A targeted selective treatment approach for effective and sustainable sheep worm management: investigations in Western Australia


Abstract. The effectiveness of a targeted selective treatment (TST) approach to the management of sheep worms in adult Merino ewes was compared with a normal worm control program on three properties in south-western Western Australia. For a TST strategy, a proportion of a flock is left undrenched when flock treatments are administered. This establishes a population of worms in refugia, isolated from the effects of anthelmintics, which dilutes the population of worms that survive drenching and, hence, minimises the development of anthelmintic resistance. The main worm genera present in this trial were Teladorsagia and Trichostrongylus. For the TST approach, an initial flock worm egg count was used to determine the proportion of the flock to be drenched at any time, and treatments were then given to that proportion of the flock, with treated individuals identified as those in the poorest body condition. Over a period of 10–12 months, the TST groups on the three properties received 60%, 53% and 73% of the number of drenches administered to the normal treatment groups, in which all sheep were drenched. No clinical signs of parasitism or adverse effects on reproductive indices occurred in the TST groups. Although bodyweight gain and wool weight were ~2 kg and 0.3 kg, respectively, lower in two of the TST groups than in the normal treatment groups, the differences were not significant, and body condition scores of the TST groups were consistently greater than optimal production recommendations. The TST concept has potential as an easily implemented approach to sustainable drench management and would reduce the cost and labour associated with worm control. However, further studies are required to develop decision indices for various environments to ensure a balance between worm control efficiency and sheep production.

Additional keywords: anthelmintic resistance, refugia, targeted selective treatment, Teladorsagia, Trichostrongylus.

Introduction

Internal parasites of sheep remain a major impediment to the Australian sheep industry and are estimated to cost the industry $370 million annually (Sackett et al. 2006). Even when recommended treatment schedules are followed, the effectiveness of worm control is increasingly compromised because of widespread and increasing resistance to anthelmintics (Besier and Love 2003; Kaplan 2004). A major challenge is to develop solutions that are effective, acceptable to industry on practical grounds and sustainable in the long term.

The major conceptual basis of strategies aimed at reducing anthelmintic resistance is to ensure that sufficient parasites escape the selective pressure of drenching (‘in refugia’) to dilute more resistant parasites surviving treatments (Besier 2008; Jackson and Waller 2008). Although non-resistant worms may be present as infective larvae on pasture after treatment, there may be times when they cannot survive due to seasonal conditions. In this situation, the only refugia available may be undrenched sheep. The absence of worms in refugia is associated with the development of anthelmintic resistance. This is evident in strongly seasonal climates such as the Mediterranean climate zone of Western Australia, where routine treatments during the hot, dry summer period have been shown to increase resistance levels to anthelmintics even though they control worm burdens (Besier 2001; Besier et al. 2001).

Strategies aiming to reduce the rate of development of anthelmintic resistance by leaving some sheep undrenched when others in a flock receive treatment have been advocated for some time. In such targeted selective treatment strategies, drenching is confined to animals that require treatment and those that are able to cope with parasites are left undrenched (van Wyk et al. 2006; Besier 2008). The FAMACHA system is a targeted selective treatment (TST) approach that has been successfully applied to control the blood-sucking parasite, Haemonchus contortus, by identifying sheep suffering anaemia on the basis of the colour of their conjunctival membranes (van Wyk and Bath 2002). This approach is not appropriate for parasites that do not cause blood loss, such as Teladorsagia (Ostertagia) circumcincta and Trichostrongylus species, which are the main nematodes of sheep in winter-rainfall regions.

The acceptability of TST systems to graziers with large flocks depends on the availability of practicable systems for identifying the sheep that are to be drenched and confidence that sheep production will not be significantly reduced by failure...
to identify sheep that are subclinically affected by worms. The aim of this investigation was to test the effects of an easily implemented TST approach on flock health and production, and the proportion of sheep requiring drenching.

**Materials and methods**

Three trials were conducted in the southern coastal region of Western Australia; Trials 1 and 2 were conducted on the Mount Barker Research Station (60 km north-west of Albany) and Trial 3 was conducted in the Kalgan River district (25 km east of Albany); for both sites, the latitude is ~35°S. The region has a relatively mild Mediterranean climate, with hot, dry summers and cool, wet winters. Pastures at the Mount Barker sites were senescent during summer and autumn (December–May), and there was vigorous growth of improved annual pasture species (mostly subterranean clover and ryegrass) in winter and spring (June–November). The Kalgan site contained similar species but received more rainfall, and some perennial pastures, especially kikuyu grass, persisted through summer in these paddocks. Supplementary feeding with grain (lupins and oats) sufficient to maintain body condition scores at a mean of 3.0 was provided in all trials until pasture growth was well established in early winter.

**Trial design**

In each of the three experimental flocks, Merino ewes maintained in a single flock were individually tagged and allocated to TST or normal treatment groups, which were then held in separate paddocks. Subgroups of worm-suppressed control sheep were maintained in each treatment group to enable adjustments to be made for between-paddock nutritional effects. The ewes were assigned to bodyweight strata, ranked according to worm egg count and then randomly allocated to a treatment group. Mean weights, body condition scores (Tables 1, 2) and worm egg counts were not statistically different between groups when the trials commenced.

Each group contained subgroups of worm-suppressed (control) sheep (25, 40 and 40 control sheep were included in Trials 1, 2 and 3, respectively). In each of the treatment groups, 50 worm egg count monitor sheep were chosen at random (70 monitor sheep were used in Trial 3), and faecal samples collected from these sheep on each measurement occasion. The total numbers of animals in each treatment were 146, 159 and 152 for Trials 1, 2 and 3, respectively, and production measurements were recorded for all sheep.

The trial paddocks were fenced to provide similar stocking rates for each trial (~16 ewes per hectare) and to ensure that the pasture environments and paddock topographies were similar. An attempt to estimate pasture contamination with worm larvae was made in Trials 2 and 3, by grazing each paddock with 206-month-old worm-susceptible sheep for 2 weeks after anthelmintic treatment. However, the worm egg counts were extremely low because of the dry pasture conditions in summer (Trial 2, less than 50 eggs per gram (epg)); Trial 3, 70 epg), and did not differ between treatment paddocks.

The ewes were mated to Merino sires for 6-week periods, to lamb in July. This was the first lambing for the ewes in Trial 2, but in the other trials the ewes were mature (4–5 years of age when mated). Pregnancy status was determined by ultrasound scanning 90 days before the commencement of lambing. The few ‘dry’ sheep (mean 4.6%) were retained in the experimental flocks, but their results were not used for the analysis. The trials commenced in January 2008 and were terminated in December 2008 (Trials 1 and 2) or March 2009 (Trial 3).

**Treatments**

The sheep in the worm-suppressed groups were treated at ~8-week intervals with a long-acting preparation of moxidectin.

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**Table 1. Bodyweight changes and fleece weights for normal treatment (Normal) and targeted selective treatment (TST) groups**

<table>
<thead>
<tr>
<th>Trial/group</th>
<th>Treatment</th>
<th>Initial weight</th>
<th>Final weight</th>
<th>Change</th>
<th>s.e.</th>
<th>Weight s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Control</td>
<td>66.7</td>
<td>64.2</td>
<td>–2.5</td>
<td>0.9</td>
<td>5.12</td>
</tr>
<tr>
<td>TST</td>
<td>Control</td>
<td>70.0</td>
<td>67.1</td>
<td>–3.0</td>
<td>1.0</td>
<td>5.07</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>62.7</td>
<td>58.2</td>
<td>–4.5</td>
<td>0.4</td>
<td>4.51</td>
</tr>
<tr>
<td>Difference: normal v. TST</td>
<td></td>
<td>1.6</td>
<td>1.5 n.s.</td>
<td></td>
<td></td>
<td>0.26</td>
</tr>
<tr>
<td>Trial 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Control</td>
<td>54.6</td>
<td>59.7</td>
<td>5.1</td>
<td>0.6</td>
<td>4.55</td>
</tr>
<tr>
<td>TST</td>
<td>Control</td>
<td>55.2</td>
<td>59.7</td>
<td>4.5</td>
<td>0.8</td>
<td>4.64</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>55.2</td>
<td>56.8</td>
<td>1.6</td>
<td>0.4</td>
<td>4.26</td>
</tr>
<tr>
<td>Difference: normal v. TST</td>
<td></td>
<td>2.0</td>
<td>1.2 (P ~0.1)</td>
<td></td>
<td></td>
<td>0.29</td>
</tr>
<tr>
<td>Trial 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Control</td>
<td>63.4</td>
<td>72.6</td>
<td>8.8</td>
<td>1.3</td>
<td>6.16</td>
</tr>
<tr>
<td>TST</td>
<td>Control</td>
<td>61.7</td>
<td>70.8</td>
<td>9.1</td>
<td>1.3</td>
<td>6.08</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>63.8</td>
<td>71.3</td>
<td>8.1</td>
<td>0.7</td>
<td>5.75</td>
</tr>
<tr>
<td>Difference: normal v. TST</td>
<td></td>
<td>–2.1</td>
<td>2.0 n.s.</td>
<td></td>
<td></td>
<td>0.04</td>
</tr>
</tbody>
</table>

*A Wool weights are for a 10-month growth period for Trials 1 and 2.*
albendazole, levamisole, abamectin and closantel (treatments consisted of a combination anthelmintic-containing infection for a 2-month period after treatment. All other treatments consisted of a combination anthelmintic-containing albendazole, levamisole, abamectin and closantel (‘Q-Drench’, Jurox, Rutherford, Australia), which was previously shown to be completely effective at both trial sites. Additional treatments with closantel, which has persistent activity specifically against H. contortus, were administered occasionally throughout the trial when this species was detected so the TST strategy could be evaluated in terms of the most important worm species in this environment.

The normal treatment groups received summer drenches in February, which have been the basis of strategic worm control in the winter-rainfall region for many years (Anderson 1972; Besier and Love 2003). In Trials 1 and 2, these treatments were administered when the sheep grazed senescent pastures, and no further treatments were administered. In Trial 3, a second drench was administered to the normal treatment group in April because of an increase in worm egg counts.

The TST groups were treated according to a two-step decision process. First, mean worm egg counts were used as an indication of the degree of parasitism within each flock and the proportion of the flock to be drenched. This aimed to maintain the group worm egg count at or below 200 worm eggs per gram of faeces, which is considered a threshold level below which worm burdens are not likely to cause production loss in this environment (Woodgate and Besier 2010). On this basis, initial treatments in February were indicated as required for 10% of sheep in the TST groups in Trials 1 and 2, and for 50% of sheep in the TST group in Trial 3; a second treatment was indicated in April as required by 50, 50 and 100% of the TST sheep in Trials 1, 2 and 3, respectively.

The second step in identifying sheep to be drenched entailed subjective selection of the sheep in the poorest body condition until the proportion identified as requiring treatment was reached. For this, an operator moved along a race as is done for drenching, and made a rapid judgement according to visual inspection (for sheep obviously in poor condition) or by palpating the lumbar region to assess the condition score (see http://www.lifetimewool.com.au, verified 20 August 2010).

### Measurements

Flock measurements were made at ~4-week intervals from February to June, when lambing commenced. The sheep were not yarded over the lambing to avoid disturbance to the flock, or observed for parasites at lamb marking because of time constraints. Due to prolonged heavy rainfall, weaning was delayed in all trials until December, when the next (final) observations were made in Trials 1 and 2. In Trial 3, monthly observations continued until shearing in March 2009.

At each sampling occasion, ewe weights and body condition scores (on a scale of 1–5 with 0.5-unit intervals) were recorded, and dag scores were assessed according to guidelines by Australian Wool Innovations (http://www.wool.com/grow_breeding_breeding-tools-available/htm, verified 20 August 2010; on a 5-point scale; 1 = negligible, 5 = severe). Faecal samples were taken from the monitor sheep in each group and from the worm-suppressed sheep at each trial visit to determine worm egg counts. During lactation when flocks could not be disturbed, freshly passed faecal deposits (n = 40) were collected from the pasture for determination of worm egg counts (in August and September). The mean worm egg counts from these samples were adjusted according to the number of worm-suppressed sheep (considered to have zero counts), on the assumption that the samples collected were in proportion to each subgroup.

### Table 2. Body condition scores for normal treatment (Normal) and targeted selective treatment (TST) groups

<table>
<thead>
<tr>
<th>Trial/group</th>
<th>Treatment</th>
<th>Initial</th>
<th>Body condition score</th>
<th>Change</th>
<th>s.c.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Normal</td>
<td>3/01/2008</td>
<td>22/12/2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>3.83</td>
<td>3.83</td>
<td>0.00</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>3.68</td>
<td>3.55</td>
<td>-0.13</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>4.11</td>
<td>3.69</td>
<td>-0.42</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>3.93</td>
<td>3.34</td>
<td>-0.59</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>Difference: normal v. TST</td>
<td></td>
<td></td>
<td>0.03</td>
<td>0.15 n.s.</td>
</tr>
<tr>
<td>Trial 2</td>
<td>Normal</td>
<td>14/02/2008</td>
<td>08/09/2008 A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.89</td>
<td>2.83</td>
<td>-0.06</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>2.86</td>
<td>2.82</td>
<td>-0.04</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.94</td>
<td>2.82</td>
<td>-0.13</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>2.94</td>
<td>2.53</td>
<td>-0.41</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Difference: normal v. TST</td>
<td></td>
<td></td>
<td>0.30</td>
<td>0.14 (P &lt; 0.05)</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Normal</td>
<td>18/01/2008</td>
<td>05/12/2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>3.03</td>
<td>3.86</td>
<td>0.83</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>3.06</td>
<td>3.74</td>
<td>0.67</td>
<td>0.05</td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>2.96</td>
<td>3.88</td>
<td>0.93</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>Treatment</td>
<td>3.02</td>
<td>3.85</td>
<td>0.83</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>Difference: normal v. TST</td>
<td></td>
<td></td>
<td>-0.06</td>
<td>0.14 n.s.</td>
</tr>
</tbody>
</table>

A Final observation when all groups were assessed.

(Cydictin LA®, Fort Dodge Australi, Baulkham Hills, Australia) to remove worm burdens and prevent further worm infection for a 2–3-month period after treatment. All other treatments consisted of a combination anthelmintic-containing albendazole, levamisole, abamectin and closantel (‘Q-Drench’, Jurox, Rutherford, Australia), which was previously shown to be completely effective at both trial sites. Additional treatments with closantel, which has persistent activity specifically against H. contortus, were administered occasionally throughout the trial when this species was detected so the TST strategy could be evaluated in terms of the most important worm species in this environment.

The normal treatment groups received summer drenches in February, which have been the basis of strategic worm control in the winter-rainfall region for many years (Anderson 1972; Besier and Love 2003). In Trials 1 and 2, these treatments were administered when the sheep grazed senescent pastures, and no further treatments were administered. In Trial 3, a second drench was administered to the normal treatment group in April because of an increase in worm egg counts.
Wool weights were recorded for all ewes at shearing in December 2008 (Trials 1 and 2) and in March 2009 (Trial 3). This represented a 12-month wool-growth period for Trial 3, and a 10-month wool-growth period for Trials 1 and 2 (although the ewes ran together for the period before this).

The numbers of lambs present at marking and weaning were recorded for each group in Trials 1 and 2 (only numbers weaned were recorded in Trial 3), but could not be related to ewe treatment within group (i.e. worm-suppressed v. general treatment).

**Analysis**

The change in weight from the commencement of the experiment to the closest available date up to a year later was calculated for each group based on the same tagged animals, with ‘dry’ ewes excluded. The weight advantage to the Normal group was then calculated as the difference between the changes in weight for the normally treated and TST groups, appropriately adjusted for different paddock nutrition using the changes in weight of the worm-suppressed groups. A similar calculation was conducted for change in condition score and for wool production. Standard errors for the advantage in weight, condition score and wool were estimated and used to evaluate statistical significance.

Worm egg counts were log-transformed [log(worm egg count + 25)] and then compared for each monitoring date using analysis of variance to determine if there were significant differences between the normal treatment and TST groups. Analyses were carried out using the statistics package GENSTAT Version 12 (Lawes Agricultural Trust, Rothamsted, UK).

**Results**

The trial provided an appropriate basis for evaluating the TST concept, as worm egg counts indicated that there was effective worm control over the year in the normal treatment subgroups in all three trials and there was minimal reduction in sheep production in comparison with the worm-suppressed groups (which maintained zero or negligible worm egg counts). It is unlikely that nutrition limited sheep production, as the mean body condition scores of sheep in the worm-suppressed control groups were relatively high (3.5 for Trials 1 and 3, and 3.0 for the younger sheep in Trial 2).

**Worm egg counts and drench treatments**

Initial worm egg counts did not differ between treatments in Trials 1 and 2. Initial worm egg counts were similar but statistically different between treatments in Trial 3 (481 v. 580 epg; P < 0.05) because of the large dataset (70 worm egg counts per treatment group). However, this did not invalidate between treatment comparisons in Trial 3, as the egg counts for the normal treatment group decreased to zero after the initial treatments in late January; there was a consequent difference between groups in April, and all egg counts went to zero after treatment in April.

The egg counts of the normal treatment groups (in which all sheep were drenched) at the Mount Barker location (Trials 1 and 2; Figs 1, 2) were typical of those of adult sheep in Western Australia (low counts in summer, dropping to a nadir after the single ‘summer drench’ in February) and remained low throughout the trial period. In Trial 3 (Fig. 3), a second treatment was required in April.

In the TST groups, drenches were indicated in February on the basis of the treatment criteria as required by ~10%, 10% and 50% of the animals in Trials 1, 2 and 3, respectively. Worm egg counts increased after these treatments and were significantly higher than in the normal treatment groups. Additional drenches were indicated as needed for ~50% of the sheep in Trials 1 and 2, and for 100% of the animals in Trial 3 in April. Counts then remained relatively low and were not different from those of the normal treatment groups for the remainder of the trials, except for one instance in Trial 3.

![Fig. 1](image-url)  
**Fig. 1.** Worm egg counts of normal treatment (Normal) and targeted selective treatment (TST) groups and the percentage of sheep drenched on each treatment date in Trial 1. Statistically significant counts are indicated with an asterisk.
The total number of drenches actually administered to the TST groups over the two treatment dates was 60%, 53% and 73% of those administered to the normal treatment groups in Trials 1, 2 and 3, respectively, with dry sheep and worm-suppressed sheep excluded (as noted in Materials and methods, the actual percentages of sheep treated differed from index-indicated values).

Differentiation of larvae in faecal samples indicated that *Teladorsagia* (*Ostertagia*) comprised 57%, 74% and 54% of the genera present in Trials 1, 2, and 3, respectively, and *Trichostrongylus* comprised 21%, 14% and 28% of the genera present in Trials 1, 2, and 3, respectively. Small proportions of *Nematodirus* and *Chabertia ovina* were found. *H. contortus* constituted 5% of genera present in Trials 1 and 2 during the lambing period, but this was unlikely to have affected production parameters because the total egg counts were very low.

**Dag scores and ill health**

Dag scores were negligible in all cases and never exceeded a score of 2 (lightly dagged), except for a single sheep in Trial 2 that had a score of 4 (extensively dagged). However, in that trial, only one other animal had dags. In Trial 1, 19 sheep in the normal treatment group and 15 sheep in the TST group had scores of 1 or 2 for dags, respectively, and in Trial 3, eight sheep in the TST group had a score of 1 for dags. In both Trials, this was a transient event that began soon after green pasture growth emerged in May; minor dag scores also occurred in some worm-suppressed
sheep. No other signs of ill health or and no mortalities related to worm infections were observed.

**Weight changes**

To adjust for differences in weight change between paddocks, data were adjusted according to the weight change of the worm-suppressed sheep and expressed as the difference between the TST groups and the normal treatment groups (expected to have the highest weight gain) (Table 1).

Over the course of the trial, sheep in Trial 1 lost weight, but this was from a high level (condition scores were higher than usual for breeding ewes). Sheep in the other two trials gained weight. Treatment comparisons indicated that the normal treatment groups in Trials 1 and 2 gained 1.6 kg and 2.00 kg, respectively, more weight than the TST groups over the course of the trial, or ~3%. In contrast, the weight-change advantage in respect of the TST group was 2 kg in favour of the TST group. No weight changes were statistically significant (Trial 2, P ~0.10).

**Body condition scores**

The condition scores over the course of the trial indicate that the sheep were in sound bodily condition (Table 2); in Trials 1 and 3, condition scores considerably exceeded LifetimeWool guidelines (Curnow et al. in press). Over all trials, body condition scores of individual sheep fell below a score of 2.0 on only 15 occasions, in Trials 1 and 2 during the lactation period, but the mean scores remained well within the guidelines. Condition scores of all groups of sheep in Trials 2 and 3 increased over the course of the trial, and those of sheep in Trial 1 decreased slightly. However, all groups had similar mean scores at the end of the trial. There were no significant differences in the change in mean scores over the trial period between the TST and normal treatment groups for Trials 1 and 3. For Trial 2, final scores were not available for the TST group, but at the September assessment there was a statistically significant advantage to the normal group of 0.3 score units. However, at the December observation, mean control and treated scores were 3.6 and 3.7, respectively, indicating a rapid increase in this treatment group, and the TST group is likely to have also improved substantially.

**Wool weights**

Fleece weights of the TST sheep in Trials 1 and 2, adjusted for paddock effects, reflected the bodyweight trends and were 0.26 kg and 0.29 kg (greasy) less than those of sheep in the normal treatment groups. Fleece weight in the TST group in Trial 3 also followed the same trend as weight change and was almost identical to that of the normal treatment group (Table 1). No wool weight differences were statistically significant (although for Trial 2, P was ~0.1).

**Reproductive performance**

Ultrasound scanning indicated that pregnancy rates were high in all trials (92–98%; Table 3). Birth and survival rates were high for Merino sheep, with virtually no lamb losses between marking and weaning. The weaning rates for the Mount Barker trials (109–123%) were very good, especially those for the maiden ewes in Trial 2. Weaning rates were lower in Trial 3 (94–100%) but are still high compared with industry averages. Reproductive performance was similar between treatment groups in Trials 1 and 2, and when weaning rates were adjusted for pregnancy rates, there was no treatment effect in Trial 3.

**Discussion**

The refugia concept is now accepted as the fundamental basis for the management of anthelmintic resistance and involves exposure of grazing sheep to pastures contaminated with worm larvae derived from worms in sheep that were not recently treated with anthelmintics (van Wyk 2001; Besier 2008; Jackson and Waller 2008; Kenyon et al. 2009; Leathwick et al. 2009; Dobson et al. 2010). Refugia can be created in a variety of ways (Leathwick and Besier 2010), including TST, which involves leaving some animals untreated when the flock is drenched (van Wyk et al. 2006; Kenyon et al. 2009). However, all refugia strategies are associated with a risk of impairing sheep health and productivity because of an excessive worm burden or larval intake. There is a perception that these strategies are difficult to comprehend and impractical to implement. In the present trial, we tested the concept of incorporating a TST approach that requires relatively little time and effort to implement into a routine strategic worm-control regimen to create refugia for non-resistant worms.

**Worm control**

In our trials, in which the dominant nematodes were Teladorsagia (Ostertagia) and Trichostrongylus, worm egg counts were typical of those in intensively managed ewes in Western Australia (Woodgate and Besier 2010) and the summer-drenching strategy used for the normal treatment groups

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**Table 3. Pregnancy, lamb marking and weaning indices for normal treatment (Normal) and targeted selective treatment (TST) groups**

<table>
<thead>
<tr>
<th>Trial</th>
<th>Treatment group</th>
<th>Pregnancy scanning (pregnant/total)</th>
<th>Lambs marked (lambs/ewes)</th>
<th>Lambs weaned (lambs/ewes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trial 1</td>
<td>Normal</td>
<td>141/146 (97%)</td>
<td>160/146 (110%)</td>
<td>159/146 (109%)</td>
</tr>
<tr>
<td></td>
<td>TST</td>
<td>139/145 (96%)</td>
<td>160/145 (110%)</td>
<td>160/145 (110%)</td>
</tr>
<tr>
<td>Trial 2</td>
<td>Normal</td>
<td>153/156 (98%)</td>
<td>187/157 (119%)</td>
<td>186/157 (118%)</td>
</tr>
<tr>
<td></td>
<td>TST</td>
<td>147/155 (95%)</td>
<td>194/158 (123%)</td>
<td>194/158 (123%)</td>
</tr>
<tr>
<td>Trial 3</td>
<td>Normal</td>
<td>145/155 (94%)</td>
<td>n.a.</td>
<td>151/151 (100%)</td>
</tr>
<tr>
<td></td>
<td>TST</td>
<td>142/155 (92%)</td>
<td></td>
<td>142/151 (94%)</td>
</tr>
</tbody>
</table>
resulted in highly effective worm control. As expected, the worm egg counts were higher in the TST groups than in the normal treatment groups on most sampling occasions, but the differences were statistically significant only immediately after the treatments were administered, and egg counts remained low in all groups from winter onward. It appears that despite the higher level of pasture contamination with worm eggs associated with the TST animals, these ewes were able to limit subsequent worm egg excretion.

The worm egg count results illustrate a basic difference between drench decisions based on resilience to worms and those based on worm resistance (Bisset et al. 2001). As sheep with low body condition scores during a worm challenge do not necessarily have higher worm egg counts than more resilient sheep (Bisset and Morris 1996), the reduction in worm egg count is likely to be in proportion to the number of sheep treated. Although this is beneficial in providing refugia for worms, there is a potential risk of adverse effects in worm-susceptible sheep (such as lambs), should these be grazed on pastures on which a TST strategy was previously applied. For this reason, adult sheep were chosen for these trials.

The danger of excessive pasture contamination with worm eggs when some sheep remain undrenched at key times in a worm control program is evident from the increases in egg counts after the February drenches in all trials. At the Mount Barker sites (Trials 1 and 2), where the sheep grazed senescent pastures, it is likely that these increases in egg counts were due to the maturation of hypobiotic larvae (Balic et al. 2000) rather than to new intake of larvae from pasture. In the more worm-prone environment of Trial 3, a new intake of larvae from pasture was likely, as egg counts increased in both the TST and normal treatment groups. Worm egg counts at critical times are important for managing TST strategies, as they indicate whether worm egg counts are higher than anticipated.

**Treatment effects on sheep production**

The TST strategy did not have an adverse effect on sheep health, nor did it result in greater levels of overt parasitism compared with the normal treatment groups in that dag scores were negligible in all treatment groups and no sheep mortalities could be attributed to worm burdens.

It also appears that the TST treatments exerted only minimal effects in terms of subclinical parasitism, as there were no statistically significant differences between the TST groups and the normal treatment groups (Table 1). Although bodyweight changes were 1.6 kg and 2 kg lower in the TST groups than in the normal treatment groups in Trials 1 and 2, respectively, when adjusted for paddock effects, the difference approached statistical significance only in Trial 2 (P = ~0.1). In contrast, in Trial 3, the TST group had a weight-change advantage of 2 kg. A similar trend was evident in body condition score (Table 2), for which there were no statistical differences between treatments in Trials 1 and 3, but a significant (0.3 score units; P < 0.05) negative effect of TST in Trial 2. None of the weight and condition score differences would have been of practical significance, as mean scores at the end of the trials were greater than those recommended for optimal reproduction (Curnow et al. in press).

TST exerted a negative effect on wool production in Trials 1 and 2: mean fleece weights (greasy) were 0.26 kg and 0.29 kg, respectively, lower than in the normal treatment groups (Table 1). Although the differences were not statistically significant, they are consistent with the lower bodyweights and condition scores of the TST groups. These losses in wool production may be greater than those that many sheep farmers would be prepared to accept, but there was no treatment difference in mean fleece weight in Trial 3. This indicates that as expected, there is an association between production effects and the level of worm control, which was greatest in Trial 3 and least in Trial 2, and that a balance between production objectives and sustainable worm control can be developed for specific situations. In Italy, Cringoli et al. (2009) recorded negative effects on milk production where relatively large proportions of adult dairy sheep were left undrenched (40–60%), in comparison to whole-group treatments, and noted that the timing of the treatments is also likely to have a major influence on the results.

The treatments did not affect lambing performance (Table 3). The treatments would not have influenced conception rate as they were not administered until after the rams were removed from the ewe flocks. Although the trial design did not permit attribution of lamb marking and weaning rates to treatments or pregnancy status, these indices were high for Merino ewes (weaning rates of 109%, 120% and 97% for Trials 1, 2 and 3, respectively).

**Effects on anthelmintic resistance**

The effects of the treatments on anthelmintic resistance were not measured because incremental changes over short periods are rarely detectable when efficacy of the anthelmintic is high, as was the case in our trials. The treatment benefits in respect of anthelmintic resistance may be inferred from the relative proportions of worm eggs deposited onto the pasture from drenched v. undrenched sheep. In our trial, in which few resistant worms survived the highly effective anthelmintic (as was evident from the post-treatment worm egg counts), the greater output of eggs from worms in undrenched sheep (see Figs 1–3) would have provided high levels of dilution. Further, the TST treatments were applied during the summer and autumn periods, which are most selective for anthelmintic resistance when all animals are drenched (Besier 2001; Woodgate and Besier 2010). In Trials 1 and 2, the 2-month period between the treatments would have contributed to greater numbers of worms in refugia than if a single initial treatment had been administered to the same proportion of sheep.

The concept of leaving a pre-determined proportion of a flock undrenched at a single critical treatment point has been tested in earlier trials, and although these involved considerably lower proportions of untreated animals, the trials were conducted with worm-susceptible lambs. In Western Australia, the tactic of leaving 10% of lambs in high condition score untreated at the time of a routine strategic treatment (summer drench) successfully minimised the development of anthelmintic resistance, compared with a group that was drenched (Besier 2001), but the increased pasture contamination in the former group led to significant parasitism. Trials in New Zealand also showed that leaving similar proportions of flocks untreated...
reduced drench resistance, and increased pasture contamination compared with treatment of all animals (Leathwick et al. 2006; Waghorn et al. 2008).

Computer modelling studies indicate that where anthelmintic efficacy is high, a useful level of refugia with minimal risk to sheep production can usually be accomplished by leaving 4–10% of a flock untreated (Dobson et al. 2010). In our trials, a considerably higher proportion of sheep were left untreated because adult sheep generally have greater tolerance of worm burdens than lambs, and because we wanted to investigate whether we could reduce the costs of drenches and labour. The relationships between refugia sufficient to decrease anthelmintic resistance and the tolerable level of parasitism can be easily modelled to determine optimal strategies for particular situations, including those that differ in favourability for worm development, anthelmintic effectiveness and the immunological status of sheep.

Selection of individual sheep for TST treatment

Although the TST index used to determine the proportion of the flock to be treated and to select individuals for drenching was intended to test the concept rather than to demonstrate a specific recommendation, it proved relatively effective and practicable. The worm egg count values used to determine the proportion of sheep to be treated in the TST groups were based on threshold values used for diagnostic purposes in this laboratory (excluding *H. contortus*). In adult sheep, counts below a flock mean of 200 epg in well nourished sheep are considered unlikely to affect sheep production, whereas a mean greater than 500 epg is usually associated with subclinical parasitism in most of the flock, in which overt signs of worm infection may also be evident. Although threshold values may vary between locations and possibly seasons according to local diagnostic precedents, TST indices can be adjusted to avoid unnecessary treatment of sheep not suffering from subclinical parasitism, while preventing parasitic disease and significant production loss. In our trials, the importance of continued worm monitoring after the initial treatments was evident in that worm egg counts in all TST groups increased between faecal collection and the availability of laboratory results, which indicated that some sheep required an additional treatment.

The criteria used to select individual sheep for treatment are central to the TST strategy. For non-haematophagous worms, this relies on the assumption that sheep that are less resilient to parasitism will be in poor bodily condition or will exhibit a low growth rate. This approach has been followed to investigate resilience to worms in New Zealand, where drenches for lambs were based on fortnightly judgements by farmers that particular individuals were not performing to growth expectations, and hence were likely to be suffering from parasitism (Bisset and Morris 1996). Later work in New Zealand used a weight basis for withholding treatment (Leathwick et al. 2006), although lower weight gains occurred in untreated lambs. In Scotland, Greer et al. (2009) used an objective treatment index based on the departure from the expected growth rate of individual lambs in relation to the pasture nutritional status to indicate which individuals would benefit most from treatment. This approach reduced anthelmintic resistance relative to whole-flock treatments, while maintaining production. However, these approaches require frequent weighing or observation of the sheep, especially of lambs, for which the risk of parasitism is greater than in adult sheep, and are likely to be feasible only for intensive sheep-production enterprises.

In our trials, selection of sheep for drenching took less time than normal drenching because, once a threshold condition score level was established, most sheep could be differentiated on visual appearance (especially if they had short wool) or on a cursory condition score judgement. Even though this process had to be conducted rapidly to relate to field situations, comparisons of the mean condition scores of the sheep selected for treatment invariably showed that these sheep had substantially lower condition scores than the rest of the flock. The consequences of misallocating some sheep or treating more than the indicated percentage are not likely to be serious, and the time needed for a rigorous assessment would not be justified.

It is important to note that TST strategies are not appropriate for all situations, especially those in which *H. contortus* is a significant risk factor and the consequences of failing to identify affected sheep are potentially fatal. The FAMACHA system has proven effective but involves frequent, close inspection of individual animals during haemonchosis-risk seasons (van Wyk and Bath 2002), which is not practicable in extensive grazing situations or when labour is scarce. In these situations, a more appropriate approach to *H. contortus* management is to make flock-by-flock assessments and to treat all sheep for which worm egg counts and other factors indicate that there is an imminent risk (Kahn et al. 2007).

Additional factors

In addition to reducing the rate of drench resistance development with minimal effort, the TST approach may be appropriate in situations in which subclinical parasitism is likely but is not recognised. In such cases, treatment of only a proportion (‘the tail of the flock’) may avert production losses, providing an additional incentive to implement a TST strategy. Further, restricting treatment to a proportion of the flock will reduce the time and effort of drenching and will save on chemical costs. This may become an attractive option should new and more expensive anthelmintics become available.

A further potential benefit of the TST approach is that it reduces the complexity of refugia-based drench-resistance management recommendations. Less than maximal worm control may be counter-intuitive, but it is essential to ensure that some worms survive to dilute the number of resistant worms. The TST approach, when optimised for a particular situation, is a relatively simple method of ensuring that refugia is provided, and is easily applied in large sheep flocks. It is also robust regarding the proportion of a flock left undrenched, which is especially important when worm status (worm burdens in sheep and infective larvae on pasture) cannot be easily estimated. It is essential that TST strategies are validated for specific environments and sheep management systems before they are applied.

Acknowledgements

The cooperation of Alan and Lois Evans at Kalgan River and Greg Bunker at Mount Barker Research Station is gratefully acknowledged. The assistance of
References


Manuscript received 22 July 2010, accepted 5 October 2010