Phytotoxicity, Poison Retention, Palatability, and Acceptance of Carriers used in Compound-1080-Foliage Baits for Control of Feral Goats

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Abstract
Feral goats have been controlled in New Zealand by treating leaves of favoured food plants with the poison sodium monofluoroacetate (compound 1080) in a suitable carrier, either carbopol gel or petrolatum grease. The effect of these two carriers on the most suitable plant species (mahoe), their retention of 1080, their comparative palatability to goats, and the acceptance of the least palatable, petrolatum, were studied in a series of trials. Both carriers caused baited leaves to absciss, and the rate of abscission increased when 1080 was included. Toxic petrolatum was three times less phytotoxic than carbopol and retained 1080 for much longer (carbopol lost most of its toxin after 200 mm of rain). Abscissed petrolatum-treated leaves retained much of their toxicity for at least a year. Goats detected and, to some extent, rejected leaves of all treatments, either by not eating them or by spitting them out (particularly petrolatum-treated leaves). However, use of iophenoxic acid as a bait marker indicated that even petrolatum-treated leaves were consumed by 24 of 30 goats tested. Carbopol with 1080 is recommended for use where its distribution is sufficient to place all goats at immediate risk. Petrolatum is not recommended for general use, although it can be used in areas where a long-life bait is needed.

Introduction
A technique using poisons mixed with gel, paste or grease carriers smeared on leaves of palatable plants has been developed to control ungulate and marsupial pests in New Zealand (Davison 1938; New Zealand Forest Service 1977, 1984; Parkes 1983; Batcheler and Challies 1988; Warburton 1990). The effectiveness of this technique depends partly on the durability of the carrier and its poison on the baited leaves (leaching and poison degradation) and the durability of the baited leaves on the branches (phytotoxicity and leaf loss). Effectiveness also depends on whether the bait is eaten by the target pest (palatability) and what proportion of the population does so (acceptance).

Feral goats (Capra hircus) are serious pests in New Zealand. About 150 herds occupy about 4.3 million ha, mostly land reserved for conservation (Parkes 1990). Control operations against goats mostly involve hunters and dogs, but foliage bait poisoning has also been tried. However, three trials in the Raukumara Range (Parkes 1983, and unpublished data) and others aimed at red deer (Cervus elaphus) on Secretary L. (New Zealand Forest Service 1977) and white-tailed deer (Odocoileus virginanus) on Stewart L. (New Zealand Forest Service 1984) revealed various problems affecting bait life. Attempts made to develop more waterproof carriers, such as petrolatum grease, mixtures of petrolatum and carbopol, and lanolin (C. N. Challies, unpublished data) had effects on bait palatability, acceptance and phytotoxicity.
This paper reports a series of trials aimed at determining the characteristics of foliage baits treated with a variety of carriers with and without 1080 and how feral goats reacted to them. Mahoe (*Melicytus ramiflorus*), a favoured food of goats (Parkes 1984; Mitchell *et al.* 1987), with ideal characteristics of growth form and leaf size and shape for use as a natural foliage bait, was the bait used in these trials.

**Methods**

**Abscission of Treated Mahoe Leaves**

Abscission rates of mahoe leaves treated with one of nine carriers were compared with that of untreated leaves in a trial conducted in Open Creek, Conway River, North Canterbury, during January–March 1987. The nine treatments were:

(1) petrolatum without 1080 (petrolatum is soft white paraffin, supplied as ‘Snow White Petrolatum’ by Shell Oil, New Zealand Ltd);
(2) carbopol gel without 1080 (a gel of ‘Carbopol 941’, supplied by B. F. Goodrich Chemical Co., and water-buffered with triethanoline to a pH of 7);
(3) petrolatum with 10% 1080 by weight;
(4) carbopol gel with 10% 1080 by weight; and
(5–9) five toxic mixtures of carbopol gel and petrolatum in the proportion 1:1, 1:1.5, 1:2, 1:2.5 and 1:3, where the 10% 1080 was initially mixed with the petrolatum.

Each carrier was smeared on the undersides of five leaves (about 0.25 g per leaf) *in situ* on each of 82 mahoe trees. All treated and five control leaves on each tree were marked with coloured tape wrapped around their petioles. The number of marked leaves remaining on the trees were counted at 3–10-day intervals over 46 days, after which most of the leaves treated with the most phytotoxic carrier had abscissed. The numbers remaining after 46 days were compared between four pairs of treatments: untreated control and non-toxic petrolatum, non-toxic and toxic petrolatum, non-toxic and toxic carbopol, and toxic carbopol and toxic petrolatum. The four comparisons were tested by $X^2$ tests, where Yates' corrected probability levels were adjusted for the four comparisons according to the Bonferroni method (Miller 1981).

**Persistence of 1080 in Carriers on Mahoe Leaves in situ**

The loss of 1080 from the seven toxic carriers was measured after 64 days by an alkali digestion-specific ion-electrode technique in which all fluoride is assumed to be from the 1080 (D. Batcheler, personal communication). Leaves with their remaining carrier were macerated and the 1080 measured. Background levels of fluoride in mahoe leaves were less than the technique's limit of detection at 0.01 mg g$^{-1}$. As leaves from each treatment were pooled for analysis, between-leaf variation could not be quantified.

**Persistence of 1080 in Petrolatum on Abscissed Mahoe Leaves**

The degradation of 1080 in petrolatum (the most persistent carrier in the previous trial) was measured on 72 abscissed mahoe leaves, each smeared with exactly 0.25 g of petrolatum with 10% 1080 before being laid on the ground under mahoe forest in March 1990 at Ashley Forest, Canterbury. Half the leaves were laid with the carrier facing the ground.

At 7–62-day intervals over the next 301 days, samples of six leaves (three facing up and three facing down) were collected, and the amount of fluoride remaining in each leaf and carrier was measured by the alkali digestion-specific ion-electrode method. Control leaves with petrolatum but without 1080 were measured at the start and end of the experiment to account for any background fluoride.

**Relative Palatability of Four Carriers**

Relative palatability of carbopol, petrolatum, a 1:2 mixture of the two, and lanolin [a carrier known to be avoided by deer (C. N. Challies, unpublished data)] was assessed on mahoe baits set up in a 5-ha pasture in Burnham, Canterbury. The non-toxic carriers and an untreated control were applied randomly among sets of five branches (38–40 branches for each treatment) stuck upright in the ground about 10 m apart along transects. Each branch had about 100 leaves, of which 10 were either smeared with about 0.25 g of a carrier or identified with a small punched hole if left untreated.
The following day, 40 re-domesticated feral goats were released into the pasture. After 30 min, the number of branches that had been browsed and those that had not were counted to see whether whole branches with carriers were being rejected (by smell or sight). Differences between the only carrier odorous to humans (lanolin) and the rest were tested by a $\chi^2$ test.

At the same time, the number of treated leaves remaining on the branches with some browse (a measure of rejection by smell or sight), and the number bitten off but left lying on the ground (a measure of rejection by taste or touch) were also counted. The hypothesis that there was no difference between the control and treatments was tested by the Kruskal–Wallis test. Comparisons were made between the number of punched control leaves left and all treatments, between the carbopol and petrolatum treatments, and between the lanolin and all other treatments, by Mann–Whitney U-tests (the distributions could not be normalised with a single transformation).

Acceptance of Petrolatum by Goats

The proportion of a population of 30 re-domesticated adult female feral goats (of known body weight) that ate mahoe leaves treated with non-toxic petrolatum (the least palatable carrier in use) was measured by adding iophenoxic acid, a plasma marker, to the carrier and then later measuring the amount of marker present in each animal's blood (Eason and Batcheler 1991).

Fifty branches of mahoe, each with about 30 leaves, of which five were treated with exactly 0.25 g of petrolatum containing 5 mg of iophenoxic acid, were laid out over a 1-ha pasture at Lincoln University, Christchurch. A 5-mL blood sample was collected from each goat after eight days so that the amount of plasma iodine could be measured.

After eight days, goats that had ingested 5 mg of iophenoxic acid (the equivalent of one treated leaf in this trial) had plasma iodine concentrations of about 50 pg per 100 mL, and those that had ingested 50 mg (the equivalent of 10 leaves in this trial) averaged about 360 pg per 100 mL (Eason and Batcheler 1991). Thus, the number of treated leaves eaten and the probability that the goat would die if toxin was present could be estimated. The plasma iodine levels in untreated goats were between 4 and 10 pg per 100 mL (Eason and Batcheler 1991).

Results

Abscission of Treated Mahoe Leaves

Both the carriers and the 1080 caused mahoe leaves to absciss (Fig. 1). Leaf loss was minimal for the first 10 days, increased rapidly over the next 10–20 days, and then slowed.

More of all treated leaves abscised after 46 days than the untreated control leaves, even the difference between the least phytotoxic treatment (non-toxic petrolatum) and the control being significant ($\chi^2 = 16.22, \text{d.f.} = 1, P < 0.0001$). The addition of 1080 to the carriers significantly increased their phytotoxicity: by a factor of 1.7 times for petrolatum ($\chi^2 = 10.93, \text{d.f.} = 1, P < 0.001$), and by 1.6 times for carbopol ($\chi^2 = 43.14, \text{d.f.} = 1, P < 0.0001$). Carbopol was about 3 times more phytotoxic than petrolatum, both with ($\chi^2 = 156.8, \text{d.f.} = 1, P < 0.0001$) and without ($\chi^2 = 88.6, \text{d.f.} = 1, P < 0.0001$) 1080. This was generally reflected in the phytotoxicity shown by the five mixtures because those with most carbopol were the most phytotoxic (Fig. 1).

Persistence of 1080 in Carriers on Mahoe Leaves in situ

The loss of 1080 from treated mahoe leaves was related to the type of carrier. After 64 days and about 208 mm of rain, most of the 1080 had leached from leaves treated with carbopol gel, little had leached from leaves treated with petrolatum, and about 60% had leached from all the mixtures (Table 1).

Persistence of 1080 in Petrolatum on Abscissed Mahoe Leaves

The reduction in 1080 concentration in petrolatum on mahoe leaves on the ground over time was linear (Fig. 2) and seemed to be by ablation as the leaf cuticles decayed off the leaf skeletons, rather than by leaching by rainfall. The effect of rainfall (if any) could not be distinguished from that of time because the two were obviously highly correlated.
Fig. 1. Percentage of treated leaves remaining on mahoe trees over 46 days following treatment with nine carriers. Leaves were counted at intervals of 3–10 days.

The average amount of 1080 on each leaf, irrespective of time, was similar on both upward- ($\bar{x} = 15.7$ mg per leaf) and downward-facing ($\bar{x} = 16.9$ mg per leaf) leaves ($P=0.58$), again suggesting no specific rainfall effect.

Table 1. Amount of 1080 remaining in seven carriers after 64 days and 208 mm of rain. About 25 mg of 1080 was applied to each mahoe leaf in situ

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of leaves combined and tested</th>
<th>Mean mg 1080 per leaf</th>
<th>% of initial loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbopol (C)</td>
<td>9</td>
<td>1.2</td>
<td>4.8</td>
</tr>
<tr>
<td>C:P 1:1</td>
<td>9</td>
<td>11.0</td>
<td>44.0</td>
</tr>
<tr>
<td>C:P 1:1.5</td>
<td>12</td>
<td>9.7</td>
<td>38.8</td>
</tr>
<tr>
<td>C:P 1:2</td>
<td>13</td>
<td>10.2</td>
<td>40.8</td>
</tr>
<tr>
<td>C:P 1:2.5</td>
<td>17</td>
<td>11.2</td>
<td>44.8</td>
</tr>
<tr>
<td>C:P 1:3</td>
<td>7</td>
<td>9.1</td>
<td>36.4</td>
</tr>
<tr>
<td>Petrolatum (P)</td>
<td>15</td>
<td>19.7</td>
<td>78.8</td>
</tr>
</tbody>
</table>

Relative Palatability of Four Carriers

The goats browsed branches with lanolin less often than all the non-odorous treatments and control combined ($x^2 = 7.45$, d.f. = 1, $P<0.01$). All other treated branches were browsed at a similar rate to untreated branches ($P>0.05$) (Table 2).
Poisoning Feral Goats

Fig. 2. Mean (± range) loss of 1080 from mahoe leaves on the ground (●), and cumulative rainfall (○) over 301 days.

The goats ate leaves treated with all carriers to some extent, but ate significantly \((P<0.001)\) fewer treated leaves than the marked untreated leaves (Table 2). There were no significant differences between lanolin and the other treatments, or between carbopol and petrolatum.

Table 2. Number of mahoe branches treated with four carriers or left untreated browsed by goats, and the frequency of treated or marked leaves left uneaten on branches otherwise browsed

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of leaves not eaten</th>
<th>No. branches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Untreated</td>
<td>17</td>
<td>2</td>
</tr>
<tr>
<td>Carbopol</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Petrolatum</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Mixture</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Lanolin</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

The goats often bit off several leaves at a time, partly chewed them, detected the carriers, then dropped the whole mouthful: treated leaves were significantly more frequent on the ground than marked untreated leaves (Table 3). Again, there was no difference between lanolin and the other carriers, but petrolatum was rejected significantly more often than carbopol.
Table 3. Frequency of treated leaves (10 per branch) found on the ground beside browsed branches

Kruskal-Wallis test, d.f. = 4, *P* < 0.01; untreated cf. carbopol, *P* < 0.05; untreated cf. petrolatum, *P* < 0.001; untreated cf. mixture and lanolin, *P* < 0.01; carbopol cf. petrolatum, *P* < 0.05; lanolin cf. all other treatments, *P* = n.s.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of leaves on ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>2 1 2 2 1</td>
</tr>
<tr>
<td>Carbopol</td>
<td>10 6 4 2 0 1</td>
</tr>
<tr>
<td>Petrolatum</td>
<td>7 4 3 3 1 2 2 1</td>
</tr>
<tr>
<td>Mixture</td>
<td>12 1 6 4 0 1 1</td>
</tr>
<tr>
<td>Lanolin</td>
<td>6 4 0 1 2 1 0 0 0 1</td>
</tr>
</tbody>
</table>

Acceptance of Petrolatum by Goats

The frequency distribution of goats with increasing plasma iodine concentrations showed that three goats ate no baited leaves, one ate part of a baited leaf, two ate one leaf each, and the rest (24) ate more than one leaf, with 16 eating 10 or more baited leaves (Fig. 3).

Fig. 3. Numbers of goats with increasing plasma iodine concentrations (on a logarithmic scale) following ingestion of iophenoxic acid in petrolatum on mahoe leaves. Those goats in the unshaded part of the figure may have survived if the baits were toxic.

Discussion

The two main carriers that have been used in poison operations against goats, carbopol and petrolatum, and mixtures of the two, provide a choice in determining bait durability. Mahoe leaves treated with toxic carbopol lost most of their 1080 after about 200 mm of rain (Table 1). Batchelor and Challies (1988) also showed that 90% of 1080 in carbopol on deer-baits (*Griselinia littoralis*) was washed off by as little as 81 mm of rain. Regardless of rainfall and losses of 1080 by leaching, toxic carbopol on mahoe had a maximum bait-life of less than about 60 days because phytotoxicity caused most baited leaves to absciss by the end of the 46-day trial (Fig. 1). Carbopol used on mahoe leaves therefore has use as a short-life bait.
In contrast, 1080 in petrolatum was highly resistant to leaching and the toxic carrier was three times less phytotoxic than toxic carbopol. Mahoe leaves treated with toxic petrolatum are likely to remain effective as baits for at least 110 days, after which time most will have abscissed. However, the abscissed leaves will remain hazardous for at least 300 days (Fig. 2) to animals that eat leaf-fall, although probably not to goats, which prefer not to eat food off the ground.

There is some evidence that goats avoid baits that smell foreign. Lanolin deterred initial browsing (Table 2), and Parkes (1983) reported that incorrectly buffered carbopol, which smells acetic, did likewise. Although petrolatum and correctly buffered carbopol have no strong odour detectable by humans, goats did reject both to a similar extent (Table 2), but by which sense is not known. Once they had bitten off a treated leaf, goats detected and dropped the greasier petrolatum-treated leaves more often than the carbopol-treated leaves (Table 3). Nevertheless, the acceptance trial showed that most goats ate petrolatum-treated mahoe leaves, and the likely mortality rate (had the carrier contained the usual 10% by weight of 1080) could be calculated.

The LD₅₀ of compound 1080 in goats is 0.5 mg 1080 per kg body weight (McIlroy 1983), and each toxic baited leaf would contain about 25 mg of 1080. The three goats that ate fewer than two baited leaves weighed 50, 61 and 59 kg and would have received doses of 0.25, 0.40 and 0.42 mg of 1080 per kg, respectively, and might have survived, but the remaining 24 goats would probably have died. This likely kill of about 80% is less than the 90% estimated by Parkes (1983) in a field trial with carbopol.

An ideal poisoning strategy places all the target animals at immediate risk to a palatable, acceptable bait that would rapidly disappear from the environment, either by being eaten by the target animal or by degrading into a harmless or unavailable form. However, because of the mountainous terrain in many goat-infested areas in New Zealand, not all goats can be placed at immediate risk because baits cannot be distributed evenly or in all sites. In such terrain, a toxic bait with a longer duration of activity is necessary to give goats time to discover it during their normal movements. Managers must therefore choose between the short-life but more palatable carbopol and the long-life but less palatable petrolatum. If they could ensure an even bait distribution and a period without heavy rain, carbopol would be indicated. If they could not, baiting a proportion of the branches with petrolatum in addition to branches baited with carbopol may increase the success of an operation, but it may increase the risk to non-target species.

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References


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