ELSEVIER

Agricultural Economics 13 (1996) 163–177

AGRICULTURAL ECONOMICS

Economic impacts of East Coast Fever immunization on smallholder farms, Kenya: a simulation analysis

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Accepted 27 August 1995

Abstract

A whole farm simulation model, Technology Impact Evaluation System (TIES), was used to assess ex-ante financial and economic impacts of immunization of dairy cattle against East Coast Fever (ECF) by the infection and treatment method (ITM) on smallholder farms from two sites in Kenya. Four alternative strategies of immunization in combination with different levels of acaricide use were compared with the current acaricide-based method of control. The economic impacts were estimated using simulated net present values, present values of ending net worth, internal rates of return, benefit–cost ratios, annual cash farm incomes, cash expenses, and net farm incomes. The results from the analysis indicate that ECF immunization strategies are financially and economically viable on smallholder farms. Based on the risk preference for risk averse producers, the most preferred strategy was to adopt ITM in combination with a 75% reduction in acaricide use. The results obtained provide a good indication of the relative orders of magnitude of the farm level financial and economic effects of ECF immunization by ITM. The whole farm simulation model used for the analysis has the advantage of incorporating the risks involved in farm production. Whole farm simulation offers a flexible method for assessing the financial and economic impacts of alternative disease control methods on smallholder farms.

1. Introduction

Cattle perform a wide variety of economic and social functions in smallholder farms in Kenya. These include food outputs such as milk and meat, crop inputs such as manure and animal traction, assets in the form of livestock capital, and social uses for feasts and ceremonies. The main types of cattle in Kenya are the indigenous Zebu cattle (*Bos indicus*), the purebred breeds (*Bos taurus*), and crosses between the two. Purebred and cross-bred cattle are referred to as grade cattle. Grade cattle are highly productive but more susceptible to tropical diseases such as East Coast Fever (ECF) than the lower producing Zebu cattle.

ECF is a disease of cattle caused by the parasite *Theileria parva* which is transmitted by ticks.

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SSDI 0169-5150(95)01169-2

The disease is a major constraint limiting livestock production and improvement in eastern, central, and southern Africa (International Laboratory Research for Animal Diseases, unpublished reports, 1990). Conventional control of ECF relies on regular use of chemical acaricides to control the tick, which acts as a vector of the disease. Annual costs of controlling ticks vary from Kenya Shillings (Kshs.) 40 to Kshs. 170 per animal (Lawrence and McCosker, 1981; Mukhebi et al., 1989). Infected animals can be treated using chemotherapeutic drugs if applied early in the disease. The treatment costs have been estimated to be as high as Kshs. 200–400 per treatment (Mutugi et al., 1988; Young et al., 1988; Young et al., 1989; Young et al., 1991).

An alternative ECF control method known as the infection and treatment method (ITM) (Radley, 1981; Morzaria et al., 1986) has proven to be efficacious and feasible both on research station and field trials. ITM is an immunization procedure whereby the animal is simultaneously infected by live *T. parva* parasites and treated using chemotherapeutic antibiotics. The resulting immune response generally protects animals against the disease for life.

Although ITM has been proven to be technically and economically viable on controlled field trials (Mukhebi et al., 1989; Mukhebi et al., 1990), its evaluation under farmer circumstances has received little attention. Economic viability of smallholder farms using ITM and existing technologies to control ECF have not been analyzed using methodologies which systematically consider the entire smallholder farm. The purpose of this article is to provide an ex-ante farm level financial and economic analysis of alternative ECF control methods for smallholder farms in two regions of Kenya, and to rank improved ECF disease control methods for risk averse smallholder farmers in terms of their potential for adoption.

2. Methods

The methodology selected for the present study was whole farm simulation. This method of analysis has been demonstrated to be useful in quantifying the economic benefits to farmers applying new technologies and alternative farming systems (US Congress, Office of Technology Assessment, 1986; Lemieux and Richardson, 1989; US Congress, Office of Technology Assessment, 1991; Yonkers, 1989). The Technology Impact Evaluation Simulator (TIES) was used for this analysis. The TIES model was selected because it is capable of simulating alternative livestock production and farming systems for smallholder farms in developing countries.

2.1. Description of TIES

TIES is a computerized simulation model which quantifies the economic impacts of alternative technologies on smallholder farms in developing countries. A detailed description of the TIES model is available in Richardson et al. (1991) (a technical description of the model and an operating manual are available from the authors). The model consists of accounting equations for the annual production, marketing, financial management, and household consumption aspects of a smallholder farm (Fig. 1). The model uses 1 year as its time step and simulates 10 years recursively by starting each year with the ending debt, asset, livestock herd, and household information for the previous year. The 10-year planning horizon is repeated 100 times using random prices and production values to generate estimates of the parameters for empirical probability distributions of key output variables, such as internal rate of return, benefit cost ratio, and net present value.

At the start of each year, TIES generates stochastic crop yields using specified probability distributions based on historical yield information and multiplies harvested hectares by the stochastic yields for the respective crop enterprises to calculate production (see Appendix A, Eq. (1)). Crop output is then available for household use, livestock feed, or sale (Eq. (2)). The cattle herd is specified by composition of different age/type cohorts and is simulated assuming a specified herd size (number of cows, oxen, and bulls) to be maintained over time (Eqs. (3)–(5)). Maintaining

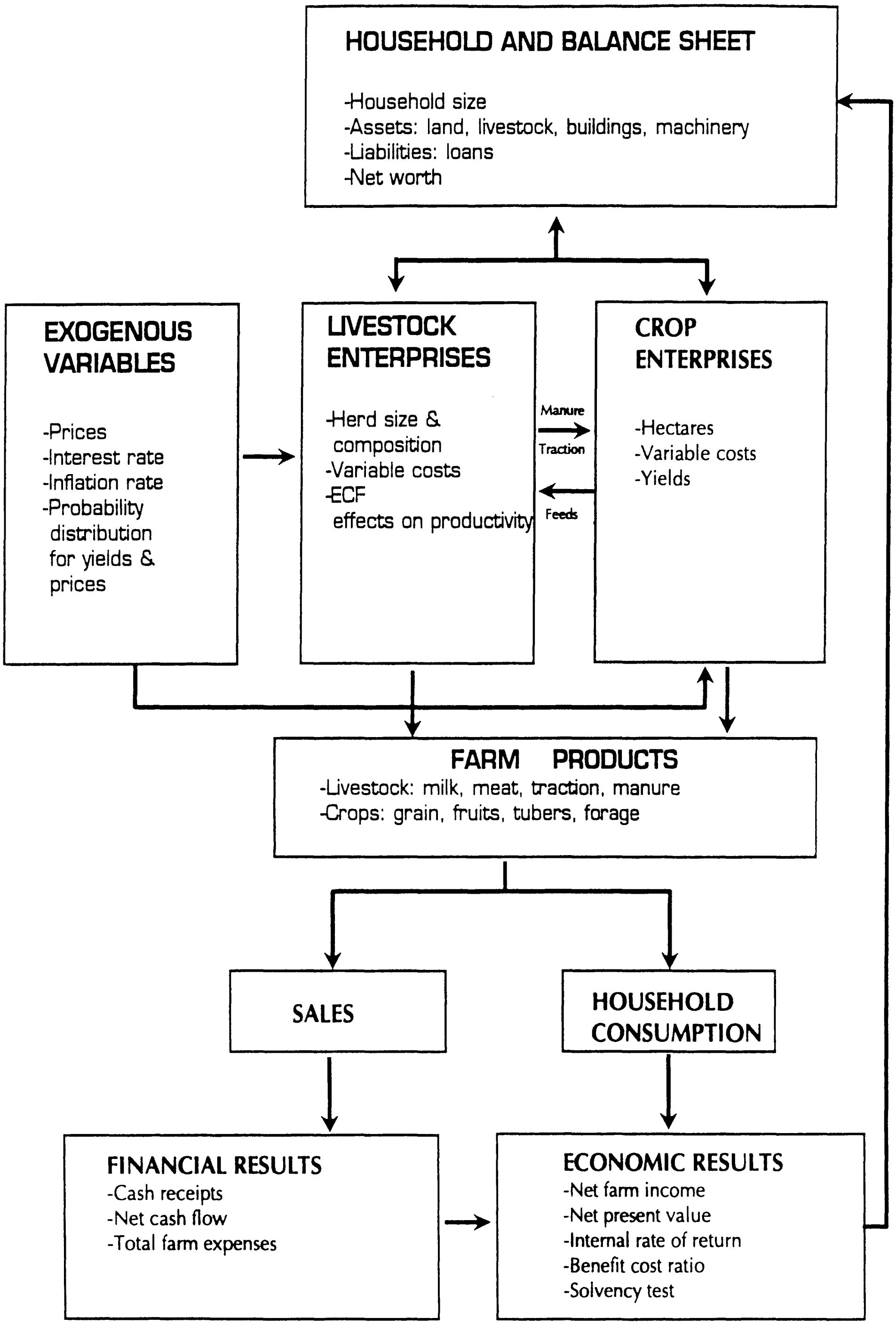

Fig. 1. Schematic diagram of TIES model.

a pre-specified herd size requires the model to account annually for raising male and female calves for both sale and replacement, and purchasing cows if insufficient replacements are available.

TIES calculates the number of female and male calves born each year based on the calving rate and the number of cows in the previous year. Calves that do not die are raised for replacements, sold, or consumed on the farm, depending on the desired herd replacement strategy and food needs of the family. The proportion of calves that die is calculated based on mortality rates for the specified technology and production practices on the farm. If a surplus of adult cows and oxen exists after normal culling, home consumption, and death losses, the surplus adult animals are sold. The fraction of animals that die, the fraction consumed on the farm, and the normal fraction sold are specified according to the producer's actual farm data and technology scenarios being analyzed. The fraction of cattle in each age group sold or culled is subject, of course, to the availability of cattle to meet the family's needs.

Livestock outputs (milk, meat, manure, and traction) are calculated based on the farm's current and projected productivity coefficients for the animals (Eq. (6)). The outputs are first used to meet household consumption needs and surpluses are sold. In the event that output for livestock products or crops is less than the quantity needed for the family or on the farm, the deficit is purchased. Household consumption of each crop is calculated from current family information and anticipated changes in the household. Livestock utilization of crop products is calculated for each type/age group of livestock, by crop enterprise (Eq. (7)). Surplus crop production and livestock products are sold at stochastic (randomly selected) prices and comprise the cash receipts for the farm (Eq. (8)).

Total annual farm expenses are calculated from variable costs incurred in crop and livestock production plus fixed costs for the farm (Eq. (9)). Variable costs of production for crops include all production expenses, harvesting, and marketing costs. Livestock variable costs include expenses such as: breeding; purchased forage and feed; disease treatment, immunization, acaricides, anthelmintics, and other health costs; and replacement costs. Livestock variable costs are calculated separately for cows, bulls, and oxen on a per head basis. Fixed cash costs, which include unallocated maintenance and permanent labor costs, are calculated for the whole farm.

Continuing the use of standard accounting equations, TIES calculates net cash farm income, updates cash flows, and the farm family's balance sheet (Eqs. (13)–(15)). After simulating the 10-year planning horizon, the model summarizes the financial and economic performance of the farm for each iteration using net present value (NPV), benefit/cost ratio (BCR), and internal rate of return (IRR) (Eqs. (10)–(12)).

At the end of the 10-year simulation period, the model then re-initializes all variables to their original input values and repeats the calculation process for the next iteration using another set of random yields, prices, and livestock production values. After simulating 100 iterations for the simulation period, TIES calculates summary statistics (mean, variance, coefficient of variation, minimum and maximum) for output variables such as IRR, NPV, BCR, cash receipts, cash expenses, net cash farm income, and net farm income.

2.2. Evaluating economic effects of ECF technology

Evaluation of the financial and economic effects of alternative ECF control strategies using TIES is a two step process. First, the model simulates the BASE farm using farm enterprise data under the current ECF control strategy (weekly dipping with acaricides) collected from the farmer and supplemented by secondary data sources. The data include crop and livestock enterprise inputs, outputs, and prices as well as costs of current ECF control based on acaricide application and chemotherapy (Nyangito, 1992). The second step is to stimulate the farm with appropriate changes for the new ECF control technology (ITM). This is accomplished by changing the relevant variables in the model that will be affected by different ITM strategies. The affected variables include the cost of ITM delivery, acaricide cost, ECF mortality rates in different cattle groups, and calving rate. Likely changes in the values for the technology-related variables following immunization are derived from results of previous field trials and from discussions with field experts on the disease (e.g. research scientists, veterinary practitioners and extension agents) (Nyangito, 1992).

The financial and economic viability of ITM strategies compared to the BASE control method can be evaluated using absolute mean values of the output variables generated by TIES, such as NPV, IRR, and BCR. However, mean values are not robust enough to always rank unequivocally the most preferred alternative while taking into consideration the risk preference of the decision maker. Such ranking is necessary to aid decision makers in selecting among the alternative control strategies based upon producer risk preference.

TIES generates cumulative empirical probability distributions of NPV which can be compared using stochastic dominance with respect to a function (SDWRF) criterion (Richardson et al., 1991) to rank alternative ECF control strategies. SDWRF is a method used to screen out inefficient, risky technology choices (i.e. ECF control strategies) that can be considered by a decision maker. The NPV distribution was chosen as the output variable for ranking the alternative ECF strategies. NPV is widely used as the criterion for selecting among alternative investments because it has the advantage of being consistent for all investments when compared to BCR and IRR criteria (Barry et al., 1988). The probability distributions were ranked under the assumption that farmers are risk averse. The risk aversion coefficient bounds used in the ranking were estimated at 0.00000–0.00001. These risk aversion coefficients were consistent with magnitudes of the NPV means, and sensitivity tests were conducted to assess robustness (Nyangito, 1992).

TIES also calculates confidence premiums for the NPV probability density functions across alternative technologies (i.e. ECF control strategies). The confidence premium is an estimated measure of the conviction held by the decision maker for a preferred strategy over the challenger, assuming all other things equal (Mjelde and Cochran, 1989). Confidence premiums can be thought of as shadow prices (marginal values or benefits). The confidence premium in this case reflects the marginal value or benefit to the farmer per additional animal immunized by a given alternative ECF control strategy over the dominated strategy.

2.3. Sources of data and study areas

The study used both primary and secondary data. Primary data were collected from farm surveys in the Uasin Gishu and Kilifi Districts of Kenya (Nyangito, 1992). The primary data were supplemented with secondary data from surveys developed by the International Laboratory for Research on Animal Diseases (ILRAD) and by Ministry of Livestock Development reports. These data included the costs of tick and tick-borne disease controls and the technical coefficients on cattle productivity associated with alternative ECF control strategies.

The Uasin Gishu District in the Rift Valley Province lies in the highland area of the country. The climatic conditions are cool and wet which makes the area suitable for keeping grade cattle. The Kilifi District in the Coast Province lies in the coastal area of the country. The climatic conditions are warm and humid. Although grade cattle are kept in the area, the climatic and environmental conditions are not as suitable for keeping grade cattle as in the Uasin Gishu District. The two areas were chosen for the study to provide a comparative analysis of the impacts of alternative ITM strategies on smallholder farms under different environments. The two areas are targeted for immunization of cattle against ECF by the Kenya Agricultural Research Institute (KARI).

2.4. Description of the case farms

The farms were selected from a random sample of 18 farms surveyed in the Kilifi District and a similar number of farms surveyed in the Uasin Gishu District (Nyangito, 1992). These were subsamples of larger samples of 77 farms in the Kilifi District (Mukhebi et al., 1991; Mukhebi et al.,

Table 1
Characteristic features of smallholder farms in Uasin Gishu and Kilifi districts

	Uasin Gishu District	Kilifi District
No. of hectares		
Total	3.8	3.0
Owned	3.8	3.0
Rented	0.0	0.0
Assets (1000 Kshs.)		
Total	397	124
Cattle	211	27
Other	186	97
Liabilities (total)	0.0	0.0
Cropland (ha)	2.0	1.8
Pastureland (ha)	1.8	1.2
Crops (ha)		
Maize	0.7	0.2
Potato	0.4	0.0
Pyrethrum	0.2	0.0
Maize–beans intercrop	0.1	0.0
Napier grass	0.6	1.0
Coconuts	0.0	0.2
Cashew	0.0	0.2
Citrus fruits	0.0	0.2
Livestock		
No. of cows	3.0	2.0
No. of heifers	2.0	2.0
No. of calves	1.0	1.0
Other livestock		
No. of sows	0.0	0.0
No. of ewes	1.0	0.0
No. of nannies	2.0	2.0

1992) and clusters of farms in the Uasin Gishu District (Curry et al., 1991) covered in farm socio-economic studies by ILRAD.

The characteristics of the case study farms used for this analysis are presented in Table 1. The Uasin Gishu farm had a land size of 3.8 ha compared with 3.0 ha for the Kilifi District farm. The Uasin Gishu farm had assets worth about three times as much as those of the Kilifi farm (estimated at Kshs. 397 000 and Kshs. 124 000, respectively). Cattle contributed a greater proportion of the assets for the farm in Uasin Gishu (53%) compared with the Kilifi farm (22%). Although the Uasin Gishu farm had only one more cow than the Kilifi farm, the value of cattle for the former farm was much higher than for the latter. Grade cattle kept in Uasin Gishu were closer in genotype to Taurine purebreds while those kept in Kilifi were closer to local Zebu breeds.

Both farms used acaricides to control tick-borne diseases. The estimated costs of acaricides were Kshs. 400 and Kshs. 274 per animal per year for the Uasin Gishu and Kilifi farms, respectively. The other costs incurred in cattle production were for feeds, helminth control, and other health items. Feed costs were a major cost component and were estimated at Kshs. 738 and Kshs. 922 per animal per year for the Uasin Gishu and Kilifi farms, respectively. The total variable costs incurred in cattle production were Kshs. 1343 and Kshs. 1380 per animal per year.

2.5. ECF control strategies analyzed

Five alternative strategies for controlling ECF were tested: (a) base farm with current ECF control method (BASE); (b) farm with ITM introduced and no change in acaricide use (ITM); (c) ITM introduced and a 50% reduction in acaricide use (ITM50); (d) ITM and a 75% reduction in acaricide use but no change in cattle mortality and productivity from (b) and (c) (ITM75-WC).

The five alternative strategies were analyzed by simulating the farm with changes in mortality rates and productivity effects on cattle associated with each strategy. Based on survey information, ECF mortality rates for calves (under 1 year old) under the BASE farms were estimated at 15% and 20% for Uasin Gishu and Kilifi farms, respectively, while the rate for mature cattle (over 1 year old) was estimated at 10% for both areas on the basis of available literature (De Leeuw and Ole Pasha, 1988 Mukhebi et al., 1992; Norval et al., 1988). The average liveweights estimated during the survey were 80 kg, 150 kg and 300 kg for calves, heifers, and mature cows, respectively, on both farms. However, the upper limit on body weights for the Uasin Gishu farm were higher than the Kilifi farm because the cattle breeds in the former were almost purebreds and the nutrition standards were better than in the latter

(Nyangito, 1992). The average annual milk yields per cow were 1680 kg and 1260 kg for the Uasin Gishu and Kilifi farms, respectively.

The introduction of ITM was assumed to reduce mortality rates and increase cattle productivity. Based on estimates by Morzaria et al. (1988), Young et al. (1991) and De Castro et al. (1985), the mortality rate was assumed to decrease by 80% to 3% and 4% for calves in Uasin Gishu and Kilifi farms, respectively, and to 2% for mature cattle in both areas. Increases in liveweight gains and milk production were derived based on estimates by Mukhebi et al. (1992). Liveweight gains were estimated at 10% and 5% for calves and immature cattle, respectively, while the increase in milk production was estimated at 25%. These estimates were assumed to prevail for strategies ITM, ITM50, and ITM75-NC. The increases in productivity for ITM75-WC were assumed to be lower than for the other ITM strategies by 5%. The lower productivity for ITM75-WC is attributed to high intensities of tick infestation resulting from the large reduction in acaricide use.

2.6. Macro-level assumptions

The simulation analysis of the alternative ECF control strategies used a 10-year planning horizon. Owing to the unavailability of a 10-year baseline of projected annual crop and livestock prices, interest rates, and rates of inflation for costs and assets, the study used constant real prices. Actual prices for the base year 1992 obtained from the farm survey were therefore held constant over the planning horizon. Annual interest rates used for long-term (more than 5 years), intermediate-term (2–5 years) and operating loans, and for cash balances averaged 12.0%, 13.0%, 14.0%, and 12.6%, respectively, during the period 1988–1991. These interest rates were assumed to prevail throughout the simulation period. The 1992 12.6% interest rate (paid by commercial banks on savings deposits) was used as the discount rate for calculating present values of future cash inflows and outflows and ending net worth.

3. Results

3.1. Uasin Gishu farm

The financial and economic performance of alternative ECF control strategies on the farm in the Uasin Gishu District are summarized in Table 2. The results indicate that all alternative ECF immunization strategies generated higher mean NPV, PVENW, IRR, BCR, annual cash receipts, and annual cash and net farm income than the BASE strategy. ITM75-NC generated the highest mean values for these variables, except for annual cash receipts which were the same as for ITM and ITM50. Based on mean values for NPV, PVENW, and IRR, the ITM75-NC was ranked first, followed by ITM50, ITM75-WC, and ITM. Ranking of the ECF control strategies, based on the means for the BCR yields ITM75-NC first, followed by ITM75-WC, ITM50, ITM, and the BASE.

The largest average NPV was generated by ITM75-NC and was estimated at Kshs. 408 000 with a standard deviation of Kshs. 26 000. The lowest average NPV was generated by the BASE and was estimated at Kshs. 321 000 with a standard deviation of Kshs. 23 000. The BASE had the highest coefficient of variation for NPV (7%), indicating the BASE was the most risky ECF control strategy in relative terms.

The average IRR for all five ECF control strategies was higher than the assumed 12.6% discount rate (Table 2). This indicates that the rate of return from investing in ECF control for all the alternatives was higher than the opportunity cost of investing elsewhere. The highest average BCR was observed for the ITM75-NC control method (5.26), while the lowest was generated by the BASE (3.99). Both the IRR and BCR values generated by the new ECF control strategies indicate that it is economically feasible to invest in any of the methods when compared with the BASE.

3.2. Kilifi farm

Simulation results for the Kilifi farm are summarized in Table 3. The results are similar to

Table 2
Summary of selected output variables from simulated alternative ECF control methods for smallholder grade cattle farm, Uasin Gishu District

	BASE [a]	ITM [b]	ITM50 [c]	ITM75-NC [d]	ITM75-WC [e]
Probability					
IRR > 12.6% (%) [f]	100.0	100.0	100.0	100.0	100.0
Probability					
B/C ≥ 1.0 (%) [g]	100.0	100.0	100.0	100.0	100.0
Net present value [h] (1000 Kshs.)					
Mean	321	391	402	408	399
SD	23	26	26	26	25
Present value ending net worth (PVENW) [i] (1000 Kshs.)					
Mean	1348	1521	1551	1565	1542
SD	63	69	69	69	68
Internal rate of return (%) [j]					
Mean	18.92	22.05	22.52	22.76	22.39
SD	1.13	1.19	1.19	1.19	1.17
Benefit/cost ratio [k]					
Mean	3.99	4.88	5.13	5.26	5.17
SD	0.21	0.24	0.25	0.25	0.25
Average annual cash receipts [l] (1000 Kshs.)					
Mean	45	51	51	51	50
SD	2	3	3	3	2
Average annual cash expenses [m] (1000 Kshs.)					
Mean	37	36	35	34	34
SD	0.18	0.18	0.18	0.18	0.18
Average annual net cash farm income [n] (1000 Kshs.)					
Mean	9	15	17	17	16
SD	2	2	2	2	2
Average annual net farm income [p] (1000 Kshs.)					
Mean	26	33	34	35	34
SD	2	3	3	3	3

[a] Current control method.
[b] ITM introduced with no reduction in current level of acaricide use.
[c] ITM and a 50% reduction in acaricide use.
[d] ITM and a 75% reduction in acaricide use but no change in productivity from (b) and (c).
[e] ITM and a 75% reduction in acaricide use and changes in productivity from (b), (c), and (d).
[f] Chance that the farm will generate an internal rate of return greater than the discount rate, 12.6%.
[g] Chance that the farm will generate a benefit/cost ratio greater than or equal to 1.
[h] After-tax net return to initial equity, assuming an after-tax discount rate of 0.126.
[i] Discounted value of farm's net worth in the last year simulated.
[j] Calculated rate of return to capital invested in the farm operation.
[k] The ratio of present value for annual returns divided by the present value of annual costs.
[l] Total cash receipts from crops, cattle, and other farm-related activities.
[m] Total cash costs for crop and livestock production, including interest costs and fixed cash costs; excludes depreciation.
[n] Total cash receipts minus total cash expenses; excludes family living expenses, principal payments, and costs to replace capital assets.
[p] Net cash farm income minus consumptive use depreciation for machinery and minus family consumption.

those for the Uasin Gishu farm. All immunization strategies (ITM, ITM50, ITM75-NC, and ITM75-WC) generated higher mean NPV, PVENW, IRR, BCR, average annual cash receipts, and average annual cash and net farm income than the BASE. Of the immunization strategies, the ITM75-NC generated the largest mean NPV, PVENW, IRR, BCR, average annual cash receipts, and average annual net cash and net farm incomes. Ranking the immunization strategies based on means of these variables indicates that ITM75-NC would be followed by ITM50. However, the results do not appear to show any real differences between the simulated mean values of these variables for ITM and ITM75-WC.

The largest average IRR was observed for the ITM75-NC strategy (34.37%) while the lowest IRR (23.46%) was observed for the BASE. The average BCR ranged from 3.2 for the BASE

Table 3
Summary of selected output variables from simulated alternative ECF control methods for smallholder grade cattle farm, Kilifi District

	BASE [a]	ITM [b]	ITM50 [c]	ITM75-NC [d]	ITM75-WC [e]
Probability					
IRR > 12.6% (%) [f]	100.0	100.0	100.0	100.0	100.0
Probability					
BCR ≥ 1.0 (%) [g]	100.0	100.0	100.0	100.0	100.0
Net present value [h] (1000 Kshs.)					
Mean	87	146	152	155	147
SD	9	12	12	12	12
Present value ending net worth (PVENW) [i] (1000 Kshs.)					
Mean	263	420	433	442	419
SD	24	31	31	31	29
Internal rate of return (%) [j]					
Mean	23.46	32.90	33.87	34.37	33.06
SD	1.93	2.17	2.18	2.19	2.11
Benefit/cost ratio [k]					
Mean	3.20	4.68	5.00	5.18	4.96
SD	0.24	0.29	0.31	0.32	0.30
Average annual cash receipts [l] (1000 Kshs.)					
Mean	28	34	34	34	33
SD	0.87	1	1	1	1
Average annual cash expenses [m] (1000 Kshs.)					
Mean	13	13	12	12	12
SD	0.04	0.04	0.04	0.04	0.04
Average annual net cash farm income [n] (1000 Kshs.)					
Mean	14	21	21	22	21
SD	0.87	1	1	1	1
Average annual net farm income [p] (1000 Kshs.)					
Mean	19	25	26	26	25
SD	1	1	1	1	1

For explanation of footnotes see Table 2.

Table 4
SDWRF rankings of NPVs for alternative ECF control strategies for smallholder farms

Ranking	District	
	Kalifi	Uasin Gishu
Most preferred method	ITM75-NC	ITM75-NC
2nd most preferred method	ITM50	ITM50
3rd most preferred method	ITM75-WC	ITM75-WC
4th most preferred method	ITM	ITM
Least preferred method	BASE	BASE

method to 5.18 for ITM75-NC. These results indicate that the ECF immunization strategies were economically superior to the BASE.

3.3. Stochastic dominance ranking

The stochastic dominance with respect to a function (SDWRF) rankings of the alternative strategies for the small Uasin Gishu District and Kilifi District farms are summarized in Table 4. The results indicate that ITM75-NC was the most preferred alternative ECF control strategy (most efficient set) for both farms. ITM50 was the second most preferred strategy for both farms, followed by ITM75-WC and ITM. The BASE was the least preferred ECF control strategy. These results implied that risk averse producers in both districts ranked immunization strategies in a similar manner.

Table 5 shows the confidence premiums associated with the SDWRF rankings of the NPV probability density functions. The confidence premium per animal per year between ITM75-NC and ITM50 is only Kshs. 64 for the Kilifi farm and Kshs. 95 for the Uasin Gishu farm. These results imply that the Kilifi producer would be willing to shift from the ITM75-NC control strategy to the ITM50 for Kshs. 64 per animal per year while the Uasin Gishu producer would be willing to shift for Kshs. 95 per animal per year. The largest confidence premiums were between the BASE and the ITM75-NC control strategy, indicating that the producers would gain the most by shifting from the BASE to ITM75-NC. For the Uasin Gishu farm, shifting from the BASE to ITM75-NC is worth Kshs. 1976 per animal per year, while the same shift is worth Kshs. 1771 per animal per year on the Kilifi farm. The second

Table 5
Mean annual confidence premiums (Kshs. year^{-1} per animal) associated with the SDWRF rankings of the NPV probability density functions

Kilifi			Uasin Gishu		
Dominant	Challenger	Kshs.	Dominant	Challenger	Kshs.
ITM75-NC	ITM50	64	ITM75-NC	ITM50	95
ITM75-NC	ITM75-WC	235	ITM75-NC	ITM75-WC	245
ITM75-NC	ITM	408	ITM75-NC	ITM	528
ITM75-NC	BASE	1771	ITM75-NC	BASE	1976
ITM50	ITM75-WC	106	ITM50	ITM75-NC	56
ITM50	ITM	215	ITM50	ITM	245
ITM50	BASE	1514	ITM50	BASE	1560
ITM75-WC	ITM	2	ITM	ITM75-WC	132
ITM75-WC	BASE	1195	ITM75-WC	BASE	1430
ITM	BASE	1130	ITM	BASE	1166

largest confidence premiums were observed for the switch from the BASE to the ITM50 control (Kshs. 1514 and Kshs. 1560 for the Kilifi and Uasin Gishu farms, respectively).

3.4. Sensitivity analyses

Sensitivity analyses were done on mortality rates, milk production, immunization costs, and acaricide costs to estimate how much these variables could change before a risk averse decision maker would prefer ITM50 over the ITM75-NC strategy. The results of the sensitivity analyses are summarized in Table 6. Mortality rates would have to increase by 125% from 3% and 2% to 6.8% and 4.5% for calves and immature cattle for the Uasin Gishu farm to prefer ITM50. For the Kilifi farm, mortality rates would have to increase by 90% from 4% and 2% to 5.7% and 3.8% for calves and immature cattle, respectively, before ITM50 is preferred. At these mortality rate changes, ITM75-NC still dominated ITM, ITM75-WC, and the BASE.

Milk production would have to decrease 10% from the initial levels used for ITM75-NC before the farms would prefer ITM50 (Table 6). The change in ranking for ITM75-NC with only a 10% change in milk production implied that the economic and financial soundness of immunization was very sensitive to milk production.

The cost of immunizing cattle by the ITM strategies was estimated at Kshs. 54.40 per animal per year (Table 6). This cost was estimated by Mukhebi et al. (1991) based on the initial trials of immunizing cattle in the Kilifi District. Sensitivity results for the Uasin Gishu farm indicated that the cost of ITM had to be increased to Kshs. 245 per animal per year (350%) before ITM75-NC was dominated by ITM50. The sensitivity results for the Kilifi farm indicate that ITM cost had to increase 350% before ITM75-NC was dominated by ITM50.

The reduction in the cost of acaricide to control ECF is one of the most important direct benefits to be realized from immunization of cattle. The percentage increase required in acaricide costs for ITM75-NC to be dominated by ITM50 were 100% for both farms when other parameters are held constant (Table 6). This means that acaricide costs associated with an initial 75% reduction have to be increased 100% before the ITM50 strategy dominates ITM75-NC.

Sensitivity analysis results demonstrate that the rankings of ITM75-NC as the most preferred ECF control strategy on both the Uasin Gishu and Kilifi farms is robust for all variables except for changes in milk yield.

4. Conclusions

The present study has demonstrated that whole farm simulation offers a flexible method for assessing the financial and economic impacts of ECF immunization for smallholder farms. Assessment was accomplished using the TIES model

Table 6
Sensitivity analysis of mortality rates, milk production, and treatment costs on preference for alternative ECF control strategies for smallholder farms in the Kilifi and Uasin Gishu districts [a]

	Kilifi		Uasin Gishu	
	Prefer ITM75-NC	Prefer ITM50	Prefer ITM75-NC	PreferITM50
Mortality rates (%)				
Calves	4.0	5.7	3.0	6.8
Cows	2.0	3.8	2.0	4.5
Milk production (kg year^{-1} per cow)	1575	1418	2100	1890
Costs of immunization (Kshs. per cow year^{-1})	54.4	245.0	54.4	245.0
Acaricide costs (Kshs. per cow year^{-1})	68.5	137.0	100.0	200.0

[a] For both farms, ITM75-NC was initially the most preferred ECF control strategy. ITM50 was initially the second most preferred strategy given the initial (ITM75-NC) values for mortality, milk per cow, immunization, and acaricide costs. Preference for ITM50 switches when the values for the ITM75-NC column change, as indicated in the ITM50 column.

which accounts for the stochastic nature of yields, prices, and livestock production. The TIES model appears to be a useful tool that could assist researchers in developing countries to assess new or alternative agricultural technologies.

The ability to estimate probability distributions for output variables such as NPV, BCR, and IRR with a generalized farm simulation model allows alternative technologies to be ranked using the stochastic dominance criteria and to estimate confidence premiums associated with the most preferred strategy. An advantage to this procedure is that it can rank alternatives unequivocally as opposed to using mean values for NPV, IRR, and BCR which often lead to inconsistent rankings.

Results demonstrated that strategies for ECF control based on ITM were financially and economically more profitable than the current acaricide-based control methods on both the Uasin Gishu and Kilifi farms. The more ITM allowed for a reduction in the cost of using acaricides, the higher the level of profitability achieved. The most preferred control strategy was the adoption of ITM with a 75% reduction in acaricide use. However, this strategy is sensitive to changes in cattle productivity, particularly milk production, even though it was shown to be stable over a wide range of cattle mortality rates, immunization costs, and acaricide costs. This implies that if higher reductions in acaricide use following immunization by ITM lead to a higher incidence rate of ECF or other tick-borne disease such that milk yield dropped, then ITM with lower reductions in acaricide use would be the more preferable control strategy.

Results have further shown that there is a trade-off between the levels of acaricide use and cattle productivity. The higher levels of acaricide use generate higher costs but result in higher productivity in milk production and liveweight gains which lead to higher benefits. However, the lower use of acaricide results in lower costs but generates higher losses in milk and live weight gains which lead to lower benefits. To determine the point of optimizing benefits would require an accurate estimation of the losses from productivity in milk and live weight gains associated with different levels of acaricide use with the adoption of ITM. This information is currently lacking and should be the focus of future technical research.

Acknowledgements

This paper is a result of collaborative research work among the Department of Agricultural Economics of the University of Nairobi, the Socioeconomics Program of the International Laboratory for Research on Animal Diseases, Nairobi, Kenya, the Kenya Agricultural Research Institute, Nairobi, Kenya, the Agricultural and Food Policy Center of the Texas Agricultural Experiment Station and Texas A&M University, USA, and the Department of Agricultural and Rural Sociology, The University of Tennessee, Knoxville, USA. The authors would like to thank Dr. C. Nderitu, Director, Kenya Agricultural Research Institute, and Dr. D. P. Kariuki, National Veterinary Research Centre, Muguga, of the Kenya Agricultural Research Institute, for permission and support to undertake field farm surveys in the Uasin Gishu and Kilifi Districts of Kenya.

Appendix A. Examples of equations in the TIES model

A.1. Crops sub-component

A.1.1. Yields

$$Qc_{it} = a_{it} Y_{it} \tag{1}$$

where Qc_{it} is total output of crop i harvested at period t; a_{it} is area (ha) of crop i harvested at period t; Y_{it} is yield of crop i per hectare at period t; $i = 1,2,3,\ldots,n$; $t = 1,2,3,\ldots,10$.

A.1.2. Utilization

$$Sc_{it} = Qc_{it} - Fc_{it} - Lc_{it} \tag{2}$$

where Sc_{it} is the surplus quantity of crop i to sell at period t; FC_{it} is total family consumption of crop i at period t; LC_{it} is total consumption of crop i fed to livestock at period t.

If $Qc_{it} = FC_{it} + Lc_{it}$, there is no surplus for sale, and, if Qc_{it} is less than $FC_{it} + LC_{it}$, there is a deficit of crop j to be purchased to meet family and livestock needs.

A.2. Livestock sub-component

A.2.1. Herd dynamics (e.g. cattle)

A.2.1.1. Herd size.

$$\mathrm{TCH}_t = \mathrm{TCW}_t + \mathrm{TCF}_t + \mathrm{THF}_t + \mathrm{TMB}_t + \mathrm{TOX}_t \quad (3)$$

where TCH_t is the total number of cattle in the herd at period t; TCW_t is the total number of cows in the herd at period t; TCF_t is the total number of calves in the herd at period t; THF_t is the total number of heifers in the herd at period t; TMB_t is the total number of mature bulls in the herd at period t; TOX_t is the total number of oxen in the herd at period t.

A.2.1.2. Cattle accounting (e.g. cows).

$$\mathrm{TCW}_{et} = \mathrm{TCW}_{st} - \mathrm{DCW}_t - \mathrm{CCW}_t + \mathrm{BCW}_t - \mathrm{SCW}_t + \mathrm{RHF}_{et} - \mathrm{ECW}_t \quad (4)$$

where TCW_{et} is the total number of cows at the end of year t; TCW_{st} is total cows at start of year t; DCW_t is the number of cows which died during year t; CCW_t is the number of cows culled during year t; BCW_t is the number of cows bought during year t; SCW_t is the number of cows sold during year t; RHF_{et} is the number of replacement heifers entering the herd at the end of year t; ECW_t is the number of cows consumed by the household during year t;

A.2.1.3. Replacement strategy at the start of the year (e.g. cows).

$$\mathrm{RCW}_{st} = \mathrm{DCW}_{t-1} + \mathrm{CCW}_{t-1} + \mathrm{ECW}_{t-1} + \mathrm{HCW}_t \quad (5)$$

where RCW_{st} is the number of cows required for replacement at start of year t; DCW_{t-1} is the number of cows which died the previous year $(t-1)$; CCW_{t-1} is the number of cows culled the previous year; ECW_{t-1} is the number of cows consumed by the household during the previous year; HCW_t is the number of cows desired for change in cow herd in year t.

Number of cows sold or bought

If $\mathrm{RCW}_{st} > \mathrm{RHF}_{et}$, a deficit of cows exists, then buy cows (BCW_t).

If $\mathrm{RCW}_{st} < \mathrm{RHF}_{et}$, a surplus exists, then sell cows (SCW_t).

A.2.2. Livestock yields

$$\mathrm{Qlc}_{jt} = b_{jt} K_{jt} \quad (6)$$

where Qlc_{jt} is the total output of product for livestock j (e.g. milk) at period t; b_{jt} is the number of livestock type j (e.g. dairy cows) at period t; K_{jt} is the yield of product from livestock j (e.g. milk yield per cow) at period t.

A.2.3. Utilization of livestock products

$$\mathrm{Slc}_{jt} = \mathrm{Qlc}_{jt} - \mathrm{Flc}_{jt} \quad (7)$$

where Slc_{jt} is surplus of livestock product j (e.g. milk) for sale at period t; Qlc_{jt} is as defined above; Flc_{jt} is the total quantity of livestock product j used by the farm family at period t; $j = 1,2,3,\ldots,n$.

A.3. Financial results sub-component

A.3.1. Farm receipts

$$TR_t = \sum_{i=1}^{i} Sc_{it} P_{it} + \sum_{j=1}^{n} \mathrm{Slc}_{jt} P_{jt} \quad (8)$$

where TR_t is total receipts at period t; P_{it} is the price of crop i at period t; P_{jt} is the price of livestock product j at period t.

A.3.2. Farm expenses

$$TC_t = FC_t + \sum_{i=1}^{n} \mathrm{VCc}_{it} + \sum_{j=1}^{n} \mathrm{VClc}_{jt} \quad (9)$$

where TC_t is total costs at period t; FC_t is total fixed costs for the farm at period t; VCc_{it} is total variable costs for crop i at period t; VClc_{jt} is total variable costs for livestock type j at period t.

A.4. Economic results sub-component

A.4.1. Net present value (NPV)

$$\mathrm{NPV} = -\mathrm{INV} + \frac{P_1}{(1+i)} + \frac{P_2}{(1+i)^2} + \cdots + \frac{P_N}{(1+i)^N} + \frac{V_N}{(1+i)^N} \quad (10)$$

where INV is initial investment costs (total farm costs); P_t is the annual net cash flow at period t ($t = 1,2,3,\ldots,n$); V_N is salvage or terminal value at end of the planning horizon; N is the length of the planning horizon; i is the interest or discount rate.

A.4.2. Internal rate of return (IRR)

$$0 = -\mathrm{INV} + \frac{P_1}{(1+i)} + \frac{P_2}{(1+i)^2} + \cdots + \frac{P_N}{(1+i)^N} + \frac{V_N}{(1+i)^N} \quad (11)$$

A.4.3. Benefit / cost ratio (BCR)

$$\mathrm{BCR} = \frac{\sum_{t=1}^{t} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t} \frac{C_t}{(1+i)^t}} \quad (12)$$

where B_t represents the returns in year t and C_t represents the costs in year t.

A.5. Household and balance sheet sub-component

A.5.1. Assets

$$TA_t = \mathrm{TVL}_t + \mathrm{TVLc}_t + \mathrm{TVB}_t + \mathrm{TVM}_t + \mathrm{TVC}_t \quad (13)$$

where TA_t is total assets at period t; TVL_t is total value of land at period t; TVLc_t is total value of livestock at period t; TVB_t is total value of buildings at period t; TVM_t is total value of machinery at period t; TVC_t is total value of crops at period t.

A.5.2. Liabilities

$$TL_t = \mathrm{TOL}_t + \mathrm{TIL}_t + \mathrm{TLL}_t \quad (14)$$

where TL_t is total liabilities at period t; TOL_t is total operating loans at period t; TIL_t is total intermediate-term loans at period t; TLL_t is total long-term loans at period t.

A.5.3. Net worth

$$NW_t = TA_t - TL_t \quad (15)$$

where NW_t is net worth at period t.

Note that a wide range of identities and accounting equations of the types given in this appendix, for example, are used to simulate various annual production, marketing, household consumption, and financial management aspects of the farm.

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