*Aust. Wildl. Res.*, 1984, **11**, 103–11

# The Toxicity and Acceptability of Warfarin and 1080 Poison to Penned Feral Pigs

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*Abstract*

Experiments were conducted which examined the toxicity and acceptability of warfarin and 1080 poison to penned feral pigs. Warfarin was very toxic and highly acceptable. Maximum mortality was 11 of 12 at 0·08% concentration for 2 or 3 days, or 0·1% concentration for 2 days. 1080 toxicity was 2 of 19 at 0·05% for 1 day. Bait intake declined significantly when bait was poisoned with 1080. The results and their implications are discussed.

## Introduction

Poisoning is a common method of feral pig control in New South Wales (Hone *et al.* 1980). The only poison recommended is sodium monofluoroacetate (1080). The percentage reduction in feral pig abundance due to 1080 has been variously estimated as 58% (Hone and Pedersen 1980), 73% (Hone 1983) and 92% (Bryant, Hone and Robards, unpublished data). The poison has several advantages over other poisons, such as its speed of action, high toxicity to pigs (Atzert 1971), and extensive operator experience.

Several problems in the use of 1080 have, however, been identified. The poison has no antidote and is very toxic to dogs (Atzert 1971). Some pigs have been observed to survive very high doses and vomiting is common (Sheehan, personal communication); this may reduce the amount of 1080 absorbed and increase the chances of secondary poisoning, especially of farm dogs. There is some evidence that pigs become bait-shy to 1080 (Bryant and Hone, unpublished data). There is a need for an alternative poison for feral pig control that overcomes the limitations of 1080.

The anticoagulant poisons offer promise as alternative toxicants. Anticoagulants avoid bait-shyness, have an antidote (vitamin K1), and non-target poisoning is less likely (Godfrey and Lyman 1980). Warfarin appears to have potential as a pig poison (Hone and Mulligan 1982). Clark (1954) listed several studies that showed warfarin, an anticoagulant, as toxic to pigs. Several authors have reported $LD_{50}$ figures for warfarin to pigs—acute 3 mg $kg^{-1}$, chronic 0·05 mg $kg^{-1}$ over 7 days (Buck 1978); chronic oral 0·4 mg $kg^{-1}$ over 5 days (Crispin *et al.* 1975); acute oral 1·5 mg $kg^{-1}$ (Kaukeinen 1979). Worthing (1979) listed a lethal dose of 1 mg $kg^{-1}$ over 5 days.

The aim of this study was to investigate the toxicity and acceptability of warfarin and 1080 to feral pigs. Emphasis was placed on the toxicity of poisons at defined concentrations in bait, not on estimating an $LD_{50}$. This approach gives results more easily extrapolated to field situations.

0310-7833/84/010103$02.00

## Methods

*Design*

The study initially tested the toxicity and acceptability of warfarin in a factorial design. Feral pigs of both sexes were offered technical-grade warfarin mixed with wheat at three concentrations (0·05%, 0·08% and 0·10%) for each of three durations (1, 2 and 3 days). Six pigs of each sex were tested at each combination of poison concentration and duration. An experimental control group was offered unpoisoned wheat.

The second part of the study examined the toxicity and acceptability of 1080 in a factorial design. Initial experimentation tested concentrations from 0·005% to 0·08% w/w 1080 mixed with wheat. Because of low mortalities and poison intakes one 1080 concentration (0·05%) was selected and its toxicity and acceptability examined in detail. The efficiency of an antiemetic (metoclopramide; Maxolon) was also tested. Metoclopramide was added to wheat containing 1080; its concentration was 0·01% or 0·05%. Pigs of both sexes were tested at 0·05%, only females were tested at 0·01% concentration.

*Experimental Procedure*

Feral pigs were trapped in north-western New South Wales, weighed, and transported to Glenfield. Male and female pigs of various ages were used. Testing of males and females was alternated, to prevent disturbance caused by intersexual activity. The alternate testing was also designed to minimize environmental effects, such as temperature, on bait intake and poison susceptibility. Pigs were given 1 week to acclimatize before testing. This was particularly important for warfarin testing, to minimize or prevent bruising which could bias toxicity results (Osweiler 1978; Kaukeinen 1982).

Experimental periods consisted of 3 days pre-poison, 1–3 days of poisoning and then up to 14 days post-poisoning. During all periods bait take was measured and new wheat offered daily to all pigs. Feral pigs offered 1080 were classed as survivors if they were still alive 3 days after removal of the poison. This is slightly shorter than the period used by McIlroy (1983), though it did not influence the results. In the present study pigs were not removed from pens until 1 or 2 days after being classed as survivors, and no pigs died in the extra time. Feral pigs offered warfarin were classed 14 days after removal of the poison. Dead pigs were weighed and a post-mortem conducted.

All animals were housed in weldmesh pens which measured 4 by 1 m, and had concrete floors. Water was provided in each pen by self-drinkers. Several pigs were tested in slightly larger pens with an earthen floor. Pigs were offered wheat *ad libitum* throughout experiments. Pens were cleaned daily.

Poisoned bait was mixed in a cement mixer for 15–30 min. Brilliant blue dye (C400) was added to poisoned bait to give a 0·01% concentration, to identify it and ensure thorough mixing of poison. 1080 was added to wheat in a water solution, and warfarin in a propylene glycol solution. The concentration of 1080 in a sample of wheat was analysed (Livanos, personal communication) and found to be correct.

Throughout the experiments every effort was made to handle the animals as humanely as possible. The experiments were conducted from January 1981 to June 1982.

*Post-mortems*

Post-mortems were conducted on all poisoned pigs. The presence or absence of haemorrhage (unclotted blood) or congestion (swelling associated with large clots of blood) was recorded in various organs and limbs. For post-mortem examination, skin was removed from the legs and body of each pig. On each leg, the neck, and the outer wall of the thoracic and abdominal cavities, the presence or absence of subcutaneous haemorrhage or congestion was noted. Individual organs were then examined. The inner linings of the thoracic cavities and chambers of the heart and the inner and outer lining of the stomach, intestines and bladder were examined. Foetuses were aged by the method of Henry (1968).

*Analysis*

*Warfarin.* The effects of warfarin concentration (0·05%, 0·08% and 0·10%), duration of feeding (1, 2 and 3 days) and sex on mortality were examined by a generalized linear model method for binomial data, by means of a logit link function. The effects of warfarin concentration, duration of feeding, and sex, on average warfarin intake by pigs killed, were tested by fixed-factor analysis of variance (AOV).

Averages were analysed after transformation to square roots. The three-factor interaction was used as the error variance. The average time till death was similarly analysed, though not transformed. One degree of freedom was subtracted from the error variance in both analyses because of missing data (Snedecor and Cochran 1967). The effect of warfarin on wheat intake was analysed from differences in the average intake per pig per day between the period of poisoning and the same number of days pre-poisoning. The effects of warfarin concentration (0, 0·05%, 0·08%, 0·10%), sex and replicates were examined in fixed-factor AOV. Error variance was estimated from the interactions of replicates with other main effects. Separate analyses were conducted for each duration of poisoning: 1, 2 and 3 days. As the level of difference between pre-poison and poison analysis may be related to the weight of the pigs, data used in the previous analysis were divided by body weight and the data reanalysed. Body weights were calculated as the means of weights before poisoning, and after death.

*1080.* The effect of 1080 on intake was analysed by calculating the difference between intake the day before poisoning and the day of poisoning. The differences were tested in a one-way AOV.

To determine why wheat intakes declined when feral pigs were offered 1080, each of the bait constituents were offered to male and female pigs. The baits offered were wheat, wheat + water, wheat + water + dye, wheat + water + 1080, and wheat + water + dye + 1080. The effects of bait constituents, sex and their interactions were examined in fixed-factor AOV. Data analysed were differences between intakes before and during poison. A second analysis followed adjustment for differences in body weight, as for pigs given warfarin.

*Environment.* As the study was conducted over 18 months, seasonal differences in climate may have influenced wheat intake by the pigs. Temperature has been reported to influence food intake by pigs (Mount 1979). The effects of maximum and minimum temperatures on wheat intake per pig were examined by correlation analyses. Wheat intakes and temperatures were averaged for a 4-day period for each batch of feral pigs. Four days' data gave a high level of precision for estimating average intake, in kilograms, per pig per day. There were no significant correlations between temperatures and wheat intakes. On this basis data on intakes were pooled across temperatures and times.

## Results

### *Warfarin*

The mortality data of feral pigs are shown in Table 1. Kills after 1 day of poisoning (47·2%) were significantly ($P<0·001$) lower than after 2 or 3 days' feeding (83·8% and 86·3% respectively). Significantly ($P<0·001$) more females (87·3%) died than males (57·8%). The effects of duration were significantly ($P<0·05$) different between the sexes. Mortality of males offered warfarin for one day (16·7%) was markedly lower than that of males at longer durations and of females at all durations. The effect on mortality of sex significantly ($P<0·05$) varied with warfarin concentration. As the concentration increased, mortality of females increased from 13 of 18 (0·05%) to 16 of 18 (0·08%) and 18 of 18 (0·10%). In contrast mortalities of males were respectively 10 of 18, 12 of 18 and 9 of 18.

Average warfarin intakes increased with increasing concentration and duration (Table 1). Male pigs ate more warfarin than female pigs. The average times till death decreased with increased duration of poisoning (Table 1). However, there were no significant effects of concentration, duration or sex on average intakes of warfarin or average time till death. The results show that some pigs survived large doses of warfarin (Table 1). For example two males survived after ingesting an average intake of 119·6 mg warfarin per kilogram body weight in 3 days.

Analysis of differences in wheat intake pre-poisoning and during poisoning showed significant ($P<0·05$) effects of sex and sex × concentration in the 1-day feeding data. Males ate more wheat before than during poisoning (0·164 kg) but females ate less before than during poisoning (−0·049 kg). The effect of sex varied with warfarin concentration, but in no clear manner. Analysis of the 2-day feeding data also showed a significant ($P<0·05$) effect of sex on differences in wheat intake. Males ate more wheat before than during poisoning (0·028 kg); so did females (0·180 kg). There were no significant differences

between wheat intake in pre-poisoning and poisoning periods for the 3-day duration of poisoning. The use of body weight to adjust for different sizes of pigs in each of the above three analyses did not alter the significance of the results.

**Table 1. Mortality, warfarin intake and time till death of penned feral pigs in no-choice warfarin experiments**

| Concentration (%) | Duration of feeding (days) | Sex | Mean weight (kg) | Mortality | Mean dose (mg kg$^{-1}$) Pigs dying | Pigs surviving | Mean days to death |
|---|---|---|---|---|---|---|---|
| 0·05 | 1 | M | 30 | 2/6 | 20·6 | 17·1 | 10·0 |
| | | F | 37 | 3/6 | 20·8 | 13·6 | 9·7 |
| | 2 | M | 39 | 4/6 | 40·5 | 41·4 | 7·3 |
| | | F | 37 | 4/6 | 33·9 | 41·5 | 8·3 |
| | 3 | M | 32 | 4/6 | 72·4 | 11·3 | 6·5 |
| | | F | 30 | 6/6 | 74·8 | — | 5·5 |
| 0·08 | 1 | M | 33 | 1/6 | 24·0 | 14·5 | 9·0 |
| | | F | 33 | 5/6 | 40·9 | 33·0 | 9·4 |
| | 2 | M | 29 | 6/6 | 60·9 | — | 8·5 |
| | | F | 33 | 5/6 | 50·6 | 32·1 | 7·8 |
| | 3 | M | 29 | 5/6 | 107·8 | 80·6 | 5·4 |
| | | F | 23 | 6/6 | 61·9 | — | 6·2 |
| 0·10 | 1 | M | 39 | 0/6 | — | 27·3 | — |
| | | F | 40 | 6/6 | 51·9 | — | 9·0 |
| | 2 | M | 26 | 5/6 | 70·6 | 76·2 | 8·4 |
| | | F | 26 | 6/6 | 66·6 | — | 5·8 |
| | 3 | M | 30 | 4/6 | 133·7 | 119·6 | 5·8 |
| | | F | 29 | 6/6 | 83·6 | — | 6·7 |

Intake of wheat by feral pigs declined as warfarin produced its symptoms (Fig. 1). Similar results were recorded for each treatment combination of warfarin concentration and duration of feeding. Other symptoms were lameness, lethargy, blood in the faeces and urine, and haemorrhage from the nostrils.

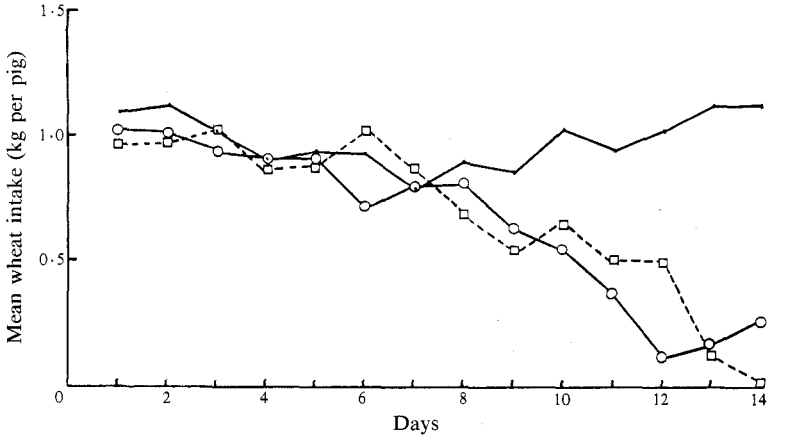


**Fig. 1.** Average daily intake of wheat by pigs before, during and after being poisoned with warfarin; only those pigs that died are included. o——o 0·08% warfarin on days 4, 5 and 6. □- - -□ 0·10% on days 4 and 5. —— Control.

Post-mortem examination found easily identifiable symptoms of warfarin poisoning. Of 78 pigs, the percentages showing haemorrhage or congestion in various organs or limbs were as follows:

| | | | |
|---|---|---|---|
| Right foreleg | 71·8 | Heart | |
| Left foreleg | 74·4 | Right atrium | 12·8 |
| Right hindleg | 62·8 | Left atrium | 10·3 |
| Left hindleg | 61·5 | Mesentery | 17·9 |
| Large intestine | 52·6 | Diaphragm | 15·4 |
| Stomach | 44·9 | Kidney | |
| Neck | 33·3 | Right cortex | 14·1 |
| Thoracic and abdominal wall | 24·4 | Left cortex | 14·1 |
| Small intestine | 28·2 | Right medulla | 14·1 |
| Right lung | 24·4 | Left medulla | 14·1 |
| Left lung | 23·1 | Ovaries + uterus | 12·8 |
| Right thoracic cavity | 23·1 | Trachea | 7·7 |
| Left thoracic cavity | 26·9 | Bladder | 6·4 |
| Heart | | Tongue | 3·8 |
| Right ventricle | 23·1 | Oesophagus | 3·8 |
| Left ventricle | 41·0 | Testes | 0 |

The forelegs were most affected, followed by the hindlegs, large intestine and stomach. Symptoms in other organs were variable, and appeared not to be related to warfarin concentration, duration of feeding or sex. One feral pig examined post mortem had no obvious haemorrhage or congestion.

During post-mortems 45 foetuses from dead sows were examined. Twenty-nine (64·4%) had been alive and healthy, 12 (26·7%) had been alive but showed haemorrhage or congestion, and four (8·9%) were dead. Five of 12 (41·7%) foetuses in the first trimester of pregnancy showed haemorrhage or congestion, as did five of nine (55·6%) and two of 24 (8·3%) in the second and third trimesters respectively. The four dead foetuses were all in the third trimester of pregnancy.

**Table 2. The effect of 1080 intake on mortality and vomiting by penned feral pigs**

Intakes of 1080 estimated from those of poisoned bait, and expressed per kilogram of body weight

| 1080 intake (mg $kg^{-1}$) | No. dosed | No. died | No. vomited |
|---|---|---|---|
| 0–2·0 | 4 | 0 | 3 |
| 2·1–4·0 | 10 | 0 | 9 |
| 4·1–6·0 | 1 | 1 | 1 |
| 6·1–8·0 | 2 | 0 | 2 |
| 8·1–10·0 | 1 | 0 | 1 |
| 10·1–12·0 | 0 | 0 | 0 |
| 12·1–14·0 | 1 | 1 | 1 |
| Total | 19 | 2 | 17 |

*1080*

Mortality due to 1080 was 2 of 19 (10·5%) of feral pigs, and 17 of 19 (89·5%) vomited. Two of 10 females, but none of nine males, died. Poison intakes ranged from near zero to nearly 14 mg $kg^{-1}$ (Table 2). The two pigs that died ingested large amounts of 1080 (>4 mg $kg^{-1}$), and two pigs that did not vomit ingested small amounts (<4 mg $kg^{-1}$). Post-mortem examinations found no identifiable symptoms of 1080 poisoning.

When wheat was poisoned with 1080 there was a significant ($P<0·005$) reduction in intake by feral pigs (Fig. 2). Intakes returned to pre-poison levels after 3 days. Analysis of the effects of bait constituents (wheat, water, dye and 1080) and sex showed that wheat intake dropped significantly ($P<0·005$) when 1080 was included. There were no significant effects

of water or dye, or any effect of sex. AOV of the data adjusted for body weight gave a similar result, but there was a significant ($P<0\cdot05$) effect of sex on intake. Females showed a greater difference than males between intake before and during poisoning. The females ate more, per kilogram of body weight, before poisoning than the males, but during poisoning intakes by both sexes were similar.

Metoclopramide did not prevent vomiting by feral pigs (Table 3). Three of 10 pigs died when offered 1080 and metoclopramide, compared to none of seven given only 1080 (Table 3).

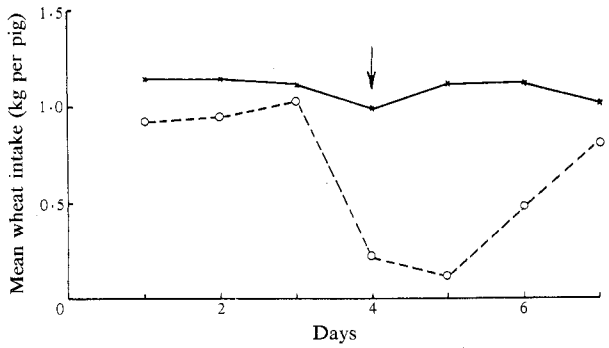


**Fig. 2.** Average daily intake of wheat by two groups each of 11 pigs. ——— Wheat not poisoned. o- - -o Wheat contained 0·05% of 1080 on day 4 (arrow) only.

**Table 3. The effect of metoclopramide on mortality and vomiting in penned feral pigs**

All pigs were offered wheat containing 1080 at 0·05% concentration

| Metoclopramide concn (%) | Sex | No. dosed | No. died | No. vomited |
|---|---|---|---|---|
| 0 | M | 4 | 0 | 4 |
| | F | 3 | 0 | 3 |
| 0·01 | M | — | — | — |
| | F | 3 | 1 | 3 |
| 0·05 | M | 4 | 0 | 4 |
| | F | 3 | 2 | 3 |

## Discussion

The results reported in this paper show that warfarin and 1080 differed in their toxicity and acceptability to feral pigs. Warfarin was highly toxic and acceptable at high concentrations and durations. At the same concentration (0·05%) for 1 day, mortalities due to warfarin and 1080 were 41·7% and 10·5% respectively.

### *Warfarin*

Pigs have been reported by several authors to be very susceptible to warfarin (Crispin *et al.* 1975; Buck 1978; Kaukeinen 1979; Worthing 1979). The present study showed feral pigs to be more tolerant of warfarin than was indicated by other studies. The toxicity of warfarin significantly increased if the pigs fed for 2 days compared to one, but there was no significant difference between mortality after 2 and 3 days feeding. Some feral pigs, especially males, survived high doses of warfarin when fed for 1 day. This suggests a need to examine warfarin tolerance or resistance in pigs, and whether this is sex-related. Warfarin

resistance occurs in the rat and house mouse (Greaves 1971), and is different in male and female house mice (Wallace and MacSwiney 1976).

Bait avoidance or shyness was not generally observed in the present study. A widely recognized advantage of warfarin and other anticoagulants is good bait acceptance (Worthing 1979). Detailed analysis of the data on bait take suggested, however, that male pigs ate less poisoned than unpoisoned wheat when it was offered for 1 day at 0·08% and 0·1% concentration. This may explain the lower kills of males on those poison regimes, rather than a specific sex difference in susceptibility to warfarin.

Symptoms of warfarin poisoning observed in this study were consistent with those reported by other authors. Osweiler (1978) outlined symptoms as lameness, stiffness, lethargy, recumbency, dark tarry faeces, and anorexia. Bartik and Piskac (1981) reported similar symptoms, as well as haemorrhage. Osweiler (1978) noted that warfarin symptoms were often of two types: a gradual onset of the above symptoms or sudden death with massive haemorrhage. These responses were both observed in the present study.

The post-mortem examinations showed easily identifiable lesions, similar to those reported by Clark (1954), McGirr and Papworth (1955) and Osweiler (1978). The occasional pig, however, can show virtually no symptoms. Dyssegard (1952) reported a similar phenomenon in other species, that led him to suggest that warfarin may sometimes cause death other than by haemorrhage. Buck (1978) suggested that such deaths could be associated with haemorrhage in the brain.

The presence of foetuses showing haemorrhage or congestion in the uterus of dead sows suggests that warfarin can have some teratogenic effects in pigs. It has been reported to cause abortions in cattle (Pugh 1968). Holzgreve *et al.* (1976) reported that warfarin could be teratogenic in the first trimester of human pregnancy, but exposure for the duration of pregnancy is necessary to develop foetal warfarin syndrome. Robinson *et al.* (1978) considered that warfarin was teratogenic in the first trimester and perhaps also in the second and third.

*1080*

Mortality due to 1080 poisoning was very low in this study. The results are very different to those reported from field studies (Hone and Pederson 1980; Hone 1983; Bryant and Hone, unpublished data) and another pen study (Sheehan, personal communication). Sheehan reported about 80% mortality, with some feral pigs surviving very high doses. Bait types and 1080 concentration were different, however, in each study.

The estimated intakes, per kilogram body weight, of 1080 in this study were quite variable, and some pigs survived high levels of 1080. Five pigs ingested more than 4 mg $kg^{-1}$, but only two died. McIlroy (1983) estimated the $LD_{50}$ and $LD_{99}$ (and 95% confidence limits) for adult males as 1·0 (0·7–1·3) and 2·3 (1·6–3381·4) mg $kg^{-1}$ respectively. These results show there is large variability in the sensitivity of feral pigs to 1080. Our method was probably slightly less accurate in estimated 1080 intakes than that used by McIlroy, but the difference would not be sufficient to account for the differing results.

Vomiting was very common in the present study. Rathore (1981) and Sheehan (personal communication) found similar results, though McIlroy (1983) reported only four feral pigs vomiting of 13 showing signs of poisoning. Metoclopramide did not prevent vomiting, in contrast to the results of Rathore (1981). Mortality increased with the use of metoclopramide. The different results between studies may have been associated with differing techniques. In the present study, non-starved pigs were offered 1080 and metoclopramide in wheat. Rathore offered 1080 and metoclopramide in water solution after starving pigs for 48 h.

Several hypotheses could be advanced for the low mortality of feral pigs to 1080 in the present study. Firstly, the size of the pen and the *ad libitum* pattern of feeding may have altered the feeding behaviour of the pigs, so that they ate small quantities more often and

exercised little. When the wheat was poisoned they quickly became sick, vomited and stopped eating. Secondly, the vomiting itself may have reduced their susceptibility to 1080. Vomiting may be an adaptive strategy to reduce the effects of ingested toxins. Whether vomiting is an obligatory component of 1080 tolerance in feral pigs is not known.

Thirdly, tolerance to 1080 may be being selected for in feral pigs. Nearly all the feral pigs used in the experiment were from a property where 1080 had been used for feral pig and rabbit control. 1080 had been used once against pigs and several times against rabbits since 1975. 1080 concentrations were lower than used in the present study and baits were also different. We may have been testing progeny of survivors from those poisoning operations. Wheeler and Hart (1979) reported no increase in 1080 tolerance of rabbits where 1080 had been used for several years. In contrast, Howard *et al.* (1973) reported an increased tolerance by rats to 1080. There is some evidence of decline in the toxicity of 1080 in field programs for pig control (Bailey, personal communication). The pigs tested by McIlroy (1983) were from an area where 1080 had not been used previously.

*General*

The poisons examined in this study need further testing in the field. In particular, the toxicity of warfarin needs to be determined when pigs have pasture available as an alternative feed. Possible non-target effects of warfarin also need examination. Ashworth (1973) showed that some dogs can be poisoned with warfarin but treatment with vitamin K1 gave high recovery rates. Prior and Derse (1962) considered that secondary poisoning of dogs, from poisoned rodents, was very unlikely. Warfarin is not however, a 'safe' poison (Crispin *et al.* 1975), but needs care in its use.

A need still exists in feral pig control for a quick-acting acute poison. The major need for feral pig control is in relation to eradication or control of exotic diseases. Constraints on the time available to control pig numbers and movements (Hone and Bryant 1981) may necessitate use of a quick-acting poison rather than a slower-acting anticoagulant. The use of fluoroacetamide (1081) for this purpose could be considered. It is slower acting than 1080 (Lisella *et al.* 1971) though not as slow as an anticoagulant. It may not cause vomiting, or may give more encouraging results with an antiemetic. Reducing the concentration of 1080 could also be considered, as vomiting was lowest on low 1080 intakes.

Emphasis within this study was on warfarin as an alternative poison to 1080. Future studies should examine the toxicity of brodifacoum to feral pigs. Its utility may, however, depend more on its cost than its toxicity. Currently it is approximately 100 times more expensive than 1080. Warfarin is half the cost of 1080.

## Acknowledgments

We wish to thank W. Atkinson for trapping most of the feral pigs used in these experiments. The Directors and staff at the Veterinary Research Station, Glenfield, and the Agricultural Research Centre, Trangie, are thanked for their assistance in many stages of the project. S. Lomas assisted with development of post-mortem techniques, and M. Brouwer with collation of data. Mr R. Rutledge allowed us to trap many of the feral pigs on his property. The Australian Meat Research Committee kindly provided financial assistance.

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Manuscript received 5 April 1983; accepted 28 July 1983