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An Economic Threshold for Tick Control Considering Multiple Damages and Probability-Based Damage Functions

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The economic threshold for tick infestations on Zambian cattle was analyzed considering both direct production losses and mortality from transmitted diseases. Probability theory applied to mortality risks was used to derive the functional form for disease damage. With only noninfectious ticks, the economic threshold based on liveweight gain losses was three ticks per calf. The threshold recommended dipping calves whenever any disease-infectious ticks were present. Similar threshold results held for cows when considering milk production and disease mortality losses. If disease control benefits are omitted, as in some past work, thresholds will be overstated and dipping recommendations understated when infectious ticks are present.

Key words: cattle, disease control, economic threshold, ticks, Zambia

Introduction

Moffitt, Hall, and Osteen, and Weersink, Deen, and Weaver have distinguished between the "entomologist's economic threshold" and the "economist's economic threshold" for pest control. The former identifies the pest density beyond which the benefits from pest control exceed the costs assuming a fixed level and cost of treatment. Often the fixed treatment level is associated with the manufacturer's "label rate" for a pesticide. The "economist's threshold" identifies the profit-maximizing rate of pesticide (or other control activity) where the marginal value product of the pesticide equals its marginal factor cost assuming a fixed pest density. While this definition extends the conventional definition of a threshold, it does introduce a desirable element of economic optimization with respect to input use. In practice, the technical and legal feasibility of adjusting the pesticide rate often will determine the suitability of the economist's threshold concept.

Agricultural economists have contributed richly to making both definitions of the economic threshold more inclusive and realistic. Several studies employing the entomologist's threshold have examined the effects of introducing uncertainty and dynamics in the underlying biological relationships (e.g., Marra, Gould and Porter; Harper et al.; Moffit, Hall, and Osteen; Pannell, 1994). Other studies have investigated the effects of crop quality and multiple pest species (Marra and Carlson; Marra, Gould, and Porter). The economist's threshold literature, now frequently described simply as bioeconomic modeling for pest control decisions, has enjoyed a surge of activity recently regarding

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the appropriate functional specification of model relationships (Blackwell and Pagoulatos; Carpentier and Weaver; Carrasco-Tauber and Moffitt; Fox and Weersink; Kwon et al.; Lichtenberg and Zilberman).

While there has been substantial research on issues of risk aversion, dynamics, and alternative functional forms for pest kill and yield damage relationships for crop agriculture, there has been relatively little research on modeling issues related to pest damage to livestock. Specifically, models should consider both livestock productivity declines and mortality caused by disease-carrying insects. Failing to do so could seriously underestimate benefits of control. Furthermore, there is a need to base functional form selection for livestock models on the biology of the infection process.

The objective of this study is to develop and apply a model for determining the economic threshold, in terms of numbers of both disease-carrying and noninfectious ticks per animal, which justifies dipping that animal in an acaricide (tick insecticide) solution. Unlike some previous work (Meltzer and Norval; Pegram et al. 1989), this analysis incorporates both the tick-transmitted disease control benefits of dipping as well as the beef and milk production benefits of dipping. It also introduces a disease damage function based on underlying probability relationships.

Meltzer and Norval estimated economic thresholds for tick (*Amblyomma hebraeum*) control in the lowveld region of Zimbabwe. That study used a linear yield damage function in response to tick density which had been estimated by Norval, Perry, and Young. This function specified that a standard adult female *Amblyomma hebraeum* tick reduced a cow's weight by 10 grams per day. Meltzer and Norval did not consider the value of tick-borne disease reductions in their threshold analysis because it was assumed that cattle had acquired resistance to tick-borne diseases prior to the experiment.

The threshold model developed in this study is applied separately to tick control in calves and cows from southern Zambia. Tick control increases liveweight gain in calves and milk offtake in cows, as well as reducing mortality risks for both groups. For describing damage due to mortality from tick-transmitted diseases, our investigation employs an alternative functional form for pest damage. This damage function is based on elementary probability theory applied to observed infection and mortality risks.

Tick Damage in the African Livestock Industry

In many areas of the world, tick-induced productivity and mortality losses inflict large costs on beef and dairy industries, and the problem remains especially severe in Africa. Mukhebi, Perry, and Kruska estimated that diseases caused by the tick-transmitted *Theileria* protozoa killed 1.1 million cattle and caused US$168 million damage in 11 countries in eastern, central, and southern Africa in 1989. In Zambia, the location of this study, Theileriosis diseases inflicted an estimated US$5.48 million in mortality losses in 1991 (Commission of the European Community). Nambota et al. estimated that 1.4 million of Zambia's three million cattle were at risk from the Theileriosis diseases of East Coast Fever and Corridor Disease. Perry et al. reported that diseases were a major contributor to the 43% mortality rate of calves on Zambia's small farms.

The problem of controlling ticks has grown for African cattle owners in the past decade because budgetary shortfalls and movements toward privatization have reduced or terminated government livestock health programs. In Zambia, for example, since 1991, the financial responsibility for dipping cattle for tick control has shifted from the government to private livestock owners.

Deriving the Economic Threshold

The economic threshold concept utilized in this analysis, referred to above as "the entomologist's threshold," can be defined as the pest population beyond which a reduction in profit occurs or, equivalently, the pest population where the rising total benefits of control equal the specified cost of eliminating the pest (Stern et al.; Stern). Dipping cattle to eliminate ticks potentially generates two benefits: the value of beef and/or milk production benefits (V_g), and the value of reduced tick-transmitted disease mortality (V_d). In this study, production benefits include greater liveweight gain for calves and increased milk production for cows. Because data on tick burdens and milk and liveweight production levels were available only for the "end points" of a tick-free dipped herd and a tick-infested undipped herd (Pegram et al. 1988), the value of production losses (V_g) function was necessarily restricted to a linear form:

(1) $$V_g = c(T_o + T_R).$$

Total ticks on the animal include the sum of the number of noninfectious (T_o) and infectious (T_R) ticks. The coefficient (c) is the average weekly value of production lost per tick as computed from the mean data from the two herds and from output price.

A functional form based on probability theory is derived for describing tick-transmitted disease mortality damage or, equivalently, the mortality reduction benefits from dipping. If T_R denotes the number of infectious ticks on an animal, and if each tick has an independent probability (P) of transmitting a fatal disease, then the probability of death (P_D) can be described by equation (2):

(2) $$P_D = 1 - (\overline{P})^{T_R},$$

where $\overline{P} = (1 - P)$ is the independent probability of any infectious tick not transmitting a fatal disease. Given independence, $(\overline{P})^{T_R}$ equals the probability of T_R ticks not killing the animal by disease. If V is the average value of a calf, the expected value, $E(V_d)$, of reduced disease mortality with dipping when T_R ticks are present on the animal can be represented as:

(3) $$E(V_d) = V\left(1 - (\overline{P})^{T_R}\right).$$

Derivatives (4) and (5) confirm that the disease-reduction benefit function is positively sloped and strictly concave with respect to the number of infectious ticks (T_R). Its shape is similar to the treatment benefit curve for the popular rectangular hyperbolic function for describing yield response to pests (Cousens; Fox and Weersink):

(4) $$\frac{\partial E(V_d)}{\partial T_R} = -V \ln(\overline{P})\overline{P}^{T_R} > 0 \qquad \text{for } 0 < \overline{P} < 1,$$

(5) $$\frac{\partial^2 E(V_d)}{\partial T_R^2} = -V\overline{P}^{T_R}(\ln(\overline{P}))^2 < 0 \qquad \text{for } 0 < \overline{P} < 1.$$

Economic threshold combinations of noninfectious and infectious ticks can be derived from (6), which equates the sum of production and disease control benefits to the cost of dipping (C_D) plus the cost of counting and classifying ticks (C_C):

(6) $$c(T_o + T_R) + V(1 - \overline{P}^{T_R}) = C_D + C_C.$$

Solving for the loci of combinations of noninfectious ticks and infectious ticks which satisfy equation (6) generates an "iso-benefit" contour for dipping or, equivalently, an "iso-damage" contour, in terms of the two tick species (Shoemaker; Pannell 1990). The value of the contour in equation (6) equals the dipping and counting cost. In the results section we present the threshold curve graphically for an application to tick control on Zambian calves.

Data

The data available for this study include herd averages over time for tick numbers, liveweight gain of calves, and milk yield of cows from a controlled experiment in southern Zambia (Pegram et al. 1988). The experiment was conducted at Lutale, 175 km west of Lusaka, from October 1985 through July 1988. It utilized two comparable herds with approximately 60 indigenous cows each, with accompanying calves. One herd was kept tick-free by routine dipping with Cypermethrin and the other was not dipped (Pegram et al. 1988). The calves were weighed weekly or biweekly, and cow milk production was monitored daily. Ticks were periodically counted and identified by species.

The untreated (nondipped) cattle were found to be hosting several noninfectious species of ticks and the *Rhipicephalus appendiculatus* (RA) species which transmits the *Theileria* diseases. All types of ticks reduced liveweight gain and milk production. Table 1 shows that untreated cows averaged 2.12 RA ticks and 15.15 noninfectious ticks, while untreated calves averaged 0.40 RA and 5.39 other ticks. The daily liveweight gain for treated (tick-free) calves averaged 212 grams, while the untreated (tick-infested) calves averaged 171 grams. Mean daily milk output for treated cows exceeded that of untreated cows by 0.06 liters.

Results

Calves

Based on the experimental data for this study, dipping calves generated an average liveweight gain per tick eliminated of 0.0495 kg per week. This represents a weekly benefit of ZK29.7 per week at the liveweight price of ZK600 per kg (1ZK = 0.0017US$ in 1994). Equating this productivity benefit function to the cost of weekly dipping per

Table 1. Herd Mean Tick Numbers and Production Levels

Description	Ticks		Liveweight Gain (grams/day)	Milk Output (liters/day)
	RA	Other		
Calves:				
Treated	0	0	211.69	—
Untreated	0.40	5.39	170.84	—
Cows:				
Treated	0	0	—	0.46
Untreated	2.12	15.15	—	0.40

Source: Pegram et al. (1988).

Notes: Sample size = 66 periodic observations. RA is *Rhipicephalus appendiculatus* tick species.

calf of ZK90 in figure 1 yields an economic threshold of approximately three ticks per calf. This threshold determination ignores any disease damage and should be employed only when infectious RA ticks are absent.

Figure 2 illustrates the remaining benefit component for Zambian calves. It plots the expected value of disease mortality reduction as specified in equation (3). Liveweight gain losses from ticks are ignored. The probability of fatal disease transmission from an RA tick for this study was estimated at 0.0276 based on the product of a 46% death rate from Theileriosis (Nambota et al.) and an estimated infection rate for RA ticks of 6%. The average value [V in equation (3)] of a Sanga calf in 1994 was estimated at ZK42,000 (70 kg × ZK600 per kg). When plotted against the cost of weekly dipping in figure 2, the model shows an extremely low economic threshold of 0.077 RA ticks. Applying this low threshold to an individual calf implies, of course, that the discovery of any RA ticks justifies dipping. The more steeply ascending benefit function in figure 2 compared to that of figure 1 shows the dominance of disease control over liveweight gain in dipping decisions when infectious ticks are present.

Total benefits (TB) of dipping for calves equal the sum of the productivity and disease control benefit functions from figures 1 and 2:

$$TB = 29.69(T_o + T_R) + 42{,}000(1 - 0.9724^{T_R}). \tag{7}$$

It is necessary to distinguish between the number of other (noninfectious) ticks (T_o) and infectious RA ticks (T_R) in (7) because both types contribute to liveweight gain losses, but only the latter transmit disease.

It is assumed that ticks will be counted and classified by young Zambian herdsmen whose opportunity cost of counting time is zero. Total benefits (TB) is set equal only to the cost of weekly dipping per calf [see equation (6)], yielding equation (8):

$$TB = 29.69(T_o + T_R) + 42{,}000(1 - 0.9724^{T_R}) = \text{ZK}90. \tag{8}$$

Solving (8) for the value of one tick type, while incrementing the other from zero to an upper bound, permits derivation of the economic threshold curve in figure 3. The combinations of noninfectious and RA ticks in figure 3 represent an "iso-benefit" contour for

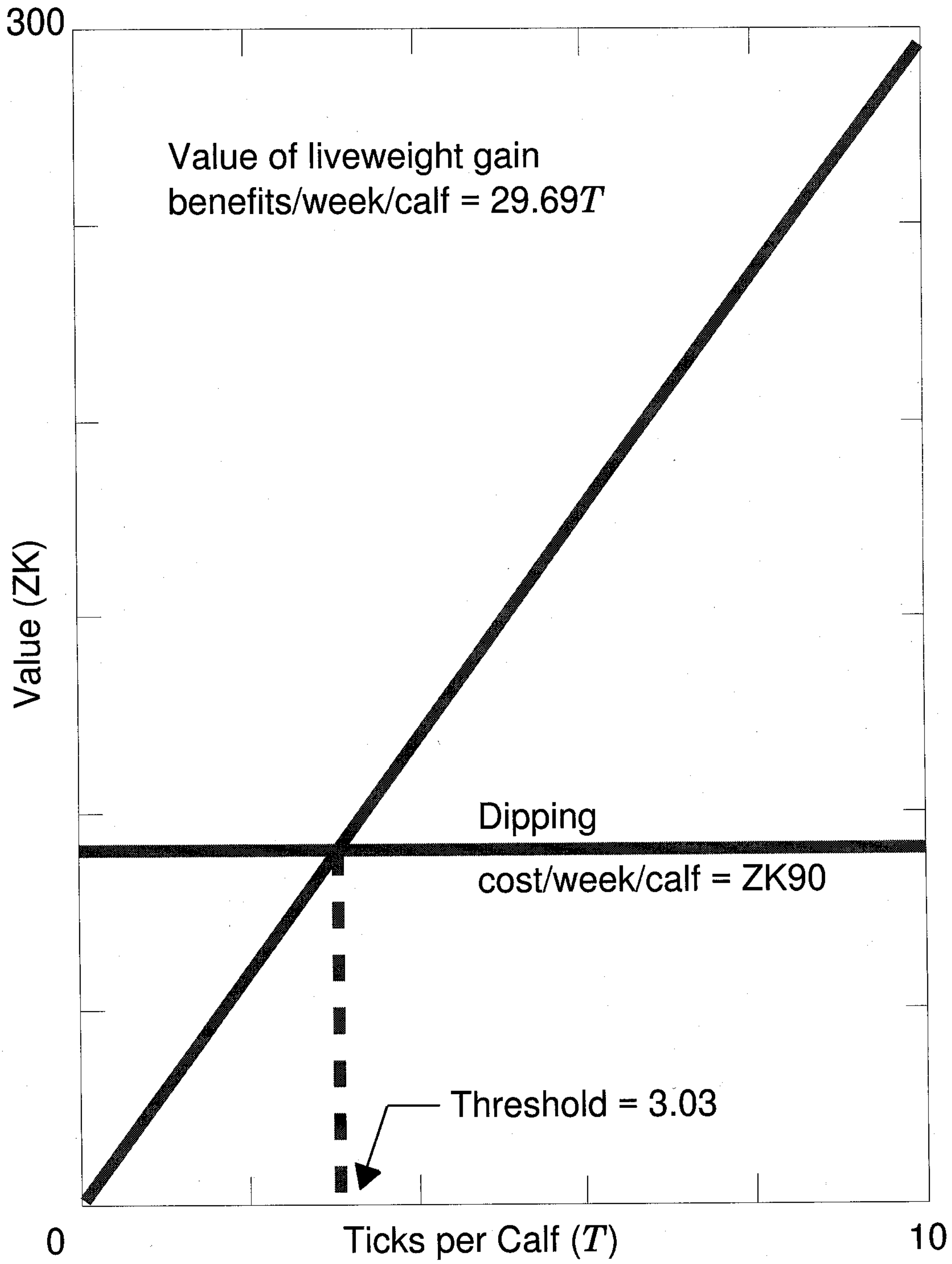

Figure 1. Economic threshold considering liveweight gain benefits only

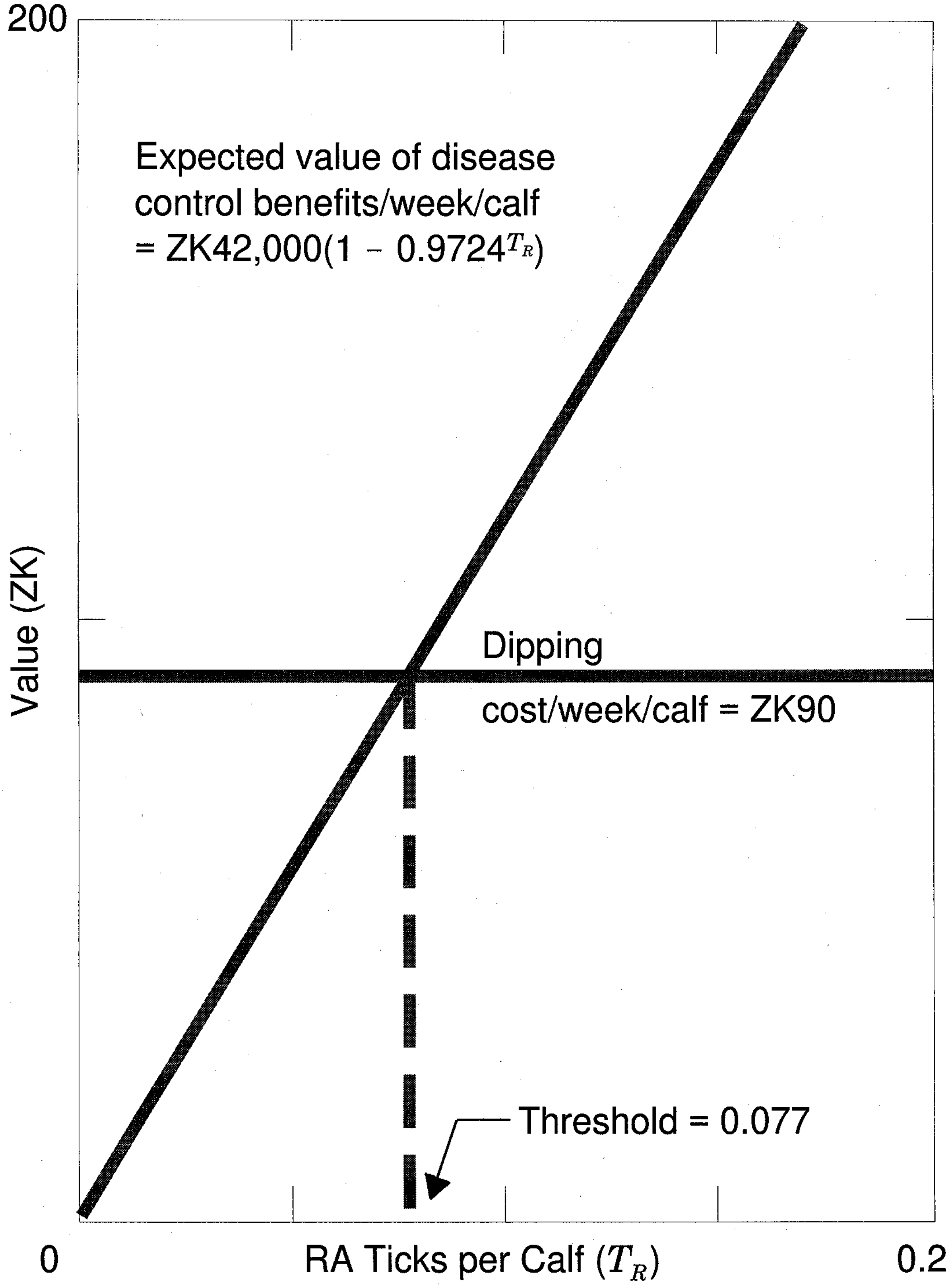

Figure 2. Economic threshold considering disease control benefits only

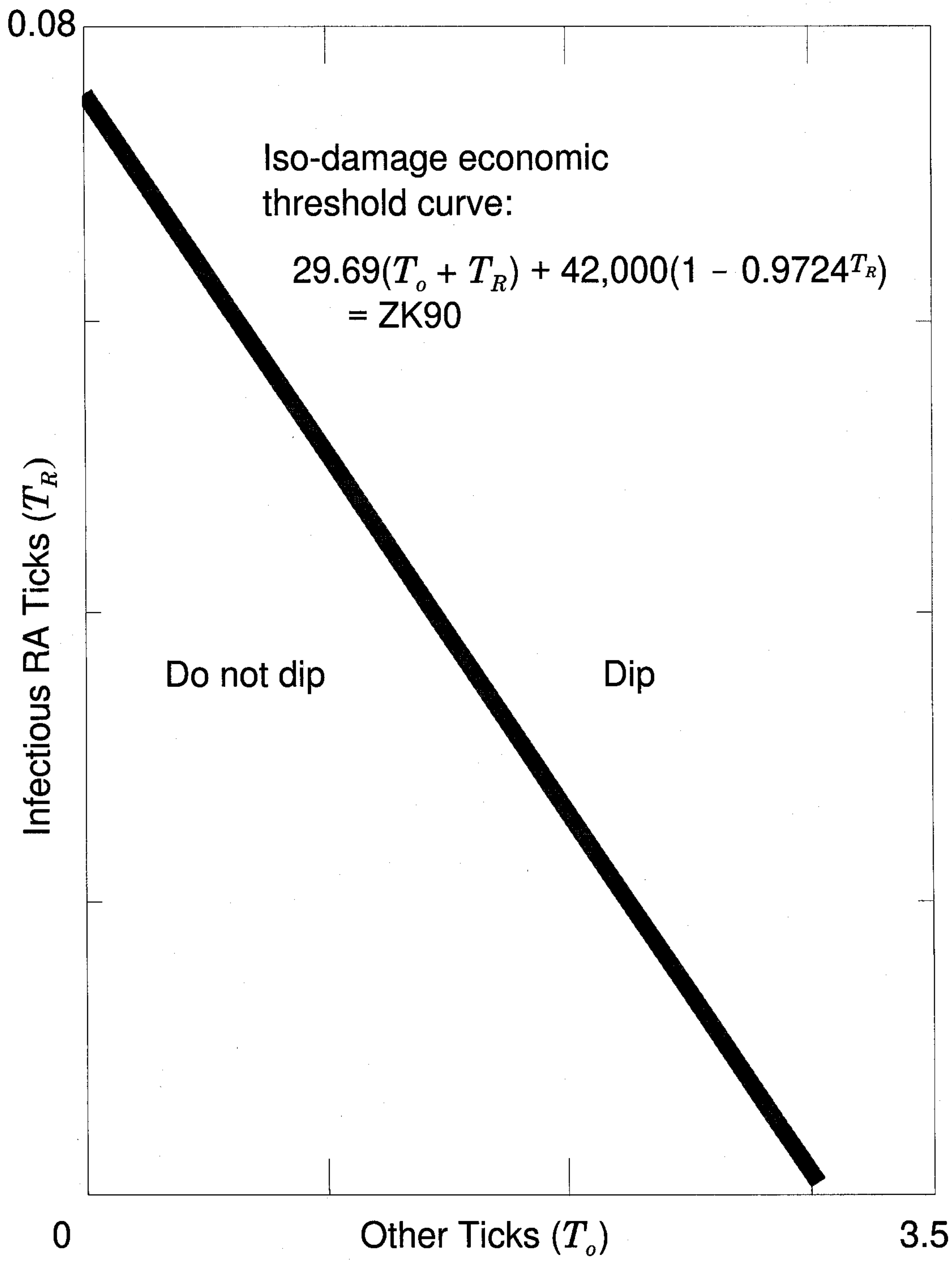

Figure 3. Economic threshold considering both live-weight gain and disease control benefits

dipping, or an "iso-damage" contour of untreated ticks. The value of the contour is ZK90. Figure 3 again confirms the dominance of disease-transmitting ticks in the economic threshold. Regardless of how few other ticks are present, whenever the number of RA ticks exceeds 0.077, the economic threshold recommends dipping. This result is rooted in the relatively high infection risk and the high economic loss associated with disease fatalities.

At contemporary prices, the threshold mixtures of RA and other ticks on calves were exceeded on 58% of the observations during 1987 in the undipped Zambian herd based on tick counts reported in Pegram et al. (1988). The 42% of the observations which were below the threshold occurred generally during the dry season when no RA ticks and very few other ticks were on the calves.

Cows

The mean number of ticks on the untreated cows in the Lutale experiment was 2.12 RA ticks and 15.15 other ticks (table 1). The average difference in milk yield per cow between the treated herd with no ticks and the tick-infested untreated herd was 0.06 liters per day. This represents an average loss of 0.003483 liters per day per tick, or ZK7.31 per week per tick given a milk price of ZK300 per liter. Zambian herdsmen use milk both for calves and for human consumption, so it was considered reasonable to value marginal production at its market price for human use. Inserting ZK7.31 into equation (1) and equating it to the cost of weekly dipping (ZK90), one can solve for the economic threshold (T^*) considering milk yield only:

$$T^* = \frac{90}{7.31} = 12.31. \tag{9}$$

By joining production and mortality damage averted, we then can derive a total benefits function for cows, as done previously for calves. Using a milk price of ZK300 per liter, a value per cow of ZK120,000, and a probability of fatal infection of 0.0276 as derived earlier, the threshold curve for cows shows that the presence of any RA ticks whatsoever makes it profitable to dip, regardless of noninfectious tick numbers. At contemporary prices, the economic threshold would have been achieved in 15 out of 26 tick counts during 1987 in the undipped herd of cows studied by Pegram et al. (1988).

Conclusions

While the specific results in this analysis are dependent upon the Zambian data used, the findings indicate the potentially powerful influence that inclusion of disease control benefits can have in justifying dipping. Ignoring disease control benefits when infectious ticks are present can greatly overstate threshold levels and understate the need for dipping. Now that most livestock owners in Africa and elsewhere must finance their own tick control, there is an important need for accurate economic threshold information which reflects the complete benefits of controlling ticks.

The basic model presented here could be extended. For example, in areas of Africa and other regions where funds for dips and acaricide are lacking, it would be desirable to adapt the model to less capital-intensive tick control technologies which may not deliver 100% tick control. It is likely there are other pest control situations where control practices generate multiple benefits or where damage functions can be logically expressed by probability relationships. The model provides a potential framework for such applications.

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