's fine wool. While this production is largely pasture based, variable quantities of a range of supplements are fed during winter and spring when pastures are in short supply. During these periods nutritional limitations are often reflected in poor wool growth and reductions in fibre diameter. Large reductions in staple strength are also common. These have serious detrimental effects on the processing and manufacturing of the wool.

In this paper some of the data collected in ACIAR project 8555 are used to relate measured change in wool growth with changes in the nutrient supply of sheep in the three grassland regions. Details of the three farms, Nan Shan farm in the Xinjiang Uygur Autonomous Region, Huang Cheng farm in Gansu Province and Aohan farm in the Inner Mongolia Autonomous Region, on which the data were collected, are described by Lindsay et al. (this report).

Variations in Wool Growth

Mean clean fleece weight of weaner and ewe flocks on each of the three farms is shown in Table 1. While the data are not directly comparable between farms because of differences in genetics, nutrition, climate, disease, etc., the individual coefficients of variation provide a guide to the large, within-farm variability. The magnitudes of the coefficients of variation indicate that there is considerable potential for improving production on each farm, especially in the weaner flocks at Nan Shan and Aohan farms.

Seasonal fluctuations in the growth rate of wool and in fibre diameter were measured on each farm using dyebanded staples of mid-side wool. Table 2 provides an example of these measurements in one year. It illustrates the large seasonal variation in wool growth rate and fibre diameter and the general similarity in patterns of production between farms. The seasonal pattern is characterised by a marked peak in summer, and a trough in winter–early spring. On the basis of the coefficients of variation in growth rates of wool, the potential for improving within-flock production appears high. The large differences between seasons suggest that improvements in management and nutrition alone may have the potential to increase wool production by 50–100%.

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Table 1. Clean fleece weights and coefficient of variation in 1988–89.

Farm	Clean fleece weight (kg)	Coefficient of variation (%)	
	Weaners		
Huang Cheng	2.1 ± 0.5	23	(n = 100)
Nanshan	1.6 ± 1.0	61	(n = 22)
Aohan	2.0 ± 0.9	43	(n = 22)
	Ewes		
Huang Cheng	2.1 ± 0.5	22	(n = 100)
Nanshan	2.2 ± 0.7	31	(n = 28)
Aohan	2.6 ± 0.6	22	(n = 22)

Wool Growth in Relation to Nutrient Intake

There is evidence that the growth rate of wool of grazing sheep can be closely associated with nutrient intake (Allden 1979). However, the physiological status of the sheep, the quantity and quality of herbage available, and environmental factors, as well as management practices, all impact on wool growth. In some experiments where the effects of such factors have been minimised the growth rate of wool has been shown to be directly proportional to feed intake (Allden 1979). Using data collected at Aohan farm in 1988–1989 no such relationship could be established. However, as shown in Figure 1, the growth rate of wool at Aohan followed a similar seasonal pattern to the intake of metabolisable energy (MEI; MJ/day) and crude protein (CPI; g/day). Significant relationships were established between wool growth rate and metabolisable and crude protein intake of both weaners and ewes. These were as follows:

Weaner

$$WGR_W = -26.22 - 0.40X_1 + 12.62X_2 - 0.73X_2^2$$
$(n = 10, r = 0.980, P < 0.01)$

Ewe

$$WGR_E = 16.59 - 0.21X_1 + 7.53X_2 - 0.34X_2^2$$
$(n = 10, r = 0.905, P < 0.05)$

where:

WGR = growth rate of clean wool (g/day)
X_1 = CPI (g/day)
X_2 = MEI (MJ/day)

The magnitude of the coefficients associated with energy and protein intake suggest that energy intake was perhaps a more important determinant of wool growth than dietary protein. This would accord with the results of Hogan (1970), who showed that the microbial protein available for digestion and absorption in the intestine was more closely related to the intake of digestible energy by the sheep than to the protein content of the diet. The lack of consistent responses in wool produc-

Table 2. Seasonal variation in growth rate of greasy wool, fibre diameter and rate of staple extension of ewes.

	Period					Overall mean	CV
	Summer	Autumn	Early winter	Winter–spring[a]	Spring		(%)
Wool growth rate (g/day)							
Nanshan	23.3	17.3	9.8	7.0	6.5	12.2 ± 6.6	51
Aohan	–	10.2	7.1	4.3	7.1	7.4 ± 2.4	33
Huang Cheng	13.5	9.7	6.4	1.8	2.9	6.9 ± 4.3	63
Fibre diameter (µm)							
Nanshan	24.5	22.8	19.8	16.6	17.5	20.2 ± 2.8	15
Aohan	–	23.2	19.6	16.4	17.1	19.1 ± 2.3	14
Huang Cheng	–	–	–	–	–	21.5 ± 2.8	13
Staple extension rate (mm/day)							
Nanshan	0.38	0.32	0.20	0.18	0.19	0.25 ± 0.07	32
Aohan	–	0.32	0.22	0.18	0.40	0.28 ± 0.09	32

[a] Lambing occurred in the winter–spring period.

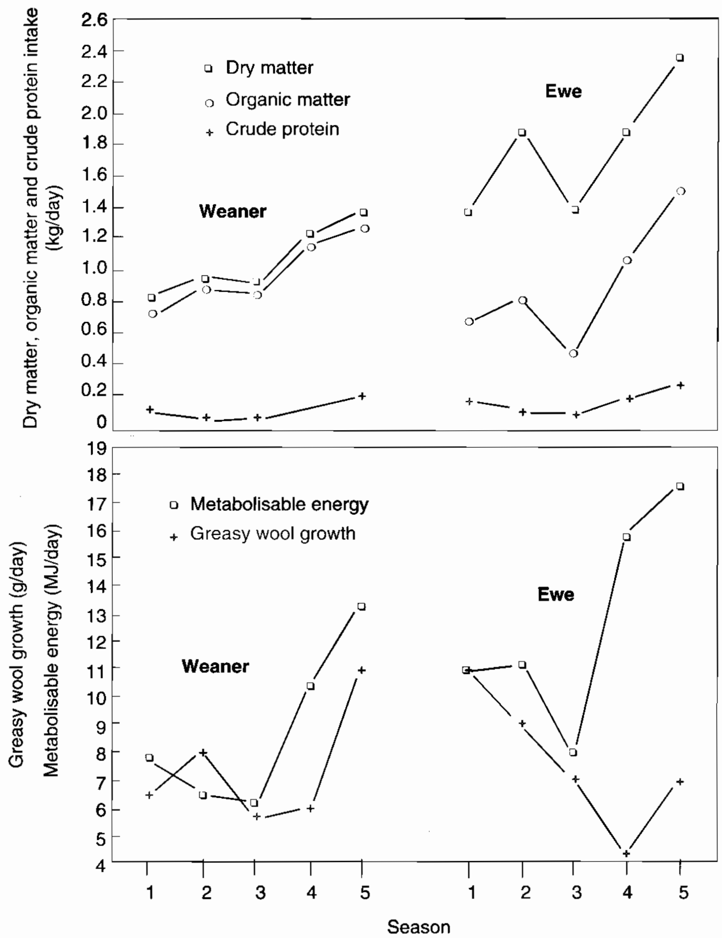

Figure 1. Seasonal changes in the growth rate of wool in relation to the intakes of dry matter, organic matter, metabolisable energy and crude protein. Season: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

tion to changes in crude protein concentrations are well documented (e.g. Ferguson 1959) and reflect the variable extent to which many proteins are fermented in the rumen. Additional information on the availability of microbial and undegraded protein is therefore needed to establish the relative importance of energy and protein intake to losses in production in northern China. Measurements of the repeatability of the results in different years and with different supplements are likewise required.

The intakes of both energy and protein (Table 3) were low or inadequate on all farms at various times of the year according to the established requirement of sheep (NRC 1985). Visual observations suggested that the quantity of pasture available may have been the cause of these limitations at some times. The quality of both pasture and hay in winter and early spring also contributed.

Wool Growth in Relation to Rumen Function

Apart from the level of intake, the potential degradability of dietary components and microbial activity in the rumen largely determine the availability of nutrients for tissue and wool growth. Concentrations of volatile fatty acids (VFA) and ammonia (NH_3) in rumen fluid (Table 4) were used as measures of microbial fermentation and the availability of dietary protein for microbial synthesis, i.e., rumen function. Seasonal variations in these two parameters and in the growth rate of wool are shown in Figure 2. Once again, all three variables followed a similar pattern and a significant relationship was derived between the growth rate of wool and VFA and NH_3 concentrations in weaners. This relationship took the form:

$$WGRW = 104.3 - 38.62X_1 - 1.31X_2 + 3.96X_1^2 + 0.7X_2^2$$

$$(n = 10, r = 0.948, P < 0.01)$$

where: WGR = growth rate of clean wool (g/day)
X_1 = VFA concentration (mM%)
X_2 = NH_3 concentration (mg/dL)

No such relationship could be established for the ewes, due possibly to the effects of pregnancy and lactation on wool growth.

Although no simple biological interpretation of the weaner relationship is possible, the lower concentrations of VFA and NH_3 in both the weaners and ewes in winter and spring suggest that rumen function was impaired. From the list of factors described by Faichney and Black (1979) as influencing rumen function, either low quality and/or availability of feed and a low protein content appeared as the most likely constraints to rumen function (see Wang et al., this report).

Wool Growth in Relation to Nutrient Partitioning

While the potential growth rate of wool is regulated by a number of genetically determined factors (Black and Reis 1979) the actual rate of synthesis depends on the availability of nutrients to the follicle and the kinetics of biochemical transactions within the follicle. The supply of nutrients to the follicle is itself a function of partitioning of nutrients between the skin and other body tissues. Partitioning can, in turn, be altered by the hormonal or physiological status of the animal or by environmental conditions. These were factors which undoubtedly influenced some of the recorded differences in wool growth between the ewes and the weaners. Such effects were reflected in the different coefficients from the significant inverse relationships between the growth rate of wool, liveweight and liveweight change for weaners and ewes (Table 5). These

Table 3. Nutrient intakes of weaners and ewes.

	Aug.	Nov.	Dec.	Feb.	May
	Dry matter intake (DMI, g/day)				
Weaners					
Aohan	829	995	919	1220	1375
Huang Cheng	1263	–	535	546	1348
Nan Shan	949	–	–	920	817
Ewes					
Aohan	1374	1898	1391	1881	2360
Huang Cheng	1393	–	418	468	1871
Nan Shan	–	1480	–	2080	1570
	Metabolisable energy intake (MEI, MJ/day)				
Weaners					
Aohan	7	6	6	10	13
Ewes					
Aohan	10	11	7	15	17
	Crude protein intake (CP, g/day)				
Weaners					
Aohan	108	55	65	121	210
Huang Cheng	–	101	29	29	212
Nan Shan	–	–	–	–	–
Ewes					
Aohan	187	114	101	195	282
Huang Cheng	–	90	23	18	327
Nan Shan	–	72	74–190	186	95–186

relationships were derived using the equation described by Allden (1979). Liveweight and liveweight change accounted for a much higher proportion of the variation in wool growth (39%) of the weaners. Competition for nutrients by the uterine and mammary tissues during pregnancy and lactation would have affected the availability of nutrients for both wool growth and liveweight gain in the ewes. It has been reported that such competition usually results in a 10–15% reduction in the annual wool production of Australian ewes, with the greatest effect during late pregnancy and early lactation (Oddy and Annison 1979). In northern China both these conditions coincide with the times of apparently poorest nutrition.

Table 4. Volatile fatty acid (VFA) and ammonia nitrogen (NH_3-N) concentration in rumen fluid from ewes at Aohan farm.

	Aug 24	Nov 3	Dec 20	Feb 16	May 15
Total VFA (mM)	4.15 ± 1.36	3.18 ± 0.46	3.23 ± 0.98	3.56 ± 1.02	5.04 ± 1.18
Acetate (mM)	2.55 ± 0.85 (61.4%)[a]	1.96 ± 0.30 (61.6%)	2.07 ± 0.59 (64.1%)	2.02 ± 0.54 (56.7%)	2.77 ± 0.75 (55.0%)
Propionate (mM)	0.83 ± 0.38 (20.0%)	0.74 ± 0.20 (23.3%)	0.68 ± 0.22 (21.1%)	0.86 ± 0.28 (24.2%)	1.39 ± 0.33 (27.6%)
Butyrate (mM)	0.63 ± 0.20 (15.2%)	0.44 ± 0.06 (13.8%)	0.43 ± 0.15 (13.3%)	0.60 ± 0.22 (16.9%)	0.71 ± 0.15 (15.3%)
NGR[b]	4.20	4.04	4.29	4.06	3.17
NH_3–N (mg/dL)	15.10	8.67	8.93	11.30	14.67

[a] Data in parentheses are the percentage of the total VFA
[b] NGR = the ratio of non-glucogenic to glucogenic VFA

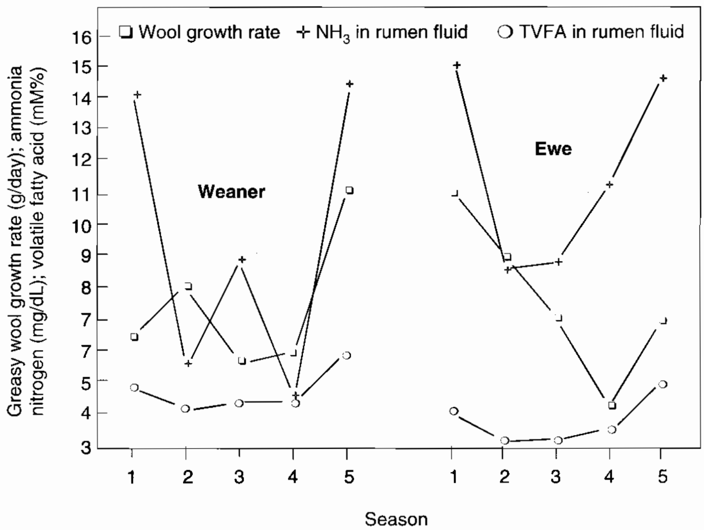

Figure 2. Seasonal patterns of the growth rate of wool in relation to volatile fatty acid and ammonia nitrogen concentrations in the rumen fluid of sheep grazing at Aohan farm (1988–89). Season: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

Table 5. Estimates of the coefficients (a, b, c) in the regression equation[a] relating rate of wool growth (Y, g/day) to live weight after shearing (X_1, kg) and live weight change (X_2, kg/day) for grazing sheep at Aohan farm.

	a	b	c	Regression coefficient (r)	Sample number
Weaners	0.137	–0.157	0.372	0.626	77
Ewes	0.047	–0.270	0.662	0.358	62

[a] $Y = c + aX_1 + bX_1$; taken from Allden (1979)

Any decision to try and improve wool growth by improving nutrition should consider also the efficiency of conversion of nutrients to wool. For example, at Aohan farm, the amounts of clean wool grown in relation to the quantities of organic matter and metabolisable energy ingested were 1.19 g/100 g and 0.83 g/MJ, respectively, for weaners, compared with 0.85 g/100 g and 0.61 g/MJ for ewes. This suggests that, given limited resources and provided reproduction in the ewes is satisfactory, the greatest and most cost-effective increases in wool production would be achieved by improving the nutrition of the weaners.

Conclusions

The wool production of fine wool sheep in northern China varies between regions and seasons, with similar seasonal patterns in all regions. Regional differences are subject to the effects of the breed of sheep (genetics), stocking rate, grazing management, supplementary feeding regimes and the environmental conditions. It is apparent from these results and those described by both Wang et al. and Peter et al. (this report) that reducing the seasonal variations in nutrition would enhance wool production substantially. Limitations of particular note are:

- the shortage of protein in winter and early spring;
- the poor quality of much of the pasture and the hay used as supplements; and
- the low energy intake during winter which probably necessitates the use of body stores to maintain body temperature.

There is considerable opportunity for improving the supply of available nutrients, especially in winter and spring, through supplementation strategies that stimulate the intake of poorer quality feeds and/or increase the rate and level of rumen digestion (Lu 1992).

Achieving better strategies for increasing wool production in northern China will require research in the following areas:

(i) Improved techniques for the measurement of the intake of grazing sheep or for predicting intake

(ii) Methods of manipulating dietary and rumen factors that affect the protein supply to the animal

(iii) An improved knowledge of partitioning of nutrients between the skin (wool) and other body tissues of sheep under different environmental and physiological conditions

(iv) The development of research, and ultimately predictive, models which integrate available pasture (feed), environmental and animal data.

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Seasonal Dynamics of the Nutritive Value of Pasture and Their Influence on Feed Intake and Production of Grazing Sheep at Aohan Farm, Inner Mongolia

H.R. Wang*, H.Z. Feng*, J.K. Reng†, H.R. Li§, D.B. Purser¶ and D.W. Peter¶

THE nutritive value of the native pastures appears as a major constraint to sheep production in the arid grasslands of northern China. Once the native pastures have hayed off in autumn, sheep lose body weight and wool growth declines unless there is some form of feed supplementation. The nutritional limitation set by these pastures increases throughout winter and early spring when they are exacerbated by extremely low temperatures. This paper uses data collected in ACIAR Project 8555 at Aohan farm in eastern Inner Mongolia to describe the seasonal variations in nutrition of grazing sheep and their consequences for wool production.

Changes in the Nutrient Content of Native Pasture

The large areas of grassland in eastern Inner Mongolia range in elevation from 400–500 m and have an average annual rainfall between 300 and 500 mm, most of which falls during July, August and September. With a temperature range from –30 to 37°C, a frost-free period of only approximately 120 days and just 150 days of vegetative growth, pasture production is severely limited. (See Lindsay et al. this report for further details.)

The native pastures are composed of a variety of perennial grasses, including wheat grass *(Agropyron)*, Chinese aneurolepidum *(Aneurolepidium chinese)*, common reed grass *(Phragmites communis)*, Chee reed grass *(Calamagrostis epigeios)*, Chinese pennisetum *(Pennisetum flaccidum*, Glseb.), Bunge needlegrass (*Stipa bungeana*, Trin) and scabrous cleistogenes (*Cleistogenes squarrosa*, Trin.), plus small amounts of various legumes and other shrubs and herbs.

The pastures are normally grazed for the entire year at a stocking rate of approximately 2 DSE/ha, with supplements of hay, corn silage and maize-based concentrates being supplied to sheep during the 7 months of plant senescence.

The seasonal patterns of pasture growth result in variations in pasture quality and nutrient content. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and lignin contents in herbage are lower, and crude protein (CP) content and dry matter digestibility (DMD) are highest during the period of active plant growth (Table 1). The ADF, NDF and lignin content increase during autumn, in accordance with the normal process of lignification associated with maturation (Van Soest 1982), reaching maxima during winter.

The high levels of lignification and the low CP content of the pastures during the period of plant senescence are associated with the minimum DMD of the pasture (Table 1). Together they result in poor pasture utilisation by the sheep and live-weight loss. However, even when pasture growth is reinitiated during late spring and early summer, ADF, NDF and lignin content decline and CP increases, sheep production is curtailed by the low plant density (5–10% ground cover) and the availability of green material. Losses in live weight are common during this period as sheep expend much energy searching for the higher quality green material (the 'crazy for green' or 'crazy running' period). In terms of both availability and quality the period of optimum nutrition occurs during late summer (August). These data are in accord with the observations of Wang et al. (1987) and Jang and

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Table 1. Seasonal variation in the nutrient content of pasture[a] at Aohan farm; Mean with s.e.m. in parentheses.

	Late summer	Late autumn	Winter	Winter/ Spring	Spring/ Summer
Organic matter (%D.M.)	87.2 (5.1)	90.9 (0.3)	85.0 (4.2)	90.7 (2.1)	83.4 (0.2)
Neutral detergent fibre (% D.M.)	49.2 (1.1)	67.0 (1.7)	64.6 (5.1)	68.1 (4.5)	50.4 (0.5)
Acid detergent fibre (% D.M.)	30.1 (0.7)	42.0 (0.6)	41.0 (5.1)	44.5 (0.5)	25.5 (0.7)
Lignin (% D.M.)	6.1 (0.8)	9.1 (2.4)	11.8 (0.7)	7.6 (1.5)	4.8 (0.6)
Crude protein (% D.M.)	13.7 (0.1)	5.3 (1.1)	5.3 (1.1)	5.3 (1.1)	17.6 (0.9)
Ether free extract (%D.M.)	3.3 (0.49)	2.3 (0.60)	1.5 (0.33)	2.2 (0.06)	2.9 (0.81)
Sulfur (% D.M. × 10^2)	8.6 (0.5)	8.4 (0.3)	8.1 (0.3)	7.2 (1.0)	12.0 (0.7)
D.M. digestibility (% D.M.)	43.2 (2.6)	41.5 (0.6)	37.5 (1.9)	45.4 (1.0)	64.7 (4.7)
Metabolisable energy (MJ/kg)	7.9 (0.08)	5.7 (0.26)	5.5 (0.02)	6.5 (0.25)	10.3 (1.75)

[a] Pastures of weaners and ewes combined.

Ba (1990) that the peak of nutritive value of pasture is in June–July, that the peak of forage production is in August–September and the peak of sheep production occurs in August.

Using the data shown in Table 1, a positive relationship between DMD and CP, and a negative relationship between DMD and lignin, was established. These relationships are as follows:

DMD (%) = 19. 40 + 2.38 CP (%) (r = 0.796, n = 24)

DMD (%) = 59.08 – 2.29 lignin (%) (r = 0.520, n = 24)

Similar findings have been made by Yang et al. (1987).

Changes in Feed Intake

Since the nutrient content and quality of pasture varies widely with season there are likewise significant variations in the nutrient intake of the grazing sheep (see Table 2). For example, the seasonal pattern of crude protein intake corresponds with that in the CP content of pasture.

Seasonal changes in feed (nutrient) intake are not, however, normally in accord with the optimum nutrient requirements of the grazing sheep. Animal requirements are influenced by physiological state and environmental conditions. By comparing the measured dry matter intakes (pasture plus supplements) of weaners and ewes with estimates of requirements derived using the computer simulation model Grazfeed (Freer and Christian 1983), it appears that there are sustained periods of feed insufficiency (Fig. 1). The feed intake of weaners appears to be limiting throughout most of the year, while the intake of ewes fails to meet the predicted requirements during late pregnancy and early lactation. It appears that the most critical period of nutrient insufficiency occurs during winter and spring when digestible crude protein and energy intakes are at a minimum. During this period the digestible crude proteins intakes are below recommended levels (NRC 1985). Values for relative feeding levels (RFL), the ratio of metabolisable energy intake (MEI) to

Table 2. Seasonal variation in the dry matter, protein and energy intake of weaners and ewes at Aohan farm.

	Late Summer		Late Autumn		Winter		Winter/Spring		Spring/Summer	
	Weaner	Ewe	Weaner	Ewe	Weaner	Ewe	Weaner	Ewe	Weaner	Ewe
Dry matter intake (DMI, g/day)										
Pasture	602	1375	731	1898	311	753	351	460	726	1124
Supplement	227	–	224	–	609	639	869	1421	649	1236
Total	829	1375	995	1898	920	1392	1220	1881	1375	2360
Digestible organic matter intake (DOMI, g/day)										
Total	458	682	516	823	458	471	773	1067	965	1591
Crude protein intake (CPI, g/day)										
Total	57	71	0	22	18	35	68	118	156	205
Metabolisable energy intake (MEI, MJ/day)										
Total	7.7	11.0	6.5	11.2	6.6	8.0	10.5	15.8	13.3	17.7
Metabolisable energy intake/metabolisable energy for maintenance (MEI/ME_m)[a]										
Total	1.29	0.90	0.85	0.73	0.83	0.56	1.31	1.14	1.63	1.24

[a] MEI/ME_m = relative feed level (RFL)

the metabolisable energy required for maintenance (ME_m) (Corbett et al. 1987) (Table 2), likewise show that the greatest energy deficit of both weaners and ewes occurs in winter. Energy deficits may also occur in autumn.

The voluntary intake of sheep may be influenced by many factors, including the potential of the animal to use nutrients, the nutrient supply to, and the function of, the rumen, and the physiological state of the animal (Arnold 1975; Langlands 1977; Black 1990). It is therefore difficult to accurately define the cause of some of the variations in intake which occurred. For example, the maximum dry matter intake of ewes in November corresponded with large falls in DMD and CP, rapidly falling temperatures and the time of mid to late pregnancy. It appears that the drive to sustain live weight and conceptus growth, and possibly an adaptive response to cold stress, counteracted the negative effects of the decline in feed quality.

Changes in rumen ammonia and volatile fatty acids

The concentrations of ammonia in rumen fluid (RA) varied widely with season, ranging from 4.6 to 14.5 mg% (mg/100 mL) and from 8.7 to 14.7 mg% in weaners and ewes, respectively. Such levels are below those of 15–25 mg% considered to be necessary to support maximum rumen fermentation (Preston and Leng 1987). As shown in Figure 2 the RA is related to CP intake. The highest levels in summer were associated with the highest CP intakes, while the low CP intake in winter resulted in lower values of RA. Based on these data it was shown that CP intake may be predicted from RA in accordance with the equation:

$$Y = 94.0 - 6.7X + 0.88X^2 \quad (R = 0.73, n = 30; p < 0.001)$$
where Y = CP intake (g/day) and X = RA (mg%)

The concentration of urea nitrogen in plasma (BUN) also varied with season (Fig. 2), in the ranges 13.1–22.6 mg% and 12.4–20.4mg% for weaners and ewes, respectively. This resulted in a close association between BUN, RA and CP content of pastures (Fig. 2). This accords with the findings that BUN can be closely related to the nitrogen intake of grazing animals (Preston et al. 1965; McIntyre 1970). Under some circumstances BUN may therefore be used as an index of the dietary protein content of healthy animals, as shown by Richardson and Kegel (1980). High values of BUN may arise, however, through catabolism of tissue protein or the loss of endogenous protein in the digestive tract during acute helminth infection (Barker 1973; Roseby and Leng 1974; Sykes 1978).

The concentration of sulfate in plasma also varied with season over the range 2.3–4.6 mg/L for weaners and 1.6–2.3 mg/dL for ewes. A significant reduction in the concentration of sulfate in plasma occurred during late pregnancy. Overall, the results indicate that the sulfur intake was often close to sufficient and able to meet requirements. Although it is uncertain what the major source of sulfur was in these studies, feed protein can be a major source (Xu 1986). This may explain why the lowest concentrations of sulfur in plasma occurred at times when protein intake was at a minimum.

The seasonal patterns of the concentration of total VFA in rumen fluid were similar to those for RA (Fig. 3). Concentrations ranged from 4.2 to 6.0 mM% in weaners and from 3.2 to 5.0 mM% in ewes. Higher concentrations of VFA were

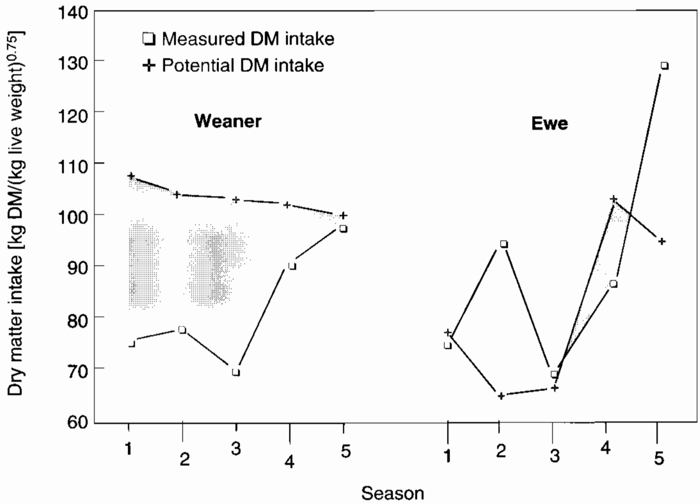

Figure 1. Comparison of measured dry matter intake with potential intake in different seasons. The hatched areas indicate the periods of feed insufficiency. Key: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

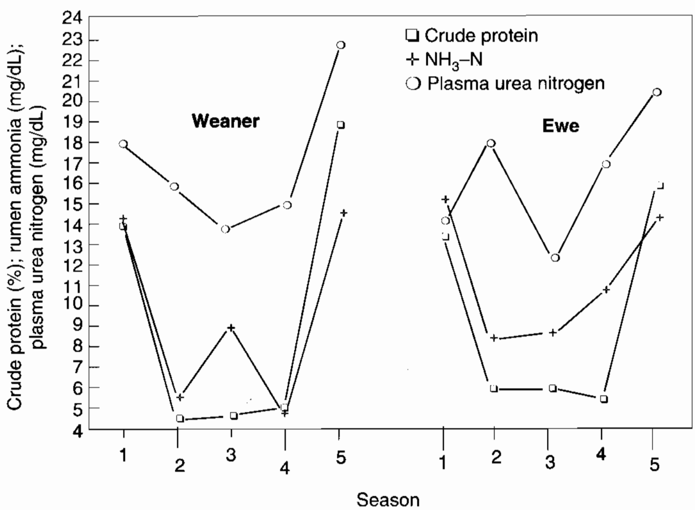

Figure 2. Seasonal patterns of rumen ammonia and plasma urea nitrogen concentrations, and of crude protein content in pasture. Key: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

recorded in the summer–autumn period than during winter–spring. This suggests that the rates of rumen fermentation were lower while the sheep were being supplemented. The depression in rumen VFAs during late pregnancy and early lactation is therefore of particular importance. At these times the ratio of non-glucogenic to glucogenic VFA was also in excess of the optimum of 2.5–3 defined by Ørskov (1975) (i.e., there was a higher proportion on non-glucogenic VFA in the total VFA pool). A higher proportion of butyric acid (C4) than proprionic (C3) is also associated with less efficient energy and protein production by the rumen microorganisims (Ørskov 1975). Given the higher proportion of butyric acid (C4) in the total VFA pool compared with that of propionic acid (C3) in most seasons, it appears that the efficiency of rumen fermentation was often less than optimal.

Associations of Live Weight with Energy and Protein Intake

While the patterns of live weight associated with season are described elsewhere in this report by Lu et al., Figure 4 provides a comparison of the rates of live-weight gain of both weaners and ewes with those in nutrient intake. The live-weight gain of the weaners was highest in late summer and autumn when the CP and ME contents of the pasture were greatest and temperatures were moderate (17–21°C). During this period the maximum live-weight gain of the weaners (67.5 g/day) was far below their expected potential, although still higher than during winter.

In contrast to the weaners, the pattern of live-weight gain of the ewes did not correspond closely to the changes in CP and ME content of the pasture. This reflects the influence of different supplements and the effects of both pregnancy and lactation on the availability of nutrients for maternal tissue growth. Despite the use of supplements during winter, when nutrient requirements for maintenance were likely to be higher due to cold strees and physiological state, intakes of CP and ME remained low. Subsequently, both the weaners and ewes lost live weight in spring–early summer as they sought the limited quantities of fresh green herbage available.

Using all the available data a significant relationship ($P < 0.001$) was established between live-weight gain and CP and ME intake as follows:

$$Y = -133.7 - 0.88\,X_1 + 31.4\,X_2 \quad (r = 0.711, n = 27)$$

where Y = live-weight gain (g/day)
X_1 = CP intake (g/day) and
X_2 = ME intake (MJ/day).

An analysis of variation showed that a much higher proportion of the variation in live-weight gain could be accounted for by the ME intake than the CP intake. This indicates that energy intake was the major determinant of live-weight changes, a conclusion supported by previous work (Zhang et al. 1990).

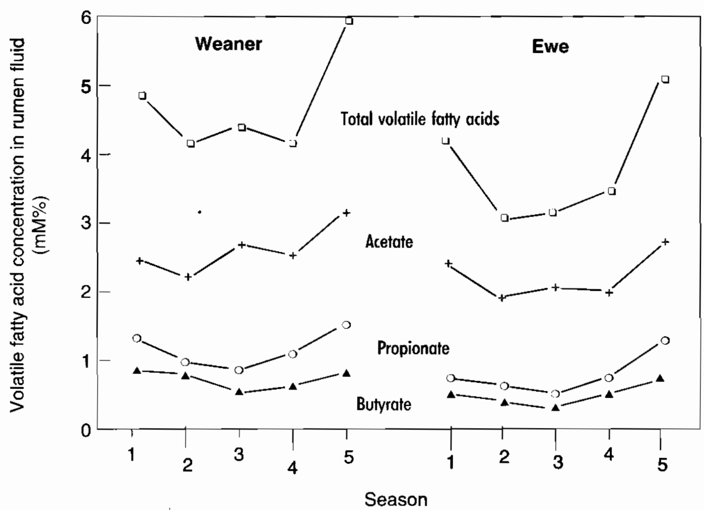

Figure 3. Seasonal patterns of volatile fatty acids in rumen fluid of the grazing sheep. Key: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

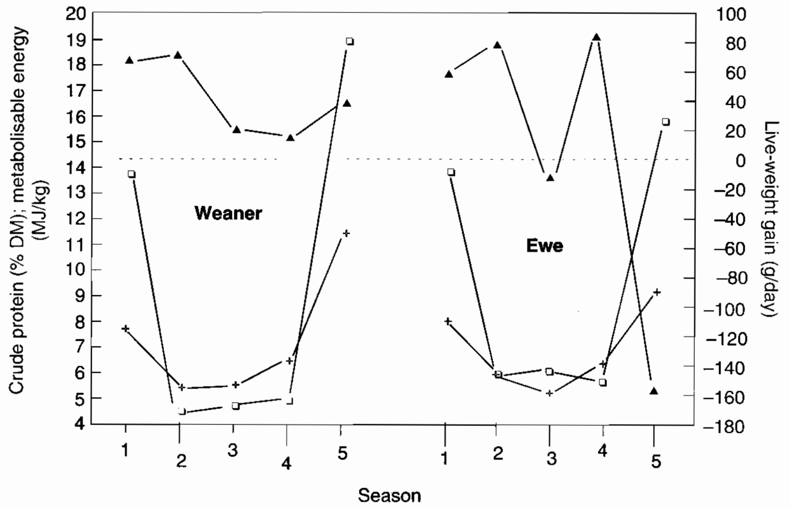

Figure 4. Seasonal patterns of live-weight gain of the grazing sheep and the crude protein and metabolisable energy content of pasture: ❑, crude protein; +, metabolisable energy; ▲, live-weight gain. Season: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

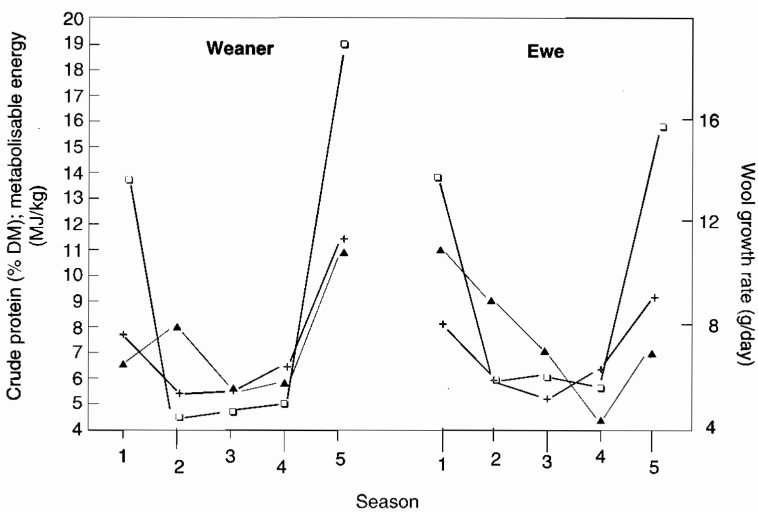

Figure 5. Seasonal patterns of wool growth rate and the crude protein and metabolisable energy content in pastures: ❑, crude protein; +, metabolisable energy; ▲, wool growth rate. Season: 1, late summer; 2, late autumn; 3, winter; 4, winter/spring; 5, spring/summer.

Associations of Wool Growth Rate with Changes in Nutrient Intake

Comparison of the seasonal changes in the rates of wool growth in weaners and ewes and the CP and ME content of the pasture is shown graphically in Figure 5. The pattern of wool growth in the weaners tended to correspond with the changes in CP and ME contents of the pasture, being lowest during winter and early spring. Rates of wool growth in the ewes declined from late autumn through to late spring and therefore failed to match fully the changes in the CP and ME content of the pastures. The start of supplementary feeding of hay in autumn may have slowed the decline in wool growth during autumn. However, the period of declining wool growth corresponds to the periods of late pregnancy and lactation when nutrient partitioning between skin and the uterine–foetal tissues or the mammary gland are known to alter (Oddy and Annison 1979; C.G. Xian, pers. comm.). Interactions between physiological state, wool growth and temperature may have also occurred (Bottomley 1979).

Details of a relationship between the growth rate of wool and dry matter, CP and ME intakes are provided elsewhere in this report by Lu et al.

Nutritional Limits to the Productivity of Grazing Sheep

Although the potential productivity of sheep is genetically determined, achieving these potentials in grazing sheep in northern China is generally constrained by the quantity and quality of pasture and supplements available. Cold stress may provide a further limitation. Therefore, while production from pastures may have economic benefits, production per animal and per unit area, as well as the quality of products, remain low. A summary of the specific nutritional problems identified at Aohan farm as limiting potential production follows.

(i) Protein deficiency — The low protein of the pasture results in an inadequate intake of protein by grazing sheep. Overstocking and pasture degradation compound the problem. The low digestibility of pasture, coupled with its low nitrogen content, result in poor rumen fermentation and a further depression in dry matter intake.

(ii) The quality of forage fed as supplements — Not only do sheep graze pastures of low quality (DMD < 46%) for up to 5 months of the year but the hay which is fed during winter and spring is also low in protein and available energy. Measurements made during these studies show that up to half of such hay may be wasted.

(iii) The shortage of green forage — The higher levels of energy and protein in green feed can assist in promoting rumen microbial activity and fermentation of poor quality feeds. However, the availability of green forage is normally limited throughout winter and early spring when both the dry pasture and roughage supplements are of low quality. There is evidence that feeding only small amounts of high quality maize silage may improve the intake of low quality hay in winter (Lu 1990).

(iv) Micro elements — The findings of ACIAR Project No. 8454 indicate that zinc, molybdenum and selenium are probably limiting in the region. Deficiencies of these elements can restrict live-weight gain and wool growth.

Conclusions

The seasonal variations in the nutritive value of pasture exert large effects on the nutritional status of grazing sheep. Major limitations to production arise through inadequate protein and energy intakes from pasture. Forage supplements supplied during in winter and spring, when cold stress increases maintenance requirements, may likewise provide insufficient energy and protein.

In order to improve sheep production at Aohan farm, better supplementary feeding strategies must be considered. These need to be integrated with grazing and sheep management strategies as suggested by Lu (1992). They should improve the efficiency of microbial metabolism in the rumen, e.g. through increases in rumen nitrogen, and in tissues, e.g. by directly increasing the supply of amino acids to the muscle and skin. Nutrient partitioning, the nutritional requirements for different metabolic processes and the interactions between physiological state and environmental and pasture factors also need to be considered. Results from this project provide the base on which to build future strategies for improving nutrition and thereby production.

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The Integration and Evaluation of Nutritional Factors Influencing the Production of Fine Wool Sheep in Northern China

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THE objectives of ACIAR Project 8555, 'The effects of helminths and nutrition on sheep production in northern China', included the measurement and comparison of the seasonal patterns of production and nutritional status of fine wool sheep. As detailed in Lindsay et al. (this report), the temperature extremes of the three state farms (Aohan, Nan Shan and Huang Cheng) used as experiment sites in the project are similar. However, there are considerable differences in the length of growing season, rainfall and evaporation rate, topography, pasture availability, pasture composition and quality, and the production of and/or access to supplementary feeds. Results obtained from these farms therefore provided the opportunity to compare sheep production and the nutritional factors affecting it under a wide range of contrasting management and supplementary feeding systems. In carrying out these comparisons there was also the opportunity to observe the effects of other factors on production.

Other papers in this report have considered different aspects of production and the nutritional factors affecting it. This paper attempts to provide a simple but more comprehensive view by using integrated data sets from the results of one as examples. An abbreviated data set generated in Western Australia is also considered. This paper also describes how the sheep production model, 'Grazfeed'®, was used in the project for the development of modified supplementary feeding strategies and how it provided additional nutritional information. Several other factors that influenced production throughout the course of the project and which may affect the development of improved production systems in future are also discussed.

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Evaluation and Comparison of Nutritional Constraints Using Simple, Integrated Data Sets

Figure 1 shows the seasonal patterns for the crude protein content of pasture and of the faeces of ewes and weaners grazing the pastures, of pasture digestibility (in vitro), and the live weight and rates of clean wool growth of the ewes and weaners at all three farms. These data relate mainly to year one of the study (1988–89). Several values from year 2 are included in the pasture protein and digestibility sets in order to provide a full seasonal pattern for all farms. The pasture samples for which analyses are presented were collected by plucking. During these collections account was taken of pasture species that the sheep are known to consume, the amounts present in the pasture and, whenever possible, sheep preference. The average concentration of protein and the digestibility of the different supplements fed at the three farms are shown in Table 1. Details of the quantities fed are given in Lindsay et al. (this report).

The important features of Figure 1 are:

(i) the similarities in the seasonal patterns of changes in pasture crude protein (CP) and digestibility (DMD) and faecal crude protein at all three sites;

(ii) the relatively similar values for pasture CP or DMD or faecal CP between sites at any given time. The only exception occurs with the May–June faecal samples at Aohan. In view of the results from subsequent years it appears there may have been an error in analysis of these samples;

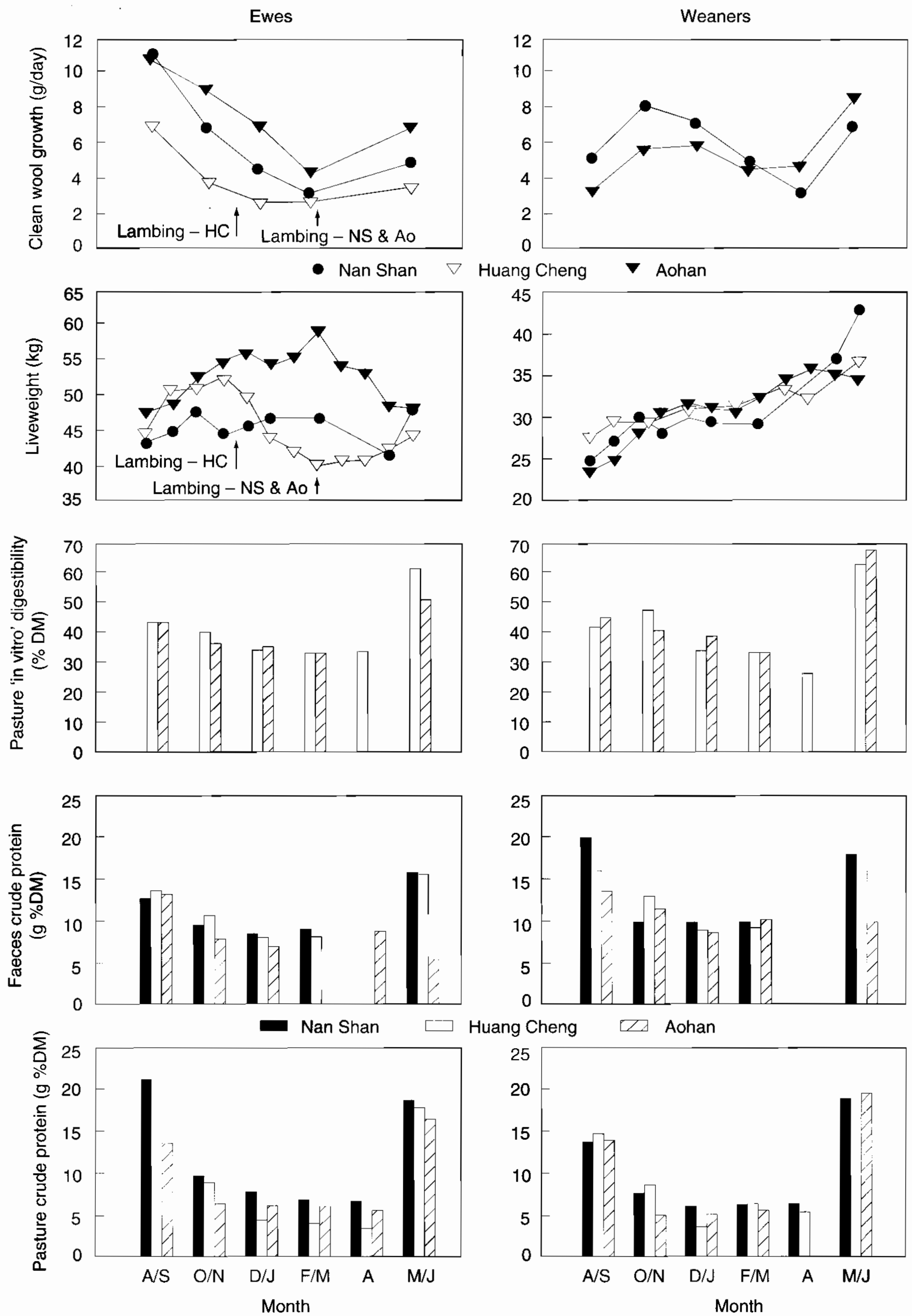

Figure 1. Seasonal patterns of crude protein content of pasture and of the faeces of ewes and weaners grazing the pastures, of pasture digestibility (in vitro), and the live weight and rates of clean wool growth of the ewes and weaners at three farms in northern China.

(iii) the similar seasonal patterns of clean wool growth between sites but the marked differences in absolute values;

(iv) the differences in the seasonal patterns of ewe live weight and often in absolute values of live weight;

Table 1. Proximate analysis of supplementary feeds used at Nan Shan, Huang Cheng and Aohan (China) and Yalanbee (Western Australia). (Values for ewe supplements only but values for weaner supplements were similar.)

Analysis	Supplement	Nan Shan	Huang Cheng	Aohan	West. Aust.
Digestibility (DM%)	Hay		41	36	55
	Silage		39	61	–
	Concentrate[a]		86	83	–
	Barley		78	–	–
	Wheat		88	–	–
	Oats		66	–	67
	Lupins		–	–	92
	Peas/Pea hay[b]		74	59	–
	Low– High[c]	–	42–82	48–60	67–84
Crude protein (g% DM)	Hay	8	5	8	7
	Silage	5	7	8	–
	Concentrate	10	11	13	–
	Barley	–	10	–	–
	Wheat	–	11	–	–
	Oats	–	11	–	10
	Lupins	–	–	–	32
	Peas/Pea hay	–	22	18	–
	Low– High[c]	5–9	7–11	9–14	14–25
NDF (% DM)	Hay	62	62	69	68
	Silage	57	62	65	–
	Concentrate	46	31	19	–
	Barley	–	89	–	–
	Wheat	–	79	–	–
	Oats	–	67	–	36
	Lupins	–	–	–	28
	Peas/Pea hay	–	42	45	–
	Low–High[c]	57–55	64–84	61–48	50–23
ADF (% DM)	Hay	35	42	40	31
	Silage	33	37	38	–
	Concentrate	7	10	10	–
	Barley	–	10	–	–
	Wheat	–	5	–	–
	Oats	–	15	–	18
	Lupins	–	–	–	12
	Peas/Pea hay	–	11	30	–
	Low–High[c]	33–23	35–7	31–21	23–14

[a] 'Concentrate' at Huang Cheng was mixed cereal grain.
[b] Peas were used at Huang Cheng and Pea hay at Aohan.
[c] 'Low' or 'High' refer to the combination of supplements (mix) with the lowest and highest quality fed at different times; the lowest could be roughage alone and the highest concentrate alone.

(v) the similar seasonal patterns of weaner live weight with an extended period of little or no live-weight change during winter; and

(vi) the difference in the time of lambing between Huang Cheng and the other two sites.

There were also marked similarities between sites in the seasonal patterns of change and in absolute values for other measures of pasture quality, e.g., neutral detergent fibre (NDF), acid detergent fibre (ADF), and lignin.

The notable features in Table 1 are the lower protein content of both the concentrate and silage at Nan Shan compared with the other two farms and, with the exception of pea hay fed to weaners at Aohan, the very poor hay quality on all farms. Overall, the quality of combined supplements was better than that of the pasture during the late autumn to early spring period, but the quality was still well below that of good quality green pasture.

The similar seasonal profiles in pasture quality between sites are clearly a reflection of the large seasonal changes in temperature, and consequently actively growing versus senesced pasture. Though further information is needed, the current data would suggest that the differences in green pasture are not great. This may be a reflection of a similar availability of soil nitrogen at all sites, the dominance of native grass in collected samples and a general absence of applied fertilizer.

Seasonal patterns in pasture and faecal protein concentrations indicate that the protein intake provided by the supplements during the late autumn to early spring period was low and generally insufficient to meet the increased demands due to physiological state and cold stress. The minimum protein concentrations of the combined supplements that were fed, shown as the 'low' value in Table 1, were only marginally higher than those of pasture. Since these 'low' supplements represented the major source of feed throughout the entire period of supplementary feeding, it is apparent why pasture and faecal protein concentrations follow the same seasonal pattern. It likewise explains why faecal protein concentrations declined over this period.

Viewing the ewe data alone (Fig. 1) it can be seen that seasonal patterns for wool growth rates and pasture quality were similar. In contrast, the seasonal changes in live weight did not reflect changes in pasture quality. These different responses suggest that the quality of the supplements was at times adequate for tissue growth but not for wool growth. The similarity of the seasonal changes in wool growth rates and pasture quality indicates that supplementary feeding was unable to compensate for the decline in the nutritional quality of the pasture. Presumably, this was due to the low protein content of many of the mixed supplements. On the other hand, ewe live-weight patterns not only reflected changes in the energy and protein supplied by the total diet but also differences in physiological state.

If the time of year is ignored and live weights are considered in relation to physiological state, the patterns of change in ewe live weights at Aohan and Huang Cheng were similar. However, they did not match the pattern at Nan Shan. After accounting for changes in live weight due to conceptus growth and the associated live-weight change at parturition, there were increases in maternal weight up to the time of parturition at both Aohan and Huang Cheng. These were followed by losses in live weight during lactation. Ewes at Huang Cheng also gained in live weight after their lambs were weaned in April. In contrast, the ewes at Nan Shan lost maternal weight during pregnancy, maintained weight during early lactation and then gained weight in later spring when transferred to spring pasture. Thus, energy was probably adequate during pregnancy but limiting during lactation at Huang Cheng and Aohan, while the reverse tended to apply at Nan Shan. It also appears that energy was probably limiting at Nan Shan during early lactation while the sheep remained on winter pastures.

Wool growth, as noted by Lu et al. (this report), was closely aligned with protein intake. The low protein content of pastures and supplements was therefore considered to be the major constraint to wool growth at all sites. The changes in wool growth and live weight at Aohan and Huang Cheng during pregnancy suggest that at least part of the decline in wool growth was a consequence of a diversion of protein from wool to body and/or conceptus tissue. During lactation, the demand for protein for milk synthesis would have further reduced the protein available for wool growth. The low protein intake may have contributed further to the inadequate energy supply at different times by reducing rumen function and restricting the digestion of the low quality, high fibre pasture and supplements. Rumen ammonia concentrations at Aohan farm in the period from late February to May were consistent with this explanation (see Wang et al., this report). However, the rumen ammonia levels at Nan Shan exceeded 9 mg% at all times during the late autumn to early spring period. Rumen function of ewes, and hence the availability of energy, was unlikely to have been limited by the availability of nitrogen. It appears therefore that the overall poor quality of the diet resulted in limitations of both energy and protein during pregnancy and lactation at Nan Shan.

Although rates of wool growth at Huang Cheng followed the same seasonal pattern as at the other farms (Fig. 1) the absolute rates of wool growth were consistently lower. This suggests either a genetic difference in wool growth or a consistent protein limitation. On the basis of a comparison of the protein contents of the pasture, the supplements and the faeces at Huang Cheng and Aohan, it appears that the use of protein for wool growth at Huang Cheng was at times probably impaired. Factors such as an increased utilisation of protein by tissues due to greater cold stress, a mineral deficiency (see Masters et al., this report) or the quality or nature of the protein available, may have been involved. The quantity of feed available may have been limiting also at times.

Interpretations of the data outlined above might be improved further if the growth rates of lambs were also to be considered as indicators of milk production by the ewes. However, as discussed in a later section, the inclusion of such results without comprehensive knowledge and consideration of management and other social factors can prove misleading.

Weaner production, unlike that of the ewes, is not confounded by pregnancy and lactation. The use of integrated data to identify nutritional constraints is therefore simplified. Consequently, similarities in the seasonal patterns of change in pasture, faeces and live weight at all farms (Fig. 1) suggest immediately that the nutritional limitations to body growth were similar on all farms. On the other hand, while seasonal patterns of wool growth were likewise similar, differences in wool growth rates between Nan Shan and Aohan probably reflected differences in environmental and management conditions (see Lindsay et al., this report) as well as differences in the quality of supplements fed. From a consideration of wool, live weight and pasture and supplement data one can conclude that energy was limiting for live-weight gain during winter while an inadequate protein intake provided the major constraint to wool growth at all times.

Although inadequate levels of nitrogen in the rumen may have affected the availability of energy, the low digestibility, high fibre content, etc., of pasture and of supplements, i.e., low quality, would have been the major constraint to weaner production on all farms. It appears that there was a greater shortage of energy and protein throughout winter at Nan Shan than at the other two farms, with a more adequate energy supply than at Aohan during spring. The winter data again reflect the lower quality of supplements fed at Nan Shan.

Except for the growth rates of weaners at Nan Shan in spring, the rates of wool and body growth failed to attain those expected if energy and protein intake had been optimal. Given the levels of protein and energy in the green pastures this immediately suggests that the quantity of edible green pasture was often limiting. While this is recognised at Aohan in early spring during the 'crazy for green' or 'crazy running' period, weaner production in general may benefit from reductions in stocking rate over spring and summer.

In conclusion, it must be noted that this evaluation of constraints to production is based on data from one year only. Integrated data sets from all three years need to be considered together before assuming that the limitations to production are similar in all years. (A preliminary examination of all the data suggests that the above conclusions are valid.) There is also a need to conduct more frequent rumen and plasma sampling, both within and between days. This would ensure that measurements of rumen ammonia and volatile fatty acids concentration and plasma urea concentration fully reflect the 'average' situation and can be relied upon to indicate when rumen function is impaired.

Comparison of Chinese and Western Australian Data

There are direct similarities between sheep production in China and Australia because of the effects of climatic conditions on pasture production. Whereas temperature is the main determinant of the seasonal pattern in China, rainfall regulates the pattern in Western Australia.

Figure 2 provides a direct comparison of the seasonal changes in pasture digestibility and crude protein content and ewe live-weight and clean wool growth in 1988–89 between the three Chinese sites and a site at Bakers Hill in Western Australia (W.A.). The Bakers Hill farm has a higher rainfall and longer growing season than any of the Chinese sites but natural soil fertility is lower. However, the mixed, subterranean-clover-based pastures at Bakers Hill have received regular applications of phosphate (and trace element) fertilizer for many years, whereas most of the pasture in China has received none. All the pasture species at Bakers Hill are annuals whereas most in China are perennials.

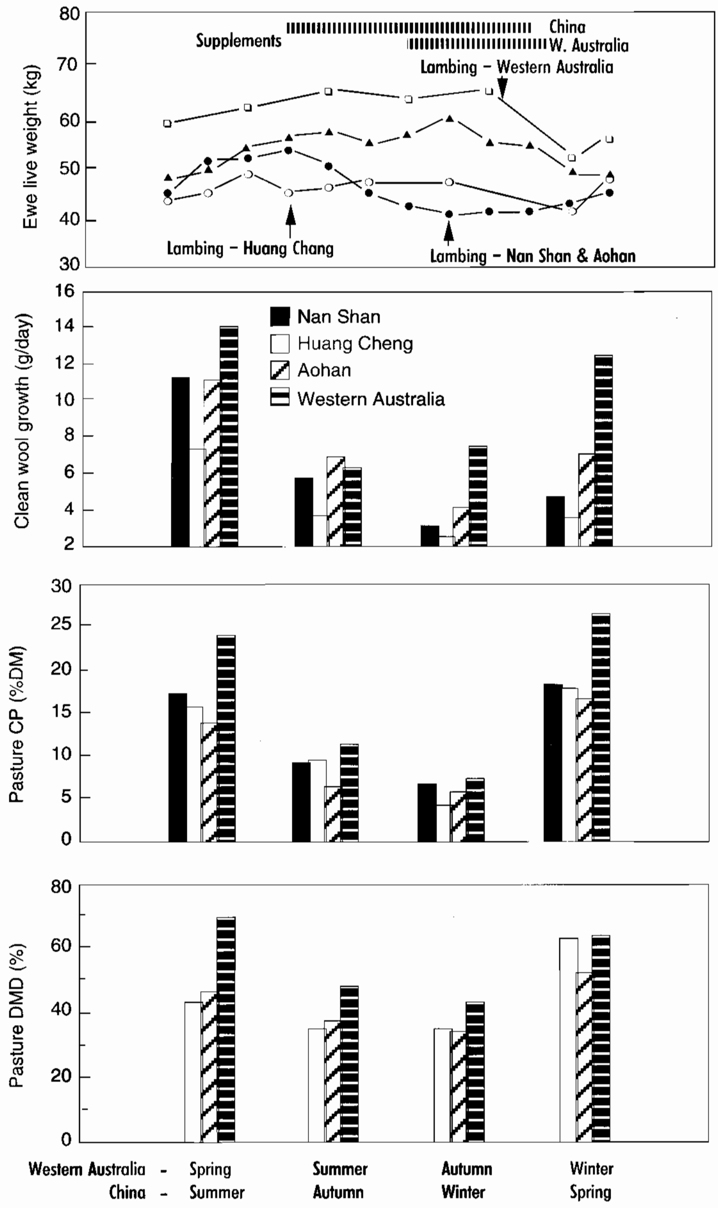

Figure 2. Comparison of seasonal changes in pasture digestibility and crude protein content, and ewe live-weight and clean wool growth, at three farms in northern China and one in Western Australia.

After adjusting for the differences in the time of year in relation to growing season it can be seen that pasture quality and ewe live weights and clean wool growth followed similar seasonal patterns in both China and W.A. The quality of green pasture was higher in W.A., reflecting the much higher legume content of the pasture and the higher levels of applied fertiliser. Both live weight and rate of wool growth were also higher in W.A during this period. While these differences may have been due in part to variations in strains of sheep, much of them is also attributed to variability in pasture digestibility and nitrogen. In summer and autumn the quality of the dry pasture available was much reduced and only marginally better than that found in China during their autumn and winter.

Wool growth in W.A., as in China, reflected the changes in pasture protein concentration although, in general, the quality of the supplements fed (during the late summer to early winter period) was also much higher (Table 1). In the example shown, hay was fed for only a limited period in late autumn–early winter. The digestibility of this hay was slightly higher than that used in China but the protein content was similar (Table 1). When fed in combination with oats and lupins the digestibility and protein content of the combined supplement ('low') were still higher than the 'highest' combination used in China (Table 1). The quantity fed was also lower than that of most of the combined supplements fed in China. The higher quality of supplement used in W.A. was able to maintain or allow marginal increases in live weight during late pregnancy. However, if conceptus weight is taken into account, maternal weight declined. Nevertheless, the body score of the ewes at parturition would have been higher than in China and hence there were greater reserves of energy available in early lactation.

Protein available to the ewes in W.A. during late pregnancy appeared to be limiting for wool growth, in the same way as it was in China. This was despite the higher quality and protein content of the supplement fed. The clean wool growth rate during supplementation was, however, marginally higher than in summer during early pregnancy. Rates of wool growth in winter while the ewes were lactating were much higher than were observed for lactating ewes in China during spring. These differences most likely reflect differences in the availability of green pasture, although genetic differences between sheep cannot be excluded

Overall, the generally higher levels of production in W.A. compared with China appear to be a reflection of the higher levels of protein and digestibility of green pasture and generally higher quality of supplements used. Visual observations also indicate that the availability of pasture in W.A. in spring exceeds the highest availability in China during summer. This is in part a reflection of the differences in the length of growing season but we suspect also that the stocking rate, relative to the seasonal production of dry matter from pasture, is often higher in China. A reduction in the stocking rate, together with pasture improvement through the introduction of suitable legumes, may well reduce the differences in levels of production illustrated in the current comparison.

Modified Management Strategies and the Use of the Grazfeed® Model

Modified supplementary feeding strategies

A further aim of this project was to develop and evaluate modified management systems for improving production. No attempts were made during the project to optimise production. Modifications that were developed and tested relied primarily on improving the supplementary feeding strategy through more efficient use of existing supplements. These changes were intended to reduce live-weight losses at some times or further increase live weight at others, to improve milk production of ewes during lactation and thereby improve lamb growth rates, and to reduce the fluctuations in wool growth throughout the year. Some further small changes in sheep management were also recommended but, as noted later, their implementation was sometimes constrained by other factors. Urea was the only additional supplement used at all sites, since nitrogen (protein) was clearly identified as being limiting. This limitation applied not only through the direct availability of protein for body or wool growth but also through restriction of rumen metabolism of the poor quality feed and reductions in the availability of energy.

Some of the results of the modified feeding are discussed in other papers in this report (Wang et al.). The benefits were generally small and often not statistically significant. This was not unexpected in view of the relatively small degree of changes made, difficulties in achieving fully satisfactory experimental designs and the variety of other factors influencing production.

Use of the Grazfeed® model

The computer model Grazfeed®, developed by the CSIRO Division of Plant Industry in Australia (Freer and Christian 1983) as a predictive model for determining the production of grazing ruminants, was used to assist with the development of the modified feeding strategies. It was commonly used as an interpretative as well as a predictive tool. While using it in this way a number of important additional nutritional factors were highlighted.

Modified feeding strategies had to be developed retrospectively, using the data from the previous year to determine where and how changes should be made and before any estimates of pasture intake were available. Therefore, the model was initially used to estimate pasture availability and its intake. These estimates were made before the start of supplementary feeding and subsequently extrapolated into the supplementary feeding period. Estimations involved the use of recorded levels of production over a given period and measurements of pasture quality for this period. It included the use of long-term averages for rainfall, maximum and minimum temperatures during the period and estimates of daily wind speed and the slope of land grazed.

A common feature of these estimations was that the sheep often failed to reach their potential intake. The most plausible interpretation of this result is that pasture availability was limiting. Visual observations support this. The model also indicated that, at times, intake was being restricted by inadequate rumen nitrogen. This had already been noted and verified by the low levels of rumen ammonia. The complex botanical composition of many of the pastures must cast some doubts on the accuracy of estimates of the nutrient composition of the pasture actually eaten by the sheep. It is therefore difficult to determine the extent to which nitrogen content and pasture availability limited the nutrient intake. The possibility also exists that other nutritional factors such as mineral deficiencies, the ingestion of an anti-nutritional factor or the low solubility or availability of ingested protein (e.g., binding of protein to tannins) may be responsible for restricting pasture intake. Whatever the cause, these results indicate the need for more detailed studies of pasture intake and the nutritional composition of the pasture actually selected by grazing sheep.

After pasture availability was estimated using the model, it was used to predict production levels during periods of supplementary feeding. Model inputs included measured levels of supplement digestibility and protein content and the quantities recorded as being fed. During this process it immediately became apparent that there were often large discrepancies between recorded and predicted levels of production. Model outputs showed that significant proportions of the supplement being fed were apparently not being consumed. This arose from the low digestibility and low protein content of the diet, with rumen function again being reduced by low nitrogen. Even when the nitrogen content of the supplements was theoretically increased, large discrepancies between predicted and recorded levels of production persisted. The model continued to indicate that the sheep could not consume the quantity of supplement fed. To reconcile these results we concluded that considerable selection of hay, and possibly silage, was occurring. Consequently, the portion of roughage actually consumed by the sheep was of higher quality than indicated by the proximate analysis of samples of the bulk roughage. (Measurements of supplement intake at Aohan subsequently confirmed that at times the sheep failed to consume all the roughage supplement fed.)

A range of procedures was used, including iteration with the model, to estimate the digestibility and protein content of the roughages 'selected' by the sheep in order to achieve recorded levels of production. These values were then put into the model to predict the most appropriate combinations and quantities of hay, silage and concentrate required to achieve a particular production outcome. Measured and estimated values for hay and silage quality were then used to calculate the true quantities proposed to be fed.

The inability to rely on proximate analyses of roughages and to assume that all supplements supplied were consumed brings into question the accuracy of estimates of feed intake during supplementary feeding and the reliability of relationships derived using these estimates. Consequently, several of the relationships between live weight or wool growth and energy and protein intake outlined in previous papers in this report should not be relied upon or widely used to predict levels of production. Additional measurements of the protein and energy content of the actual supplement and pasture consumed, along with more detailed and accurate measurements of pasture and supplement intake, are needed to ensure these relationship are accurate. Only then can they be widely used in developing reliable, new strategies for improving production in northern China.

Although it is acknowledged that large errors may have been associated with the predicted outcomes, the procedure showed clearly that:

a) nutritional measurements associated with hay, silage, and possibly pasture samples do not reflect the quality of feed eaten;

b) the potential production of immature, growing sheep during the winter period was restricted by the quality of both supplements and pastures. This was despite the possibility of selection and the addition of urea to improve rumen nitrogen; and

c) most pastures and supplements could not sustain live weight during lactation.

Traditional Management and Socioeconomic Factors

One of the consequences of this research project (particularly for the development and evaluation of modified feeding strategies) was the recognition of the role that traditional management and socioeconomic factors sometimes play in production outcomes. This was first recognised at the start of the project when difficulties were sometimes encountered in establishing experimental programs. Because of the 'responsibility system' shepherds were often reluctant to alter their flock management in case it reduced production relative to their peers and thus affected their income. For example, they were reluctant to have controlled-release devices (CRDs) containing anthelmintics or chromic oxide administered regularly to their sheep because they thought they might reduce the production of their flock. In order to emphasise the important role that these factors can and do play in production we present further examples of a more general nature. Several of these suggest that scope exists for increasing production without major economic inputs.

Example 1. The production of higher quality hay and silage is constrained by the way labour is organised to suit traditional practices. More importantly, farmers are paid on a volume and weight basis. Any improvement in quality will therefore require alterations in allocation of labour and time for different tasks, plus payment for quality and not quantity. Unfortunately, even in a so-called technologically advanced and developed country like Australia, hay and silage production are often still based on a quantity, not quality, system.

Example 2. The shepherds at all three sites take the sheep from the sheep shed and yards to the pasture for 'grazing' in both the morning and the afternoon during winter. The absence of free water for drinking and the consequent need of the sheep to eat snow is part of the reason for these movements. However, depending on the severity of the weather, it appears likely that the expenditure of energy in walking, digging under snow for pasture to eat and in maintenance of their body temperature in exposed conditions may exceed the energy gained from the low quality pasture ingested. Restricting sheep movements when weather is severe and developing systems for providing drinking water at the sheep sheds could therefore benefit production.

The building of water catchments from snow in the winter grazing area, which has commenced at Nan Shan farm, may nevertheless be causing another problem. Before the advent of the snow tanks and drinking water, the sheep had to be removed from the winter grazing area once the snow disappeared. The provision of water now allows the sheep to remain in the winter grazing area for a longer time before being moved to spring pasture. Observations made in 1991 suggest that this may cause overgrazing of the pastures and lead to severe erosion, with consequently reduced production.

Example 3. The shepherds at Nan Shan farm not only take the ewes grazing irrespective of the weather but traditionally confine the suckling of the 2-day to 4-week-old lambs to restricted periods twice a day. More frequent or prolonged suckling is considered to cause lamb diarrhoea. Scientific evidence for this cannot be found and Chinese veterinarians refute such ideas. However, it is possible that bacterial growth in the gut is enhanced by a single large intake of milk followed by a sustained period of non-suckling. Furthermore, because the lambs are closely confined in a semi-enclosed shed for most of the day, cross-infection could become rife if any lamb does develop a severe gastrointestinal infection. Allowing more frequent, complete suckling, and maintaining the lambs with the ewe whenever they are in the yards, may therefore enhance lamb growth and survival significantly.

The traditional ewe–lamb management system and a failure to alter it as requested were considered the reason for the failure to observe improved lamb growth in the first test of modified feeding. Other results were as predicted. The failure to allow the lambs to suckle completely and regularly would have prevented the benefits of increases in milk production being expressed through improved lamb growth.

Example 4. Until recently, the price paid to farmers and shepherds for their wool was entirely on a greasy weight basis. Consequently, there has been no incentive to restrict overgrazing and reduce dust problems, or to handle sheep in yards in a manner which prevents fleece contamination. Traditional sheep-handling methods appear to be a consequence of the easy access to unskilled labour, particularly women and younger children. Well designed yards that assist in sheep handling and could reduce contamination are more expensive in the short-term than payment of a large, relatively unskilled, labour force. Moreover, reducing or removing the need for this labour may have serious economic consequences for those whose labour is no longer needed, and have further flow-on social effects.

Wool Quantity versus Wool Quality?

The data on wool quality collected in this and the other ACIAR projects show that, in terms of fibre diameter (20–23 μm), the wool produced in northern China often apparently satisfies the requirements of a medium-fine wool. Unfortunately, the average fibre diameter along the staple can range from as low as 13 μm to more than 30 μm. Changes in diameter generally coincide with changes in growth rate of wool and thereby with season (see Lu et al., this report). As already discussed, nutrition plays a major role in the seasonal variations in wool growth and thereby in the variations in diameter.

The large variations in diameter along the staple on all three farms are accompanied by low tensile strengths. Data obtained in Project 8454 (D.G. Masters et al., pers. comm.) showed that the tensile strength of staples from midside samples collected at Huang Cheng ranged from 3 to 18 N/ktex with a mean of 7.6 ± 0.6 N/ktex (n = 30). In simple terms, all of the wool was extremely tender and much was rotten.

Fibre diameter, uniformity of fibre and staple strength are not taken into account currently in the price paid by woollen mills to producers in China; this should occur sometime in the future. It is important, therefore, that wool quality be included in strategies for increasing wool production in northern China. Unfortunately, given the current areas of wool production, the status of pastures and supplements and the restricted availability of protein supplements, it is unlikely that there can be any sustained increase in the quantity of wool produced without further declines in quality. Nutritional and production data, such as those provided in this study, will be critical in developing production strategies to improve attributes of quality. Even so, it may at times be necessary to sacrifice quantity for the ability to have quality as part of sustainable production systems.

Conclusions

The studies carried out in Project 8555 have generated many data relating to the nutrition and associated production of fine wool sheep in northern China. The results highlight the important constraints of energy and protein to both weaner and ewe production at various times of the year. These are most notable throughout the period November–March when temperatures are low, pastures are in a non-vegetative state and supplementary feeding is required. Nutritional constraints during this period have major effect on wool quality as well as growth. Analytical and production data clearly show the low digestibility and protein content and high fibre content of most roughage supplements and their influence on wool quality and quantity. Responses to improvements in protein intake by using higher protein concentrates are likely to be limited unless the digestibility of the roughage is likewise improved. Some gains in wool growth and quality may be achieved by using concentrates containing a high proportion of rumen undegradable protein. Responses may still be limited by energy deficits, leading to the metabolism of some amino acids for energy. Furthermore, the high cost and low availability of supplements containing rumen un-degradable protein mitigates against the use of such supplements. A further option for improving wool production and possibly production in general is to substantially increase the legume content of grazed pastures.

The data indicated little or no significant effects on production of interactions between nutrition and helminth infections. Whether this is normal or was caused by the low levels of infection on some farms, the variability in infection between seasons or the timing of peaks of infections in relation to the level of nutrition, is uncertain. It is also possible that, given better nutrition, the effects of helminth infections on production may have been greater. From the nutrition studies alone we have identified a lack of reliable estimates of pasture and supplement intake, the uncertainty surrounding the nutritional composition of the pasture and roughage supplements eaten by grazing sheep, and an absence of measurements of the availability of pasture (which sheep will eat) as important constraints to understanding of nutrition and production of grazing sheep in northern China. Once this information becomes available, more reliable energy–protein–production relationships, of the kind derived by Lu et al. (this report), can be developed. These, together with other data, will have wide application in developing strategies for improving the nutrition and production of fine wool sheep in northern China.

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A Description of the Trace Element Status of Sheep in Three Areas of Northern China

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In an environment characterised by seasonal extremes, such as northern China or the Mediterranean zone in Western Australia, the availability and quality of pasture for grazing may fluctuate widely during the year (Purser 1980; Masters et al. 1990). Where sheep are concurrently stressed by an inadequate supply of energy, minerals and protein, responses to minerals may still be significant. For example, in the Mediterranean environment of Western Australia, responses to selenium, cobalt (Gardiner 1969), zinc (Masters and Fels 1980), copper (Bennetts 1959) and multi-element supplements (White et al. 1992) have been reported.

Trace element deficiencies that occur under these grazing conditions may reduce the production of meat and wool from sheep. Grazing animals or animals receiving feed from a restricted geographical area are particularly susceptible to both deficiencies or toxicities (Underwood 1981). These may be present as overt symptoms, characterised by specific pathological changes, or as marginal deficiencies that are not easily identified, are often undetected, but may cause a significant depression in production (Judson et al. 1987; Masters and Peter 1990).

Deficiencies may result from low concentrations of minerals in the soil and plants, or be induced by interactions between trace elements or between trace elements and other nutrients.

In China, both trace element deficiencies and toxicities may influence animal production. Liu et al. (1987), in a national investigation of plant material and animal feedstuffs, reported that 70% of the counties in China grew pastures with selenium concentrations less than 50 µg/kg DM. In the northern province of Heilionjiang, 93% of feedstuffs contained less than 20 µg/kg. The concentration considered to be minimum for sheep is between 30 and 50 µg/kg (ARC 1980; SCA 1990). Copper deficiency has been reported in Xinjiang Uygur Autonomous Region and in the east of Inner Mongolia (R.Z. Yang, L.H. Wu, pers. comm.). The mountainous areas of China are also low in iodine and iodine deficiency disorders (IDD) in humans are widespread (Hetzel and Maberly 1986). Naturally occurring selenium and fluorine toxicities have also been reported.

Few reports have been published on the trace element status of grazing sheep, and most recent trace element research has concentrated on pastures or on monogastric animals such as pigs and poultry. The aim of the current study was to investigate the trace element status of grazing sheep at three locations in northern China and describe the changes caused by seasonal variation and the different physiological states of the sheep. The farms — Huang Cheng (Gansu Province), Nanshan (Xinjiang Uygur Autonomous Region) and Aohan (Inner Mongolia Autonomous Region) — are representative of major fine-wool sheep growing areas (Lindsay et al. this report). One hundred and forty 2 or 3-year-old breeding ewes were used in the study.

Selenium

On all farms, selenium concentrations in pasture were within or below the marginal range for sheep (ARC 1980; SCA 1990) of 30 to 50 µg/kg DM at some times during the year (Fig. 1). The low and different levels of selenium in pasture were reflected in both plasma and liver (Fig. 1). Selenium levels tended to be lowest in summer, when pasture and animal growth are at their highest. Concentration of selenium in the liver fell below

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100 µg/kg wet weight during the year. A high incidence of white muscle disease has been reported by others in sheep flocks with mean selenium concentrations in liver of less then 90 µg/kg (Gabbedy et al. 1977). These results indicate that ewes at Huang Cheng and Nanshan farms, but not Aohan, are at risk from selenium deficiency. The higher concentrations of selenium in tissues collected from Aohan farm probably resulted from the higher concentrations of selenium in pastures in summer and in the concentrates and silage fed in winter and autumn (Table 1).

Concentrations of selenium in plasma at Huang Cheng and Nanshan farms (>20 µg/L, Fig. 1) approached, but were not as low as those reported in the experiments of Langlands et al. (1991a,b,c) (5-19 µg/L). In these experiments, marginal selenium deficiency in reproducing ewes resulted in reduced wool growth, fibre diameter, lambs weaned and live weight of lambs at birth and weaning.

Copper, Iron and Molybdenum

The lowest concentrations of copper in the liver were at Huang Cheng farm (3.7 mg/kg wet weight, Fig. 2). This is below the deficient level reported by Paynter (1987) of 5 mg/kg wet weight and the concentration at which Hogan et al. (1971) reported depressed wool and body growth and connective tissue lesions (8.6–14.2 mg/kg). Copper deficiency can be induced by a lack of copper in feedstuffs (Underwood 1981), by high intakes of molybdenum and sulphur (Dick 1953) or by high intakes of iron (Humphries et al. 1983). As copper in pasture was only occasionally below requirements for sheep (<5 mg/kg DM: SCA 1990) on any of the farms (Fig. 3) and copper concentration in tissues was not related to the time of the year or physiological state of the ewes, the low concentrations in liver were probably caused by an interaction of copper with iron or molybdenum and sulphur.

Iron in pasture was extremely high at Nanshan and Huang Cheng for part of the year (Fig. 4). The highest concentration of 4000 mg/kg DM was 100 times requirement (30–40 mg/kg DM: SCA 1990) and higher than the concentrations of iron shown to reduce copper status in other experiments with sheep (Wang and Masters 1990). These high pasture concentrations were reflected in faeces, with concentrations up to 7000 mg/kg DM at Huang Cheng and Nanshan (Fig. 4). Much of the iron measured in faeces may have been derived from soil contamination of pasture and, at Huang Cheng, to the habitual consumption of soil, caused by a lack of sodium. Consumption of high iron soils has previously been shown to reduce copper status in sheep (Suttle et al. 1984). Molybdenum in pasture was sufficiently high to interact with copper (Suttle and McLauchlan 1976) but not as high as observed to cause severe copper deficiency (Hogan et al. 1971). The concentration of sulphur in pastures at Huang Cheng was not high enough to induce copper deficiency (Lu et al., this report).

High intakes of iron not only decrease the copper status of sheep but may also depress liveweight gain through mechanisms not associated with copper deficiency (Wang and Masters 1990). The high iron consumption of ewes at Huang Cheng and Nanshan may therefore have had a direct effect on productivity. Iron in the liver at Huang Cheng ranged from a low of 88 mg/kg wet weight in September to a high of 207 mg/kg wet weight in May. When these are compared with the concentrations in the liver of sheep fed known amounts of iron in the animal house (Wang, unpublished data), the lower concentrations corresponded to adequate intakes of iron while the highest corresponded to those in sheep fed more than 500 mg/kg DM, or more than 14 times requirement.

Table 1. Concentration of trace elements in feed supplements (mg/kg DM)

	Concentrates			Hay			Silage		
	HC[a]	NS[b]	AH[c]	HC	NS	AH	HC	NS	AH
Selenium	0.021	0.092	0.083	0.021	0.047	–	0.021	–	0.06
Copper	4.50	11.3	11.6	3.27	6.38	–	4.57	–	4.14
Molybdenum	0.85	1.43	0.72	0.74	1.44	–	1.40	–	1.82
Iron	159	272	287	150	310	–	354	–	372
Manganese	26.6	36.0	28.7	33.8	53.0	–	53.4	–	56.7
Zinc	23.9	46.8	30.1	16.5	29.5	–	20.5	–	10.9

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

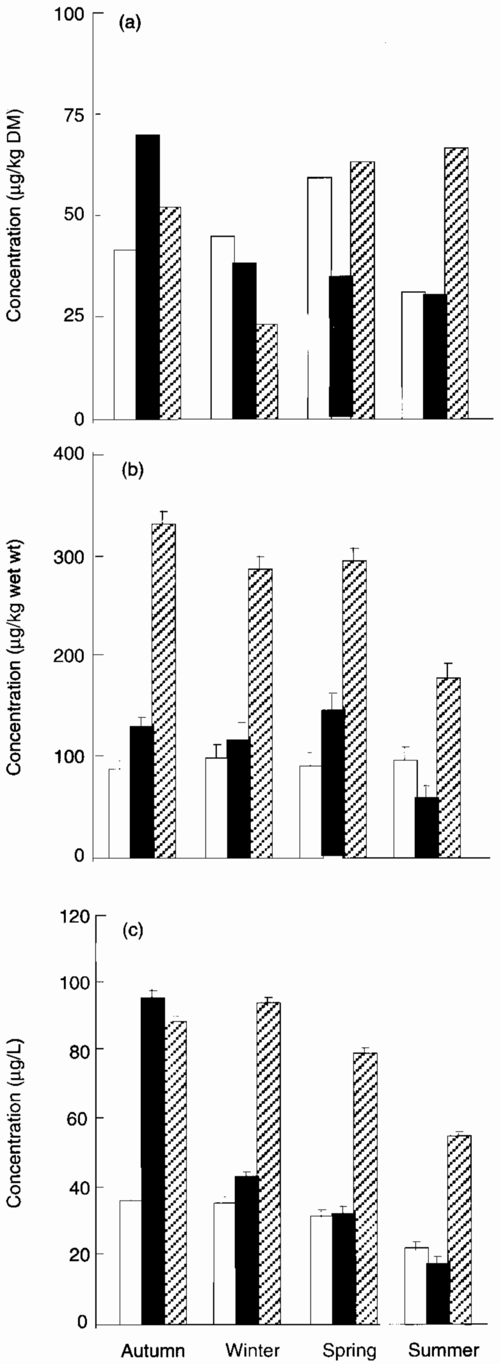

Figure 1. Selenium concentrations in (a) pasture, and in (b) the liver and (c) plasma of reproducing ewes, at Huang Cheng (blank box), Nanshan (filled box) and Aohan (hatched box) farms during each season.

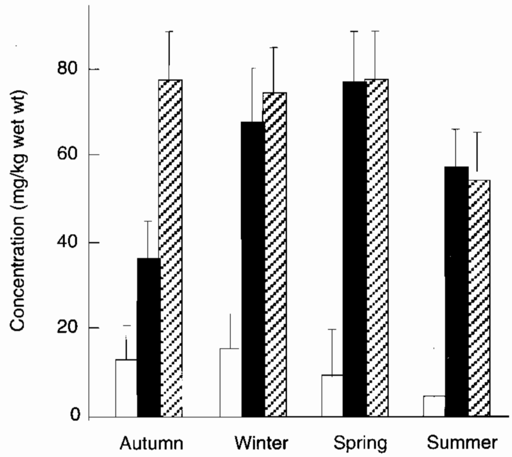

Figure 2. Copper concentrations in the liver of reproducing ewes, at Huang Cheng (blank box), Nanshan (filled box) and Aohan (hatched box) farms during each season.

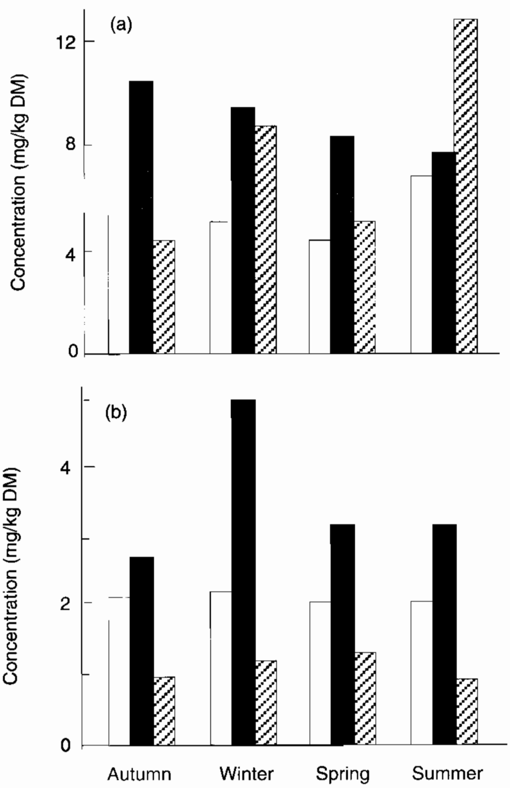

Figure 3. (a) Copper and (b) molybdenum concentrations in pasture at Huang Cheng (blank box), Nanshan (filled box) and Aohan (hatched box) farms during each season.

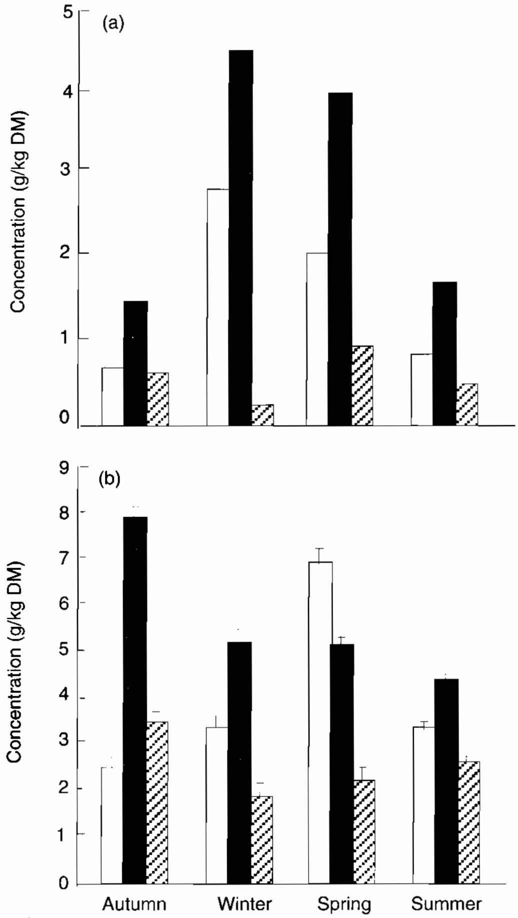

Figure 4. Iron concentrations in (a) pasture and (b) faeces at Huang Cheng (blank box), Nanshan (filled box) and Aohan (hatched box) farms during each season.

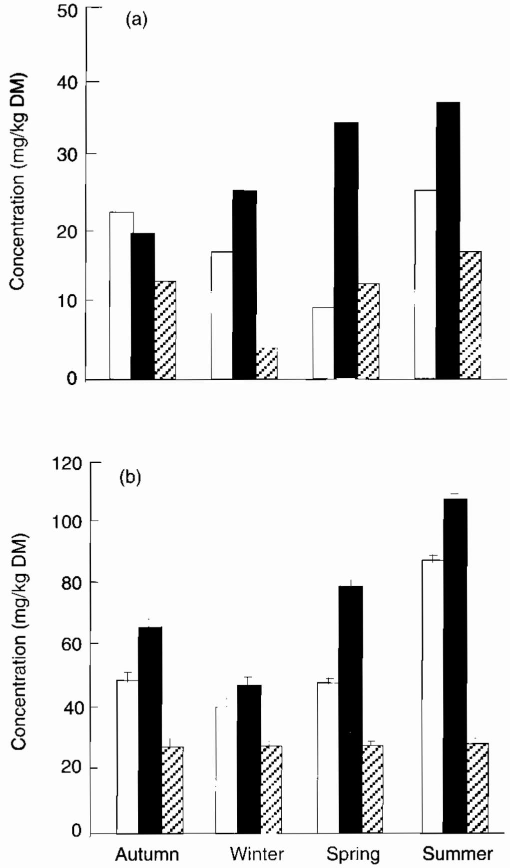

Figure 5. Zinc concentrations in (a) pasture and (b) faeces of reproducing ewes, at Huang Cheng (blank box), Nanshan (filled box) and Aohan (hatched box) farms during each season.

Zinc

Zinc in pasture ranged from 4 to 37 mg/kg DM (Fig. 5) and was always less than 20 mg/kg at Aohan farm. The lower values recorded were below the recommended intakes for sheep (9–15 mg/kg DM: SCA 1990). Some low zinc values in faeces were also observed, particularly at Aohan farm (Fig 5). The concentration of zinc in faeces would normally be 2–4 times higher than in the ingested feed. This indicates that the intake of zinc at Aohan farm was between 7 and 15 mg/kg DM throughout the year.

Despite the low levels of a number of trace elements, no clinical signs of deficiency were observed during the study. The low concentrations of selenium at Huang Cheng and Nanshan, and copper at Huang Cheng, however, are consistent with marginal deficiencies of these elements.

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Some Aspects of Macromineral Nutrition of Grazing Sheep in Northern China

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THE macrominerals sodium, potassium, phosphorus, chlorine, magnesium and sulfur are all essential for animals (Underwood 1981). In many parts of the world, disorders in livestock production are due to naturally occurring deficiencies of one or more of these essential elements in forages or other feedstuffs. However, there are no papers on macromineral nutrition of grazing sheep in northern China. In northern China, there are vast areas of grasslands in both arid and alpine environments. These are used for grazing animals and support more than 55% of the sheep population in China. In most areas, little fertilizer is used to promote pasture production; feed supplements are often inadequate to maintain live weight of sheep and usually are locally produced (Masters et al. 1990). Under such condition, the dependence on low or poor quality forage for more than 7 months of a year increases the risk of macromineral deficiencies, since normally dry forages are characterised by lower availability of macroelements. The aim of this study was to determine the macromineral levels in pasture, supplements, and sheep at different seasonal times at the three farms in northern China described by Lindsay et al. (this report). On each farm 140, 2 or 3-year-old reproducing ewes were used.

Sodium, Potassium and Magnesium

Sodium concentrations in pasture were below the levels recommended for optimal animal production at the three farms — Huang Cheng, Nanshan and Aohan — for all or part of the year (Table 1).

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Morris and Peterson (1975) suggested that a sodium intake of 0.87 g/kg DM was required to maintain an adequate Na:K ratio in the parotid saliva of pregnant ewes. Vincent et al. (1986) reported that milk production and lamb growth were unaffected by intakes of sodium as low as 0.1 g/kg, but at the lowest sodium intakes the ewes were in negative sodium balance. Only in autumn, at Nanshan, did pastures reach the levels indicated by Morris and Peterson (1975) and, for much of the year at Huang Cheng and Aohan, concentrations were below 0.1 g/kg (Table 1). Deficiency of sodium is a recognised problem in northern China and salt supplements are usually provided to grazing sheep on state-owned farms. However, it is often difficult to transport such supplements to the mountainous summer pastures and sheep do not get supplements regularly throughout the year.

Morris (1980) suggested that the Na:K ratio in the parotid saliva, and adrenal histology, were the most sensitive indices of sodium insufficiency. Urinary sodium excretion is an alternative index of contemporary sodium intake (Caple and Halpin 1985). However, none of these indices was determined in the current study. As an indication of low sodium intakes in summer and autumn, the concentrations of sodium in faeces at both Aohan and Huang Cheng (0.45–0.93 g/kg, Table 1) were below those reported for sodium-deficient cattle (1.4 g/kg, Murphy and Gartner 1974). In winter, when sheep were housed and fed supplements containing higher sodium concentrations (Table 2) and salt, faecal sodium was much higher (1.65–2.74 g/kg).

Of the three farms, Huang Cheng appears to be most affected by low sodium intakes. On this farm, the concentration of sodium in plasma was always below the other farms and the normal concentration of 3300 mg/L reported by Vincent et al. (1986) (Table 1). The high faecal potassium concentrations at Huang Cheng (Table 1) indicate that

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).

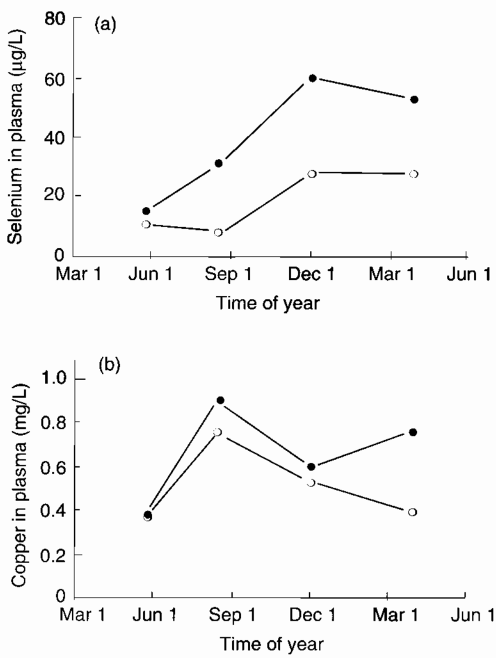

Figure 1. (a) Concentration of selenium in plasma with (●) and without (○) additional selenium; and (b) concentration of copper in plasma with (●) and without (○) additional copper.

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)

	Greasy fleece weight (kg)		Live weight at end of expt (kg)	
Flock 1 (+ protein/energy)				
	+ 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)				
	+ 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.

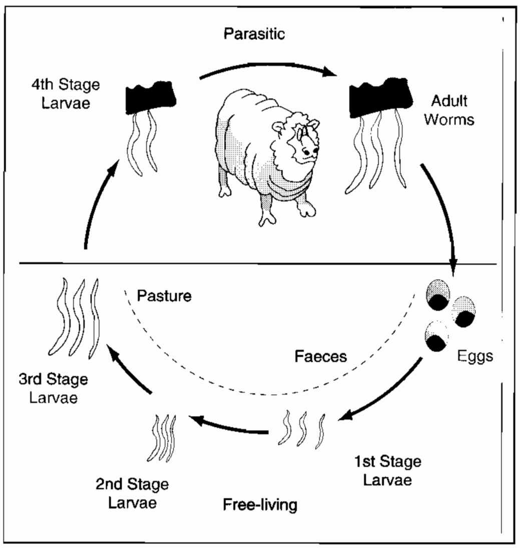

Figure 1. Simple direct life-cycle of a sheep nematode parasite

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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).

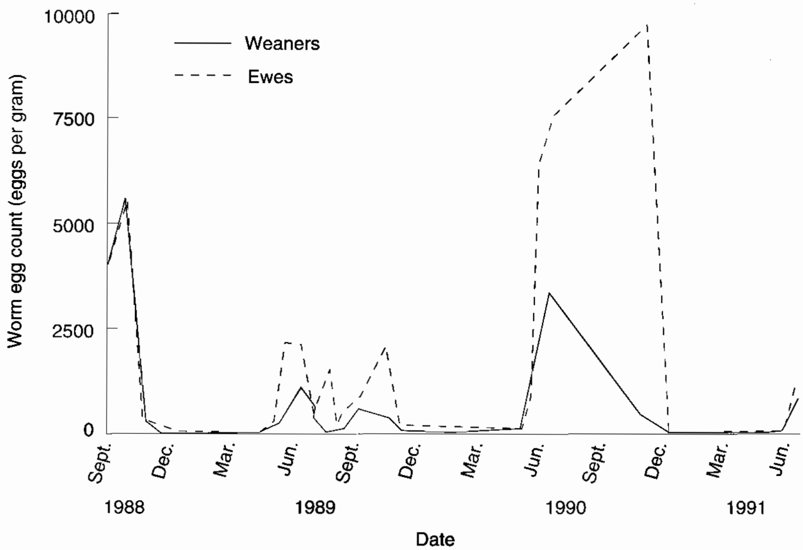

Figure 1. Mean counts of worm eggs in the faeces of untreated weaners (solid line) and ewes (dotted line) at Aohan farm over three years.

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.

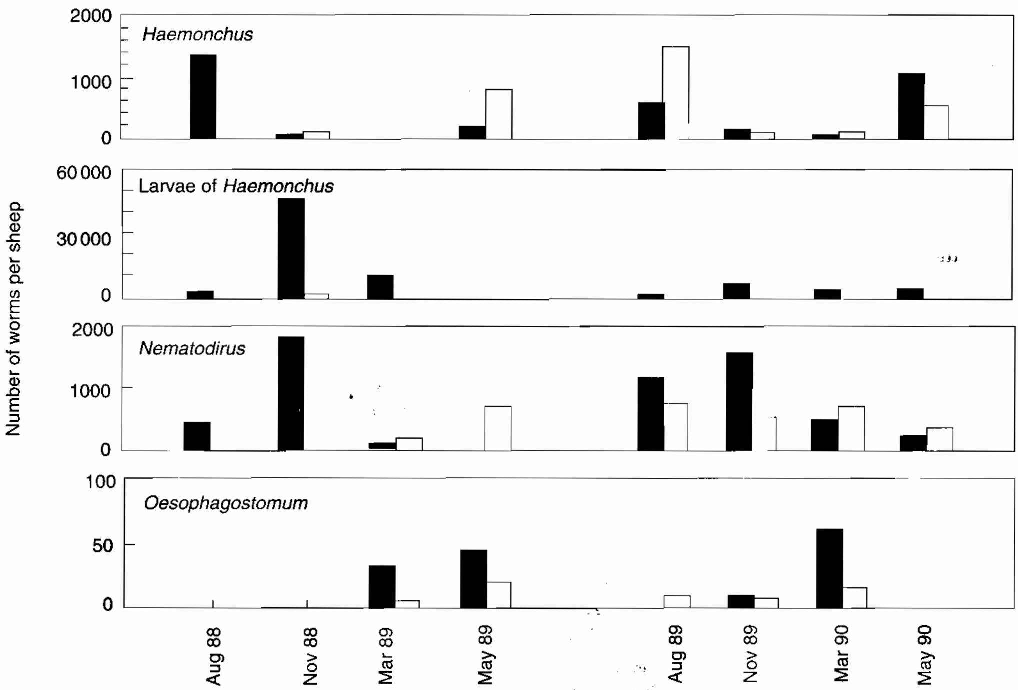

Figure 2. Mean worm counts from 4 weaners (solid bar) and 4 ewes (open bar) killed at Aohan farm over the first two years of the study.

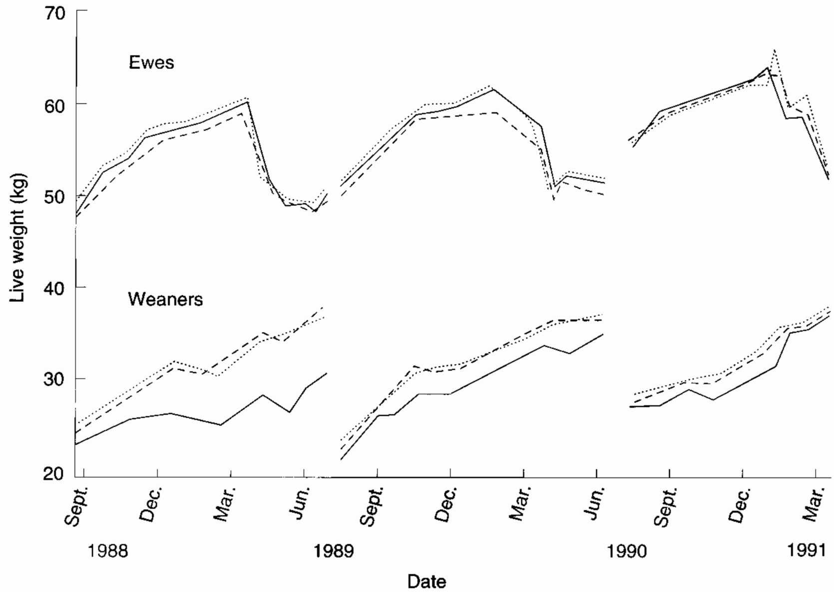

Figure 3. Live weights of weaners and ewes at Aohan Farm over the three years of the study. Groups shown are: untreated (solid line); routine treatment (dashed line); capsule treatment (dotted line).

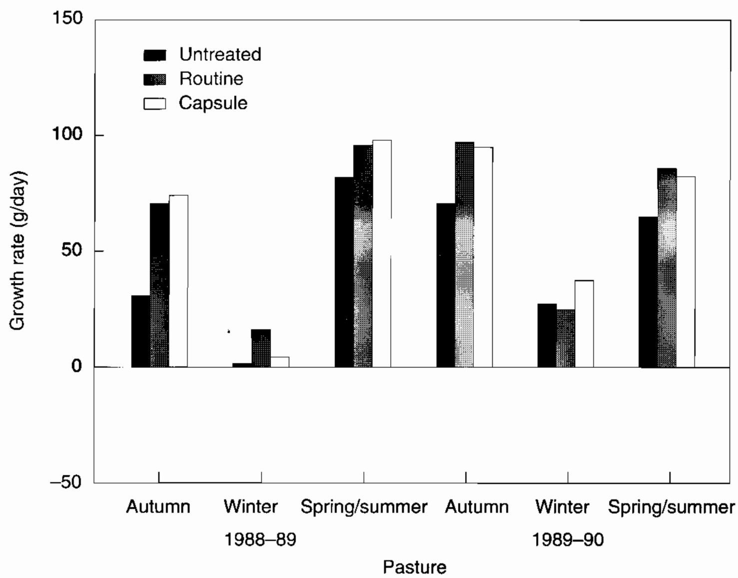

Figure 4. Weight gains of weaners over the first two years of the study. The year is divided into three periods related to the pasture grazed at the time.

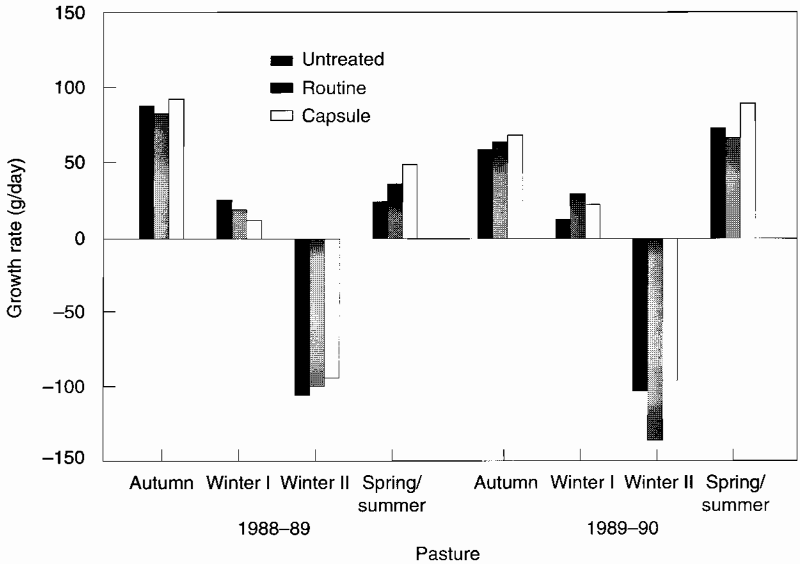

Figure 5. Weight gains of ewes for the first two years of the study. The year is divided into four periods based on the pasture grazed at the time. Winter I = winter pasture, before lambing; Winter II = winter pasture, after lambing.

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

Year	Group	Birth weight		Weaning weight	
		Mean	s.d.	Mean	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

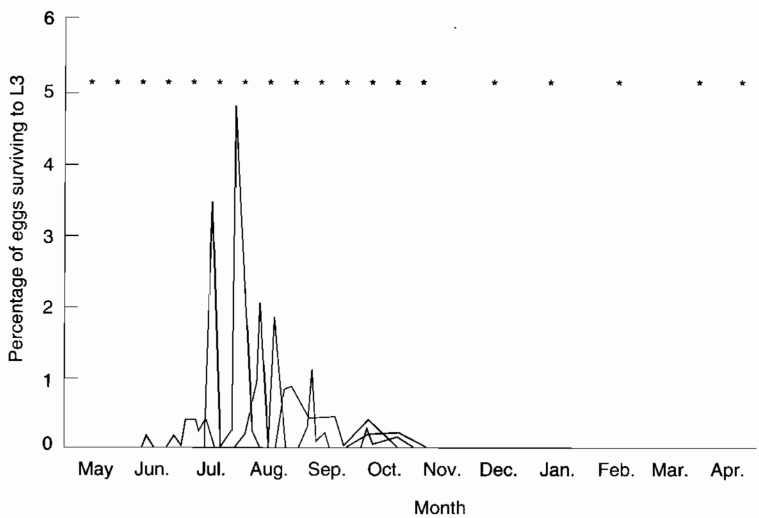

Figure 1. The proportion of *O. circumcincta* eggs which developed to infective larvae (L3) on the pasture at Huang Cheng farm from April 1990 to April 1991. Asterisks indicate the times of deposition of faeces.

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.

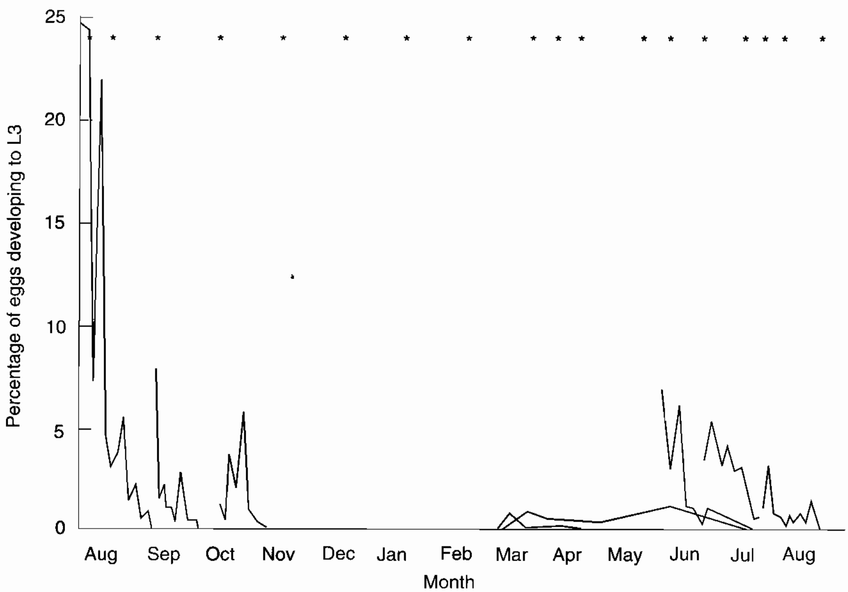

Figure 2. The proportion of *H. contortus* eggs which developed to infective larvae (L3) on the pasture at Aohan farm from August 1990 to August 1991. Asterisks indicate the times of deposition of faeces.

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

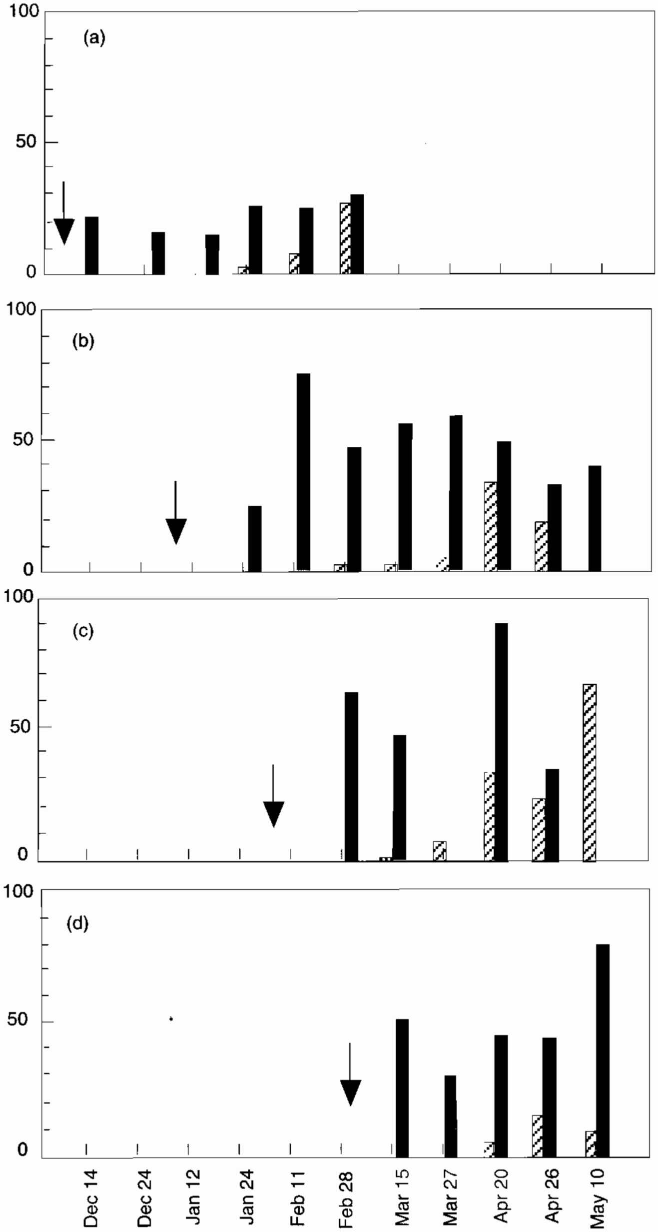

Figure 3. Mean worm egg counts from untreated ewes (hatched bars) and treated ewes (solid bars) at Huang Cheng farm during the winter of 1991. The letters a, b, c and d represent different groups, half of which were treated with albendazole (10 mg/kg) on the first day of December, January, February and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

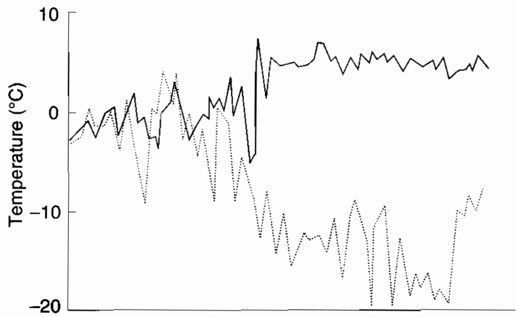

Figure 4. Mean daily temperatures recorded inside the sheep sheds (solid line) and in the sheep yards (dotted line) at Huang Cheng farm during winter 1992.

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.

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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

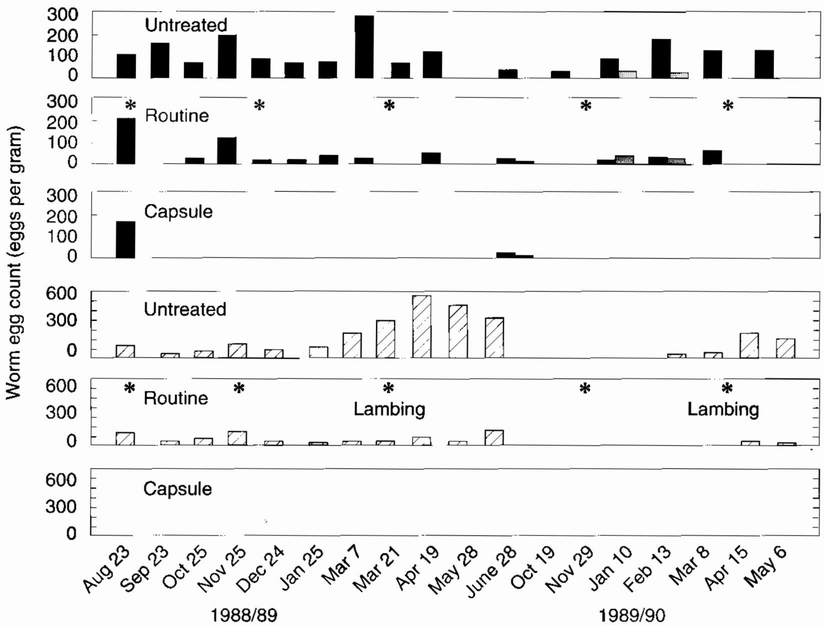

Figure 1. Mean worm egg counts in faeces from all treatment groups and classes of sheep at Nan Shan farm. Heavy shading = worm egg counts from weaners. Light shading = counts of *Nematodirus* spp. eggs from weaners. Cross hatch = worm egg counts from ewes. Asterisks indicate times of routine treatment.

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.

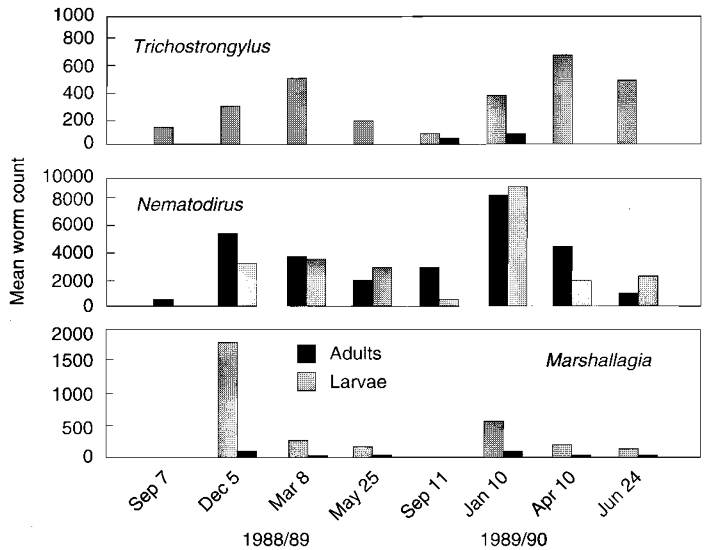

Figure 2. Worm counts from untreated weaners at Nan Shan farm.

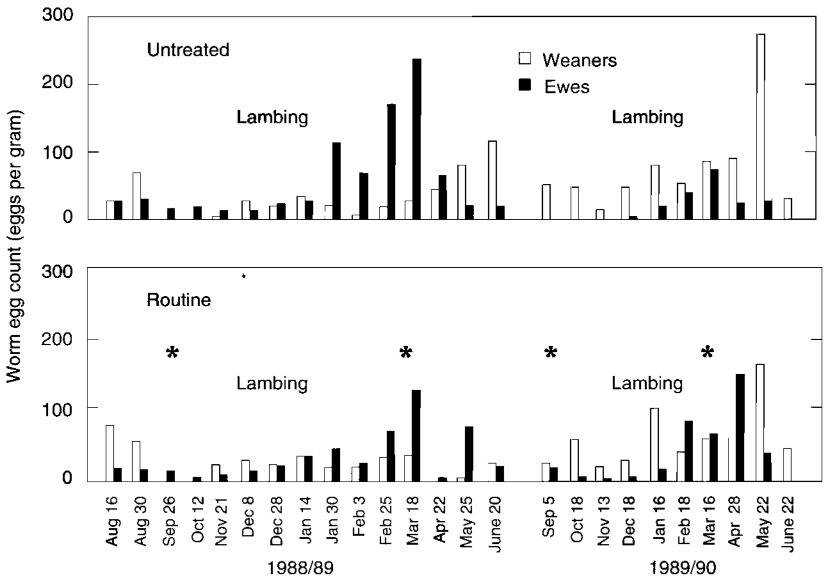

Figure 3. Mean egg counts from untreated and routine-treatment groups of weaners and ewes at Huang Cheng farm. Asterisks indicate times of routine treatment.

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.

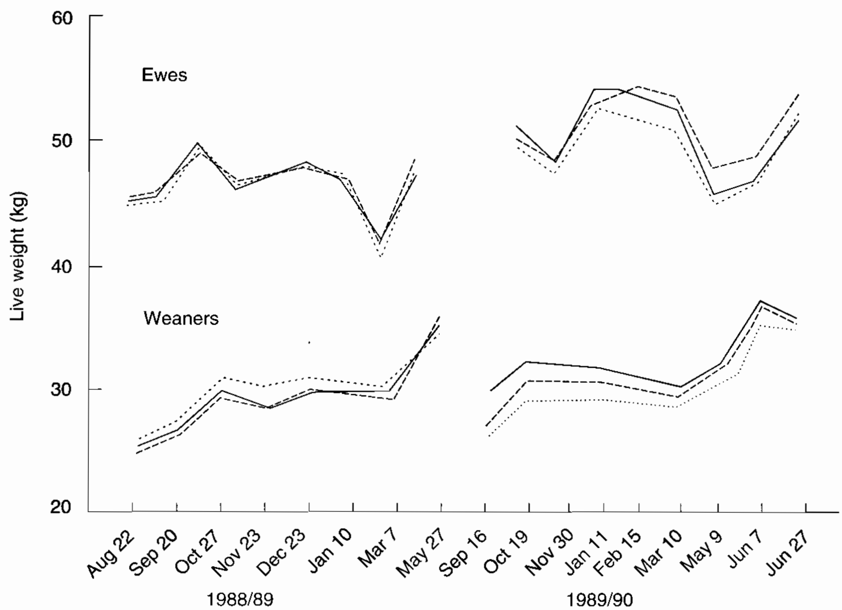

Figure 4. Mean live weights of weaners and ewes at Nan Shan farm over the first two years of the study. The groups of sheep are: solid line, untreated; dashed line, routine treatment; dotted line, capsule treatment.

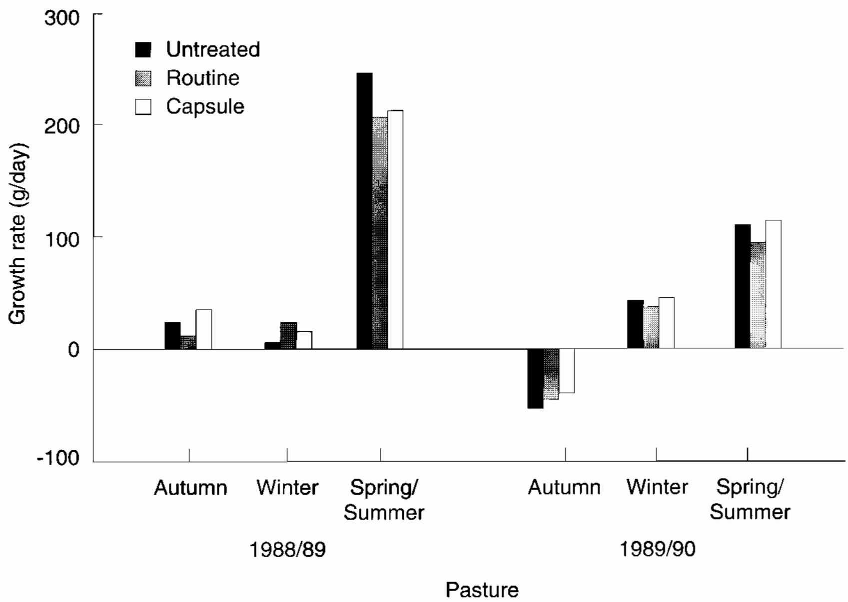

Figure 5. Weight gains of weaners at Nan Shan farm over the first two years of the study.

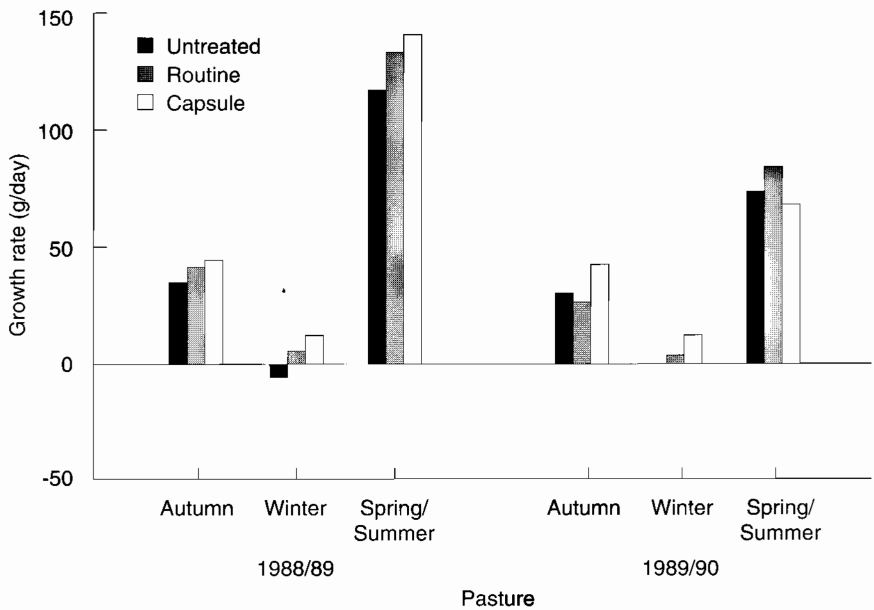

Figure 6. Weight gains of ewes at Nan Shan farm over the first two years of the study.

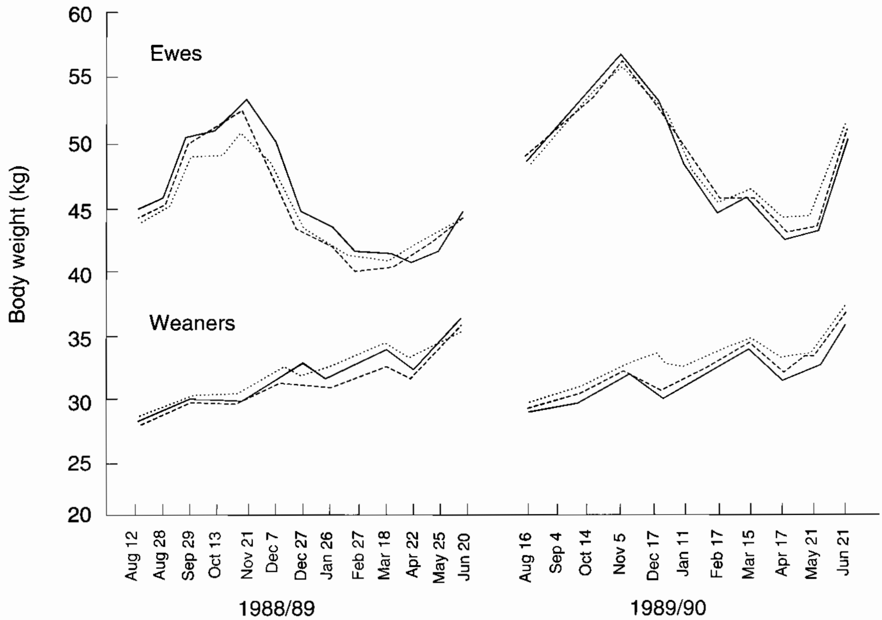

Figure 7. Liveweights of weaners and ewes at Huang Cheng farm. Groups of sheep are: solid line — control; dashed line — routine treatment and dotted line — capsule.

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

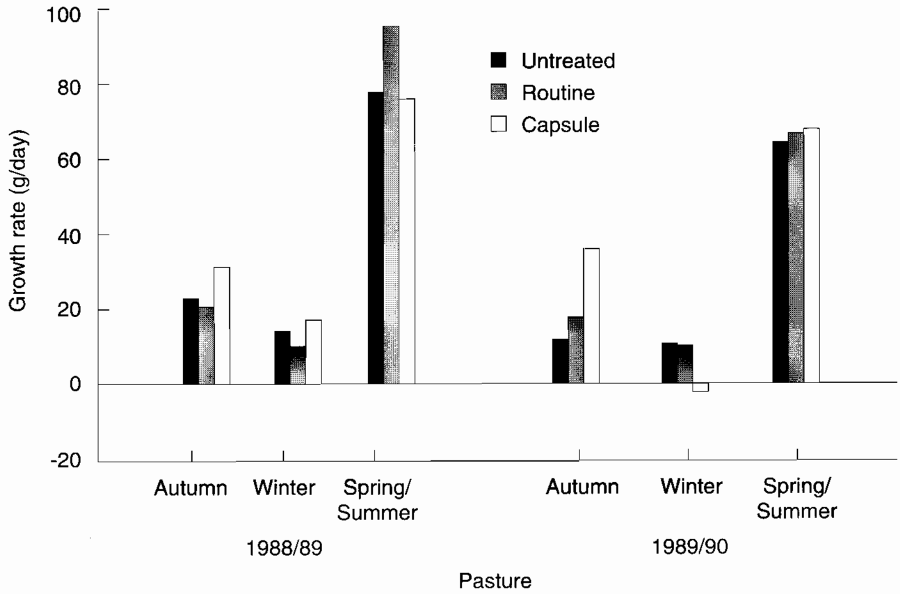

Figure 8. Weight gains of weaners at Huang Cheng farm over the first two years of the study.

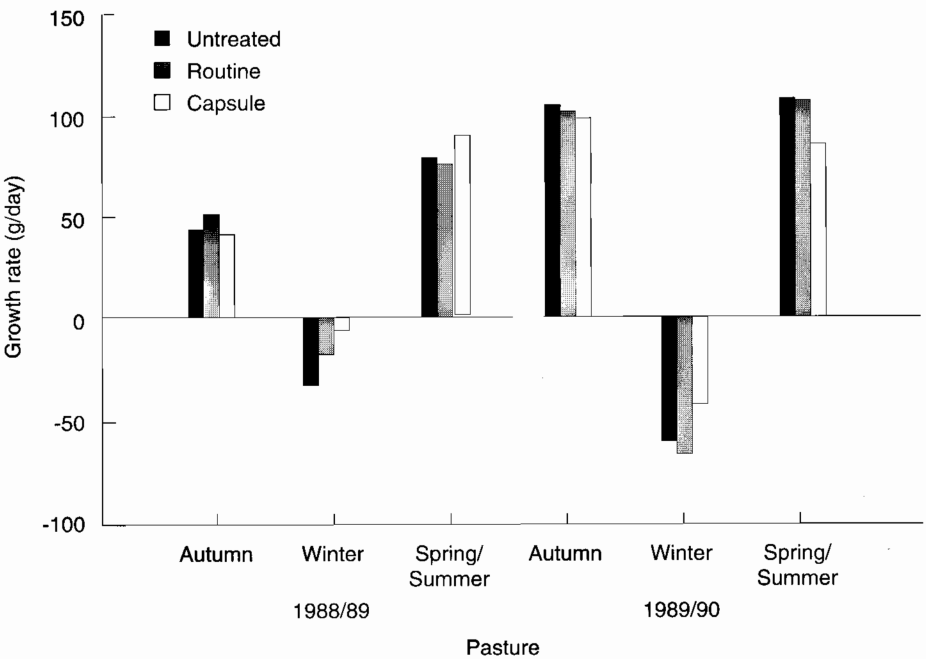

Figure 9. Weight gains of ewes at Huang Cheng farm over the first two years of the study.

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

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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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