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 (25.3%). 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 weight0.75 (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 weight 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 calf grow faster – that is, they gain more body weight per day than smaller calf. However, previous research suggest that the growth rates of smaller calves 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 (Aragno & 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 (Aragno & 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 ($NE_i$) 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 ($NE_p$). Thus:

$$NE_i = NE_m + NE_g + NE_l + NE_p$$

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):

$$f(t) = A (1 - B^t)$$

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

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

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

$k =$ growth rate.

$t =$ time after $k$, 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

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

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

$$NE_g = RE = 0.0635 \times EBW^{0.75} \times EBG^{1.097} \text{ (Mcal)}$$

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:

$$EBSBW = SBW \times (SBW/FSBW)$$

$$EBSBW = 0.891 \times EBSBW$$

$$EBG = 0.965 \times SWG$$

$$NE_g = RE = 0.0635 \times EBSBW^{0.75} \times EBG^{1.097}$$

where $EBSBW =$ equivalent shrunken body weight.

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

$FSBW =$ final shrunken 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.

$EBSBW =$ equivalent empty body weight.

$EBG =$ empty body weight gain.

$SWG =$ shrunken 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:

\[ NE_t = \frac{Y_t}{E} \]

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

\[ E = (0.092 \times \text{fat percent}) + (0.049 \times \text{SNF percent}) - 0.0569 \]

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):

\[ Y_t = \frac{n}{a^k} \]

Where

- \( n \) is the time, in weeks, postpartum.
- \( a = 1/(\text{peak milk yield} \times k \times e) \).
- \( k = 1/\text{week of peak milk yield} \).

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:

\[ MY = CW^{0.75}/30 \times \text{kg}^{0.75} \times 10 \text{ kg/day} \]

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:

\[ NE_t = 0.576 \times \text{birth weight}^{0.4504} - 0.0000766t \times e^{0.00233 - 0.00002735t} \]

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-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 829 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 days, 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 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 could 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 R35,599, 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 Supelfos were used in this research. It was assumed that lick intake was directly equivalent to NE, requirements, and the highest NE 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 R5.00 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 829 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 rate 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 cattle 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).
| 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, SSC, FCC, 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)      | R1898.55/5 l                |
| Valbazen                 | Zoetis (2018)              | Roundworm and milk tapeworm                                               | Bulls, MC, SSC, FCC, RCC from MC                     | 1 May, 1 Nov                    | (bulls, MC, SCC, FCC)         | R1999.40/5 l                |
| Vit-Aid                  | Afrivet (2018)             | Vitamin A supplement                                                      | Bulls, MC, SSC, FCC, 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 from MC                     | 1 Nov (bulls, MC, SCC)          | 1 ml/100 kg                   | R1997.09/500 ml             |
| **Vaccinations**         |                            |                                                                            |                                                      |                                |                               |                             |
| Cattle Master +          | Zoetis (2018)              | Bovine viral diarrhea                                                     | Bulls, MC, SSC, FCC, RCC from MC                     | 1 Nov (bulls, MC, SCC, FCC)    | 2 ml/animal                   | R818.28/25 doses             |
| Supavax® (MSD)           | MSD (2018)                 | Botulism, anthrax, blackquarter                                           | All animals                                          | 1 Nov (bulls, MC, SCC, FCC)    | 2 ml/animal                   | R741.92/50 doses             |
| Bovilis S                | MSD (2018)                 | Paratyphoid (inactivated)                                                 | Pregnant animals                                     | 1 Aug (MC, SCC)                 | 2 ml/animal                   | R47.00/10 ml                |
| RB-51                   | MSD (2018)                 | Brucella abortus                                                          | Female animals before breeding                       | 1 Nov (MC, SCC, FCC)           | 2 ml/animal                   | R1009.63/25 doses            |
| Bovi-Tect III            | MSD (2018)                 | Pasteurella                                                               | Female animals                                       | 1 Aug (RCC)                     | 1 ml/animal                   | R1839.42/100 ml             |
| Rift Valley fever (OBP)  | OBP (2018)                 | Rift Valley fever                                                        | Bulls, MC, SCC, FCC, 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)             | 5 ml/50 kg                    | R3250.50/6 l                |
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.](image)

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 is 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.](image)

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.

| Item                      | 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  |
| Bulls                     | 19   |      |      |      |      |      |      |      |      |      |      |      |      |
| SCC                       | 66.2 | 66.1 | 66.1 | 66.0 | 49.5 | 49.4 | 49.4 | 49.3 | 49.3 | 49.2 | 49.2 |      |      |
| Pregnant SCC Calving (%)  | 7    | 49.7 | 49.6 | 49.5 | 49.5 | 49.4 | 49.4 | 49.3 | 39.4 |      |      |      |      |
| Open SCC                  | 16.6 | 16.5 | 16.5 | 16.5 |      |      |      |      |      |      |      |      |      |
| Deaths Death (%)          | 1    | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 9.8  |      |      |      |
| Culls                     |      |      |      |      |      |      |      |      |      |      |      |      |      |
| FCC                       | 74.3 | 66.8 | 66.8 | 66.7 | 66.6 | 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 | 66.7 | 66.6 | 66.6 | 49.7 |      |      |      |      |
| Open FCC                  | 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  |
| 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 | 74.4|
| Pregnant RCC              |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Open RCC                  |      |      |      |      |      |      |      |      |      |      |      |      |      |
| 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|      |      |      |      |      |      |      |      |      |
| Deaths Death (%)          | 3    | 0.5  | 0.5  | 0.5  | 0.5  |      |      |      |      |      |      |      |      |
| Calves sold from MC       |      |      |      |      |      |      |      |      |      |      |      |      | 108.4|
| RCC from MC               |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Deaths Death (%)          | 3    |      |      |      |      |      |      |      |      |      |      |      |      |
| Calves from SCC           | 49.0 | 48.8 | 48.7 | 48.6 |      |      |      |      |      |      |      |      |      |
| Deaths Death (%)          | 3    | 0.1  | 0.1  | 0.1  | 0.1  |      |      |      |      |      |      |      |      |
| Calves sold from SCC      |      |      |      |      |      |      |      |      |      |      |      |      | 48.5 |
| Calves from FCC           | 65.6 |      |      |      |      |      |      |      |      |      |      |      |      |
| Deaths Death (%)          | 3    | 0.2  |      |      |      |      |      |      |      |      |      |      |      |
| Calves sold from FCC      | 65.4 |      |      |      |      |      |      |      |      |      |      |      |      |
| Bulls                     | 15.1 | 15.1 | 15.1 | 15.1 |      |      |      |      |      |      |      |      |      |
| Deaths Death (%)          | 1    | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |      |      |      |      |
| Culls                     |       |      |      |      |      |      |      |      |      |      |      | 2.9  |      |
| Purchased Replace (%)     | 20   |      |      |      |      |      |      |      |      |      |      |      | 3.0  |
|                | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|----------------|------|------|------|------|------|------|------|------|------|------|------|------|
| MC             | 171.9| 171.9| 171.7| 171.6| 171.5| 171.1| 171.5| 171.6| 171.6| 171.5| 171.5| 171.5 |
| Pregnant MC    | 80   | 137.5| 137.4| 137.3| 137.2| 137.1| 136.9| 136.8| 136.7| 136.6| 136.5| 136.4 |
| Open MC        | 34.4 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 34.3 | 27.3 |
| Deaths         | 1    | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  |
| Bulls          |      |      |      |      |      |      |      |      |      |      |      |      |
| Purchased      |      |      |      |      |      |      |      |      |      |      |      | 2.1  |
| Stock Flow for a herd of medium-sized cattle |

Table 4. Stock flow for a herd of medium-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 | 80   | 109.5| 109.4| 109.4| 109.3| 109.2| 109.1| 109.0| 108.9| 108.8| 108.7| 108.6| 86.8 |
| Open MC  | 27.4 | 27.4 | 27.3 | 27.3 | 27.3 | 27.3 | 27.3 | 27.3 | 27.3 | 27.3 | 27.3 | 27.3 | 21.7 |
| Deaths   | 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 | 28.5 |
| Pregnant SCC | 75  | 28.7 | 28.7 | 28.7 | 28.7 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 | 28.6 |
| Open SCC | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 9.6  | 5.7  |
| Deaths   | 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  |      |      |      |      |      |      |      |      |      |      |      | 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 | 38.4 | 38.4 |
| Pregnant FCC | 90 | 38.7 | 38.7 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 38.6 | 28.8 |
| Open FCC | 4.3  |      |      |      |      |      |      |      |      |      |      |      | 9.6  |
| Deaths   | 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 | 43.1 | 43.1 |
| Pregnant RCC | 38.8 |      |      |      |      |      |      |      |      |      |      |      |      |
| Open RCC | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  | 4.3  |
| Deaths   | 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 | 109.8 | 108.5 | 108.3 | 108.3 | 108.3 | 108.3 | 108.3 | 108.3 | 108.3 |
| Deaths   | 3    | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  |
| Calves sold from MC | - |      |      |      |      |      |      |      |      |      |      |      |      |
| RCC sold from MC | 44.4 | 44.3 | 44.2 | 44.1 | 44.0 | 43.9 | 43.8 | 43.6 | 43.5 | 43.4 | 43.3 | 43.2 | 43.1 |
| Deaths   | 3    | 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 SCC | 28.3 | 28.3 | 28.2 | 28.1 |      |      |      |      |      |      |      |      |      |
| Deaths   | 3    | 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 sold from SCC | 28.0 |      |      |      |      |      |      |      |      |      |      |      |      |
| Calves from FCC | 38.0 |      |      |      |      |      |      |      |      |      |      |      |      |
| Deaths   | 3    | 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  | 8.7  | 8.7  |
| Deaths   | 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 NEₐ 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 NEₐ 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 NEₐ for NEₐ than productive mature animals, as well as the fact that bulls have to be retained on the resource base. NEₐ 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 NEₐ. 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 162.56 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. There was a negligible difference in 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 21,125 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.

| Herd energy composition | Small   | Medium  | Large   |
|-------------------------|---------|---------|---------|
| MC: NEₐₑ                   | 413,135 | 406,870 | 402,129 |
| MC: NEₑ                   | 154,729 | 152,383 | 150,607 |
| MC: NEₑ                    | 31,646  | 34,491  | 36,631  |
| MC: NECₐ                   | 599,510 | 593,744 | 589,367 |
| SCC: NEₑ                   | 107,864 | 106,228 | 104,990 |
| SCC: NEₑ                    | 2,157   | 2,445   | 2,670   |
| SCC: NECₐ                   | 21,591  | 21,263  | 21,016  |
| SCC: NECₑ                   | 7,887   | 9,049   | 9,610   |
| SCC: NECₑ                    | 139,499 | 138,985 | 138,286 |
| FCC: NEₑ                   | 126,800 | 124,525 | 123,422 |
| FCC: NEₑ                    | 6,329   | 7,174   | 7,855   |
| FCC: NECₐ                   | 40,813  | 40,194  | 39,725  |
| FCC: NECₑ                   | 10,127  | 11,038  | 11,723  |
| FCC: NECₑ                    | 184,069 | 183,283 | 182,706 |
| RCC: NEₑ                   | 126,442 | 124,525 | 123,074 |
| RCC: NECₑ                   | 16,027  | 18,168  | 19,842  |
| RCC: NECₑ                    | 188     | 205     | 218     |
| Calves from MCs: NEₐₑ     | 97,998  | 78,769  | 77,852  |
| Calves from MCs: NECₑ       | 37,961  | 43,034  | 46,997  |
| RCC from MC: NEₐₑ          | 67,637  | 66,611  | 65,835  |
| RCC from MC: NECₑ          | 18,444  | 20,909  | 22,835  |
| Calves from SCC: NEₐₑ     | 20,191  | 19,885  | 19,653  |
| Calves from SCC: NECₑ       | 9,059   | 10,269  | 11,215  |
| Calves from FCC: NEₑ       | 27,165  | 26,753  | 26,442  |
| Calves from FCC: NECₑ       | 11,715  | 13,280  | 14,503  |
| All calves: NEₑ             | 272,156 | 279,512 | 285,333 |
| Bulls: NEₐₑ                 | 35,085  | 34,553  | 34,151  |
| Bulls: NECₑ                 | 35,085  | 34,553  | 34,151  |
| Total herd: NEₐₑ            | 1,004,303 | 989,073 | 977,548 |
| Total herd: NEₑ              | 101,692 | 115,280 | 125,898 |
| Total herd: NECₑ             | 217,133 | 213,840 | 211,348 |
| Total herd: NECₑ             | 49,849  | 54,783  | 58,182  |
| Total herd: NECₑ             | 1,372,976 | 1,372,976 | 1,372,976 |

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

| Income | Small cattle | Medium cattle | Large cattle |
|--------|--------------|---------------|--------------|
| Cattle sales | | | |
| Culled MC | Class C2/3 | R 20.38 | 14,146.99 | 288,254.91 | 15,418.80 | 314,169.95 | 16,375.52 | R 333,662.74 |
| Culled FCC | Class C2/3 | R 20.38 | 4,737.41 | 96,528.15 | 5,163.31 | 105,206.00 | 5,483.68 | R 111,733.90 |
| Culled replacement heifers | Class B2/3 | R 21.05 | 1,949.50 | 41,036.73 | 2,124.76 | 44,725.92 | 2,256.60 | R 47,501.11 |
| Live weaners sold | Weaners | R 32.25 | 28,034.07 | 903,979.45 | 30,554.32 | 985,246.95 | 32,450.18 | R 1,046,380.28 |
| Culled bulls | Class C2/3 | R 20.38 | 862.53 | 17,574.74 | 940.08 | 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 | 101,660.30 | 989.32 | 110,799.54 | 1,050.70 | R 117,674.51 |
| Licks | | Price/kg | Total kg | Total kg | Total kg |
| Winter | R 4.10 | 161,16.34 | 66,093.13 | 16,160.73 | 66,275.17 | 16,188.80 | R 66,390.28 |
| Summer | R 5.21 | 10,328.66 | 53,771.03 | 10,307.35 | 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 | 25,603.57 | 138,408.96 | 27,905.32 | 146,997.06 | R 29,636.81 |
| Milk tapeworm | 1 ml/4kg | R 0.38 | 56,633.95 | 5,376.12 | 61,725.33 | 5,859.43 | 65,555.31 | R 6,223.00 |
| Roundworm and milk tapeworm | 1 ml/10 kg | R 0.40 | 233,462.21 | 9,335.69 | 254,450.39 | 10,174.96 | 260,625.27 | R 10,806.31 |
| Vitamin A | 1 ml/250 kg | R 2.08 | 121,485.17 | 1,012.12 | 132,460.66 | 1,103.11 | 140,563.22 | R 1,171.55 |
| Trace minerals | 1 ml/100 kg | R 3.99 | 124,287.27 | 4,964.26 | 135,461.66 | 5,410.54 | 143,876.22 | R 5,746.26 |
| Vaccinations | | Price/ml | Total animals | Total animals | Total animals |
| BVD | 2ml/animal | R 16.37 | 468.82 | 15,344.97 | 340.64 | 11,149.65 | 271.33 | R 8,881.11 |
| Botulism, anthrax, blackquarter | 2ml/animal | R 7.42 | 1,069.83 | 15,874.57 | 775.34 | 11,534.46 | 619.18 | R 9,187.62 |
| Paratyphoid (inactivated) | 2ml/animal | R 20.34 | 304.16 | 12,372.08 | 291.00 | 8,989.55 | 176.04 | R 7,160.50 |
| Brucella abortus | 2ml/animal | R 20.19 | 377.84 | 15,529.23 | 274.54 | 11,087.36 | 216.86 | R 8,831.49 |
| Pasteurella | 1 ml/animal | R 18.39 | 454.59 | 8,361.75 | 330.30 | 6,075.65 | 263.10 | R 4,839.48 |
| Rift Valley fever (inactivated) | 2ml/animal | R 6.88 | 469.61 | 6,465.84 | 341.22 | 4,698.08 | 271.80 | R 3,742.19 |
| Dips | | Price/ml | Total kg | Total kg |
| Ticks, tsetse flies, red lice | 5 ml/50 kg | R 0.54 | 262,360.64 | 14,213.39 | 285,946.79 | 15,491.17 | 303,438.93 | R 16,452.37 |
| Other costs | | Price/animal | Total animals | Total animals | Total animals |
| Processing | | R 70.00 | 76.75 | 5,372.35 | 55.76 | 3,903.55 | 44.42 | R 3,109.32 |
| Veterinary services | | R 52.61 | 765.67 | 40,282.09 | 556.34 | 29,268.96 | 443.14 | R 23,313.79 |
| Allocated costs | | R 401,362.47 | 383,386.56 | 376,783.53 |
| 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 | 83.2 | 83.1 | 83.1 |
| Pregnant MC      |      |      |      |      |      |      |      |      |      |      |      | 56.2 |
| Calving (%)      | 67.67%| 83.8 | 83.8 | 83.7 | 83.6 | 83.5 | 83.5 | 83.4 | 83.3 | 83.3 | 83.3 | 83.3 |
| 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  |
| Culls            |      |      |      |      |      |      |      |      |      |      |      | 31%  |
| Pregnant SCC     |      |      |      |      |      |      |      |      |      |      |      |      |
| Calving (%)      | 63.44%| 41.3 | 41.2 | 41.2 | 41.2 | 41.1 | 41.1 | 41.0 | 41.0 | 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  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  | 0.1  |
| Culls            |      |      |      |      |      |      |      |      |      |      |      | 23.7 |
| Pregnant FCC     |      |      |      |      |      |      |      |      |      |      |      |      |
| Calving (%)      | 76.13%| 65.7 | 65.6 | 65.6 | 65.5 | 65.4 | 65.4 | 65.3 | 65.2 | 65.1 | 65.1 | 65.1 |
| Open FCC         |      | 20.6 |      |      |      |      |      |      |      |      |      | 41.3 |
| 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  |
| Culls            |      | 20.6 |      |      |      |      |      |      |      |      |      |      |
| RCC              |      |      |      |      |      |      |      |      |      |      |      |      |
| Calving (%)      | 87.1 | 87.1 | 87.0 | 86.9 | 86.9 | 86.8 | 86.7 | 86.6 | 86.6 | 86.5 | 86.4 | 86.4 |
| Open RCC         |      | 20.7 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 | 20.6 |
| Pregnant RCC     |      |      |      |      |      |      |      |      |      |      |      | 65.9 |
| Calves from MC   |      |      |      |      |      |      |      |      |      |      |      | 65.9 |
| Death (%)        | 3%   | 0.2  | 0.2  | 0.2  | 0.2  |      |      |      |      |      |      | 0.2  |
| Calves sold from MC |      |      |      |      |      |      |      |      |      |      |      | (7.1) |
| RCC from MC      |      |      |      |      |      |      |      |      |      |      |      |      |
| Calves from SCC  |      |      |      |      |      |      |      |      |      |      |      |      |
| Calves from FCC  |      |      |      |      |      |      |      |      |      |      |      |      |
| Death (%)        | 3%   | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  | 0.2  |
| Calves sold from FCC |      |      |      |      |      |      |      |      |      |      |      |      |
| Bulls            |      |      |      |      |      |      |      |      |      |      |      |      |
| Death (%)        | 1%   | 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% |  |  |  |  |  |  |  |  |  |  | 2.2

Table 9: Stock flow of a herd of large cattle at a reproduction rate lowered to 75.5% of the base model.

|                  | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov | Dec |
|------------------|------|------|------|------|------|------|------|------|------|------|-----|-----|
| **MCs**          |      |      |      |      |      |      |      |      |      |      |     |     |
| Calves sold      | 78.7 | 78.7 | 78.6 | 78.6 | 78.5 | 74.3 | 74.2 | 47.2 | 47.2 | 47.1 | 47.0 | 47.0 |
| Calves from      |      |      |      |      |      |      |      |      |      |      |     |     |
| Pregnant MCs     | 60.28% | 47.4 | 47.4 | 47.4 | 47.3 | 47.3 | 47.2 | 47.2 | 47.2 | 47.1 | 28.3 |     |
| Death (%)        | 1%   | 0.1  | 0.1  | 0.1  | 0.1  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| Culls            | 39%  |      |      |      |      |      |      |      |      |      |     | 31.2 |
| **SCC**          |      |      |      |      |      |      |      |      |      |      |     |     |
| Pregnant SCC     | 56.51% | 32.0 | 32.0 | 32.0 | 31.9 | 31.9 | 31.9 | 31.9 | 31.9 | 31.9 | 31.8 | 31.8 |
| Open SCC         |      | 24.6 | 24.6 | 24.6 | 24.6 |      |      |      |      |      |     | 19.1 |
| Deaths           | 1%   | 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**          |      |      |      |      |      |      |      |      |      |      |     |     |
| Pregnant FCC     | 67.81% | 57.2 | 57.2 | 57.1 | 57.1 | 57.0 | 57.0 | 57.0 | 57.0 | 57.0 | 57.0 | 32.0 |
| Open FCC         |      | 27.2 |      |      |      |      |      |      |      |      |     | 24.7 |
| Deaths           | 1%   | 0.1  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |
| Culls            | 27.1 |      |      |      |      |      |      |      |      |      |     |     |
| **RCC**          |      |      |      |      |      |      |      |      |      |      |     |     |
| Pregnant RCC     |      | 85.3 | 85.2 | 85.1 | 85.0 | 85.0 | 84.9 | 84.8 | 84.8 | 84.8 | 84.5 | 84.5 |
| Open RCC         |      |      | 27.3 | 27.2 | 27.2 | 27.2 |      |      |      |      |     |     |
| Deaths           | 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 |
| Deaths           | 3%   | 0.1  | 0.1  | 0.1  | 0.1  |      |      |      |      |      | 0.1  | 0.1  |
| Calves sold from |      |      |      |      |      |      |      |      |      |      |     |     |
| MCs              | (40.8)|      |      |      |      |      |      |      |      |      |     |     |
| RCC from MCs     |      |      |      |      |      |      |      |      |      |      |     |     |
| Deaths           | 3%   | 0.2  | 0.2  | 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 |      |      |      |      |      |      |     | 31.3 |
| Deaths           | 3%   | 0.1  | 0.1  | 0.1  | 0.1  |      |      |      |      |      | 0.1  | 0.1  |
| Calves sold from | 31.3 |      |      |      |      |      |      |      |      |      |     |     |
| SCC              |      |      |      |      |      |      |      |      |      |      |     |     |
| Calves from FCC  | 56.1 |      |      |      |      |      |      |      | 57.0 | 56.9 | 56.7 | 56.6 |
| Deaths           | 3%   | 0.1  |      |      |      |      |      |      | 0.1  | 0.1  | 0.1  | 0.1  |
| Calves sold from | 56.0 |      |      |      |      |      |      |      |      |      |     |     |
| FCC              |      |      |      |      |      |      |      |      |      |      |     |     |
| 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           | 1%   | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  | 0.0  |

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

| Income | Small cattle: changed reproduction rate | Medium cattle: reproduction rate 85% of small cattle | Large cattle: reproduction rate 75% of small cattle |
|--------|----------------------------------------|-------------------------------------------------|--------------------------------------------------|
| 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 | R 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 | | R 32.25 | 20,387.40 | R 411,740.00 | 17,745.60 | R 572,220.07 | 10,658.67 | R 343,698.83 |
| Cull | R 20.38 | 4,737.41 | R 96,528.15 | 10,208.11 | R 207,997.38 | 14,108.41 | R 287,468.83 |
| Total income from cattle sales | | | | R 1,347,373.98 | R 1,336,085.76 | R 1,332,676.55 |

| Expenses | Price/kg | Total kg | Total kg | Total kg |
|----------|---------|---------|---------|---------|
| Bull purchases | R 112.00 | 907.71 | R 101,660.30 | 995.01 | R 111,436.84 | 101,660.30 | 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 | 17,193.61 | R 72,981.68 |
| Summer | R 5.21 | 10,328.66 | R 53,771.03 | 9,811.57 | R 51,079.05 | 9,811.57 | 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 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 52,350.18 | R 4,969.47 | 49,860.12 | R 4,716.18 |
| Roundworm and milk tapeworm | 1 ml/10 kg | R 0.40 | 233,462.21 | R 255,225.13 | R 10,205.94 | 272,031.05 | R 10,877.32 |
| Vitamin A | 1 ml/250 kg | R 2.08 | 121,485.17 | 1,012.12 | 133,207.07 | 1,012.12 | 141,054.00 | R 1,754.15 |
| Trace minerals | 1 ml/100 kg | R 3.99 | 124,287.27 | R 4,964.26 | 140,811.53 | 5,624.39 | 153,191.23 | R 6,118.73 |
| Vaccinations | 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 15,847.57 | 750.10 | R 11,130.24 | 584.18 | R 8,668.32 |
| Paratyphoid (inactivated) | 2ml/animal | R 20.34 | 404.16 | 12,372.08 | 189.82 | R 7,721.09 | 136.03 | R 5,533.30 |
| Brucella abortus | 2ml/animal | R 20.19 | 377.84 | 15,259.23 | 275.82 | R 11,139.19 | 220.31 | R 8,897.15 |
| Pasteurella | 1 ml/animal | Price/ml | Total kg | Price/ml | Total kg | Price/ml | Total kg | Price/ml | Total kg |
|-------------|-------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Rift Valley fever (inactivated) | 2ml/animal | R 18.39 | 454.59 | R 8,361.75 | 364.54 | R 6,705.42 | 306.97 | R 5,646.43 |
| Dips | Price/ml | Total kg | Price/ml | Total kg | Price/ml | 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 | Price/animal | Total animals | Price/animal | 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 386,865.05 |
| 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**   |      |      |      |      |      |      |      |      |      |      |      |      |
| Pregnant MC | Calving (%) | 80  | 170.0 | 169.9 | 169.7 | 169.6 | 169.5 | 169.3 | 169.2 | 169.0 | 168.9 | 168.7 | 168.6 | 168.5 |
| Open MC   |      | 42.5 | 42.5 | 42.5 | 42.5 |      |      |      |      |      |      |      |      |      |
| 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**  |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Pregnant TCC | Calving (%) | 80  | 44.6 | 44.6 | 44.5 | 44.5 | 44.5 | 44.4 | 44.4 | 44.3 | 44.3 | 44.3 | 44.2 | 44.2 |
| Open TCC  |      | 11.2 | 11.1 | 11.1 | 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     |      | 11.1 |      |      |      |      |      |      |      |      |      |      |      |      |
| **SCC**  |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Pregnant SCC | Calving (%) | 75  | 56.3 | 56.3 | 56.2 | 56.2 | 56.1 | 56.1 | 56.0 | 56.0 | 55.9 | 55.9 | 55.8 | 55.8 |
| Open SCC  |      | 18.8 | 18.8 | 18.7 | 18.7 |      |      |      |      |      |      |      |      |      |
| 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     |      | 11.1 |      |      |      |      |      |      |      |      |      |      |      |      |
| **FCC**  |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Pregnant FCC | Calving (%) | 100 | 75.8 | 75.8 | 75.7 | 75.7 | 75.7 | 75.6 | 75.6 | 75.5 | 75.5 | 75.4 | 75.3 | 75.3 |
| Open FCC  |      | -    | -    | -    | -    |      |      |      |      |      |      |      |      |      |
| 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 |      |      |      |      |      |      |      |      |
| Deaths    | Death (%) | 3   | 0.4  | 0.4  | 0.4  | 0.4  |      |      |      |      |      |      |      |      |
| Culls sold from MC |      | 88.8 |      |      |      |      |      |      |      |      |      |      |      |      |
| RCC from MC |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Pregnant RCC |      |      |      |      |      |      |      |      |      |      |      |      |      |
| Open RCC  |      | -    |      |      |      |      |      |      |      |      |      |      |      |      |
| Deaths    | Death (%) | 3   | 0.2  | 0.2  | 0.2  | 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 |      |      |      |      |      |      |      |      |
| Deaths    | Death (%) | 3   | 0.1  | 0.1  | 0.1  | 0.1  |      |      |      |      |      |      |      |      |
| Culls sold from TCC |      | 43.5 |      |      |      |      |      |      |      |      |      |      |      |      |
| Calves from SCC |      |      | 55.5 | 55.4 | 55.2 | 55.1 |      |      |      |      |      |      |      |      |
| Deaths    |      | 3   | 0.1  | 0.1  | 0.1  | 0.1  |      |      |      |      |      |      |      |      |
| Culls sold from SCC |      | 55.0 |      |      |      |      |      |      |      |      |      |      |      |      |
Table 12. Stock flow of a herd of medium cattle bred at 15 months.

| 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  |
| Calves sold from FCC |      | 74.0 |
| Bulls          | 16.8 | 16.8 | 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  |
| Culls          | 3.2  |
| Purchased      | Replace (%) | 20  |      |      |      |      |      |

| Calves from FCC | 74.8 | 74.6 | 74.4 | 74.2 | 75.3 | 75.1 | 75.0 |
|----------------|------|------|------|------|------|------|------|
| Deaths         | Death (%) | 3   | 0.3  | 0.3  | 0.3  | 0.3  | 0.3  |
| Calves sold from FCC |      | 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 |  |
| --- | --- |
| Deaths | Death (%) | 3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 |
| 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 | 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 | Death (%) | 3 | 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 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 | 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 | 13.2 | 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.

| Income | Small cattle | Medium cattle | Large cattle | As in base model |
| --- | --- | --- | --- | --- |
| Cattle sales | 100% early calving rate | 54.7% early calving rate |  |
| | Price/kg | Total kg | Total kg | Total kg |
| Collected MC | Class C2/3 | R 20.38 | 12,708.80 | R 258,950.82 | R 16,375.52 | R 333,662.74 |
| Collected TCC | Class C2/3 | R 20.38 | 3,191.86 | R 65,036.30 | R 67,154.85 |
| Collected SCC | Class C2/3 | R 20.38 | 5,045.82 | R 102,812.10 | R 5,210.19 | R 106,161.19 |
| Collected FCC | Class B2/3 | R 21.05 | 0 | R 0.00 | R 323,431.44 | R 2,256.60 | R 47,501.11 |
| Live weaners sold | Weaners | R 32.25 | 32,983.39 | R 1,063,574.09 | R 25,062.17 | R 32,450.18 | R 1,046,380.28 |
| Collected bulls | Class C2/3 | R 20.38 | 957.01 | R 19,499.76 | R 23,280.88 | R 998.41 | R 20,343.23 |
| Total income from cattle sales | | | | R 1,509,873.07 | R 1,595,562.73 | R 1,559,621.26 |

**Expenses**

| | 100% early calving rate | 54.7% early calving rate |  |
| --- | --- | --- | --- |
| | Price/kg | Total kg | Total kg | Total kg |
| Bull purchases | R 112.00 | 1,007.14 | R 112,795.48 | R 134,667.23 | R 105.70 | R 117,674.51 |
| Licks | Price/kg | Total kg | Total kg | Total kg |
| Winter | R 4.10 | 14,515.27 | R 59,527.14 | R 63,112.67 | R 16,188.80 | R 66,390.28 |
| Summer | R 5.21 | 10,854.52 | R 56,508.63 | R 10,677.51 | R 6,297.50 | R 65,555.31 | R 6,223.00 |
| 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 | R 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 | R 66,340.11 | R 6,297.50 | R 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 | 270,298.72 | R 10,806.31 |
| Vitamin A | 1 ml/25 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 |

| Vaccinations | 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 14,023.87 | 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 7,554.09 | 335.78 | R 6,176.33 | 263.1 | R 4,839.48 |
| Rift Valley fever (inactivated) | 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 tssete flies, red lice | 5 ml/50 kg | R 0.54 | 242,372.50 | R 13,190.53 | 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 3,109.92 |
| 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 | R 1,101,901.45 | R 1,182,864.73 | R 1,182,864.73 |
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\textsubscript{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.

| Size         | Small | Medium | Large |
|--------------|-------|--------|-------|
| Final weight (kg) | 293   | 257    | 292   |
| % of mature mass | 97.5  | 57.1   | 42.1  |
| NE\textsubscript{m+g} (Mcal) | 6870  | 7151   | 7255  |
| NE\textsubscript{m}/NE\textsubscript{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 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\textsubscript{m+g} by even a small amount reduced growth in all sizes, since energy will first be used for maintenance. Furthermore, NE\textsubscript{g} was 10.3, 11.7, and 12.8% of NE\textsubscript{m+g}, respectively, for small, medium, and large cows. When NE\textsubscript{m+g} is reduced by 10% over the growth cycle of 1552 days, a small cow will grow to a weight of 294 kg or 78.1% of its mature weight, a medium calf to 353 kg or 78.8% 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.

| Size         | Small | Medium | Large |
|--------------|-------|--------|-------|
| Final weight (kg) | 254   | 353    | 473   |
| % of mature mass | 78.1  | 78.5   | 78.9  |
| NE\textsubscript{m}(Mcal) | 6337  | 8615   | 10,712|
| NE\textsubscript{m}/(NE\textsubscript{m+g} X 90%) | 91.9% | 90.7%  | 89.8% |

At maturity, small, medium, and large cows allocated 5.7% of NE\textsubscript{g} (2,930 Mcal), 6.3% of NE\textsubscript{g} (3,996 Mcal), and 6.8% of NE\textsubscript{g} (4,981 Mcal) to reproduction. If feed were reduced by 5.7% in this instance, a few large cattle might become pregnant, 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 13.90Mcal 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:

\[ NE_m = 1.35W + 0.0146H^2 \]  
(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 \( NE_g \) is linear and depends only on live weight gain \( (LWG) \) and live weight \( (H) \). 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 \( NE_g \) as calculated for a LSU is:

\[ NE_g = LWG \times (1.500 + 0.0045W)/(0.2388 - 0.0717LWG) \]  
(converted to Mcal).

When lactation is considered, the LSU underestimates \( NE_{m+1} \) requirements for all sizes compared to the calculation used in this study and, because it underestimates \( NE_{m+1} \) 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:

\[ NE_{m+1} = (3054P + W^{0.75}(0.6481 + 2.1P))/238.846 \]  
(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-frame, respectively. This makes problematic a fair comparison between the values given as LSU and the equations used in this study. Using the value for \( NE_{m+1} \) from this study for the last day (day 283) of pregnancy compared to the LSU, the latter overestimated the energy requirements for \( NE_{m+1} \) 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 \( NE_{m+1} \), in Table 18 for \( NE_{m+g} \), in Table 19 for \( NE_{m+1} \) and in Table 20 for \( NE_{m+1} \).

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, 75% more small cattle (766) and 25% more medium cattle (556) than large cattle (445) 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

\[ R = S \times h/L \]

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\textsubscript{m} requirements as calculated by LSU and Lofgreen & Garrett.

| Mature size (kg) | 300 | 450 | 600 |
|-----------------|-----|-----|-----|
| LSU NE\textsubscript{m} (Mcal) | 6.0 | 8.3 | 10.6 |
| Lofgreen & Garrett NE\textsubscript{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\textsubscript{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 weight | 550 kg current weight | 600 kg current weight |
|-------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| LSU NE\textsubscript{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\textsubscript{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\textsubscript{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\textsubscript{m+g}, 600 kg mature size, 500 g daily gain (Mcal) | 3.13 | 4.24 | 5.26 | 6.21 | 7.13 | 8.00 | 8.44 | 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\textsubscript{m+l}.

| Daily milk yield | 5 kg/day | 10 kg/day | 15 kg/day |
|------------------|---------|---------|---------|
| Cow weight       | 300 g   | 450 g   | 600 g   | 300 g   | 450 g   | 600 g   | 300 g   | 450 g   | 600 g   |
| LSU NE\textsubscript{m+l} (Mcal) | 8.38 | 10.05 | 11.58 | 12.29 | 14.02 | 15.60 | 16.28 | 18.06 | 19.70 |
| NRC NE\textsubscript{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% |
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.

**Table 10. Comparison between LSU and calculation recommended by NRC for NE<sub>me</sub>**

| Cow weight (kg) | 500 | 525 | 550 |
|----------------|-----|-----|-----|
| **Calf size at 6.67% of mature weight for NRC equation (kg)** | 33  | 35  | 37  |
| LSU NE<sub>me</sub>, unspecified stage of pregnancy (Mcal) | 19.64 | 21.62 | 23.61 |
| NRC NE<sub>me</sub>, last day of pregnancy (Mcal) | 12.81 | 13.35 | 13.88 |
| Difference: LSU and NRC | 35%  | 38%  | 41%  |

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