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THE RIGHT-SIZED COW FOR EMERGING AND COMMERCIAL BEEF FARMERS IN SEMI-ARID SOUTH AFRICA: CONNECTING BIOLOGICAL AND ECONOMIC EFFICIENCY

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ABSTRACT
The study investigates the right size of cow in terms of both biological and economic efficiency under a typical production system in semi-arid South Africa. Cow size influences biological efficiency of individual animals, which influences herd composition and stock flow on a predetermined resource base. This in turn influences the economic efficiency of the herd. Individual cows were classified as either small, medium, or large and their individual biological efficiency determined. When similar reproduction and growth rates were assumed, large cows were the most biologically efficient, followed by medium and small cows. Income from the herd of small cattle was the lowest, as fewer kilograms of beef were available to sell. Allocated costs for the herd of small cattle were the highest, due to a large number of expenses being charged per head of cattle. Subsequently, when economic efficiency was calculated, the herd of large cattle was more profitable than its smaller counterparts. The herd of large and medium cattle would become less profitable than the herd of small cattle at lower reproduction rates, and these reproduction rates were calculated. Smaller cattle have a faster maturity rate than larger cattle. A faster maturity rate provides the opportunity for early breeding. The effect of limiting feed intake of small, medium, and large cattle was compared and yielded varying results. The study concluded that cattle size influences biological efficiency, biological efficiency influences economic efficiency however there are many more variables that influence biological and economic efficiency other than size, such as reproduction rates.

Contribution/Originality: The study contributes to body of knowledge by investigating the right size of cow a farmer could breed. The study is one of the few in South Africa, as there is little or no literature about the right size of cow in the study area.

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1. INTRODUCTION
South Africa is a net importer of beef, suggesting ample room for expansion of the beef industry (Department of Agriculture Forestry & Fisheries, 2015). Most beef cattle in South Africa are managed under extensive conditions and utilize natural pasture. According to results from the National Cattle Survey undertaken in South Africa, with emphasis on beef, around 75% of beef production systems are extensive (Scholtz, Bester, Mamabolo, & Ramsay, 2008).

The South African beef industry is deeply segmented, with large differences among commercial, emerging, and communal farmers. Commercial farmers produce mostly for the feedlot. According to a survey by Scholtz et al. (2008), 70% of all beef that was slaughtered in the formal sector had been fattened in the feedlot. A common production system is the weaner system (Department of Agriculture Forestry & Fisheries, 2016). Emerging farmers are those that have the potential to commercialize and are actively looking to become more efficient, and therefore they could adopt the same management practices as commercial farmers (Oduniyi, 2018). This research focusses on farmers aiming to produce for commercial feedlots.

Results from the National Cattle survey show that farmers put much consideration into size when selecting breeding stock. The survey listed several reasons for bull selection, namely: performance, conformation, temperament, size, availability, color, and horns. Commercial farmers first consider performance, conformation, and temperament, but 8.8% still predominantly selected a bull based on size. Emerging farmers' main consideration was performance (30.3%), followed by size (23.5%). Thirty-three per cent of communal farmers considered size to be the most important factor and, as the author put it, still believe "bigger is better" (Scholtz et al., 2008). Despite the considerable role that size plays in selection, the effect thereof, under typical conditions and management practices in the semi-arid areas of South Africa, remains still unclear.

2. LITERATURE REVIEW

Previous literature points out that the most efficient size of cow will depend on the production system and environment. Body size influences a multitude of biological functions, including energy requirements, growth and maturity rates, milk production, reproduction rates, and adaptation. Biological efficiency of individual animals in turn determines the composition and performance of the herd. This in turn influences the economic efficiency of the herd as a whole.

When using energy requirements as the primary input, the most biological efficient beef cow will be the one that uses less energy to produce more meat. The four most relevant biological functions for which cows use net energy are maintenance, growth, lactation, and reproduction. They also partition energy in this order (Johnson, Radakovich, & Dunn, 2010; Lofgreen & Garrett, 1968; National Research Council, 2000). Research on energy requirements of cattle is extensive but, even so, results normally vary within a thin range. The most comprehensive research on energy requirements is that of the National Research Council (NRC). The NRC consolidated much of the previous research in their publications of energy requirements of ruminants (National Research Council, 1984, 2000).

The energy requirements for the four biological functions can be calculated from equations suggested by the NRC as well as other previous research. Smaller animals have proportionately higher maintenance energy requirements than larger animals. Metabolic weight is widely used to calculate energy requirements for maintenance, where metabolic weight = live weight$^{0.75}$ (Kleiber, 1932). The work of Lofgreen & Garrett, commonly referred to as the California Method, is still the most common equation used to calculate net energy requirements for growth and maintenance (Lofgreen & Garrett, 1968). A non-pregnant, non-lactating cow will retain energy for maintenance and growth. Growth can be measured, and so the net energy used for growth can be measured and therefore energy for maintenance can be measured by subtracting the net energy used for growth from the total net energy retained. To calculate maintenance energy from their equation, the live weigh of the cow must be known. While growth can be easily measured, it is much more complex to calculate. The composition of growth changes as the animal nears its mature size. The equation used to calculate net energy for growth, as suggested by NRC, uses empty body weight gain, a reference weight, and equivalent shrunk body weight among the variables. To calculate the net energy requirements required to produce one kilogram of milk, this is equal to the net energy content of the milk, which is dependent on the milk's composition. The equation proposed by Tyrrell and Reid (1964) is commonly used. Energy requirements for lactation are, however, very complicated since milk composition changes throughout lactation. Also, daily milk yield varies and is again dependant on a multitude of other variables. Net energy requirements for production are equal to the net energy content of the gravid uterus. The work of Ferrell, Garrett, and Hinman (1976) is commonly used to calculate net energy for production. Birth weight and time after conception are the main variables in this equation.

Large cattle grow faster – that is, they gain more body weight per day than smaller cattle. However, previous research suggest that the growth rates of smaller animals are faster and that small animals reach mature weight sooner than large animals (Arango & Van Vleck, 2002; Dickerson, 1978; Fiss & Wilton, 1989; Morris & Wilton, 1976). Cattle that will have a larger mature weight are larger throughout all other life stages as well – for example, puberty and weaning (Arango & Van Vleck, 2002; Fiss & Wilton, 1993; Morris & Wilton, 1976). Despite extensive existing research, there is no calculation that directly compares expected mature size to growth or maturity rate. Brody's growth model is a good fit to calculate the daily gain of beef cattle, if growth rate and mature weight can be assumed (Brody, 1945; Teleken, Galvão, & Robazza, 2017).

The size of a cow will influence milk production. This is a complex area of research and, as yet, milk yield cannot be calculated from animal size. However, existing research shows that heavier mature animals are heavier at all life stages, including birth to weaning. Thus, they have higher energy requirements and therefore need more milk while suckling. So, it can be argued that larger cows produce more milk to provide more energy for their larger calves. From another angle, if a cow has a higher lactation yield she will produce a bigger calf (Arango & Van Vleck, 2002; Jenkins & Ferrell, 2002; Johnson et al., 2010).

Reproduction rates is arguably the most complex of biological functions, with countless variables affecting reproduction. Although the correlation between size and reproduction rates cannot be expressed numerically, from previous research it is safe to assume that gestation lengths in larger cattle are longer and, most importantly, under similar conditions, reproduction rates of smaller cattle are higher (Arango & Van Vleck, 2002; Dickerson, 1978; Fiss & Wilton, 1989).

Current literature suggest that a smaller body size is an adaptation to semi-arid and arid environments. This adaptation can be expressed in a multitude of ways, including higher reproduction rates, lower mortality rates, and disease resistance among others. Some research suggests that smaller animals tend to be more efficient when feed supply is limited, as in the case of dry climates (Arango & Van Vleck, 2002; Dickerson, 1978; Jenkins & Ferrell, 2002).

Body size doesn't necessarily directly impact economic efficiency but, due to biological differences, variation in incomes and expenses is observed in herds of different-sized animals. Body size influences biological efficiency, and biological efficiency influences economic efficiency (Arango & Van Vleck, 2002; Dickerson, 1978; DiCostanzo & Meiske, 1994; Johnson et al., 2010). When examining economic efficiency, the herd as a whole should be considered because knowing the biological efficiency of individual cows is still a long stretch from knowing the most economically efficient size of cow for the herd. Results connecting size and economic efficiency vary greatly in previous research. In a weaner system, income is generated from selling calves to the feedlot, as well as from culls. Expenses that can be allocated to the beef enterprise are charged either per live mass or per head of cattle.

3. MATERIALS AND METHODS

Cattle were grouped as either small, medium, or large, with mature weights of 300, 450, and 600 kg, respectively. The net energy requirements of individual cattle were then calculated for maintenance, growth, lactation, and fetal production for each of the three sizes. The total daily energy requirements (NE_t) were calculated as the sum of the net energy for maintenance (NE_m), the net energy for growth (NE_g), the net energy during lactation (NE_l), and the net energy during pregnancy (NE_y). Thus:

$NE_t = NE_m + NE_g + NE_l + NE_y$

The order in which energy is prioritized for physiological functions is also important. For example, in the case where feed is limited, animals will first compensate by failing to reproduce, since they will allocate energy to the other functions first.

To determine net energy requirements, the growth rates of small, medium, and large cows were first calculated. This was done using Brody's model (Brody, 1945):

$$f(t) = A\ (1\text{-}B^{-kt})$$

where

$f(t)$ gives the expected weight of the animal at time t.

A = asymptotic weight or average adult weight as $t \to \infty$.

B = the constant of integration; thus where $t = 0$, in this case when the calf is born.

k = growth rate.

t = time after t_0 in days.

The mature animal weights of 300, 450, and 600 kg were substituted for A. The birth weight of calves was set at 6.67% of their mature weight, and it was assumed that animals reached 97.5% of mature weight at 1552 days. By solving the values in this equation, the weight at each day, as well as the daily gain, from birth to 1552 days was calculated for small, medium, and large cows.

To calculate maintenance energy requirements

$$daily\ NE_m = 0.077 Mcal/BW^{0.75}$$

where BW is the body weight of the animal (Lofgreen & Garrett, 1968). The body weight of each animal increased daily as the animal grew, which meant that daily NE_m increased daily until animals were classified as mature at 1553 days.

The energy requirement for growth was calculated using the equation

$NE_g = RE = 0.0635 * EBW^{0.75} * EBG^{1.097}$ (Mcal)

where EBW is empty body weight and EBG is empty body gain (Garrett, 1980; National Research Council, 1984, 2000). EBW and EBG were used in the equation because it takes into account that the composition of gain from birth to maturity varies. Shortly after birth, animals deposit proportionately more protein and, closer to maturity, proportionately more fat in the form of daily gain. The equations for calculating EBW and EBG used were:

$EQSBW = SBW * (SRW/FSBW)$

$EQEBW = 0.891 * EQSBW$

$EBG = 0.965 * SWG$

$NE_g = RE = 0.0635 * EQEBW^{0.75} * EBG^{1.097}$

where

$EQSBW$ = equivalent shrunk body weight.

SRW = standard reference weight, which refers to the 478 kg mature weight of the comparative slaughter experiments mentioned above.

$FSBW$ = final shrunk body weight which, in this case, was taken as the mature weight of the animals, and thus 300, 450, and 600 kg for this study.

$EQEBW$ = equivalent empty body weight.

EBG = empty body weight gain.

SWG = shrunk body weight gain which, in this case, is the daily gain as computed using Brody's growth model, as discussed above.

Growth rates of steers and heifers were assumed to be equal, as little difference was found in growth rates where bull calves were castrated early (National Research Council, 2000). To calculate the growth of calves from first- and second-calf cows, the expected mature weight was set at, respectively, 92 and 95% of the expected mature weight of calves from mature cows, in line with results from previous research as cited by the NRC (National Research Council, 2000).

Net energy requirements for lactation were calculated from the equation:

$NE_l = Y_t * E$

where Y_t is daily milk yield in kg and E is the energy content of 1 kg of milk

E was calculated as 0.7178 Mcal/kg from the equation of Tyrrell and Reid (1964):

$E = (0.092 * \textit{fat percent}) + (0.049 * \textit{SNF percent}) - 0.0569$

A fat content and SNF (solids non-fat) content of 4 and 8.3%, respectively, was used as recommended by the NRC. To determine milk yield, the equation prescribed by Jenkins & Ferrell was used (Jenkins & Ferrell, 1984):

$Y_n = n/ae^{kn}$

Where

n is the time, in weeks, postpartum.

$a = 1/(\text{peak milk yield} * k * e)$.

$k = 1/\text{week of peak milk yield}$.

By sighting previous research, the NRC concluded that peak milk yield occurred at 8.5 weeks on average. This was calculated over a wide range of beef cow breeds. Therefore

$k = 1/8.5$

was taken for all sizes.

Little information is available in terms of milk yield in the South African beef sector. A peak milk yield of 10 kg/day was used for medium cows, in accordance with previous research done on Bonsmara cows (Maiwashe et al., 2013). The calf weight of small-, medium-, and large-framed breeds was assumed to be 20, 30, and 40 kg, respectively. By assuming that metabolic weight and the net energy requirements of calves are proportionate, and thus arguing that milk yield is dependent on metabolic weight, the peak milk yield for small- and large-framed cows was calculated as follows:

$MY = CW^{0.75}/30\ \text{kg}^{0.75} * 10\ \text{kg/day}$

where

MY is the calculated peak milk yield and CW is the birth weight for small and large calves, respectively, giving a peak milk yield of 7.38…kg/day and 12.41…kg/day for small and large cows, respectively.

It is common practice to wean calves at 7 months. Thus, the lactation time was assumed to be 205 days irrespective of size. Furthermore, it was assumed that 2-year-old heifers produce 26% less milk and 3-year-old cows produce 12% less milk throughout the first and second lactations, in accordance with results published by the NRC (National Research Council, 2000).

To calculate net energy for production, the NRC derived an equation from the work of Ferrell et al. (1976), which gives:

$NE_y = 0.576\ \textit{birth weight}\ (0.4504 - 0.000766t)\ e^{(0.03233 - 0.0000275t)t}$ kcal

where t is the time after conception. For this study, birth weight was assumed to be 6.67% of mature weight, similar to data reported in the *Performance Information from Breeds Participating in the National Beef Recording and Improvement Scheme* of South Africa (Scholtz, 2010), where the average calf birth weight was 6.7% of cow weight in the seed stock industry from 1999 to 2008. Gestation length was assumed to be 283 days for all three sizes. Therefore, using the above equations, growth and net energy requirements of individual cows could be calculated.

The resource base was defined as a farm that can maintain 500 non-pregnant, non-lactating cows of 450 kg live weight, and thus the annual total net energy available on the resource base was calculated to be 1,372,976 Mcal. It was assumed that feed was available as required by the animals throughout the year. Thus, there were no periods when there was a feed shortage. An extensive weaner production system, as is most commonly applied in the research area, was used to determine herd composition and stock flow. Animals were managed on savannah or grassland and grazed year round with no supplementary feeding, although mineral licks were supplied.

Animals were divided into six classes:

1) Mature cows (MC): cows were classified as MC at 1553 days. These are cows that had two or more calves. MC were bred and fell pregnant on 23 December. Non-pregnant MC were culled on 30 April. MC calved on 1 October.

2) Second-calf cows (SCC): cows were classified as SCC at 1188 days. These cows were bred for the second time on 23 December at 1179 days, culled on 30 April, and calved on 1 October.

3) First-calf cows (FCC): cows were classified as FCC at 823 days. These cows were bred for the first time on 22 September at 722 days, culled on 31 January, and calved on 1 July.

4) Retained cow calves (RCC): heifers were classified as RCC at 458 days. These were heifers retained to replace culls from the other cow groups. All RCC came from MC rather than FCC or SCC.

5) Calves: calves from either MC, SCC or FCC. Calves from MC and SC were born on 1 October, weaned 23 April at 205 days, and sold on 30 April at 212 days. Calves from FCC were born on 1 July, weaned on 21 January at 205 day,s and sold on 31 January at 215 days.

6) Bulls: bulls were assumed to be mature throughout their lifetime in the herd. The number of bulls was assumed to be 1/25 of all breedable cows at the highest quantity. Bulls were replaced at 20%, and they were culled and replaced on 30 November after compensating for loss due to mortality.

The targets from the Department of Agriculture & Rural Development suggests that farmers aim for a calving percentage of 90% for heifers bred at 2 years, 75% for FCC and 80% for MC, and these targets were used to compile the stock flow. A mortality rate of 1% was assumed for all animals except calves, which was set at 3%. Deaths were calculated monthly.

From the growth rate calculation, for every single day that the animal spends in the herd, its weight was known. From the energy requirement calculation, the exact energy need of each animal in the herd for every day was also known. From the stock flow calculation, the number of animals of each class was known. By matching the energy requirements of individual animals to stock flows, the energy requirements of the herd cold be calculated. Animal numbers were increased until the herd consumed 1,372,976 Mcal annually.

To determine the economic efficiency of the herd, net profit over allocated costs was calculated. This was done from the stock flows. Income was generated from calf sales and culls of cows and bulls. MC and SCC culls were sold as C2/3 beef; FCC culls were sold as B2/3 beef. The classification of beef was done according to the recommendations of Brody (1945). Prices for culls and weaners were obtained from the Red Meat Producers Association (RMPA) and ABSA, and the average prices for 2017 were used. It was assumed that all animals of all classes yielded a carcass of 52% of live weight, which gave a live price of R21.05/kg and R20.38/kg for B2/3 and C2/3, respectively, and a live price of R32.25/kg for weaners (Red Meat Producers Organization ABSA ABSA Weekly Prices, 2018).

Bulls were replaced by buying breeding stock. It was assumed that the cost of a bull was eight times the market value of a weaner calf, a practical rule of thumb. This gave a price of R112.00/kg or R33,599, R50,398 and R67,198 for a 300-, 450- and 600-kg replacement bull, respectively.

Other expenses were adapted from the production budgets of Senwes Agricultural Services for extensive beef production in the North-West and Free state provinces (Senwes Agricultural Services, 2017). The expenses used to calculate all allocated costs, the motivation for the expense, the animal classes to which it applies, the timing thereof, the dosage, and the price are summarized in Table 1. Protein lick was given for 6 months through winter, starting 1 May, and a phosphate lick for 6 months through summer, starting 1 November. Voermol's Premix 450 and Supefos were used in this research. It was assumed that lick intake was directly equivalent to NE_t requirements, and the highest NE_t of an individual animal was matched to the maximum recommended intake for the lick. Feed prices were obtained from Voermol's sales representative in the Potchefstroom/Klerksdorp region. Prices for Vit-Aid, Bovitect III, and Cattle master 4 were obtained from ANB Veterinary Wholesalers (2018). The price for the Rift Valley Fever vaccine was obtained from ONB's sales representative. Prices for all other doses, vaccines, and dips were obtained from Vet Products Online (2018). All product prices were inclusive of VAT.

Retained cow calves were processed and given ear tags, which incurred a direct cost of R70.00 per animal. Veterinary costs were R50.00 per animal, as in Senwes Agricultural Services (2017) and applied to cows in the months in which they were tested for pregnancy and culled (April and January), calves in the months they were sold (April and January), retained heifers in April, and bulls in December. Where expenses were charged per head, these were matched to the animal numbers in the herd. Where expenses were charged according to body weight, these were matched to the live weights (kg) of the animals to which they applied on the day they were administered. By calculating income and expenses as described above, the gross profit above allocated costs was determined.

Since previous research suggests that larger cattle have a lower reproduction rate than smaller cattle under similar conditions, the reproduction rate where the herds of large and medium cattle would become less profitable than those of small cattle was calculated. This was done by lowering the reproduction rates of MC, SCC, and FCC proportionately until the profitability of the herds of large and medium cattle became less profitable than those of small cattle. All other assumptions were left unchanged. Lowering reproduction rates changed the herd composition and stock flow, but the calculation thereof was unchanged. Income and expenses were matched to the adapted stock flows similarly, as described above.

Previous literature suggests that smaller cattle mature faster and therefore provide the opportunity for earlier breeding. The lifetime energy requirements of early-bred heifers were calculated in a similar manner as before. The profitability of a herd where heifers were bred at 15 months for small and medium cattle was calculated. This calculation led to a change in the classes of animals and subsequent change in the stock flow described previously. The RCC class was inapplicable, while the FCC was classified as such at 458 days and was already bred at 449 days on 23 December, culled on 1 April, and calved on 1 October. SCC were classified as such at 823 days and were bred at 814 days on 23 December, culled on 30 April, and calved on 1 October; a reproduction rate of 75% was assumed. TCC were classified as such at 1188 days, bred at 1179 days on 23 December, culled on 30 April, and calved on 1 October; a reproduction ate of 80% was assumed. MC were unchanged from the initial calculation but had one more calf before they were mature, and a reproduction rate of 80% was assumed. Next, the stock flow and production budget for the herds of small and medium cows that were bred early were calculated following the guidelines described earlier. The reproduction rates of early-bred FCC that would make the herds of small and medium cattle more profitable than those of large cattle, bred late, were calculated.

Previous research suggests that different-sized cattle perform differently when feed is limited. The effect of feed restriction on cows of the three sizes was examined where:

1. Feed is limited to a specific quantity per animal, regardless of animal size.
2. The calculated energy requirements of small, medium, and large cattle are considered and then reduced by a percentage.
3. Feed is limited as a proportion of metabolic weight.
4. Feed is made available according to large-stock unit (LSU).

Table-1. Supplementary feed, dosing, vaccinations, and dipping schedule and expenses (personal collection from various sources).

Product	Manufacturer and reference	Motivation	Relevant animals	Timing	Dosage	Price
Licks						
Voermol Premix 450	Voermol Our Products (2018)	Protein lick for winter	All	1 May–31 Oct	Max: 500g/ animal/day	R205.05/ 50 kg
Voermol Superfos	Voermol Our Products (2018)	Phosphate lick for summer	All	1 Nov–30 Apr	Max: 240g/animal/day	R260.30/50 kg
Dosing						
Tramisol Plus	Afrivet (2018)	Roundworm and liver fluke	Bulls, MC, SCC, FCC, RCC, RCC from MC	1 Nov (all relevant animals)	15 ml/50 kg	R134.41/200 ml
Ex-A-Lint	MSD (2018)	Milk tapeworm	Calves	1 Jan, 1 Apr (calves from MC and SCC) 1 Oct, 1 Jan (calves from FCC)	1 ml/4 kg	R1898.55/5 l
Valbazen	Zoetis (2018)	Roundworm and milk tapeworm	Bulls, MC, SCC, FCC, RCC, RCC from MC	1 May, 1 Nov (bulls, MC, SCC, FCC) 1 Feb, 1 Aug (RCC, RCC from MC)	1 ml/10 kg	R1999.40/5 l
Vit-Aid	Afrivet (2018)	Vitamin A supplement	Bulls, MC, SCC, FCC, RCC, RCC from MC	1 Jul (all relevant animals)	1 ml/250 kg	R208.28/100 ml
Multimin	Virbac (2018)	Trace mineral supplement	Bulls, MC, SCC, FCC, RCC, RCC from MC	1 Nov (bulls, MC, SCC) 1 Aug (FCC, RCC, RCC from MC)	1 ml/100 kg	R1997.09/500 ml
Vaccinations						
Cattle Master 4	Zoetis (2018)	Bovine viral diarrhea	Bulls, MC, SCC, FCC, RCC, RCC from MC	1 Nov (bulls, MC, SCC, FCC) 1 Aug (RCC, RCC from MC)	2 ml/animal	R818.28/25 doses
Supavax® (MSD)	MSD (2018)	Botulism, anthrax, blackquarter	All animals	1 Nov (bulls, MC, SCC, FCC) 1 Aug (RCC and RCC from MC) 1 Jan,1 Apr (calves from MC and SCC) 1 Oct, 1 Jan (calves from FCC)	2 ml/animal	R741.92/50 doses
Bovilis S	MSD (2018)	Paratyphoid (inactivated)	Pregnant animals	1 Aug (MC, SCC) 1 May (FCC)	2 ml/animal	R47.00/10 ml
RB-51	MSD (2018)	*Brucella abortus*	Female animals before breeding	1 Nov (MC, SCC, FCC) 1 Aug (RCC)	2 ml/animal	R1009.63/25 doses
Bovi-Tect III	MSD (2018)	*Pasteurella*	Female animals	1 Aug (all relevant animals)	1 ml/animal	R1839.42/100 ml
Rift Valley fever (OBP)	OBP (2018)	Rift Valley fever (incativated)	Bulls, MC, SCC, FCC, RCC, RCC from MC	1 Aug (all relevant animals)	2 ml/animal	R688.42/100 ml
Dip						
Drastic Deadline	Bayer (2018)	Ticks, tsetse flies, red lice	All animals	1 Nov (all animals) 1 May (bulls, MC, SCC, RCC, RCC from MC)	5 ml/50 kg	R3250.50/6l

4. RESULTS AND DISCUSSION

4.1. Biological Efficiency of Individual Cows

All individual cattle used more than 70% of total lifetime net energy requirements purely for maintenance (71.8, 71.1, and 70.8% for small, medium, and large cows, respectively). This left a small portion for the functions growth, lactation, and reproduction, consistent with previous research (Jenkins & Ferrell, 2002; National Research Council, 2000). The net energy requirements of a medium cow are illustrated visually in Figure 1.

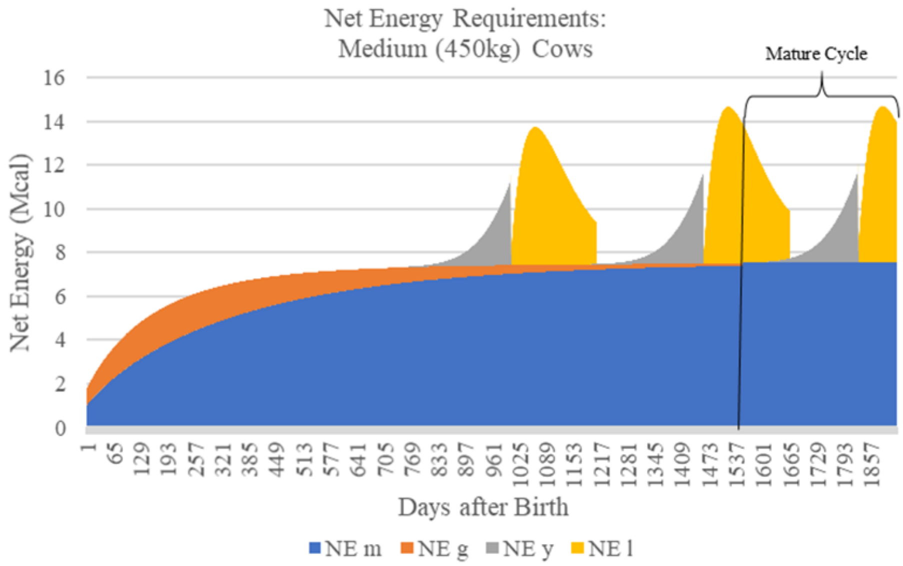

Figure-1. Net energy requirements of medium-sized cow from birth to 1979 days.

Although small cows need less energy for all physiological functions at any moment, they need proportionately more net energy than larger cows. To illustrate this, a small cow is 50% the size of a large cow but the net energy needs of the former are 58% (23,669 Mcal) that of the latter (40,553 Mcal). The composition of energy requirements for small, medium, and large cows ais different, as larger cows use proportionately less net energy for maintenance and lactation. Net energy requirements for small, medium, and large cows until the end of their first adult cycle are summarized in Table 2.

Table-2. Lifetime energy requirements of small, medium, and large cows.

		Growing animals			Mature animals			Total time in herd		
		Birth to 1552 days			One mature cycle			Birth to 3377 days		
		Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
NE requirements (Mcal)	NE_m	6,870	9,311	11,554	2,026	2,746	3,407	16,999	23,041	28,590
	NE_g	793	1,237	1,696	-	-	-	793	1,237	1,696
	NE_l	1,042	1,412	1,752	736	997	1,238	4,721	6,399	7,940
	NE_y	315	484	646	168	252	336	1,155	1,746	2,328
	NE_t	9,019	12,445	15,647	2,930	3,996	4,981	23,669	32,423	40,553
NE requirements (% of NE_t)	NE_m	76.20	74.80	73.80	69.10	68.70	68.40	71.80	71.10	70.50
	NE_g	8.80	9.90	10.80	0.00	0.00	0.00	3.30	3.80	4.20
	NE_l	11.60	11.30	11.20%	25.10	25.00	24.80	19.90	19.70	19.60
	NE_y	3.50	3.90	4.10	5.70	6.30	6.80	4.90	5.40	5.70
	NE_t	100.00	100.00	100.0	100.00	100.00	100.00	100.00	100.00	100.00

4.2. Stock Flows and Herd Composition

For a resource base that has an annual energy yield of 1,372,976 Mcal, more small cows could be kept on the resource base. Herd compositions were different but, as an example, the resource base could support 236.6 small mature cows, 171.9 medium mature cows, or 136.9 large mature cows. The stock flow is summarized with monthly animal numbers in Tables 3–5. From these tables it is clear that the herd of small cattle has more heads of all classes of animals at any stage, but the composition is different for each herd. From the stock flows, both income and expenses could be calculated.

Table-3. Stock flows for a herd of small-sized cattle.

-			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MC		236.6	236.6	236.4	236.2	236.0	188.6	188.5	188.3	188.2	188.0	187.8	187.7	187.5
Pregnant MC	Calving (%)	80	189.3	189.1	188.9	188.8	188.6	188.5	188.3	188.2	188.0			150.0
Open MC			47.3	47.3	47.2	47.2								37.5
Deaths	Death (%)	1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Culls		19				47.2								
SCC			66.2	66.1	66.1	66.0	49.5	49.4	49.4	49.4	49.3	49.3	49.2	49.2
Pregnant SCC	Calving (%)	7	49.7	49.6	49.6	49.5	49.5	49.4	49.4	49.4	49.3			39.4
Open SCC			16.6	16.5	16.5	16.5								9.8
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						16.5								
FCC			74.3	66.8	66.8	66.7	66.6	66.6	66.5	66.5	66.4	66.4	66.3	66.3
Pregnant FCC	Calving (%)	90	66.9	66.8	66.8	66.7	66.6	66.6						49.7
Open FCC			7.4											16.6
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls			7.4											
RCC			75.0	75.0	74.9	74.9	74.8	74.7	74.7	74.6	74.5	74.5	74.4	74.4
Pregnant RCC											67.1	67.0	67.0	66.9
Open RCC											7.5	7.4	7.4	7.4
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calves from MC			186.6	186.1	185.7	185.2						188.0	187.5	187.1
Deaths	Death (%)	3	0.5	0.5	0.5	0.5						0.5	0.5	0.5
Calves sold from MC						108.4								
RCC from MC						76.7	76.6	76.4	76.2	76.0	75.8	75.6	75.4	75.2
Deaths	Death (%)	3				0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Calves from SCC			49.0	48.8	48.7	48.6						49.3	49.2	49.1
Deaths	Death (%)	3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						48.5								
Calves from FCC			65.6	-					66.6	66.4	66.3	66.1	65.9	65.8
Deaths	Death (%)	3	0.2						0.2	0.2	0.2	0.2	0.2	0.2
Calves sold from FCC			65.4											
Bulls			15.1	15.1	15.1	15.1	15.1	15.1	15.0	15.0	15.0	15.0	15.0	15.1
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls													2.9	
Purchased	Replace (%)	20											3.0	

Table-4. Stock flow for a herd of medium-sized cattle.

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MC		171.9	171.9	171.7	171.6	171.5	137.1	136.9	136.8	136.7	136.6	136.5	136.4	136.3
Pregnant MC	Calving (%)	80	137.5	137.4	137.3	137.2	137.1	136.9	136.8	136.7	136.6			109.0
Open MC			34.4	34.3	34.3	34.3								27.3
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls		19				34.3								
SCC			48.1	48.1	48.0	48.0	36.0	35.9	35.9	35.9	35.8	35.8	35.8	35.7
Pregnant SCC	Calving (%)	75	36.1	36.0	36.0	36.0	36.0	35.9	35.9	35.9	35.8			28.6
Open SCC			12.0	12.0	12.0	12.0								7.1
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						12.0								
FCC			54.0	48.5	48.5	48.5	48.4	48.4	48.3	48.3	48.3	48.2	48.2	48.1
Pregnant FCC	Calving (%)	90	48.6	48.5	48.5	48.5	48.4	48.4						36.1
Open FCC			5.4											12.0
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls			5.4											
RCC			54.5	54.5	54.4	54.4	54.3	54.3	54.3	54.2	54.2	54.1	54.1	54.0
Pregnant RCC											48.7	48.7	48.7	48.6
Open RCC											5.4	5.4	5.4	5.4
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calves from MC			135.6	135.2	134.9	134.6						136.6	136.3	135.9
Deaths	Death (%)	3	0.3	0.3	0.3	0.3						0.3	0.3	0.3
Calves sold from MC						78.8								
RCC from MC						55.8	55.6	55.5	55.3	55.2	55.1	54.9	54.8	54.7
Deaths	Death (%)	3				0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calves from SCC			35.6	35.5	35.4	35.3						35.8	35.7	35.7
Deaths	Death (%)	3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						35.2								
Calves from FCC			47.7	-					48.4	48.3	48.1	48.0	47.9	47.8
Deaths	Death (%)	3	0.1						0.1	0.1	0.1	0.1	0.1	0.1
Calves sold from FCC			47.5											
Bulls			11.0	11.0	11.0	11.0	10.9	10.9	10.9	10.9	10.9	10.9	10.9	11.0
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls													2.1	
Purchased	Replace (%)	20											2.2	

Table-5. Stock flow for a herd of large-sized cattle.

-			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MC		136.9	136.9	136.8	136.7	136.6	109.2	109.1	109.0	108.9	108.8	108.7	108.6	108.5
Pregnant MC	Calving (%)	80	109.5	109.4	109.4	109.3	109.2	109.1	109.0	108.9	108.8			86.8
Open MC			27.4	27.4	27.3	27.3								21.7
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls		19%				27.3								
SCC			38.3	38.3	38.3	38.2	28.6	28.6	28.6	28.6	28.5	28.5	28.5	28.5
Pregnant SCC	Calving (%)	75	28.7	28.7	28.7	28.7	28.6	28.6	28.6	28.6	28.5			22.8
Open SCC			9.6	9.6	9.6	9.6								5.7
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						9.5								
FCC			43.0	38.7	38.6	38.6	38.6	38.5	38.5	38.5	38.4	38.4	38.4	38.3
Pregnant FCC	Calving (%)	90	38.7	38.7	38.6	38.6	38.6	38.5						28.8
Open FCC			4.3											9.6
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls			4.3											
RCC			43.4	43.4	43.4	43.3	43.3	43.3	43.2	43.2	43.1	43.1	43.1	43.0
Pregnant RCC											38.8	38.8	38.8	38.7
Open RCC											4.3	4.3	4.3	4.3
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Calves from MC			108.0	107.7	107.5	107.2						108.8	108.5	108.3
Deaths	Death (%)	3	0.3	0.3	0.3	0.3						0.3	0.3	0.3
Calves sold from MC						62.8								
RCC from MC						44.4	44.3	44.2	44.1	44.0	43.9	43.8	43.6	43.5
Deaths	Death (%)	3				0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calves from SCC			28.3	28.3	28.2	28.1						28.5	28.5	28.4
Deaths	Death (%)	3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						28.0								
Calves from FCC			38.0	-					38.5	38.4	38.3	38.3	38.2	38.1
Deaths	Death (%)	3	0.1						0.1	0.1	0.1	0.1	0.1	0.1
Calves sold from FCC			37.9											
Bulls			8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.8
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls													1.7	
Purchased	Replace (%)	20											1.8	

4.3. Energy Requirements of Herds

The NE_t values for individual animals of each of the different classes were used to calculate the total number of small, medium, and large cows that can be maintained on a resource base in terms of total net energy. Results showed differences in the composition of NE_t and are summarized in Table 6. Net energy for maintenance for herds of small, medium, and large cattle was 73.1, 72.0, and 71.2%, respectively. This is mainly due to the fact that growing animals use a larger proportion of NE_t for NE_m than productive mature animals, as well as the fact that bulls have to be retained on the resource base. NE_m of the productive cow herd (MC, SCC, and FCC) amounted to 70.2, 69.6, and 69.3% for herds of small, medium, and large cattle, respectively, when calculated as a portion of total herd NE_t. Similar results were obtained by Jenkins and Ferrell (1984). Therefore, the herd of large cattle allocated more energy to growth and reproduction, making it comparatively biologically efficient.

4.4. Economic Efficiency

The herd of large cattle was more profitable under the initial assumptions. The herd of small cattle had more heads of weaners (222.34) but less weight (28,034 kg) for sale, compared to 161.56 weaners and 30,554 kg for the herd of medium cattle and 128.68 weaners and 32,450 kg for the herd of large cattle. Cow and bull culls from the herd of small cattle yielded less weight (19,747 kg for C2/3 and 1,950 kg for B2/3) than the herd of medium (21,522 kg for C2/3 and 2,125 kg for B2/3) and large (22,858 kg for C2/3 and 2,833 kg for B2/3) cattle. As a result, the herd of small cattle had the lowest income (R1,347,373.98) compared to R1,468,502.53 and R1,571,754.71 for the herds of medium and large cattle, respectively. Some expenses were charged on a per-head basis and some were charged on a live weight basis. Bull replacement costs for the herd of small cattle were the lowest of the three, since bull replacements were calculated as a price per kg of live bull. The herd of small cattle replaced 907.7 kg of live bull (3 heads) compared to 989.3 kg (2.2 heads) and 1,050.7 kg (1.8 heads) for the medium and large cattle. There was a negligible difference in the cost of supplementary licks between the three herds, with the herd of small cattle having the lowest cost.

Table-6. Energy requirements of animal classes in herds of small, medium, and large cattle.

Herd energy composition	Small		Medium		Large	
MC: NE_m	413,135	30.10%	406,870	29.60%	402,129	29.30%
MC: NE_l	154,729	11.30%	152,383	11.10%	150,607	11.00%
MC: NE_y	31,646	2.30%	34,491	2.50%	36,631	2.70%
MC: NE_t	599,510	43.70%	593,744	43.20%	589,367	42.90%
SCC: NE_m	107,864	7.90%	106,228	7.70%	104,990	7.60%
SCC: NE_g	2,157	0.20%	2,445	0.20%	2,670	0.20%
SCC: NE_l	21,591	1.60%	21,263	1.50%	21,016	1.50%
SCC: NE_y	7,887	0.60%	9,049	0.70%	9,610	0.70%
SCC: NE_t	139,499	10.20%	138,985	10.10%	138,286	10.10%
FCC: NE_m	126,800	9.20%	124,877	9.10%	123,422	9.00%
FCC: NE_g	6,329	0.50%	7,174	0.50%	7,835	0.60%
FCC: NE_l	40,813	3.00%	40,194	2.90%	39,725	2.90%
FCC: NE_y	10,127	0.70%	11,038	0.80%	11,723	0.90%
FCC: NE_t	184,069	13.40%	183,283	13.30%	182,706	13.30%
RCC: NE_m	126,442	9.20%	124,525	9.10%	123,074	9.00%
RCC: NE g	16,027	1.20%	18,168	1.30%	19,842	1.40%
RCC: NE_y	188	0.00%	205	0.00%	218	0.00%
RCC: NE_t	142,658	10.40%	142,899	10.40%	143,134	10.40%
Calves from MCs: NE_m	79,982	5.80%	78,769	5.70%	77,852	5.70%
Calves from MCs: NE_g	37,961	2.80%	43,034	3.10%	46,997	3.40%
RCC from MC: NE_m	67,637	4.90%	66,611	4.90%	65,835	4.80%
RCC from MC: NE_g	18,444	1.30%	20,909	1.50%	22,835	1.70%
Calves from SCC: NE_m	20,191	1.50%	19,885	1.40%	19,653	1.40%
Calves from SCC: NE_g	9,059	0.70%	10,269	0.70%	11,215	0.80%
Calves from FCC: NE_m	27,165	2.00%	26,753	1.90%	26,442	1.90%
Calves from FCC: NE_g	11,715	0.90%	13,280	1.00%	14,503	1.10%
All calves: NE_t	272,156	19.80%	279,512	20.40%	285,333	20.80%
Bulls: NE_m	35,085	2.60%	34,553	2.50%	34,151	2.50%
Bulls: NE_t	35,085	2.60%	34,553	2.50%	34,151	2.50%
Total herd: NE_m	1,004,303	73.10%	989,073	72.00%	977,548	71.20%
Total herd: NE_g	101,692	7.40%	115,280	8.40%	125,898	9.20%
Total herd: NE_l	217,133	15.80%	213,840	15.60%	211,348	15.40%
Total herd: NE_y	49,849	3.60%	54,783	4.00%	58,182	4.20%
Total herd: NE_t	1,372,976	100.00%	1,372,976	100.00%	1,372,976	100.00%

Dosing and dip expenses were administered on a live kilogram basis. In all instances the herd of small cattle had the fewest body weight and the herd of large cattle had the highest body weight for which dosing and dips were administered, which resulted in lower expenses in this category for the herd of small cattle. Vaccination and processing and veterinary costs were charged on a per-head basis, and subsequently the herd of small cattle had the highest costs since more heads of small cattle were on the resource base at any time. Total allocated costs were the highest for the herd of small cattle at R401,362.47, followed by the medium cattle at R383,386.56. The allocated costs for the herd of large cattle were the lowest at R376,756.53, due to various costs being charged on a per-head basis. The work of Dickerson (1978) and Johnson et al. (2010), among others, also stipulated that switching from a herd of large to small cows will increase variable costs.

The gross profit above allocated costs was 9% higher for the herd of large cattle (R1,182,864.73) than the herd of medium cattle (R1,085,115.97) and 25% higher than the herd of small cattle (R946,011.50). The full production budgets, which detailing both income and expenses, are provided in Table 7.

4.5. Reproduction Rates and Profitability

Larger cows normally have a lower reproduction rate under similar circumstances. When reproduction rates are higher, feed efficiency and profitability increase. In fact, Dickerson (1978) observed the following; "Increasing N (reproduction rates) reduces female replacement, maintenance feed and fixed costs in almost direct proportions to 1/N, including the fixed cost of pregnancy and lactation status."

The reproduction rates where large and medium cows would become less profitable than small cows were calculated. From the results, when reproduction rates of medium cattle were 84.59% that of small cattle, both sizes were equally profitable. Therefore, at reproduction rates <67.67% for mature cows, 63.44% for SCC ,and 76.13% for FCC, medium cattle will be less profitable than small cattle. When reproduction rates of large cattle were 75.35% that of small cattle, they were equally profitable. Therefore, at reproduction rates <60.28% for MC, 56.51% for SCC, and 67.81% for FCC, large cattle were less profitable than small cattle. Lowering the reproduction rate of the herds of medium and large cattle led to a change in the stock flow. More cows were culled, and more replacement cows needed to be raised. The medium and large herds therefore used more net energy for maintenance. Stock flows for the herds of medium and large cattle at these lower reproduction rates are given in Tables 8 and 9. The subsequent production budget with net income matched for the three herds is given in Table 10.

4.6. Maturity Rates and Profitability

Smaller cattle mature faster than larger cattle, which provides the opportunity for early breeding. When cows were bred at 15 months, this changed lifetime energy requirements and is illustrated in Figure 2 for medium cows. This can be directly compared to Figure 1 where medium cows were bred at 24 months. When small cattle were bred at 15 months, at a calving rate of only 44.5% it was more profitable than when the same small cows were bred at 24 months. When medium cattle were bred at 15 months, a calving rate of 37.8% was needed to be more profitable than when similar-sized cows were bred at 24 months. Even when the herd of small cattle were bred at 15 months with a reproduction rate of 100%, it was still less profitable than the herd of large cattle bred at 24 months, providing that the reproduction rates of all other classes of animals were similar. When the herd of medium cattle were bred at 15 months, at a calving rate of 54% for FCC, it matched the profit of the herd of large cattle that were bred at 24 months, providing that the reproduction rates of other classes were equal.

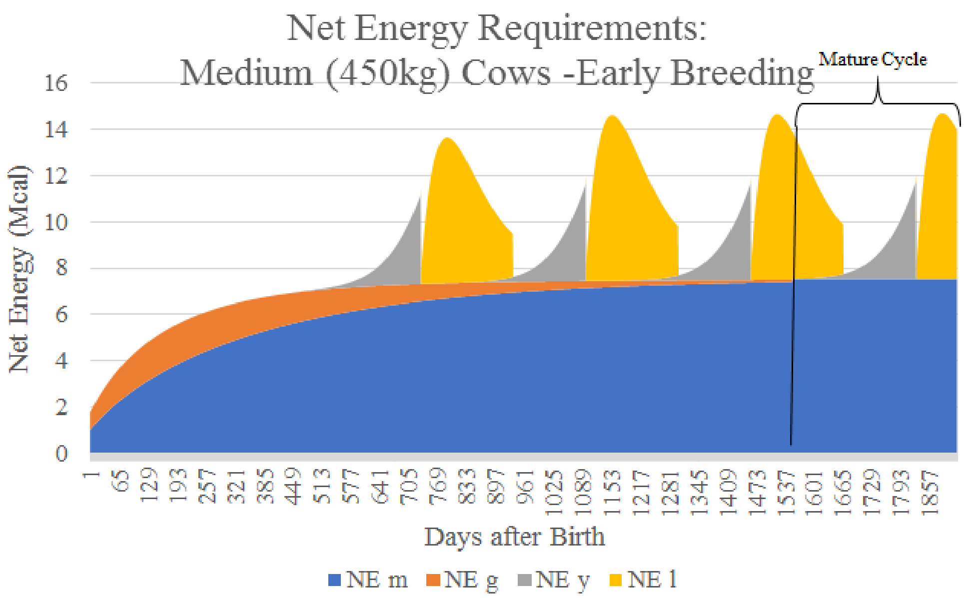

Figure-2. Net energy requirements of medium-sized cows from birth to 1979 days when bred at 15 months.

Table-7. Production budget for herds of small, medium, and large cattle.

			Small cattle		Medum cattle		Large cattle	
Income								
Cattle sales		Price/kg	Total kg		Total kg		Total kg	
Culled MC	Class C2/3	R 20.38	14,146.99	R 288,254.91	15,418.80	R 314,168.95	16,375.52	R 333,662.74
Culled FCC	Class C2/3	R 20.38	4,737.41	R 96,528.15	5,163.31	R 105,206.00	5,483.68	R 111,733.90
Culled replacement heifers	Class B2/3	R 21.05	1,949.50	R 41,036.73	2,124.76	R 44,725.92	2,256.60	R 47,501.11
Live weaners sold	Weaners	R 32.25	28,034.07	R 903,979.45	30,554.32	R 985,246.95	32,450.18	R1,046,380.28
Culled bulls	Class C2/3	R 20.38	862.53	R 17,574.74	940.08	R 19,154.71	998.41	R 20,343.23
Total income from cattle sales				R1,347,373.98		R1,468,502.53		R1,559,621.26
Expenses								
Bull purchases		R 112.00	907.71	R 101,660.30	989.32	R 110,799.54	1,050.70	R 117,674.51
Licks		Price/kg	Total kg		Total kg		Total kg	
Winter		R 4.10	16,116.34	R 66,093.13	16,160.73	R 66,275.17	16,188.80	R 66,390.28
Summer		R 5.21	10,328.66	R 53,771.03	10,307.35	R 53,660.07	10,293.88	R 53,589.94
Dosing		Price/ml	Total kg		Total kg		Total kg	
Roundworm and liver fluke	15 ml/50 kg	R 0.67	126,992.38	R 25,603.57	138,408.96	R 27,905.32	146,997.06	R 29,636.81
Milk tapeworm	1 ml/4kg	R 0.38	56,633.95	R 5,376.12	61,725.33	R 5,859.43	65,555.31	R 6,223.00
Roundworm and milk tapeworm	1 ml/10 kg	R 0.40	233,462.21	R 9,335.69	254,450.39	R 10,174.96	270,238.72	R 10,806.31
Vitamin A	1 ml/250 kg	R 2.08	121,485.17	R 1,012.12	132,406.66	R 1,103.11	140,622.32	R 1,171.55
Trace minerals	1 ml/100 kg	R 3.99	124,287.27	R 4,964.26	135,460.66	R 5,410.54	143,865.82	R 5,746.26
Vaccinations		Price/ml	Total animals		Total animals		Total animals	
BVD	2ml/animal	R 16.37	468.82	R 15,344.97	340.64	R 11,149.65	271.33	R 8,881.11
Botulism, anthrax, blackquarter	2ml/animal	R 7.42	1,069.83	R 15,874.57	777.34	R 11,534.46	619.18	R 9,187.62
Paratyphoid (inactivated)	2ml/animal	R 20.34	304.16	R 12,372.08	221.00	R 8,989.55	176.04	R 7,160.50
Brucella abortus	2ml/animal	R 20.19	377.84	R 15,259.23	274.54	R 11,087.36	218.68	R 8,831.49
Pasteurella	1 ml/animal	R 18.39	454.59	R 8,361.75	330.30	R 6,075.65	263.10	R 4,839.48
Rift Valley fever (incativated)	2ml/animal	R 6.88	469.61	R 6,465.84	341.22	R 4,698.08	271.80	R 3,742.19
Dips		Price/ml	Total kg		Total kg		Total kg	
Ticks, tsetse flies, red lice	5 ml/50 kg	R 0.54	262,360.64	R 14,213.39	285,946.79	R 15,491.17	303,689.43	R 16,452.37
Other costs		Price/animal	Total animals		Total animals		Total animals	
Processing		R 70.00	76.75	R 5,372.35	55.76	R 3,903.55	44.42	R 3,109.32
Veterinary services		R 52.61	765.67	R 40,282.09	556.34	R 29,268.96	443.14	R 23,313.79
Allocated costs				R 401,362.47		R 383,386.56		R 376,756.53
Gross profit above allocated costs				R 946,011.50		R1,085,115.97		R1,182,864.73

Table-8. Stock flow of a herd of medium cattle at a reproduction rate lowered to 84.59% of the base model.

-			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MCs		123.9	123.9	123.8	123.7	123.6	83.5	83.5	83.4	83.3	83.3	83.2	83.1	83.1
Pregnant MC	Calving (%)	67.67%	83.8	83.8	83.7	83.6	83.5	83.5	83.4	83.3	83.3			56.2
Open MC			40.0	40.0	40.0	39.9								26.9
Deaths	Death (%)	1%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls		31%				39.9								
SCC			65.0	65.0	64.9	64.9	41.1	41.1	41.1	41.0	41.0	40.9	40.9	40.9
Pregnant SCC	Calving (%)	63.44%	41.3	41.2	41.2	41.2	41.1	41.1	41.1	41.0	41.0			27.7
Open SCC			23.8	23.8	23.7	23.7								13.2
Deaths	Death (%)	1%	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						23.7								
FCC			86.3	65.6	65.6	65.5	65.5	65.4	65.4	65.3	65.2	65.2	65.1	65.1
Pregnant FCC	Calving (%)	76.13%	65.7	65.6	65.6	65.5	65.5	65.4						41.3
Open FCC			20.6											23.8
Deaths	Death (%)	1%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls			20.6											
RCC			87.1	87.1	87.0	86.9	86.9	86.8	86.7	86.6	86.6	86.5	86.4	86.4
Pregnant RCC											65.9	65.8	65.8	65.7
Open RCC											20.7	20.6	20.6	20.6
Deaths	Death (%)	1%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calves from MC			82.6	82.4	82.2	82.0						83.3	83.1	82.9
Deaths	Death (%)	3%	0.2	0.2	0.2	0.2						0.2	0.2	0.2
Calves sold from MC						(7.1)								
RCC from MC						89.1	88.9	88.7	88.5	88.2	88.0	87.8	87.6	87.4
Deaths	Death (%)	3%				0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Calves from SCC			40.7	40.6	40.5	40.4						41.0	40.9	40.8
Deaths	Death (%)	3%	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						40.3								
Calves from FCC			64.4	-					65.4	65.2	65.1	64.9	64.8	64.6
Deaths	Death (%)	3%	0.2						0.2	0.2	0.2	0.2	0.2	0.2
Calves sold from FCC			64.3											
Bulls			11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.1
Deaths	Death (%)	1%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls													2.1	

Purchased	Replace%	20%											2.2	

Table-9. Stock flow of a herd of large cattle at a reproduction rate lowered to 75.35% of the base model.

-			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MCs		78.7	78.7	78.6	78.6	78.5	47.3	47.2	47.2	47.2	47.1	47.1	47.0	47.0
Pregnant MCs	Calving (%)	60.28%	47.4	47.4	47.4	47.3	47.3	47.2	47.2	47.2	47.1			28.3
Open MCs			31.3	31.2	31.2	31.2								18.7
Deaths	Death (%)	1%	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls		39%				31.2								
SCC			56.7	56.6	56.6	56.5	31.9	31.9	31.9	31.8	31.8	31.8	31.8	31.7
Pregnant SCC	Calving (%)	56.51%	32.0	32.0	32.0	31.9	31.9	31.9	31.9	31.8	31.8			19.1
Open SCC			24.6	24.6	24.6	24.6								12.6
Deaths	Death (%)	1%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						24.6								
FCC			84.4	57.2	57.1	57.1	57.0	57.0	56.9	56.9	56.9	56.8	56.8	56.7
Pregnant FCC	Calving (%)	67.81%	57.2	57.2	57.1	57.1	57.0	57.0						32.0
Open FCC			27.2											24.7
Deaths	Death (%)	1%	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls			27.1											
RCC			85.3	85.2	85.1	85.0	85.0	84.9	84.8	84.8	84.7	84.6	84.5	84.5
Pregnant RCC											57.4	57.4	57.3	57.3
Open RCC											27.3	27.2	27.2	27.2
Deaths	Death (%)	1%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Calves from MCs			46.8	46.6	46.5	46.4						47.1	47.0	46.9
Deaths	Death (%)	3%	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from MCs						(40.8)								
RCC from MCs						87.2	87.0	86.8	86.5	86.3	86.1	85.9	85.7	85.5
Deaths	Death (%)	3%				0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Calves from SCC			31.6	31.5	31.4	31.3						31.8	31.7	31.6
Deaths	Death (%)	3%	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						31.3								
Calves from FCC			56.1	-					57.0	56.9	56.7	56.6	56.4	56.3
Deaths	Death (%)	3%	0.1						0.1	0.1	0.1	0.1	0.1	0.1
Calves sold from FCC			56.0											
Bulls			8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Deaths	Death (%)	1%	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Culls													1.7	
Purchased	Replace%	20%											1.8	

Table-10. Production budget for different reproduction rates and equal profitability of small, medium, and large cattle.

			Small cattle: changed reproduction rate		Medium cattle: reproduction rate 85% of small cattle		large cattle: reproduction rate 75% of small cattle	
Income								
Cattle sales		**Price/kg**	**Total kg**		**Total kg**		**Total kg**	
Culled MC	Class C2/3	R 20.38	14,146.99	R 288,254.91	17,960.83	R 365,964.57	18,691.83	R 380,859.15
Culled FCC	Class C2/3	R 20.38	4,737.41	R 96,528.15	10,208.11	R 207,997.38	14,108.41	R 287,468.83
Culled replacement heifers	Class B2/3	R 21.05	1,949.50	R 41,036.73	8,106.43	R 170,638.86	14,257.70	R 300,121.99
Live weaners sold	Weaners	R 32.25	28,034.07	R 903,979.45	17,745.60	R 572,220.07	10,658.67	R 343,696.85
Culled bulls	Class C2/3	R 20.38	862.53	R 17,574.74	945.48	R 19,264.88	1,007.56	R 20,529.74
Total income from cattle sales				R1,347,373.98		R1,336,085.76		R1,332,676.55
Expenses								
Bull purchases		R 112.00	907.71	R 101,660.30	995.01	R 111,436.84	1,060.33	R 118,753.36
Licks		**Price/kg**	**Total kg**		**Total kg**		**Total kg**	
Winter		R 4.10	16,116.34	R 66,093.13	17,193.61	R 70,510.98	17,796.07	R 72,981.68
Summer		R 5.21	10,328.66	R 53,771.03	9,811.57	R 51,079.05	9,522.39	R 49,573.57
Dosing		**Price/ml**	**Total kg**		**Total kg**		**Total kg**	
Roundworm and liver fluke	15 ml/50 kg	R 0.67	126,992.38	R 25,603.57	145,526.75	R 29,340.38	159,337.43	R 32,124.82
Milk tapeworm	1 ml/4kg	R 0.38	56,633.95	R 5,376.12	52,350.18	R 4,969.47	49,681.92	R 4,716.18
Roundworm and milk tapeworm	1 ml/10 kg	R 0.40	233,462.21	R 9,335.69	255,225.13	R 10,205.94	272,014.65	R 10,877.32
Vitamin A	1 ml/250 kg	R 2.08	121,485.17	R 1,012.12	133,125.04	R 1,109.09	141,054.00	R 1,175.15
Trace minerals	1 ml/100 kg	R 3.99	124,287.27	R 4,964.26	140,814.52	R 5,624.39	153,191.23	R 6,118.73
Vaccinacions		**Price/ml**	**Total animals**		**Total animals**		**Total animals**	
BVD	2ml/animal	R 16.37	468.82	R 15,344.97	375.02	R 12,274.89	315.38	R 10,322.91
Botulism, anthrax, blackquarter	2ml/animal	R 7.42	1,069.83	R 15,874.57	750.10	R 11,130.24	584.18	R 8,668.32
Paratyphoid (inactivated)	2ml/animal	R 20.34	304.16	R 12,372.08	189.82	R 7,721.09	136.03	R 5,533.30
Brucella abortus	2ml/animal	R 20.19	377.84	R 15,259.23	275.82	R 11,139.19	220.31	R 8,897.15

Pasteurella	1 ml/animal	R 18.39	454.59	R 8,361.75	364.54	R 6,705.42	306.97	R 5,646.43
Rift Valley fever (incativated)	2ml/animal	R 6.88	469.61	R 6,465.84	375.52	R 5,170.34	315.75	R 4,347.31
Dips		**Price/ml**	**Total kg**		**Total kg**		**Total kg**	
Ticks tsetse flies, red lice	5 ml/50 kg	R 0.54	262,360.64	R 14,213.39	294,989.40	R 15,981.05	319,320.50	R 17,299.19
Other costs		**Price/animal**	**Total animals**		**Total animals**		**Total animals**	
Processing		R 70.00	76.75	R 5,372.35	89.13	R 6,238.99	87.19	R 6,103.18
Veterinary services		R 52.61	765.67	R 40,282.09	559.53	R 29,436.91	447.19	R 23,526.45
Allocated costs				R 401,362.47		R 390,074.26		R 386,665.05
Gross profit above allocated costs				R 946,011.50		R 946,011.50		R 946,011.50

Table-11. Stock flow of a herd of small cattle bred at 15 months.

			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MC		212.5	212.5	212.3	212.2	212.0	169.5	169.3	169.2	169.0	168.9	168.7	168.6	168.5
Pregnant MC	Calving (%)	80	170.0	169.9	169.7	169.6	169.5	169.3	169.2	169.0	168.9			134.8
Open MC			42.5	42.5	42.4	42.4								33.7
Deaths	Death (%)	1	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls		19				42.4								
TCC			55.8	55.7	55.7	55.6	44.5	44.4	44.4	44.3	44.3	44.3	44.2	44.2
Pregnant TCC	Calving (%)	80	44.6	44.6	44.5	44.5	44.5	44.4	44.4	44.3	44.3			35.4
Open TCC			11.2	11.1	11.1	11.1								8.8
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						11.1								
SCC			75.1	75.0	75.0	74.9	56.1	56.1	56.0	56.0	55.9	55.9	55.8	55.8
Pregnant SCC	Calving (%)	75	56.3	56.3	56.2	56.2	56.1	56.1	56.0	56.0	55.9			44.6
Open SCC			18.8	18.8	18.7	18.7								11.2
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						18.7								
FCC			75.8	75.8	75.7	75.7	75.6	75.5	75.5	75.4	75.3	75.3	75.2	75.1
Pregnant FCC	Calving (%)	100	75.8	75.8	75.7	75.7	75.6	75.5	75.5	75.4	75.3			56.4
Open FCC			-	-	-	-								18.8
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls						0.0								
Calves from MC			167.6	167.2	166.8	166.4						168.9	168.5	168.0
Deaths	Death (%)	3	0.4	0.4	0.4	0.4						0.4	0.4	0.4
Calves sold from MC						88.8								
RCC from MC						77.6	77.4	77.2	77.0	76.8	76.6	76.4	76.2	76.0
Pregnant RCC														76.0
Open RCC														-
Deaths	Death (%)	3				0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Calves from TCC			44.0	43.9	43.8	43.6						44.3	44.2	44.1
Deaths	Death (%)	3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from TCC						43.5								
Calves from SCC			55.5	55.4	55.2	55.1						55.9	55.8	55.7
Deaths		3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						55.0								

Calves from FCC			74.8	74.6	74.4	74.2						75.3	75.1	75.0
Deaths	Death (%)	3	0.2	0.2	0.2	0.2						0.2	0.2	0.2
Calves sold from FCC						74.0								
Bulls			16.8	16.8	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.6	16.6	16.8
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls													3.2	
Purchased	Replace (%)	20											3.4	

Table-12. Stock flow of a herd of medium cattle bred at 15 months.

			Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
MC		146.3	146.3	146.2	146.1	145.9	116.6	116.5	116.5	116.4	116.3	116.2	116.1	116.0
Pregnant MC	Calving (%)	80	117.0	116.9	116.8	116.7	116.6	116.5	116.5	116.4	116.3			92.8
Open MC			29.3	29.2	29.2	29.2								23.2
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Culls		19				29.2								
TCC			38.4	38.3	38.3	38.3	30.6	30.6	30.6	30.5	30.5	30.5	30.4	30.4
Pregnant TCC	Calving (%)	80	30.7	30.7	30.7	30.6	30.6	30.6	30.6	30.5	30.5			24.3
Open TCC			7.7	7.7	7.7	7.7								6.1
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						7.7								
SCC			51.7	51.6	51.6	51.6	38.6	38.6	38.6	38.5	38.5	38.5	38.4	38.4
Pregnant SCC	Calving (%)	75	38.8	38.7	38.7	38.7	38.6	38.6	38.6	38.5	38.5			30.7
Open SCC			12.9	12.9	12.9	12.9								7.7
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						12.9								
FCC			97.2	97.1	97.1	97.0	52.0	52.0	51.9	51.9	51.9	51.8	51.8	51.7
Pregnant FCC		54	52.2	52.2	52.1	52.1	52.0	52.0	51.9	51.9	51.9			38.8
Open FCC			45.0	45.0	44.9	44.9								12.9
Deaths	Death (%)	1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls						44.9								
Calves from MC			115.4	115.1	114.8	114.5						116.3	116.0	115.7
Deaths	Death (%)	3	0.3	0.3	0.3	0.3						0.3	0.3	0.3
Calves sold from MC						15.1								
RCC from MC						99.4	99.2	98.9	98.7	98.5	98.2	98.0	97.7	97.5
Pregnant RCC														52.3

Open RCC														45.1
Deaths	Death (%)	3				0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Calves from TCC			30.3	30.2	30.1	30.0						30.5	30.4	30.3
Deaths	Death (%)	3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from TCC						30.0								
Calves from SCC			38.2	38.1	38.0	37.9						38.5	38.4	38.3
Deaths		3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from SCC						37.8								
Calves from FCC			51.5	51.3	51.2	51.1						51.9	51.7	51.6
Deaths	Death (%)	3	0.1	0.1	0.1	0.1						0.1	0.1	0.1
Calves sold from FCC						51.0								
Bulls			13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.2	13.2	13.4
Deaths	Death (%)	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Culls													2.5	
Purchased	Replace (%)	20											2.7	

Table-13. Production budget early-bred small cattle with FCC reproduction rate 100%, early-bred medium cattle with FCC reproduction rate 55% and large cattle as in the base model.

			Small cattle		Medium cattle		Large cattle	
Income			**100% early calving rate**		**54.7% early calving rate**		**As in base model**	
Cattle sales		**Price/kg**	**Total kg**		**Total kg**		**Total kg**	
Culled MC	Class C2/3	R 20.38	12,708.80	R 258,950.82	13,122.79	R 267,386.12	16,375.52	R 333,662.74
Culled TCC	Class C2/3	R 20.38	3,191.86	R 65,036.30	3,295.83	R 67,154.85		
Culled SCC	Class C2/ 3	R 20.38	5,045.82	R 102,812.10	5,210.19	R 106,161.19	5,483.68	R 111,733.90
Culled FCC	Class B2/3	R 21.05	0	R 0.00	15,365.04	R 323,431.44	2,256.60	R 47,501.11
Live weaners sold	Weaners	R 32.25	32,983.39	R1,063,574.09	25,062.17	R 808,148.24	32,450.18	R1,046,380.28
Culled bulls	Class C2/3	R 20.38	957.01	R 19,499.76	1,142.58	R 23,280.88	998.41	R 20,343.23
Total income from cattle sales				R1,509,873.07		R 1,595,562.73		R1,559,621.26
Expenses								
Bull purchases		R 112.00	1,007.14	R 112,795.48	1,202.43	R 134,667.23	1,050.70	R 117,674.51
Licks		**Price/kg**	**Total kg**		**Total kg**		**Total kg**	
Winter		R 4.10	14,515.27	R 59,527.14	15,389.58	R 63,112.67	16,188.80	R 66,390.28
Summer		R 5.21	10,854.52	R 56,508.63	10,677.51	R 55,587.10	10,293.88	R 53,589.94
Dosing		**Price/ml**	**Total kg**		**Total kg**		**Total kg**	
Roundworm and liver fluke	15 ml/50 kg	R 0.67	117,719.50	R 23,734.02	135,275.64	R 27,273.60	146,997.06	R 29,636.81
Milk tapeworm	1 ml/4kg	R 0.38	64,247.26	R 6,098.83	66,340.11	R 6,297.50	65,555.31	R 6,223.00
Roundworm and milk tapeworm	1 ml/10 kg	R 0.40	218,747.76	R 8,747.29	235,192.35	R 9,404.87	270,238.72	R 10,806.31

Vitamin A	1 ml/250 kg	R 2.08	108,579.44	R 904.60	122,629.28	R 1,021.65	140,622.32	R 1,171.55
Trace minerals	1 ml/100 kg	R 3.99	117,719.50	R 4,701.93	135,275.64	R 5,403.15	143,865.82	R 5,746.26
Vaccinacions		**Price/ml**	**Total animals**		**Total animals**		**Total animals**	
BVD	2ml/animal	R 16.37	436.75	R 14,295.33	347.69	R 11,380.21	271.33	R 8,881.11
Botulism, anthrax, blackquarter	2ml/animal	R 7.42	1,117.98	R 16,589.02	816.63	R 12,117.54	619.18	R 9,187.62
Paratyphoid (inactivated)	2ml/animal	R 20.34	344.76	R 14,023.37	237.33	R 9,653.45	176.04	R 7,160.50
Brucella abortus	2ml/animal	R 20.19	420.12	R 16,966.51	334.45	R 13,506.77	218.68	R 8,831.49
Pasteurella	1 ml/animal	R 18.39	421.55	R 7,754.09	335.78	R 6,176.33	263.1	R 4,839.48
Rift Valley fever (incativated)	2ml/animal	R 6.88	438.22	R 6,033.66	349.05	R 4,805.82	271.8	R 3,742.19
Dips		**Price/ml**	**Total kg**		**Total kg**		**Total kg**	
Ticks tsetse flies, red lice	5 ml/50 kg	R 0.54	242,372.50	R 13,130.53	273,799.04	R 14,833.06	303,689.43	R 16,452.37
Other costs		**Price/animal**	**Total animals**		**Total animals**		**Total animals**	
Processing		R 70.00	77.56	R 5,429.47	99.44	R 6,960.69	44.42	R 3,109.32
Veterinary services		R 52.61	774.22	R 40,731.73	579.67	R 30,496.38	443.14	R 23,313.79
Allocated costs				R 407,971.62		R 412,698.00		R 376,756.53
Gross profit above allocated costs				R1,101,901.45		R 1,182,864.73		R1,182,864.73

4.7. Limiting Feed Intake

4.7.1. Limiting Feed Intake to a Specific Amount Per Animal

When feed was limited to a specific amount (Mcal), smaller cattle were found to be more biologically efficient. In fact, cattle with potential for small mature size could grow to a larger size than cattle with potential for medium and large mature size. We considered the growth phase, where lactation and reproduction are ignored for simplicity, and animals reach 97.5% of mature weight at 1552 days. The NE_{m+g} requirements will be 7,663, 10,548 and 13,249 Mcal, respectively, for small, medium, and large calves. If feed is limited to 7,663 Mcal for each of the three calves, the small calf's growth and maintenance will be unaffected but the medium and large calves will grow up to a point after which the remaining energy is used purely for maintenance requirements to 1552 days, if feed availability could be planned in such a way. Medium calves will grow to a weight of 257 kg, then stop growing and use the remaining energy to maintain this weight. Large calves will grow up to a weight of 252 kg and then use the remaining energy for maintenance. This is summarized in Table 14. Smaller cattle would be more efficient at lower specified amounts of net energy.

Table-14. Results of limiting feed to 7,633 Mcal during the growth stage of small, medium, and large cattle.

Size	Small	Medium	Large
Final weight (kg)	293	257	252
% of mature mass	97.5	57.1	42.1
NE_m (Mcal)	6870	7151	7255
NE_m/NE_{m+g} (%)	89.7	93.3	94.6

If feed were limited to a specific amount per animal during the lactation or reproduction phases, small cattle would again outperform their larger counterparts. If the net energy requirement of a mature cycle is considered, therefore excluding growth for simplicity, small, medium, and large cows would need a total of 2,930, 3,996, and 4,981 Mcal per year, respectively. If feed were limited to any level below 4,981 Mcal per animal, large cows' reproduction rates would beould be negatively affected whereas small and medium cows would still have surplus feed available. If feed were limited to 2,930 Mcal, smaller cows would be able execute their physiological functions normally but medium cows would likely not reproduce and lactation would be hindered, whereas large cows would likely not reproduce, lactate properly, or even maintain their current weight. Similarly, at lower feed amounts, small cows would be the most effective although physiological functions would be negatively influenced.

4.8. Limiting Feed Intake by Percentage of Calculated Requirements

When available energy was reduced by a percentage of calculated energy requirements, large cows were more efficient. During the growth phase, limiting NE_{m+g} by even a small amount reduced growth in all sizes, since energy will first be used for maintenance. Furthermore, NE_g was 10.3, 11.7, and 12.8% of NE_{m+g}, respectively, for small, medium, and large cows. When NE_{m+g} is reduced by 10% over the growth cycle of 1552 days, a small cow will grow to a weight of 234 kg or 78.1% of its mature weight, a medium calf to 353 kg or 78.5% of its mature weight, and a large calf to 473 kg or 78.9% of its mature weight. These results are summarized in Table 15.

Table-15. Small, medium, and large cows fed 90% of calculated NE_{m+g} during the growth cycle.

Size	Small	Medium	Large
Final weight (kg)	234	353	473
% of mature mass	78.1	78.5	78.9
NE_m (Mcal)	6337	8613	10,712
$NE_m/(NE_{m+g}$ x 90%)	91.9%	90.7%	89.8%

At maturity, small, medium, and large cows allocated 5.7% of NE_t (2,930 Mcal), 6.3% of NE_t (3,996 Mcal), and 6.8% of NE_t (4,981 Mcal) to reproduction. If feed were reduced by 5.7% in this instance, a few large cattle might reproduce, fewer medium cattle would fall pregnant and, most likely, no small cattle would become pregnant. The same can be argued for the lactation phase, from the assumption that mature cows will use energy for maintenance, then lactation and then reproduction, resulting in large cows being more efficient under the above-mentioned conditions.

4.9. Limiting Feed Intake According to Metabolic Weight

When energy was limited to an amount per unit of metabolic weight, all sizes were equally efficient (or inefficient) in the maintenance and lactation phases. Maintenance and lactation are a direct function of metabolic weight. The net energy used for growth per unit of metabolic weight was 11.00, 12.66, and 13.99Mcal for small, medium, and large cows, respectively, over the growth cycle. Net energy used for fetal production was 16.02, 17.87, and 19.20 Mcal per unit of metabolic weight for the three sizes, respectively. Therefore, when feed is limited to a unit of metabolic weight, large cattle will be the first to show an energy deficiency in growth and reproduction. The highly cited work of Jenkins and Ferrell (1984) concluded that smaller cattle are more efficient when fed as a portion of metabolic weight. Here, the above calculation not only confirms the work of Jenkins & Ferrell, but also provides the reason for it. Although Jenkins & Farrell's research studied differences among breeds, the same argument is valid within any breed.

4.10. Energy Requirements According to LSU

The LSU is commonly used to match animal numbers to their resource base in South Africa, yet the LSU calculation differs greatly from the recommendations of the NRC and those used in this research. The LSU mostly overestimates the amount of energy animals require for maintenance, growth, and fetal production, and mostly underestimates that needed for lactation, but results vary. The LSU does not consider metabolic weight for maintenance (Meissner, 1983), and the equation used to calculate LSU is:

$NE_m = 1.354 + 0.0146W$ (converted to Mcal),

For each of the three sizes the LSU overestimates net energy requirements for maintenance, compared to the equation of Lofgreen & Garrett. Furthermore, since the LSU doesn't consider metabolic weight, maintenance requirements of small cattle are overestimated proportionately less than those of large cattle. In the growth phase, the LSU assumed that NEg is linear and depends only on live weight gain (LWG) and live weight (W). This is very different from the equation used by the NRC, where the composition of gain changes over time. The LSU equivalent mostly overestimates NE_{m+g}, except for small cattle at heavier weights. The equation used to determine NEg as calculated for a LSU is:

$$NE_g = LWG\ (1.500 + 0.0045W)/(0.2388 - 0.0717LWG) \text{ (converted to Mcal).}$$

When lactation is considered, the LSU underestimates NE_{m+l} requirements for all sizes compared to the calculation used in this study and, because it underestimates NE_{m+l} for small cows proportionately less, small cows will be at an advantage, or at a lesser disadvantage. The equation to compute LSU for maintenance and lactation is:

$$NE_{m+l} = (3054P + W^{0.75}\ (0.6*(481 + 2.1P)))/238.846 \qquad \text{(converted to Mcal),}$$

where P = daily milk yield in kg. The LSU expresses only approximate values for pregnant cows: no mention is made of the stage of pregnancy. Three different-sized mature cows in calf were provided in the Meissner tables – 500, 525, and 550 kg - and were termed small-, medium-, and large-framed, respectively. This makes problematic a fair comparison between the values given as LSU and the equations used in this study. Using the value for NE_{m+y} from this study for the last day (day 283) of pregnancy compared to the LSU, the latter overestimated the energy requirements for NE_{m+y} significantly. The energy requirements for large cattle were overestimated proportionately more, giving them an advantage over their smaller counterparts. The comparison between the LSU and the calculations used in this research is given in Table 16 for NE_m, in Table 17 for NE_{m+g}, in Table 18 for NE_{m+l} and in Table 19 for NE_{m+y}.

4.11. Further Considerations Related to Size

A smaller body size has been proven as an adaptation to warmer climates and certain associated diseases and parasites, as well as an environment where feed availability fluctuates. These adaptations can be expressed in a number of ways, including rates of reproduction, mortality, and growth.

Physical facilities at the farm, feedlot, or abattoir could lead to preference of one size over another. Handling a small cow is easier than handling a large cow of the same breed. Despite smaller cattle being easier to handle, from the model in this study, 73% more small cattle (766) and 25% more medium cattle (556) than large cattle (443) required veterinary services. Not only did this increase veterinary costs but could also have increased labour costs and/or opportunity costs.

Having more cattle on a set resource base gives wider genetic variation. In this research, in the case of small cattle, farmers had 185.2 (72.8% more than large cattle) calves to choose from for replacements compared to 134.6 (25.5% more than large cattle) for medium cattle and 107.2 for large cattle. When using the breeder's equation

$R = S\ x\ h^2/L$

where R is the response to selection, S is the genetic variation of the trait from the mean of the population, h the heritability of the trait selected for, and L the length of cycle interval, the herd of small cattle had a higher value for S and lower value for L.

5. CONCLUSION

Cattle size influences biological efficiency, which influences economic efficiency; however there are many more variables that influence biological and economic efficiency other than size, including reproduction rates. Individual small cows were the least biologically efficient and used more energy for maintenance than medium and large cattle at similar reproduction and growth rates. As a result, the herd of small cattle proved to make the least efficient use of feed. Where economic efficiency was considered, the herd of large cattle yielded the highest income, mostly due to the resource base being able to support more kilograms of cattle in the large herd. Smaller cattle had the highest expenditure, due to higher expenses charged per head. As a result, the herd of large cattle was the most profitable at similar reproduction and growth rates. A higher reproduction rate normally leads to higher profitability. The reproduction rates where medium and large cattle will become less profitable than the herd of small cattle were calculated. Smaller cattle mature faster than larger cattle and could provide the potential for early breeding at low reproduction rates. For FCC, early breeding is more profitable than late breeding although small cattle that were bred early could not match the profitability of large cattle bred late; all other classes of animals had similar reproduction rates.

Table-1. Comparison between NE_m requirements as calculated by LSU and Lofgreen & Garrett.

Mature size (kg)	300	450	600
LSU NE_m (Mcal)	6.0	8.3	10.6
Lofgreen & Garrett NE_m (Mcal)	5.6	7.5	9.3
Difference between LSU and Lofgreen & Garrett (%)	7.8	9.5	12.0

Table-17. Comparison between LSU and calculation recommended by NRC for NE_{m+g}.

Current cattle weight, gaining 500g per day	100 kg current weight	150 kg current weight	200 kg current weight	250 kg current weight	300 kg current weight	350 kg current weight	400 kg current weight	450 kg current weight	500 kg current weightn	550 kg current weight	600 kg current weight
LSU NE_{m+g}, 500g daily gain (Mcal)	4.16	5.06	5.97	6.88	7.79	8.67	9.58	10.49	11.39	12.30	13.18
NRC NE_{m+g}, 300 kg mature size, 500 g daily gain (Mcal)	3.60	4.88	6.05	7.15	8.20	N/A	N/A	N/A	N/A	N/A	N/A
NRC NE_{m+g}, 450 kg mature size, 500 g daily gain (Mcal)	3.29	4.46	5.54	6.55	7.50	8.42	9.31	10.17	N/A	N/A	N/A
NRC NE_{m+g}, 600 kg mature size, 500 g daily gain (Mcal)	3.13	4.24	5.26	6.21	7.13	8.00	8.84	9.66	10.45	11.23	11.98
Difference: LSU and NRC for 300 kg mature size	13.4%	3.7%	-1.3%	-4.0%	-5.3%						
Difference: LSU and NRC for 450 kg mature size	20.8%	11.9%	7.3%	4.8%	3.6%	2.8%	2.8%	3.0%			
Difference: LSU and NRC for 600 kg mature size	24.8%	16.3%	12.0%	9.7%	8.5%	7.7%	7.7%	7.9%	8.3%	8.7%	9.1%

Table-18. Comparison between LSU and calculation recommended by NRC for NE_{m+l}.

Daily milk yield	5 kg/day			10 kg/day			15kg/day		
Cow weight	**300 g**	**450 kg**	**600 kg**	**300g**	**450 kg**	**600 kg**	**300g**	**450 kg**	**600 kg**
LSU NE_{m+l} (Mcal)	8.38	10.05	11.58	12.29	14.02	15.60	16.28	18.06	19.70
NRC NE_{m+l} (Mcal)	9.14	11.11	12.92	12.73	14.70	16.51	16.32	18.29	20.10
Difference: LSU and NRC	-9.1%	-10.6%	-11.6%	-3.6%	-4.9%	-5.9%	-0.2%	-1.3%	-2.1%

Table-19. Comparison between LSU and calculation recommended by NRC for NE_{m+y}.

Cow weight (kg)	500	525	550
Calf size at 6.67% of mature weight for NRC equation (kg)	**33**	**35**	**37**
LSU NE_{m+y}, unspecifyied stage of pregnancy (Mcal)	19.64	21.62	23.61
NRC NE_{m+y}, last day of pregnancy (Mcal)	12.81	13.35	13.88
Difference: LSU and NRC	35%	38%	41%

Where feed is limited, the biological efficiency of different-sized animals yielded varying results. It did, however, illustrate that even slightly overstocking a resource base would negatively impact reproduction, then lactation and then growth. It is more profitable to slightly understock a resource base than to overstock. There are further considerations the farmer needs to take into account to find the right-sized cow for their situation, including adaptation, infrastructure, and selection goals. Nonetheless, biological and economic efficiency is at the heart of finding the right-sized cow for the individual enterprise.

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