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Bio-Economic Model to Support Breeding of Indigenous Chicken in Different Production Systems

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Abstract: A deterministic bio-economic model was developed to support breeding of indigenous chicken and used to evaluate biological and economic variables that characterise indigenous chicken (*Gallus domesticus*) production systems in Kenya. The systems were defined on the basis of the feeding regime, level of confinement and healthcare provided and included; confined full ration system, where the chicken are confined all the time and provided with commercial feed and proper healthcare; semi-intensive system, where the chicken are confined part of the time and given crop residues and kitchen waste, with no healthcare; and free range system, where the chicken are left to roam around the homestead picking whatever feed resource they get and without healthcare. The input parameters are divided into four categories: biological variables which include animal traits, managemental variables, nutritional variables and economic variables. These parameters assume typical indigenous chicken production in Kenya. However, the input parameters may be adjusted to suit specific situations and also assess the biological and economic performance of various production systems of other domestic avian species. The model's ability to simulate live weight changes, feed intake of various chicken categories, revenues, cost and profitability of the three production systems is illustrated. The bio-economic models can be used to develop breeding goals and estimate economic values for the genetic improvement of indigenous chicken.

Key words: Indigenous chickens, production systems, bio-economic model, Kenya

Introduction

Indigenous chickens (*Gallus domesticus)* have been kept in Africa for many generations in subsistence systems. They currently constitute about 80% of the continent's poultry flock (Gueye, 1998) and 73% of the chickens in Kenya. However, management interventions are limited or non-existent under most of these systems (Tadelle *et al.*, 2000). When compared to commercial layers and broilers, the indigenous chickens produce fewer eggs and have smaller bodies respectively (Ebangi and Ibe, 1994; Safalaoh, 2001). It has been shown that the indigenous chickens tend to have lower feed efficiency (King'ori *et al.*, 2003; Tadelle *et al.*, 2003b). The economic strength of the indigenous chickens however, lies in the low cost of production when compared to the value of the outputs.

In Kenya, attempts at genetic improvement of the indigenous chickens were made through the National Poultry Development Programme (NPDP), which was launched in 1976. The programme concentrated on the exchange of exotic breeds of chickens with the local types with the general aim of improving egg production and body weight (Nyange, 1995). The programme did not succeed because the commercial birds could not survive in the harsh environment; there was lack of a continuous supply of the exotic breeding stock and the inability to select the indigenous chickens at the farm level, probably due to lack of breeding goals (Nyange, 1995). Breeding goals are linear combinations of traits that have an influence on the profitability of a given domestic species, weighted with their respective economic values. It has been argued that when emphasis is put on the wrong traits or when important traits are left out of the breeding goal, genetic change is likely to be in the wrong direction or probably to be worse than none at all (Ponzoni, 1984).

For Kenya to effectively utilise and conserve indigenous chicken genetic resources available there is need to define breeding goals for the indigenous chicken production systems. The process of defining breeding goals involves specification of the production systems, identification of sources of income and expenses and biological traits influencing revenues and costs (Charfeddine, 2000). Modelling and data simulation are used in the process of defining breeding goals since most biological processes are costly or time consuming to study. In addition, models are useful in predicting the effects of planned interventions beforehand (Muir, 1997; Kitalyi, 1998) and have the capacity to capture the relationships between animal traits, revenues and costs. Therefore, it is important to model the variable indigenous chicken production systems taking into account the local circumstances since these will influence the level of utilisation of these genetic resources. The aim of this study was to develop a bio-economic model to support breeding of indigenous chicken and use it to evaluate biological and economic variables that characterise indigenous chicken production systems in Kenya.

Materials and Methods

In Africa, a number of indigenous chicken production systems have been identified with variable management regimes (Gueye, 1998; Tadelle *et al.*, 2003b). Most of these systems are subsistent but some products (eggs or live animals) are sold to supplement family income while others are given out as gifts (Tadelle *et al.*, 2003b). Subsistence production systems supply an estimated 80% of the rural population with food (Amer *et al.*, 1998). Under these systems, management interventions are usually limited (Gueye, 1998). These systems, however, are expected to be relevant for livestock production in Africa for the foreseeable future, mainly due to competition for grains between livestock and man (Kristensen and Pedersen, 2003).

The indigenous chickens under subsistence systems have not only shown a remarkable ability to perform, albeit poorly, under constant disease and parasite challenge, but also to sustain their populations through natural incubation (Kitalyi, 1998). Most households combine all production activities in one set-up, i.e., they are not divided into distinct stages with different tiers. The chickens breed within the homestead, eggs are laid and incubated by broody hens, and chicks grow as they run around with the dam in search of feed resources (Gondwe and Wollny, 2002).

General descriptions of indigenous chicken production systems: Typically, based on types and levels of inputs and the various outputs, three indigenous chicken production systems can be identified:

- Free range system (FRS) or scavenging system (Kitalyi, 1998), where no feed is supplied at all. Both the chicks and the mature chicken are left to forage within the homestead. About 95% of the indigenous chickens are raised under the FRS by rural smallholder farmers (Tadelle *et al.*, 2003a).
- Semi-scavenging system (SIS) or semi-intensive system (Gunaratne, 1998), where the chickens are partly confined, especially in relation to the prevailing activities in arable agriculture, e.g., when crops are at a stage where foraging chickens could destroy them. Chickens are confined to avoid conflicts, but are provided with crop residues, grains and kitchen wastes to supplement their daily feed requirements. The flock is not vaccinated but given ethno-veterinary attention (Gueye, 1998).
- Confined full-ration system (CFRS) or intensive system (Gunaratne, 1998), where the flock is confined all the time and supplied with a balanced diet. Vaccination against endemic diseases is common under this system. This system is not common in most field situations because of the inputs required (Kitalyi, 1998; Maphosa *et al.*, 2004). It was included in this study since this would give an idea of the viability of the production system when unimproved indigenous chicken genetic resources are used. In addition, the relative economic importance of each trait is needed to ensure that genetic improvement is proportional to the overall objective of the production system. Improvement in genetic potential of the indigenous chicken should be accompanied by a concomitant improvement in the standard of management.

In SIS, wet seasons tend to be the times of maximum crop production activity and therefore will usually be the period of greatest confinement. During the dry seasons, the chickens are left to roam the homesteads picking crop residues and kitchen refuse. It has, however, been shown that inadequate amounts of critical minerals (Calcium and Phosphorus) are obtained from the foraging activities (Gunaratne, 1998). In FRS and SIS, indigenous chickens have limited foraging ranges, which keeps the feed resource base fixed. Consequently, the fixed feed resource base results in a fixed carrying capacity and any extra chicken above the carrying capacity will lead to a reduction in average productivity (McArthur, 1987).

The three systems were modelled taking into account the production circumstances since these influenced their biological and economic performance. Generally, in all systems, the hens incubate the eggs naturally and each hen sits on twelve to fifteen eggs at a time (Roberts, 1995). In this study, it was assumed that hens sit on fifteen eggs during brooding and that they stay with the chicks until they are three months old. This means the hen spends a total of 112 days (including the incubation period of 22 days) for every batch of chicks raised. The average weight of indigenous chickens at 147 days of age (21 wks) has been reported to be 1.5 kg for cockerels and 1.1 kg for pullets (Chemjor, 1998; Birech, 2003). After the grower stage, the excess cockerels are finished and sold off for meat at a uniform age of 20 weeks (Reports of European Commission, 1999). Maturing cockerels are recruited to replace cocks culled-for-age or dead ones through exchange of cockerels with other farmers. Pullets replace hens culled for age, low productivity or those that die during the year. In all systems, the hatching weight was set at 30.7g. In CFRS, from 0-6 weeks, the chicks are on chick starter mash *ad libitum*. From 7 weeks of age onwards,

Table 1: Biological, managemental and nutritional variables in indigenous chicken production systems

Variables	Abbreviation	Production system[1]		
		CFRS	SIS	FRS
Biological variables				
Age at first egg (days)	AFE	168	168	168
Asymptotic live weight in females (kg)	ALW_F	1.64	1.70	1.35
Asymptotic live weight in males (kg)	ALW_M	1.96	2.20	1.99
Chick survival rate (%)	CSR	85	60	50
Clutches/yr	Ncl	3	3	3
Egg weight (g)	EW	44	44	44
Eggs/clutch	Necl	50	33	20
Fertility (%)	FRT	91.6	91.6	91.6
Grower survival rate (%)	GSR	90	70	55
Growth potential attained (%)	gp	84.5	75	74.5
Hatchability (%)	HTC	83	83	83
Hatching weight (g)	HW	30.7	30.7	30.7
Layer survival rate (%)	LSR	95	85	70
Laying percent (%)	lpc	75	75	75
Productive life time (days)	PLT	730	730	730
Managemental variables				
Mothering period/ batch of chicks (days)	brd	112	112	112
Sale age of surplus birds (days)	SAg	147	147	147
Nutritional variables				
Metabolisable energy content in chick mash (kCal/kg DM)	enc_C	2784	2784	2417
Metabolisable energy content in growers' mash (kCal/kg DM)	enc_G	2920		2417
Metabolisable energy content in layers' mash (kCal/kg DM)	enc_L	2500	2417	
Metabolisable energy content in scavenged feed (kCal/kg DM)	enc_R	-	2417	2417

[1] CFRS = confined full ration system; FRS = free range system; SIS = semi-intensive system

they are on growers' mash *ad libitum*. Table 1 presents the biological, managemental and nutritional variables for the three production systems. The biological and managemental variables are based on studies in the tropics (Trail, 1961; Wickramaratne *et al.*, 1993; Gueye, 1998; Kitalyi, 1998; Mopate and Lony, 1998; MALDM, 2000; Tadelle *et al.*, 2003a). To simplify the calculations, some of the parameters (e.g. laying % and number of settings) were assumed to be the same for all systems, although this may not always be true because management and production may differ from one system to another.

Flock dynamics: Defining the flock dynamics aids in identifying age and numerical distribution of the flock. The flock dynamics of indigenous chickens in FRS (base situation) are shown in Fig. 1. The flock dynamics also apply for the other systems (SIS and CFRS) but with modifications on the parameters used in Table 1. The parameters used are based on flock averages. The number of chickens in a given flock can therefore easily be adjusted. The composition by sex of the chicks at day old was assumed to be 1:1. Various workers have reported a variety of mating ratios for the village production systems (Mwalusanya, 1998; Mopate and Lony, 1998; Kaudia and Kitalyi, 2002). For this study, a mating ratio of 1 cock to 5 hens was assumed for all production systems. The replacement policy was such that 50% of mature birds (old stock) were culled each year (MALDM, 2000). Excess cockerels and pullets were sold off when they reached sexual maturity. A pullet coming into lay replaced an old hen. The unimproved hen is able to lay 20-60, 30-100 and 80-150 eggs a year under the FRS, SIS and CFRS, respectively and usually in three clutches (Sonaiya *et al.*, 1999). Using proportions of chickens participating in various activities in the course of the year, the amounts and types of products generated from the family flock were computed.

Model description: The process of model development involved the description of outputs and inputs. Data deficiencies were apparent in village chicken production systems because of their subsistence nature. However, use of available data was maximized in the design of the current model. All outputs were valued at market levels. It was assumed that the expression of a trait follows the infinitesimal model (Bulmer, 1971). This means that additive genetic effects are entirely responsible for observed phenotypes (Muir, 1997). For simplicity, it was also assumed that there was no variation in the efficiency of feed utilisation among the birds.

The model incorporates the biological traits that are to be genetically improved. The biological traits that

Table 2: Biological traits influencing revenues and costs in indigenous chicken

Trait	Unit	Abbreviation
Age at first egg	days	AFE
Chick survival rate	%	CSR
Feed intake of laying hens	"	CFI_{hens}
Feed intake to sale age (cockerels)	kg DM	CFI_c
Feed intake to sale age (pullets)	kg DM	CFI_p
Fertility	"	FRT
Grower survival rate	"	GSR
Hatchability	%	HTC
Hatching weight	g	HW
Layer survival rate	"	LSR
Live weight of cockerels at 21 weeks	kg	LW_C
Mature live weight of cocks	kg	LW_M
Mature live weight of hens	kg	LW_F
Live weight of pullets at 21 weeks	"	LW_P
Number of eggs per clutch	-	Necl
Productive lifetime	days	PLT

influence revenues and costs for various categories of chickens are shown in Table 2. No carcass traits were included because, first, a large percentage of the indigenous chickens are sold live to the consumers, and secondly, the consumers have not shown discrimination between carcasses of different indigenous chickens. Indigenous chicken production systems were evaluated individually. The chickens kept under the FRS and SIS are exposed to open environmental stresses because they are not confined most of the time. Their nutritional, reproductive, disease status and ultimate productive performances are influenced by many factors. Amongst specific groups of indigenous chickens, variation is observed for most of the traits.

The model uses a modified Gompertz function to predict live weights at different ages for the different categories of chicken. A comparison of the suitability of the Gompertz and Bertalanffy functions has been presented by Yakupoglu and Hulya (2001) for broilers. They recommended the Gompertz function for purposes of predicting the live-weight at a given age. The robustness of this growth model in estimation of growth in chicken has also been illustrated by Mignon-Grasteau *et al.* (2000) and Novák *et al.* (2004). The basic Gompertz function is written as follows:

$$Y = A \text{ x } e^{-b} \text{ x } e^{-kxt} \qquad (1)$$

where Y = prediction of live-weight at age t (kg), A = asymptotic or predicted final weight (kg), B = integration constant or time scale parameter equivalent to $\ln(A/bwt_0)$ where bwt_0 is the hatching weight (kg), K = function of the ratio of maximum growth rate to mature size (maturing index) and t = the time in days. The Gompertz function, however assumes that there are no environmental factors limiting the performance of the animal, and therefore, there is need to modify the function to adjust for limiting growth conditions by adding a multiplier, gp (Amer *et al.*, 1997). A similar approach has been used by Conington *et al.* (2004). The equation used in this model is as follows:

$$W_t = ALW \text{ x } \exp \{-\exp [G - B (t_2 - t_1)]\} \qquad (2)$$

where W_t= predicted bird live weight at time t (kg),
ALW = asymptotic or expected mature live-weight (kg),
$G = \ln[-\ln(HW/ALW)]$, $B = 0.0365/ALW^{0.75} \times gp$,
HW = hatching weight (kg),
gp = proportion of growth potential achieved and
t_2-t_1 = time in days from hatching to date of the prediction.

For each sex, the daily gain (g) (DG) was calculated as $(W_{t+1} - W_t) \times 1000$ and the average daily gain (ADG) was calculated by getting the mean of all the daily gains generated. It was assumed that male and female attain maturity live weight when they are 24 weeks (168 days) old and maintain this weight to culling.

The model estimates feed intake using the energy requirements equation (NRC, 1994) and caloric density of the feed resources available within the three production systems. Total metabolisable energy (TME) requirements (kCal) per day for chickens are estimated as:

$$TME = \{W_t^{0.75} \text{ x } [173-(1.95 \text{ x } T)] + (5.5\text{x}DG)+(2.07\text{x}E)\} \qquad (3)$$

where W_t is the predicted live weight at time t (kg), T is the ambient temperature (^{o}C), DG is the daily gain (g) and E is the egg mass (g) laid per day estimated as:

$$E = \frac{Necl \text{ x } lpc \text{ x } Ncl \text{ x } EW}{365} \qquad (4)$$

where Necl is the number of eggs laid per hen per clutch, lpc is the laying percentage, Ncl is the number of clutches per year, EW is the egg weight (g). For chicks, growers and cocks, the last term in equation 3 was zero since they do not lay eggs. Dry matter intake (FI) per day (kg) for animal category i (i = chicks, pullets, cockerels, hens or cocks) was computed as

$$FI = \frac{TME}{enc_{type}} \qquad (5)$$

where enc_{type} = energy content in the feed (kCal/kg DM) and subscript type represents the type of feed resources depending on the animal category and production system. Due to the variations in the types of feed resources utilised, it was necessary to test the sensitivity of the feed intake prediction equations to changes in feed quality. Under CFRS, the standard caloric density of commercial feeds for each age category was used.

In general, the model estimates profitability as follows:

$$P = R - C \qquad (6)$$

where P is the profit per hen per year (KSh), R is the revenue per hen per year (KSh) and C is the cost per hen per year (KSh). The revenues (R) were calculated using the equation:

$$R = R_{egs} + R_{pullets} + R_{ecocks} + R_{ococks} + R_{ohens} \qquad (7)$$

where R_{eggs} is the revenue from the sale of eggs (KSh), $R_{pullets}$ is revenue from the sale of excess pullets (KSh), R_{ecocks} is the revenue from the sale of excess cockerels (KSh), R_{ococks} is revenue from the sale of old cocks (KSh) and R_{ohens} is the revenue from the sale of old hens (KSh).

Table 3: Economic[1] variables in the three production systems

Variable	Abbreviation	Production system[2]		
		CFRS	SIS	FRS
Price per egg	p_{egg}	5.00	5.00	5.00
Meat price per kg live weight	p_{meat}	150.00	150.00	150.00
Price per kg DM of chick mash	p_{cmash}	19.60	19.60	
Price per kg DM of finishers' mash	p_{fmash}	17.40		
Price per kg DM of growers' mash	p_{gmash}	17.40		
Price per kg DM layers' mash	p_{lmash}	16.30		
Price per kg DM of scavenged feed	p_{sfr}		2.20	2.20
Fixed costs	C_{fixed}	335.00	60.00	0

[1]All units in Kenya Shillings (1US$ = KSh. 75.00).

[2]CFRS = confined full ration system; FRS = free range system; SIS = semi-intensive system.

Costs (C) were derived from the following equation:

$$C=BC_{eggs}+FC_{chick}+FC_{pullets}+FC_{cockerels}+FC_{hens}+C_{lab}+C_{vet}+C_{fixed} \quad (8)$$

where BC_{eggs} is the costs as a result of brooding activities of the hen (KSh), FC_{chick} is the feed costs for chick (KSh), $FC_{pullets}$ is the feed costs for pullets (KSh), $FC_{cockerels}$ is the feed costs for cockerels (KSh), FC_{hens} is the feed costs for laying hens also includes the feed costs for cocks (KSh), C_{lab} is the cost of labour (KSh), C_{vet} is the cost of health care (KSh) and C_{fixed} is fixed costs associated with shelter and equipment (KSh). Economic variables used in all the production systems are presented in Table 3. All the costs and prices are stated in Kenya Shillings (KSh). The study considered the 2005 prevailing market prices. Any fluctuations in costs and prices were ignored. The various components of R and C were calculated as shown in Appendix A.

Results

The deterministic bio-economic model developed was able to predict the live weight of chickens during the growth period. The growth parameters obtained were used to estimate feed intake. To deal with the performance limiting conditions within the various production systems, the growth equations were internally adjusted. Some field data on live weight could not be obtained, consequently, it was not possible to validate the model by comparing estimated values with actual observations from experimental results. The other outputs of this model included feed intake of various chicken categories, revenue, costs and profitability of the three production systems which are very difficult to collect under field conditions. However, the model was executed under the base situation and the simulated outputs checked to determine whether they were reasonable or not.

Table 4 shows the simulated live-weight changes and feed intake of various chicken categories for each production system. The three systems showed marked differences in average daily gains. The average daily gain for males was 9.96g, 9.24g and 9.07g in CFRS, SIS and FRS, respectively. The corresponding daily gain in females was 9.14g, 8.61g and 7.68g. The live weight of cockerels and pullets at 21 weeks of age and of mature live weight of cocks and hens followed a similar trend to that observed for daily gain with chicken in CFRS being heavier than in the other production systems. Feed intake patterns revealed that on average, the chick feed intake per bird was lowest in SIS and highest in FRS. On the other hand, the feed consumption of growers (pullets and cockerels) was higher in the SIS than in the other systems whereas layer feed consumption was highest in the CFRS.

Simulated relationships between daily gain and feed intake in cockerels are presented in Fig. 2 for CFRS since this system utilises commercial feeds whose composition is well known. An increase in daily gain was associated with an increase in feed intake up to week 12. Thereafter, daily gain increased gradually probably as a result of a reduction in feed intake. From week 0 to 22, chicken pass through different development stages that require feeds with different energy contents. Therefore an assessment of the influence of energy content of the feeds utilised in various stages on feed intake is important. Fig. 3 shows the simulated changes in feed intake of growers and layers when there is an increase in the energy content in feed. These changes were simulated for CFRS. When the caloric density of the feed increased, the amount of feed consumed reduced. This behaviour in CFRS might also indicate that the energy content of the feed resources influences feed intake of the birds in SIS and FRS.

Simulated revenues, costs and profits for each of the production systems are presented in Table 5. The values obtained for each system depend on the flock structure used since the three systems had different flock composition. Most of the revenue in all systems came from the sale of cockerels which had higher body weights and fewer cockerels than pullets were required for replacement (Fig. 1). Eggs contributed to revenues in all production systems (17.46% in CFRS, 8.52% in SIS and 6.67% in FRS) indicating that egg production traits

Table 4: Simulated live weight changes and feed intake of various chicken categories in each production system

Model Outputs	Abbreviation	Production system[1]		
		CFRS	SIS	FRS
Live weight changes				
Average daily gain (0 to day 147) in males (g/d)	ADG_m	9.96	9.24	9.07
Average daily gain (0 to day 147) in females (g/d)	ADG_f	9.14	8.61	7.68
Live weight of cockerels at 21 weeks (kg)	LW_C	1.50	1.39	1.36
Live weight of pullets at 21 weeks (kg)	LW_P	1.38	1.30	1.16
Mature live weight of cocks (kg)	LW_M	1.63	1.57	1.51
Mature live weight of hens (kg)	LW_F	1.47	1.42	1.22
Feed intake of various categories				
Cumulative feed intake of chicks (kg DM)	CFI_{chick}	1.01	0.83	1.13
Cumulative feed intake of pullets (kg DM)	$CFI_{pullets}$	8.27	11.11	8.64
Cumulative feed intake of cockerels (kg DM)	$CFI_{cockerels}$	7.06	9.65	7.70
Cumulative feed intake/hen/yr (kg)	CFI_{hen}	47.71	32.72	29.00

[1] CFRS = confined full ration system; FRS = free range system; SIS = semi-intensive system.

Table 5: Revenues, costs and profitability of the indigenous chicken production systems[1]

Description	Production system[2]		
	CFRS	SIS	FRS
Revenues			
Eggs	450.00	137.50	82.50
Pullets	677.22	467.00	345.60
Cockerels	1322.34	898.80	729.34
Culled hens	104.52	90.53	64.05
Culled Cocks	23.28	20.02	15.86
Total (a)	2577.37	1613.85	1237.35
Costs			
Brooding activity	350.60	180.40	155.16
Feed costs for chicks	338.64	341.17	71.72
Feed costs for pullets	852.17	98.21	92.84
Feed costs for cockerels	803.79	80.72	67.29
Feed costs for hens	777.67	72.00	63.80
Labour	1736.79	868.40	173.68
Veterinary care	115.98	0.00	0.00
Total (b)	4975.64	1700.88	624.49
Fixed Cost (f)	670.00	60.00	0.00
Profit without f [a-b]	-2398.27	-27.00	612.86
Profit [a-(b+f)]	-3068.27	-87.04	612.86

[1] All units in Kenya Shillings (1US$ = KSh. 75.00).

[2] CFRS = confined full ration system; FRS = free range system; SIS = semi-intensive system.

are also important in these production systems. Labour contributed significantly to the total costs in all systems (34.91% in CFRS, 52.92% in SIS and 28.12% in the FRS). Profits were simulated using two evaluation bases; with fixed costs and without fixed costs. This was done since inclusion of all fixed costs in a single year can cause distortion of the economic performance and mask the actual merit of a production system. In both evaluation bases, CFRS was least and FRS the most profitable (Table 5). On average per hen per year, the use of indigenous chicken was profitable in FRS and not in CFRS and SIS.

Discussion

The objectives of this study were to develop a deterministic bio-economic model for use in the biological and economic evaluation of production systems utilising the indigenous chickens in Kenya. The bio-economic models were assumed to be linear and the outcomes were completely determined by the initial input parameters. The input parameters used (Table 1) were based on flock averages and may be adjusted to suit specific situations. With slight modifications, the model can be used to assess the biological and economic performance of various production systems of other domestic avian species. Bio-economic models have been used to represent livestock production systems for purposes of economic evaluation in broiler (Groen *et al.*, 1998), dairy (Kahi and Nitter, 2004), sheep (Kosgey *et al.*, 2004), goat (Bett *et al.*, 2005) and beef (Rewe *et al.*, 2005) production systems.

The average daily gains obtained from the model were higher than those reported by Mwalusanya (1998) but comparable to those reported by Tadelle *et al.* (2003a). This was probably because of among other factors, the hatching weight (HW) used as an input in the model which was higher than that reported by Mwalusanya (1998) but similar to that reported in Tadelle *et al.* (2003a). This observation suggests that hatching weight may have a significant influence on the subsequent growth performance of the indigenous chickens.

Feed intake peaked at week 12 and reduced thereafter (Fig. 2). Indigenous chickens tend to have high feed conversion ratios as a result of either the poor type of feeds usually available especially in extensive systems or low genetic potential for feed conversion efficiency or both (Roberts, 1999; Tadelle *et al.*, 2003a). However, high conversion ratios in indigenous chicken have also been reported in cases where they were provided with commercial feeds (Kingori *et al.*, 2003). Genetic variation has been observed for feed conversion efficiency among

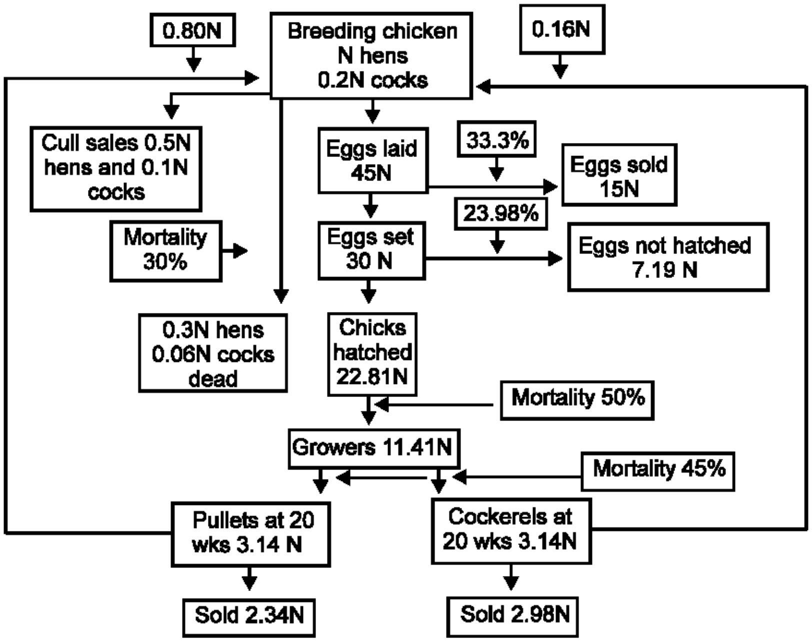

Fig. 1: Structure of indigenous chicken production systems per year in a base situation (FRS)

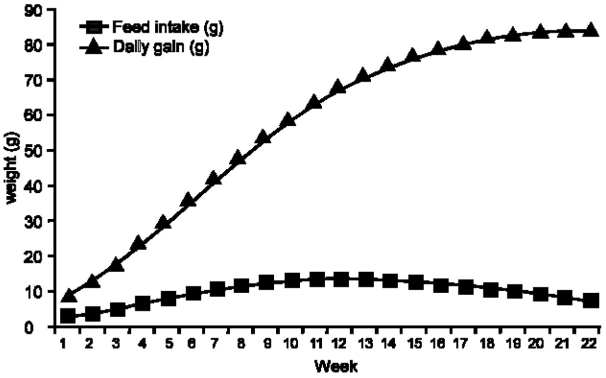

Fig. 2: Simulated curves for daily gain and feed intake of cockerels form week 1 to 21 in CFRS

strains of indigenous chickens implying that selective breeding can be used to improve feed efficiency (Tadelle *et al.*, 2003a).

Several factors are known to influence the actual feed intake of chickens on extensive production systems. These factors include the energy content of the feed material (Wickramaratne *et al.*, 1993; Roberts, 1999) and the actual ability to scavenge (forage) (Gueye, 1998). In this study, the feed intake trends within the CFRS were taken to be indicative of the feed intake under the SIS and the FRS. It was difficult to attach a specific value to the feed consumed under the FRS and SIS, yet it was necessary to represent the cost associated with feed intake in the model for the two systems. Therefore, a marginal value of KSh.1.00 kg^{-1} for fresh free range feed resources was used. Attempts at estimating feed costs are better than no attempts at all (Kahi *et al.*, 1998). Ponzoni and Newman (1989) showed that excluding feed costs has the effect of exaggerating profitability of the production system because feed costs constitute a large percentage of overall production costs.

The production variables included in the model (e.g., LW, HW, Necl, Ncl, CFI, CSR, GSR, LSR) were partly influenced by the genetics of the birds and had direct effects on profit. These variables represent potential breeding goal traits. The inclusion of traits such as fertility, hatchability and chick survival was justifiable as these traits determined the bird off-take. Carcass quality traits were left out because consumers generally do not discriminate amongst indigenous chicken products although many prefer eggs and meat from indigenous chickens over those from the commercial birds (Gueye, 1998). In most village production systems in sub-Saharan Africa, farmers use more eggs for hatching chicks than for sale or consumption (Kitalyi, 1998; Maphosa *et al.*, 2004). Therefore, in this study it was assumed that farmers obtain all their supplies of day-old chicks by natural incubation using broody hens. The number of day old chicks obtained was not only dependent on eggs available, hatchability and fertility but also on the settings. The input parameter settings represented the perceived need for chicks by the farmer and this was the number of times the hen was allowed to incubate eggs. In order to evaluate all systems using the same criteria, a uniform figure of two settings was used in this study. In the commercial production systems, the purchase of day-old chicks constitutes a major item of expenditure (Groen *et al.*, 1998), which

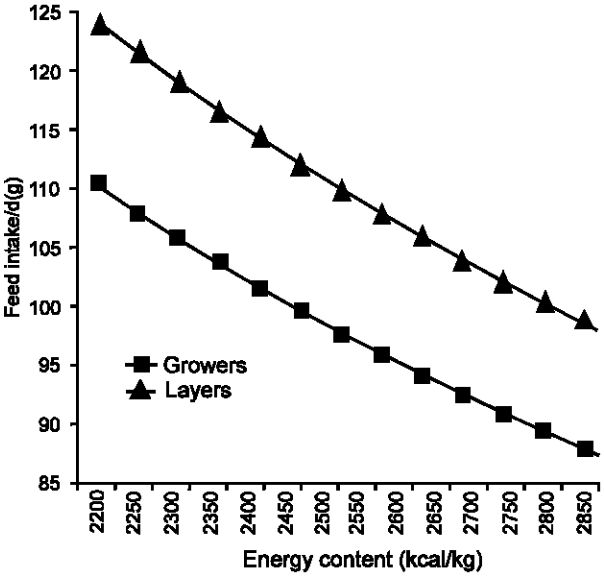

Fig. 3: Simulated changes in feed intake of male growers and layers as a result of changes in the energy content of feed in CFRS

implies that appropriate adjustments must be made if this model were to be used for evaluating systems where day-old chicks are sourced from outside.

In chicken production systems, disease resistance is important. However, it was not included in the bio-economic model. Resistance has multifold influences on inputs and outputs, which in turn affect profit. It is further complicated by environmental factors, nonlinearity effects and interactions (Sivarajasingam, 1995). This makes it difficult to incorporate measures of disease resistance into a bio-economic model. Indigenous chickens in Africa have been reported to be resistant to some tropical poultry diseases (Gueye, 1998; Msoffe *et al.*, 2002). Disease resistance is difficult to measure *per se* but indicator traits for resistance are available. For example, resistance to Marek's and other diseases, general fitness and productivity have been associated with the B system haplotype of the Major Histocompatibility Complexes which has enabled gene assisted selection to be done (Reports of European Commission, 1999; Msoffe *et al.*, 2002). Recently, a new system in addition to the above, which correlates with reduced incidence of tumour formation upon exposure to Marek's disease virus, has been identified. The system has been called the Rfp-Y (Restriction fragment polymorphism-Y) and is thought to be due to additive genetic effects (Miller *et al.*, 1994).

The results show that the model can be applied to the smallholder poultry production systems in Kenya and in other tropical countries with similar production conditions. Profitability trends suggest that the chickens can be utilised profitably in FRS. Although CFRS showed negative profitability under both evaluation bases, it cannot be ignored because the transition from subsistence to commercial production is desirable and requires that management levels get better as the genetic potential of the birds is also improved. The profitability in SIS was also negative. However, this could be an underestimate. The negative profitability may indicate a rise in labour cost since a cost was assigned to family labour. The cost for labour is absent when children and sometimes adults provide labour. Studies in small ruminants have shown that inclusion of own labour cost in economic evaluation largely inflates the total costs with negative effects on profitability (Hamadeh *et al.*, 2001). The potential of chickens to act as a viable source of income for the rural households has been reported before (Gueye, 1998; Roberts, 1999; Permin *et al.*, 2001; Sonaiya, 2001). An indigenous chicken enterprise's initial capital requirements are modest and many poor families may find it the only manageable alternative. There are other roles which add to the worth of the indigenous chickens to the smallholder farmers. For example, the poultry flocks are reported to have enabled faster recovery for smallholder farmers from disasters like droughts and disease outbreaks in Southern Africa in which case they acted as a form of insurance (Songolo and Katongo, 2001).

The primary objective of indigenous chicken farmers usually, is to improve the profitability of their indigenous chicken flocks by producing more meat and eggs. The farmers are also interested in traits that make the birds easily manageable such as disease resistance and broodiness. Defining a breeding goal involves the identification of animal characteristics that contribute to changes in profit and the relative worth of the animal (Barlow, 1987). The breeding goals should relate positively with the needs and aspirations of the farmers to be sustainable (Kahi and Nitter, 2004). In a breeding goal, breeding values of traits are weighted by their respective economic weights to come up with a total index, which is expressed in monetary terms. Economic weights are an indication of the relative importance of traits in a given system. The bio-economic model developed in this study can be used to derive economic weights for breeding goal traits for the indigenous chicken production systems.This will be the subject of a subsequent study.

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Appendix A

Calculation of revenues: The sources of revenues in all production systems were eggs, surplus pullets, cockerels and cull- for-age cocks and hens. For simplicity, the set percentage (setpc), number of day-old chicks (Nchicks) and of pullets (Npullets) per hen per year were first calculated as:

$$\text{setpc} = \frac{15}{\text{Necl x Ipc}} \text{ x } 100 \qquad (9)$$

$$\text{Nchicks} = \sum_{i=1}^{\text{Nset}} (\text{Necl x Ipc x setpc x HTC x FRT})_i \qquad (10)$$

and

$$\text{Npullets} = 0.5 \text{ x Nchicks x CSR x GSR} \qquad (11)$$

where Necl = number of eggs laid per hen per clutch, Ipc = laying percentage, setpc = percentage of eggs set, Nsett = number of settings per year, HTC = hatchability (%), FRT = egg fertility (%), CSR = chick survival rate (%) and GSR = grower survival rate (%). With a sex ratio of 0.5, Npullets is equal to the number of cockerels per hen per year (Ncockerels).

Revenue from eggs (R_{egg}): Depending on the farmer's needs and the capability of the hens to incubate, a certain percentage of eggs were set each year. The remainder of the eggs were available for sale or consumption. Revenue from eggs (R_{egg}) was computed as:

$$R_{egg} = \left[\sum_{i=1}^{\text{Nset}} \{\text{Necl x Ipc x (1-setpc)}\}_i + \{\text{Necl x Ipc x (Ncl - Nsett)}\}\right] \text{ x } P_{egg} \qquad (12)$$

where Ncl = number of clutches per year and p_{egg} = price per egg (KSh).

Revenue from pullets ($R_{pullets}$): Revenue from pullets is attained from those not needed for replacement. The number of pullets not needed for replacement ($N^{culled}_{pullets}$) was estimated as:

$$(N^{culled}_{pullets}) = \text{Npullets x (1 - HRr)} \qquad (13)$$

where HRr = replacement rate (%) of hens estimated as:

$$\text{HRr} = \frac{365}{\text{PLT}} \qquad (14)$$

where PLT = productive lifetime (days). The revenue from pullets ($R_{pullets}$) was therefore computed as;

$$\text{Rpullets} = (N^{culled}_{pullets}) \text{ x } LW_p \text{ x } p_{meat} \qquad (15)$$

where LW_P = live-weight of a pullet at day 147 (week 21) (kg) and p_{meat} = price per kg live-weight (KSh).

Revenue from cockerels ($R_{ecockerels}$): Revenue from cockerels is from those not needed for replacement. The number of cockerels not needed for replacement ($N^{culled}_{pullets}$) was estimated as:

$$(N^{culled}_{pullets}) = \text{Ncockerels x (1-CRr)} \qquad (16)$$

where CRr = replacement rate of cocks (%). Assuming a cock to hen ratio of 1:5, CRr was estimated as:

$$\text{CRr} = \frac{365}{\text{PLT}} \text{ X } \frac{1}{5} \qquad (17)$$

The revenue from cockerels ($R_{ecockerels}$) was therefore computed as;

$$R_{ecockerels} = (N^{culled}_{pullets}) \text{ x } LW_c \text{ x } p_{meat} \qquad (18)$$

where LW_C = live-weight of a cockerel at day 147 (21 weeks) (kg).

Revenue from culled hens (R_{ohens}): This is the revenue from the number of hens that are culled (N^{old}_{hens}) due to age or lowered productivity estimated as:

$$(N^{old}_{hens}) = \frac{365 \text{ x LSR}}{\text{PLT}} \qquad (19)$$

where LSR = survival rate of layers (%). The revenue from culled hens (R_{ohens}) was therefore computed as;

$$R_{ohens} = N^{old}_{hens} \text{ x } LW_f \text{ x } p_{meat} \qquad (20)$$

where LW_F is the mature live-weight of a hen at day 168 (24 weeks) (kg).

Revenue from culled cocks (R_{ococks}): Besides the cocks that die in the course of the year, a proportion of cocks were culled because their daughters attained sexual maturity. Therefore, the number of cocks culled (N^{old}_{cocks}) was derived as:

$$(N^{old}_{cocks}) = \frac{1}{5} \text{ x } N^{old}_{hens} \qquad (21)$$

The revenue from culled cocks (R_{ococks}) was therefore computed as;

$$\text{Rococks} = N^{old}_{cocks} \text{ x } LW_M \text{ x } p_{meat} \qquad (22)$$

where LW_M is the mature live-weight of a cock at day 168 (24 weeks) (kg).

Calculation of costs: Costs arose from brooding activities of the hen, husbandry, feeds and fixed assets. No marketing costs were included for all systems as all the products were assumed consumed at home and incase there was any surplus, marketing was done on-farm.

Cost of brooding (BC_{egg}): The cost of brooding was equivalent to the value of eggs lost due to brooding activities. This was as a result of failure of eggs to hatch and the number of days spent by the hen brooding. In this study, it was assumed that hens spend a total of 112 days (including the incubation period of 22 days) for every batch of chicks raised. The cost of brooding was:

$$BC_{egg} = \left[\sum_{I=1}^{\text{Nset}} \{(\text{Necl x Ipc x setpc}) \text{ x } (1 - (\text{HTC x FRT})\}_i + \frac{\text{Necl x Ncl x Ipc x Nsett x brd}}{365}\right] \text{ x } p_{egg} \qquad (23)$$

where brd = mothering period per batch of chicks (days).

Feed costs for chicks from day 0 to day 42 (FC_{chick}): Chicks in the SIS and CFRS are fed chick mash from day 0 to day 42 whereas those in FRS are fed on scavenged feed resources. The feed costs (FC_{chicks}) were computed as follows:

$$FC_{chicks} = [\text{N chicks x } CFI_{chick}] \text{ x } p_{cmash} \qquad (24)$$

where CFI_{chick} is the cumulative feed intake per chick (kg DM) and p_{cmash} is the price per kg DM of chick mash (KSh). For the FRS, the price per kg DM of scavenged feed (p_{sfr}) was used instead of the $p_{cmash.}$ The cumulative feed intake (DM) per chick was computed as:

$$CF_{Ichick} = \sum_{i=1}^{42} (Fi_{chick})_i \qquad (25)$$

whereby FI_{chick} is the feed intake per chick per day (kg DM).

Feed costs for pullets and cockerels from day 43 to sale age (day 147): The model assumes selection of replacement pullets and cockerels occurs at day 126. The cockerels are used for breeding when they are 148 days old while pullets lay their first egg at day 168. Pullets and cockerels in CFRS are fed growers and finishers' mash from day 43 to day 147 whereas those in SIS and FRS are fed on scavenged feed resources. In CFRS, pullets and cockerels to be culled are fed on finisher mash until attaining the sale age of 147 days. For the replacement pullets and cockerels, they continue being fed growers' mash until day 147. For simplicity, three feeding costs and intake are simulated for three periods: for all pullets and cockerels from day 43 to day 126, for culled pullets and cockerels from day 127 to day 147 and for replacement pullets and cockerels from day 127 to day 147. In CFRS, the feed costs from day 43 to day 126 for pullets ($FC_{pullets1}$) were estimated as:

$$FC_{pullets1} = (N_{pullets} \text{ x } CFI_{pullets1}) \text{ x } p_{gmash} \qquad (26)$$

where $CFI_{pullets1}$ is the cumulative feed intake of a pullet from day 43 to day 126 (kg DM) and p_{gmash} is the price per kg DM of growers' mash. The cumulative feed intake of a pullet from day 43 to day 126 ($CFI_{pullets1}$) was calculated as:

$$CFI_{pullets} = \Sigma\ (Fi_{pullets})_i \qquad (27)$$

The feed costs ($FC_{cockerels1}$) and cumulative feed intake ($CFI_{cockerels1}$) from day 43 to day 126 for cockerels were estimated using equations (26) and (27), respectively. In SIS and FRS, p_{gmash} was substituted with p_{sfr}. In CFRS, the feed costs for culled pullets from day 127 to day 147 ($FC_{pullets2}$) were estimated as:

$$FC_{pullets2} = (N^{culled}_{pullets} \text{ x } CFI_{pullts2}) \text{ x } p_{fmash} \qquad (28)$$

where $CFI_{pullets2}$ is the cumulative feed intake of a culled pullet from day 127 to day 147 (kg DM) calculated using equation (27) but summation was done from day 127 to day 147 and the type of feed used changed to finishers mash in equation (5) and p_{fmash} is the price per kg DM of finishers' mash (KSh). Similarly, the feed costs ($FC_{cockerels2}$) and the cumulative feed intake for culled cockerels from day 127 to day 147 ($CFI_{cockerels2}$) and were estimated as $FC_{pullets2}$ and $CFI_{pullets2}$ above, respectively, but substituting $N^{culled}_{pullets}$ with $N^{culled}_{cockerels}$ in equation (28). In SIS and FRS, the feed costs and intake for culled pullets and cockerels from day 127 to day 147 were estimated as above but p_{fmash} was substituted with p_{sfr} in equation (28) and the type of feed used changed to scavenged feed resources in equation (5). In CFRS, the feed costs from day 127 to day 147 for replacement pullets ($FC_{pullets3}$) were estimated using equation (26) but substituting Npullets with the number of replacement pullets ($N^{rep}_{pullets}$) and $CFI_{pullets1}$ with the cumulative feed intake of a replacement pullets from day 127 to day 147 ($CFI_{pullets3}$). A similar approach was used to calculate the feed costs ($FC_{cockerels3}$) and cumulative feed intake ($CFI_{cockerels3}$) of replacement cockerels. The number of replacement pullets ($N^{rep}_{pullets}$) was calculated as:

$$N^{rep}_{pullets} = N_{pullets} \text{ x } H.Rr \qquad (29)$$

In SIS and FRS, the feed costs and intake for replacement pullets and cockerels from day 127 to day 147 were estimated as above but p_{sfr} instead of p_{fmash} was used in equation (28) and the metabolizable energy content in scavenged feed (enc_R) used instead of the metabolizable energy content in growers' mash (enc_G) in equation (5).

Feed costs of replacement pullets from day 148 to age at first egg (day 168): In CFRS, the feed costs of replacement pullets from day 148 to age at first egg (AFE) ($FC_{pullets4}$) were estimated using equation (26) but substituting $N^{rep}_{pullets}$ and $CFI_{pullets1}$ with the cumulative feed intake of a replacement pullet from day 148 to day 168 ($CFI_{pullets4}$). In SIS and FRS, $FC_{pullets4}$ and $CFI_{pullets4}$ were estimated using parameters (p_{sfr} and enc_R) for the available feed resource.

Total feed costs of pullets ($FC_{pullets}$) and cockerels ($FC_{cockerels}$): The total feed costs of pullets ($FC_{pullets}$) and cockerels ($FC_{cockerels}$) were calculated as:

$$FC_{pullets} = FC_{pullets1} + FC_{pllets2} + FC_{pullts3} + Fc_{pullets4} \qquad (30)$$

and

$$FC_{cockerels} = FC_{cockerels1} + FC_{cockerels2} + Fc_{cockerels3} \qquad (31)$$

Cumulative feed intake of pullets ($CFI_{pullets}$) and cockerels ($CFI_{cockerels}$): The cumulative feed intake of pullets ($CFI_{pullets}$) and cockerels ($CFI_{cockerels}$) were calculated as:

$$CFI_{pullets}=CFI_{pullets1}+CFI_{pullets2}+CFI_{pullets3}+CFI_{pullets4} \qquad (32)$$

and

$$CFI_{cockerels} = CFI_{cockerels1} + CFI_{cockerels2} + CFI_{cockerels3} \qquad (33)$$

Feed cost of hens and cocks (FC_{hens}): The feed cost of hens and cocks in the flock (FC_{hens}) were estimated as:

$$Fc_{hens}= [(LSR \text{ x } CFIhens1)+\{\frac{LSR}{5} \text{ x } CFI_{cocks1}\}] \qquad (34)$$

where CFI_{hens1} and CFI_{cocks1} are the cumulative feed intake per hen and cock, respectively (kg DM) and p_{cmash} is the price per kg DM of chick mash (KSh). For the SIS and FRS, p_{sfr} was used instead of the $p_{lmash.}$ The cumulative feed intake (kg DM) per hen (CFI_{hens}) was computed as:

$$CFI_{hens} = \sum_{I=1}^{365}(Fi_{hens})_i \qquad (35)$$

where FI_{hens} is the feed intake per hen per day (kg DM). The cumulative feed intake (kg DM) per cock (CFI_{cocks}) was computed using equation (35).

Total feed intake of hens and cocks: The total feed intake of hens and cocks (CFI_{hen}) was estimated as:

$$CFI_{hen} = (LSR \times CFI_{hens1}) + \left[\frac{LSR}{5} \times CFI_{cocks1}\right] \qquad (36)$$

Labour costs (C_{lab}): Under CFRS, time is needed to feed and water the birds. In a typical family flock of five hens, the time needed to do these chores each day is 50 minutes. Under SIS, this time was reduced by 50% and under the FRS, it was assumed that a person needed 10% of that time to collect eggs or do other relevant and necessary tasks related to the free-range chickens (Gueye, 1998). This time was valued using the current official payment rates per day (KSh. 228.40) for unskilled agricultural labour in Kenya (Chune, 2003). The government payment rates are computed based on an eight-hour working day. Labour costs per year were computed as:

$$C_{lab} = \frac{50}{60} \times 365 \times \frac{228.40}{8} \times time \times \frac{1}{5} \qquad (37)$$

where time = 1 for CFRS, 0.5 for SIS and 0.10 for FRS.

Healthcare costs (C_{vet}): This includes money spent on purchasing and administration of medication. Under CFRS, there is vaccination against New Castle disease/Infectious bronchitis (at KSh 2/= $bird^{-1}$) for all chicks and mature chickens, Infectious bursal disease (at KSh 1/= $bird^{-1}yr^{-1}$) for all chicks and Fowl pox (at KSh 1/= $bird^{-1}$) for all chicks and adult birds. In addition, there is treatment against coccidiosis (at KSh 0.50 $bird^{-1}yr^{-1}$) for all birds in the family flock. Under FRS and SIS, the birds are only given herbal preparations, which are commonly known among members of the communities (Gueye, 1998). Veterinary costs were therefore not included in the total costs for these two systems.

Fixed costs (C_{fixed}): Fixed costs relate to the structures built and equipment obtained for the purpose of keeping the chickens. For CFRS, the owner will build a small shelter, usually with locally available materials with feeders and drinkers provided together with laying nests. Under, FRS no shelter is built but birds shelter in kitchens or other perching. In SIS, the farmer buys coops in which the birds are confined. Under FRS, no fixed costs are incurred. The fixed costs per year in CFRS and SIS are presented in Table 3.

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