Clinical evaluation of anaemia in sheep: early trials

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ABSTRACT

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Trials were conducted on a farm in Mpumalanga Province in South Africa to test the possibility of grading the colour of the ocular mucous membranes of sheep as an indication of the extent to which the animals are affected by *Haemonchus contortus* infection. The range of observed colour shades were classified into five categories, from red, through red-pink, pink and pink-white to white.

Over a period of 125 days routine drenching of a flock of 388 sheep on irrigated kikuyu (*Pennisetum clandestinum*) pasture was terminated. During this time the animals were examined at practically weekly intervals and haematocrit determinations done for all the sheep with pale conjunctivae. Only those sheep having a haematocrit of 15 % or lower were treated.

Compared to a previous drenching tempo of close to every 3 weeks during the *Haemonchus* season on the farm, drenching was reduced by approximately 90 %, as 70 % of the sheep did not require salvage drenching and only 10 % of the flock had to be given more than one salvage treatment.

At the time of the trial the five clinical classifications were not related to predetermined haematocrit categories. However, when compared to categories that were set in later trials, 94 % of the clinical estimates in the present trial were either in the correct haematocrit category, or, if not, the sheep were probably not disadvantaged by the errors. In 2.6 % of cases the incorrect estimate may have placed the sheep concerned in jeopardy, as the haematocrit values were so low that salvage drenching was required, while the sheep were not regarded as anaemic.

Changes in the mean haematocrit values of drenched and undrenched sheep were mirrored reciprocally by the changes in clinical colour estimates.

Lactating ewes were by far the most susceptible class of sheep, as only 44.6 % of them were able to manage without drenching, compared to 83 % of dry, and 70.6 % of pregnant ewes. Correlations between the haematocrits and clinical estimates were highly significant, although the associations were not high enough to give reasonable surety that the haematocrit values of individual animals could be predicted with confidence from their clinical classifications.

Exceptionally large numbers of worms were recovered from seven of the 14 sheep that were culled because of age at the end of the trial, but these were reflected neither in their faecal worm egg counts, nor, with one exception only, in clinical signs.

Keywords: Anaemia, haematocrit, *Haemonchus contortus* infection, irrigated pasture, sheep

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INTRODUCTION

Waller (1997) described anthelmintic resistance as the biggest global threat to grazing livestock production, and surveys in South Africa indicate that the levels of resistance in South Africa may be the worst in the world (Van Wyk, Stenson, Van der Merwe, Vorster & Viljoen 1999).

The cost involved in developing new anthelmintics and registering them for field use are so high (McKellar 1994; Soll 1997; Waller 1997), that it is far beyond the budgets of research institutions in South Africa. Thus we decided to concentrate on developing alternative, largely biological methods of worm management for delaying further escalation of resistance to existing anthelmintics.

A most promising method for delaying the onset of resistance is to leave a proportion of the flock or herd undrenched: "Barger (1985) demonstrated that important nematodes of sheep are overdispersed with more than half of the worms contained in less than half of the hosts. He argued that if treatment was confined to a relatively small proportion of heavily infected individuals, then this is likely to achieve worthwhile reductions in mortality and production loss, without imposing a strong selection for anthelmintic resistance" (Waller 1993). This is particularly important when the animals need to be moved to worm-free pasture after drenching. However, as pointed out by Waller (1993), the problem to date has been the difficulty in identifying the individuals that are unable to withstand the worm challenge.

We contemplated the possibility that the colour of the mucous membranes of the eyes of sheep could be used for clinical evaluation of anaemia (Malan & Van Wyk 1992). This would make it possible to treat only those individuals that are in danger of being overwhelmed by worm infection, instead of the conventional practice of drenching all the animals when one or two die or are clinically badly affected.

It is common knowledge that, while the ocular mucous membranes of healthy sheep and cattle are red in colour, those of animals that are terminally ill from *Haemonchus contortus* infection are practically white. As this nematode is the most important in small ruminants in the major sheep-producing regions of South Africa, we investigated whether clinical evaluation of the progressive change in the colour of the conjunctivae could give an indication of the extent to which individual animals are suffering from haemonchosis (Malan & Van Wyk 1992).

MATERIALS AND METHODS

A privately-owned commercial farm near Badplaas (25°55'S, 30°35'E) in Mpumalanga Province was used for the study. The climate is hot and humid in summer, with temperatures of up to 35 °C. The winters are mild, and the mean minimum temperatures varied between –0.3 °C and 13.5 °C for June and from 0–11.8 °C for July between 1984 and 1989 [measured at the Vygeboom Dam, about 15 km from the Badplaas farm (A. Topham, Agrometeorology, personal communication 2000). During the study in 1991 there were only one or two instances of light frost. Before the commencement of the study sheep on the farm had to be drenched approximately every three weeks during the *Haemonchus* season to prevent deaths. Drenching was according to the conventional custom of deworming all sheep when any showed signs of heavy infection.

A flock of 388 South African Mutton Merino ewes and a few rams was drenched with levamisole at a dosage of 7.5 mg kg^{-1} at the commencement of the trial and were run for the next 125 days, from March to July 1991, on irrigated kikuyu (*Pennisetum clandestinum*) pasture, on which they had grazed all summer. During this period routine drenching was suspended and replaced with salvage treatment of badly affected animals only. Consequently, conditions were ideal for an increase in *H. contortus* on pasture and in the animals.

At approximately weekly intervals (a mean of every 8 days) the sheep were inspected for submandibular oedema (bottle-jaw), and the colour of the ocular mucous membranes of every sheep were classified into one of the following clinical categories: red, red-pink, pink, pink-white or white (Table 1). Every sheep that was judged to have conjunctivae in one of the last two categories (pink-white or white) or that appeared to have submandibular oedema was bled for microhaematocrit determination. Only those animals with a haematocrit of 15 % or less were treated with levamisole (Tramisol, HoechstRoussel Vet—now IntervetSA) at the above dosage.

The clinical evaluation of the trial flock was mostly done by more than one person at a time. Consequently individual sheep were seldom evaluated by the same person on different occasions. Both the numbers of persons and the individuals taking part varied from time to time, but no record was kept of the persons involved.

On six occasions during the trial clinical evaluation of anaemia was done and blood was drawn from all the experimental sheep.

The clinical categories listed above (red through to white) were not, before or during the trial, individually related to different ranges of haematocrit values. However, to obtain an indication of the "success rate" and repeatability of the evaluations, the haematocrit ranges decided on for later trials, during which the FAMACHA© concept was developed (Bath, Malan & Van Wyk 1996; Van Wyk, Malan & Bath 1997), were subsequently matched to the clinical categories listed in Table 1. Thereafter, on the six occasions when all the sheep were sampled, the individual clinical category estimates were correlated with their corresponding haematocrit ranges. For these correlations, the various clinical categories were allocated numerical values of 1 ("red") through 5 ("white") (Table 1).

Faecal samples were collected at intervals from the sheep, and were frozen for later faecal worm egg counts (FECs). However, when worm egg counting commenced it was discovered that many of the ova were damaged by the freezing (as described by Goldman & Johnson 1950), thus invalidating the egg counts. Consequently, these counts were disregarded in the evaluation of the trial results.

A total of 166 ewes (42.8 % of the experimental flock) lambed: 112 up to almost 2 months before commencement of the trial (and were therefore lactating during the study), 51 soon after termination of the trial (pregnant during the trial) and 3 both before and after the trial. The latter three ewes had lambs afoot when the investigation commenced and conceived during the course of the study, to lamb again soon thereafter.

While not part of the study, the ± 1 500 other sheep on the farm were also treated individually, but based only on clinical evaluation of the conjunctivae, without haematocrit determinations.

At the end of the trial 14 of the ewes that were culled by the farmer because of old age were killed for worm recovery after faecal egg counts had been done on fresh, unfrozen faeces of each sheep. The sensitivity of the FECs was 67 eggs per gram of faeces (EPG). Worm recovery, pepsin digestion and worm identification and counting were done according to Reinecke (1973). For every sample of ingesta the worms in 3 x 1/10 aliquots were counted. However, when the worms were so numerous that it was impractical to count all in the 1/10 aliquots, a further 1/10 aliquot of each of these was made. Hence, when there were very large numbers of worms, those in only 3 x 100 aliquots were counted. The first 100 worms recovered per aliquot were identified, but if there were fewer than 100 worms all were identified.

TABLE 1 Haematocrit ranges matched to various clinical anaemia categories

Clinical category	Colour classification	Haematocrit range* (%)
1	Red	≥ 28
2	Red-pink	23–27
3	Pink	18–22
4	Pink-white	13–17
5	White	≤ 12

* Ranges for the FAMACHA© system, developed after conclusion of the study at Badplaas

RESULTS

The results are summarized in Tables 2–8 and Fig. 1–4.

Drenching was reduced by an estimated 90 %, considering that all the sheep were previously dewormed at intervals of almost 3 weeks during the *Haemonchus* season, and 70 % of the sheep were not drenched at all over the 125 days, with only 10 % requiring more than one treatment. Some of the sheep developed submandibular oedema and were drenched on this criterion, irrespective of changes in the colour of the conjunctivae, but in the records no distinction was made between drenching because of the above, or a low haematocrit, or both.

In the peak *Haemonchus* season the haematocrit values of some of the ewes dropped by up to 7 percentage points within 7 days. On the other hand, the maximum recovery rate after drenching was similarly 7 percentage points after a week.

During the course of the trial five ewes (1.3 %) were killed by scavengers, or died from unknown causes. However, the haematocrit values recorded for these five the last time each one was bled before she died, varied from 23–28 % and during the last 10 clinical evaluations the lowest clinical category recorded for these animals was "pink", indicating a haematocrit value that is probably higher than 18 % (Table 1).

The haematological data of these five sheep are summarized in Table 2. The lowest haematocrit recorded at the last inspection before they died, was 23 %, and in three of the five the haematocrit never dropped below 23 % during the entire trial. Both

TABLE 2 Sheep that died during the trial: haematological data in the period before death

Sheep	Haematocrit	Clinical colour category of conjunctivae (%)***				
	(%)**	Red	Red-pink	Pink	Pink-white	White
R06	23	60	0	40	0	0
R47	26	40	10	50	0	0
R104	28	90	0	10	0	0
G89	26	80	0	20	0	0
O36	28	100	0	0	0	0

** Last reading before the death of each sheep
*** Percentage of last 10 observations before the death of the animal

TABLE 3 Pearson correlation coefficient between haematocrit and clinical anaemia category, ignoring reproductive classes and drenching of the ewes

Day of trial	Haematocrit (mean)	Clinical category (mean)	Correlation coefficient[a]	
			r	r^2 x 100
0	29.6 (± 4.3)	1.1 (± 0.4)	−0.29	8.4
41	27.0 (± 6.5)	1.6 (± 1.2)	−0.62	38.9
51	25.9 (± 5.3)	1.5 (± 0.9)	−0.54	28.6
63	27.5 (± 5.0)	1.3 (± 0.7)	−0.46	20.8
92	27.3 (± 5.1)	1.2 (± 0.7)	−0.51	25.6
136	24.3 (± 5.5)	1.3 (± 0.8)	−0.51	25.7
Mean (overall)	26.9	1.3	−0.58[b]	33.6%[b]

[a] All correlations are highly significant ($P < 0.001$)
[b] Excluding day 0, at the start of the trial

TABLE 4 Accuracy of estimates of anaemia

Estimate accuracy	Percentages of 2 367 observations* %
1. Correct category estimated	55.6
2. Estimate too high (more serious)	
(a) Category 2 classed as 1	25.1
(b) Category 3 classed as 1	8.4
(c) Category 5 classed as 4	3.2
(d) Category 4 classed as 1	**2.0**
(e) Category 5 classed as 2	**0.2**
(f) Category 4 classed as 2	**0.2**
(g) Category 5 classed as 3	**0.2**
Total % too high	39.3
3. Estimate too low (Less serious)	
(a) Estimate 1 category too low	3.3
(b) Estimate 2 categories too low	1.8
Total % too low	5.1

* The figures in bold comprise instances where incorrect classification was regarded as potentially having endangered the lives of the sheep

sheep R47 and G89 had each required a single salvage treatment 2 and 3 months before they died, respectively, and Table 2 indicates that in both cases their haematocrits had recovered very well between drenching and their deaths.

As far as could be ascertained there were also no deaths from haemonchosis among the other 1 500 sheep on the farm that were not part of the trial, but long distances made it impossible to have sheep that died examined by a veterinarian.

The Pearson correlation coefficients between the haematocrit and clinical anaemia classifications of the animals on the six occasions at which all the

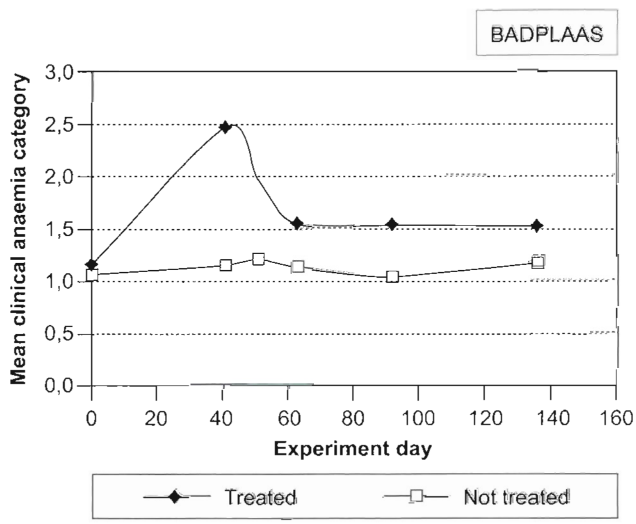

FIG. 1 Mean clinical anaemia categories of treated and untreated sheep

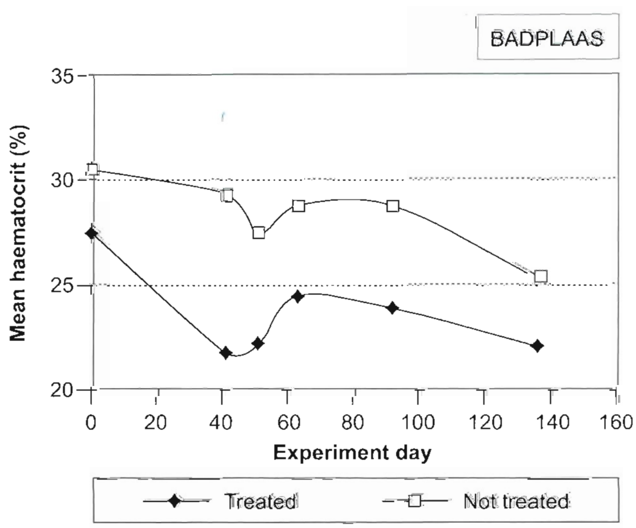

FIG. 2 Mean haematocrit values of treated and untreated sheep

TABLE 5 Drenching during the trial

Ewes		No. of drenches per ewe (% of class)				
Class	No. (n)	0	1	2	3	4
Dry	206	83.0	13.6	2.4	0.5	0.5
Lactating	112	44.6	32.1	16.1	5.4	1.8
Pregnant	51	70.6	21.6	5.9	2.0	0.0
Lactating + pregnant	3	100.0	0.0	0.0	0.0	0.0
Total number (% of total number)	372	260 (70)	75 (20)	26 (7)	8 (2)	3 (1)

TABLE 6 A comparison of anaemia in drenched and undrenched ewes

Group	n	Percentage	Mean haematocrit ± SD	Mean anaemia category ± SD
Not drenched	260	69.9	**28.4 ± 3**	1.13 ± 0.4
Drenched	112	30.1	23.8 ± 3	1.46 ± 0.5

TABLE 7 Mean haematocrits and clinical anaemia category values for the different reproductive classes, irrespective of the number of treatments received

Reproductive status	No. of ewes (%)	Mean haematocrit (± S.D.)*	Mean clinical category (± S.D.)*
Dry	206 (55)	28.2 (± 3.3)[a]	1.2 (± 0.4)[a]
Lactating	112 (30)	24.5 (± 3.5)[b]	1.6 (± 0.6)[b]
Pregnant	51 (14)	27.8 (± 3.6)[a]	1.2 (± 0.3)[a]
Lactating + pregnant	3 (1)	29.7 (± 3.2)[a]	1.1 (± 0.2)[ab]
Total that lambed	166 (45)	25.6 (± 4)	1.5 (± 0.5)

* Different superscripts within a column indicate a significant difference ($P < 0,01$), while common superscripts do not differ significantly at this level

sheep were examined, varied from –0.3 to –0.6 (Table 3). The mean values of the haematocrits and clinical classifications varied between 24.3 % and 29.6 % and 1.1 and 1.6, respectively, with overall means of 26.9 % and 1.3 on the six sampling occasions.

Accuracy of the clinical anaemia estimates is summarized in Table 4. In 55.6 % of cases the sheep were clinically classed "correctly" according to the haematocrit category created subsequent to the present trial. Of the 44.4 % "incorrect" estimates, 86.9 % (39.3 % of the total estimates) did not endanger the sheep concerned, as the haematocrits of the animals were such that they did not require salvage drenching, or were in category 5 while being classed as category 4, in both categories in which drenching was indicated. Consequently in the case of 97.4 % of sheep the estimates were either correct, or, when incorrect, the animals were probably not disadvantaged by the error. However, in 2.6 % of the incorrect estimates (printed in bold in Table 4) the sheep were at risk, as their haematocrits were so low that salvage drenching was definitely indicated.

Drenching of the various reproductive classes of ewes is summarized in Table 5. A total of 70 % of the 372 ewes for which data were available at each occasion, did not need salvage drenching during the trial, and a further 20 % required only one treatment. Thus only 10 % required two or more treatments. In the dry ewes the corresponding percentages were 83.0 %, 13.6 % and 3.4 %, in the pregnant ewes, 70.6 %, 21.6 % and 7.9 %, and in the lactating ewes, 44.6 %, 32.1 % and 23.3 %.

On the six occasions when all were sampled, the haematocrits and clinical category estimate means of the ewes that did not require drenching were 28.4 % and 1.13, respectively, as against corresponding values of 23.8 % and 1.46 for those that required 1–4 salvage drenches (Table 6). The mean clinical anaemia and haematocrit categories are plotted in Fig. 1 and 2, respectively. The trends in the two sets

TABLE 8 Worm burdens of 14 ewes that were culled on age and processed for worm recovery after the end of the trial

Sheep no.	Lambed (days before trial)	Drench[a]	FEC[b]	Haematocrit (range) %	Worm burden[c]				
					H. contortus		*T. colubriformis*	*T. circumcincta*[d]	
					L4 (% of total)	Adult (% 5th)	Adult (% 5th)	L4 (% 5th)	Adult (% 5th)
08	17	Nil	0	17–33	0	0	150 (0)	0	30 (33.3)
R69	No lamb	Nil	0	24–31	1 991 (100)	0	0	2 109 (100)	0
O11	11	Nil	0	18–27	123 (100)	0	0	2 590 (67.7)	1 233 (30.0)
G91	No lamb	Nil	0	24–32	0	1 330 (9.1)	0	483 (6.5)	6 907 (24.5)
R15	No lamb	Nil	0	28–30	3 714 (62.5)	2 229 (66.7)	0	2 600 (21.2)	9 657 (20.2)
O2	No lamb	Nil	0	22–33	3 217 (28.5)	8 063 (33.4)	19 840 (24.3)	0	0
G92	62	1 (82 d)	133	15–29	0	0	10 (0)	0	1 800 (0)
G97	63	1 (78 d)	0	14–33	522 (26.7)	1 436 (0)	0	131 (4.8)	2 612 (5.0)
O99	50	1 (67 d)	733	14–27	740 (17.9)	3 383 (6.2)	116	0	3 172 (0)
R99	47	1 (99 d)	1 133	12–29	830 (21.9)	1 779 (40.0)	0	1 067 (7.9)	12 499 (12.4)
R14	No lamb	1 (50 d)	467	27–35	9 388 (77.3)	2 761 (0)	0	1 657 (4.4)	30 020 (20.2)
R100	50	1 (96 d)	0	13–37	8 591 (100)	0	3 164 (0)	22 909 (20.0)	91 737 (17.2)
G29	45	1 (100 d)	67	11–30	2 523 (10.5)	21 466 (64.3)	2 200 (0)	360 (4.0)	8 650 (41.7)
R115	No lamb	2 (67 d)	2 267	13–25	819 (5.6)	11 466 (17.6)	960 (0)	0	10 920 (13.0)

[a] In brackets—days between last drench and slaughter for worm recovery
[b] FECs 6–7 days before slaughter
[c] In brackets—percentage of young fifth stage worms, or percentage L4 of the total for the worm genus concerned
[d] Including *Teladorsagia trifurcata*

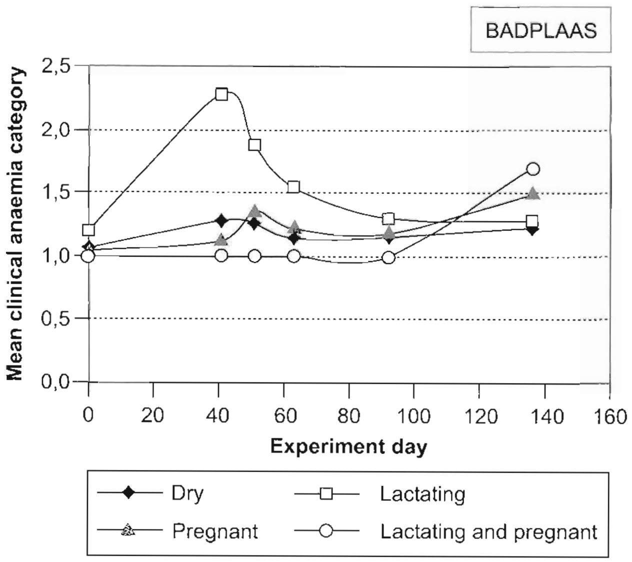

FIG. 3 Effect of reproductive status on mean clinical anaemia category

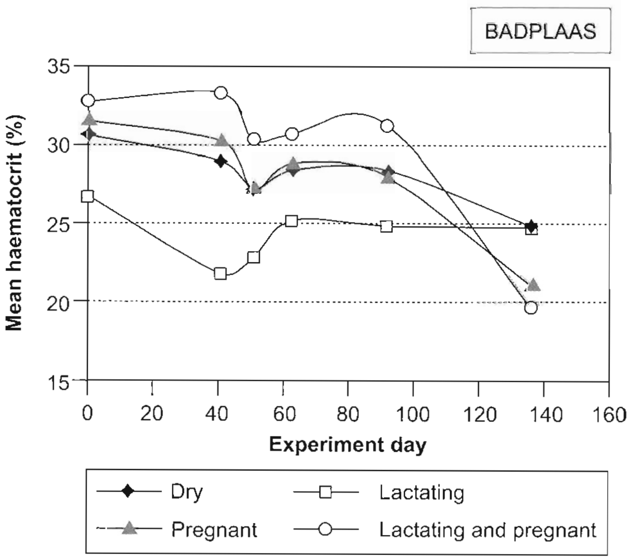

FIG. 4 Effect of reproductive status on mean haematocrit value

of values are practically the reciprocal of one another (Fig. 1 and 2).

The effect of the reproductive status of the sheep on the haematocrit and clinical anaemia status of the sheep is shown in Table 7. The mean haematocrit of the lactating ewes was 24.5 % and their clinical evaluation category 1.6, compared to corresponding values of 28.2 % and 1.2 and 27.8 % and 1.2 for the dry ewes and those that were pregnant during the trial, respectively. The trends in these haematocrits and clinical category estimates are graphically illustrated in Fig. 3 and 4.

While six of the 14 dry ewes slaughtered for worm recovery at the end of the trial did not require salvage drenching during the 125 days of the trial, the eight that did, had not been drenched for 67–100 days before they were killed a week after the conclusion of the experiment (Table 8). The adult *H. contortus* burdens of the undrenched ewes varied from 0–8 063, the numbers of adult *Teladorsagia circumcincta* from 0–9 657, and of *Trichostrongylus colubriformis* from 0–19 840. The corresponding ranges of the three worm species for those ewes that were drenched once, were 0–21 466, 1 800–91 737 and 0–3 164 (Table 8). The FECs of these sheep immediately before they were killed varied from 0–2 267 EPG, and the animals showed no signs of overt diarrhoea or emaciation—they were culled purely on age at the conclusion of the trial.

In a number of the experimental sheep "self-cure" appeared to have taken place, as their haematocrits dropped to low levels (often close to 15 %, at which level they would have been drenched), and then started rising again (mostly to high levels), without the animals having been drenched.

DISCUSSION

The Badplaas farm was chosen for the trial because of serious anthelmintic resistance on the property. When first isolated in 1989, the geometric mean susceptibility of the Badplaas strain of *H. contortus* in slaughter trials was found to be between 29.2 % and 61.0 % to closantel, dinitrophenol, fenbendazole, ivermectin and rafoxanide (arithmetic mean 38.1–62.0 %) (Van Wyk, Malan & Randles 1997). Only morantel and levamisole were practically 100 % effective. When the tests were repeated in 1991 on a second isolate from the same farm, the geometric mean efficacy of the above five compounds, plus oxfendazole varied between 4.7 and 52.5 % (arithmetic mean 3.0–50.4 %). This second isolate was 85.8 % susceptible to nitroxynil (arithmetic mean, 75.6 %), but was still close to 100 % susceptible to morantel and levamisole (the latter at both 7.5 and 3.5 mg kg^{-1}). A trichlorphon plus coumaphos combination also gave an efficacy of 100 % in the trial. The fact that of the modern compounds only the imidasothiazole group of anthelmintics remained for controlling this worm strain initiated the attempt, reported in this paper, to maintain the usefulness of the remaining effective anthelmintics by drenching only individual sheep.

The observation of a reduction in haematocrit value of up to 7 percentage points in a week at the peak of the *Haemonchus* season has the important implication that some sheep may be lost if the intervals between the clinical examinations of the animals are longer than 7 days. However, these cases were the exception. An equally dramatic recovery of the haematocrit values of some of the animals after effective drenching can be put to practical use as a means of evaluating the efficacy of the anthelmintic used clinically (Bath *et al.* 1996). If the clinical FAMACHA© classification in the system developed after the conclusion of the present trial does not improve by at least one category within a week, it may indicate that the drench was not effective.

The haematocrit value of 15 % was chosen as the level for treatment, as it was regarded as the lowest level that was still safe for the animal (on condition that the helminth infection was terminated immediately), while at the same time also constituting a good test of the ability of the animal to withstand the worm challenge unaided. The decision was based on the observation that sheep that are critically ill from *H. contortus* infection have a haematocrit of 5 % (the lowest we have recorded in a field case that was *in extremis*) to 10 % (F.S. Malan, & J.A. van Wyk, unpublished observations 1992).

While there is a highly significant correlation between the various clinical anaemia categories with the haematocrit values of the sheep (Table 3), it is important to note that a total of 44.4 % of the estimates fell outside the corresponding FAMACHA© haematocrit categories that were later created (Table 4). Fortunately, 86.9 % of the "mistakes" (39.3 % of the total estimates) were not at all serious, as the haematocrits of the animals concerned were well above the level of 15 %, at which drenching occurred. On the other hand, in 2.6 % of the total number of estimates (5.9 % of the "incorrect" classifications) the error could have had serious consequences, had haematocrit determinations not been done and the animals been drenched, since the sheep could otherwise perhaps have become critically ill, or even have died. However, the presence of bottle-jaw served as a "safety factor" to identify anaemic animals that were missed when the conjunctivae were examined. It is encouraging that, even though a considerable proportion of the estimates did not coincide with the corresponding haematocrit category, the graphs of the mean haematocrits of the drenched versus the undrenched sheep were practically the reciprocal of the respective clinical category estimates (Fig. 1 and 2). This was also the case in the comparisons of the effect of reproductive class on haematocrit and clinical category estimates (Fig. 3 and 4).

Despite probably ideal conditions for *H. contortus* infection, 83 % of dry ewes did not require treatment during the period of heavy worm challenge (Table 5). Even in the case of the pregnant animals less than 30 % may have succumbed had they not been drenched. On the other hand, the lactating sheep were by far the most susceptible of the reproductive classes, since 55.4 % of them would have been in serious danger had there not been an effective anthelmintic available. These differences were also clearly illustrated in the respective haematocrit values and clinical estimates (Table 7; Fig. 3 and 4). Extraordinarily, the 3 sheep that lambed both shortly before and after the period of observation (Tables 5 and 7), had even higher haematocrit values than those of the dry ewes.

The reduction in drenching frequency in the present trial was dramatic, but it is unlikely that farmers will be able to match this on their own without the help of the research team and facilities for haematocrit determinations. On the other hand, if the system of clinical evaluation can be used to leave only as small a proportion as 10 % of the flock undrenched during the worm season (Besier 1997), the reduction in selection for anthelmintic resistance will be well worth while.

As could be expected from the fact that animals were drenched only at a low haematocrit level, there was a considerable difference in the mean haematocrit values and clinical anaemia categories of the drenched and undrenched sheep (Table 6). What was unexpected, however, was the high mean haematocrit value of 28 % for the undrenched animals. Not only did they cope unaided with the worm challenge, but also maintained excellent haematocrit levels for most of the period of challenge.

In the present study there was no colour standard against which the colours of the conjunctivae could be compared (such as the FAMACHA© chart that was developed later—Bath *et al.* 1996; Van Wyk *et al.* 1997), nor were colour classifications related to haematocrit ranges used. Nevertheless, although the r^2 x 100 values were not high enough to give reasonable surety that the haematocrit values of individual animals could be predicted with confidence from their clinical classifications, the correlations between the clinical classification of the anaemia of the sheep and their haematocrit categories were highly significant (Table 3). The fact that both the numbers of persons and the individuals who did the clinical evaluations differed from time to time, probably resulted in the accuracy being lower than if the same person had done all the evaluations.

The worm burdens of the 14 culled animals that were slaughtered at the end of the trial (Table 8) were unexpectedly high and of considerable concern, sounding a warning for future application of the system. Most striking in Table 8 are the low or negative FECs of the seven most heavily infected ewes, something that would have been judged almost impossible, had it not been for experienced staff in the laboratory that performed the FECs (Intervet Malelane Research Unit).

Seven of the culled animals harboured potentially lethal worm burdens (Gordon 1981), for instance, a total of 21 466 fifth stage and adult *H. contortus* in sheep G29 (Table 8). Considerable numbers of parasites were in the fourth larval stage in the animals with the large worm burdens (10.5–100 % of the

Haemonchus and 4.0–21.2 % of the *Teladorsagia*), or in the early fifth stage (0–66.7 %, 17.2–41.7 % and 0–24.3 % of *H. contortus*, *T. circumcincta* and *T. colubriformis*, respectively). However, with only one exception that was anaemic, none of these sheep had overt clinical signs of worm infection, such as anaemia, diarrhoea or emaciation, although the mean haematocrit values of all the animals dropped from 27.3 % to 24.3 % between days 92 and 136 (Table 3). In contrast, four of the ewes were obviously highly resistant to worm infection, as they harboured relatively small numbers of worms of all three species and voided 0–133 EPG of faeces , while a fifth (G97) probably harboured fewer adult worms than could be expected to be very pathogenic for an average dry ewe (Gordon 1981).

The large proportion of immature worms and low FECs indicated hypobiosis. However, particularly in the case of *Teladorsagia* and *Trichostrongylus* spp. it may also indicate that very heavy infections were building up during the cooler winter conditions at Badplaas. The possibility of non-haematophagous worm species accumulating and becoming important when the system of clinical evaluation of anaemia is used, is a decided threat to general application unless infection is monitored.

Another possible explanation for the absence of clinical signs in the heavily infected sheep is resilience to the effect of the various worm species. While there is a marked overdispersion of worm burdens in a given host population (Barger 1985), it is not necessarily the animals with the highest worm burdens that succumb. In a previous trial involving 112 sheep chosen at random from a single flock in which some animals were dying from haemonchosis, one individual with an FEC of 46 000 had one of the highest haematocrits of the group (27 %). Another with a haemaotcrit of 13 % had an FEC of only 3 500 (Malan & Van Wyk, unpublished observations 1994).

As mentioned earlier, in both 1989 and 1991 practically a pure culture of *H. contortus* was recovered from trial sheep that were infected with larvae cultured from sheep on the Badplaas farm. Consequently we did not expect large infections with non-haematophagous worm species in the present trial conducted shortly thereafter. Possible reasons for this are that the larvae for the previous slaughtering trials were cultured from faeces in the midst of the *Haemonchus* season (in which case *Haemonchus* larvae would have overwhelmed the culture). At the same time sheep on the farm were being drenched at short intervals with levamisole, which would have considerably reduced the numbers of all three worm species.

Burdens of *Teladorsagia* and *Trichostrongylus* spp. of the magnitude recovered in the present trial have not previously been recorded in Mpumalanga Province. Horak (1981a) drew up a distribution map of the helminth parasites of sheep, cattle, impala and blesbok for South Africa, according to nine climatological regions. On this map the Badplaas farm is situated in the easternmost climatological region ("L" on the map in the paper) of what was previously the Transvaal Province (now Mpumalanga). As suggested by Horak (1981a), neither *Teladorsagia*, nor *Trichostrongylus* spp. are "definitive parasites" of sheep in this region, which is described as "subtropical, warm and muggy, except in mid winter". He defines definitive parasites as "... prevalent in a large percentage of the population, often in fairly large numbers and capable of reproduction and a long period of survival" (Horak 1981a). The farm is situated close to the western boundary of the "L" region, but even for the adjoining region in the West ("H" on the map—"warm, temperate monsoonal type of climate, dry winter", Horak 1981a) only *Trichostrongylus* spp. and not *Teladorsagia* spp. (the dominant genus of the two in the present trial) are listed as "definitive". Furthermore, Horak (1981b) concluded: "... the Transvaal [now Mpumalanga and other provinces] climate is not ideal for the survival of free-living stages of *Trichostrongylus* spp."

In a previous seasonal survey from March 1983 to March 1984 on the same Badplaas farm a mean of 1931 *H. contortus* was recovered from 12 groups of worm-free sentinel lambs (each grazing the trial pasture for a month), compared to a mean of 332 *Trichostrongylus* spp. (the second most numerous species recovered) in the same lambs (Malan, unpublished data 1984). Similarly, a mean of 1 782 *H. contortus* was recovered in another survey from September 1983-September 1984 on a farm near Barberton (situated close to Badplaas, but in the very hot and humid Lowveld of Mpumalanga), compared to a mean of 372 *Trichostrongylus* spp. (Malan, unpublished data 1984).

From Table 8 it is obvious that sheep R14 (which was dewormed once only), was drenched incorrectly, as its haematocrit never dropped below 27 %.

At first glance it would appear as if the lambing rate of the trial ewes was low, considering that they ran with rams throughout the study. However, the ewes were not scanned for pregnancy and we stopped recording births soon after the end of the trial, while many of the ewes that were classified as "dry", lambed later.

The "self-cure" recorded in a number of the sheep in the study is also noteworthy. This phenomenon, first described by Stoll (1929) for *H. contortus* "... is seen as a sudden throwing off of an existing worm burden, followed in most instances by the development of a new infestation within a few weeks, [being] provoked by administration of a large dose of infective larvae to a sheep already harbouring an infestation" (Gordon 1949). While frequent in Australia, self-cure is apparently not so in South Africa (Reinecke 1983), although it has been recorded (Muller 1968; Horak & Louw 1977). It is of limited practical significance in the field, however, as "... it is usual for a few animals to die of haemonchosis before 'self-cure' occurs" (Gordon 1948). The present results are in accordance with those of Gordon (1948), as it is likely that up to 30 % of the animals may have died, had they not been given salvage drenches.

In conclusion, while taking heed of the above warnings about the potential dangers of applying the system of clinical evaluation of anaemia, the advantages are considerable, particularly as concerns lower drenching costs and, most importantly, dramatically reduced selection for anthelmintic resistance. The undrenched animals continue to void an undiminished number of worm ova on the pasture, while the drenched animals pass a small fraction of the ova they had before treatment, provided an effective anthelmintic has been used. The system also makes it possible for farmers to identify overly susceptible animals that cannot cope with worm infection. These animals can be culled and fattened for marketing, in the process improving the ability of the flock to withstand worm challenge.

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