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CONSERVATION VERSUS TRADITIONAL CATTLE FARMING - THE ECONOMIC IMPLICATIONS

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ABSTRACT

In many areas of South Africa traditional subsistence farming practices entail overstocking of cattle. The resulting damage to the veld can be arrested only by providing the farmers with economic incentives to reduce stocking densities. In this paper cattle offtake strategies are investigated with a view to maximising revenue at lower stocking densities. This is achieved by developing a mathematical model which predicts the revenue generated by a given strategy. It is shown that although the model is nonlinear, a transformation can be made to enable optimisation by linear programming.

INTRODUCTION

Soil erosion and general veld degradation are serious problems in many parts of South Africa and elsewhere. One of the causes of this problem is overstocking of cattle in areas where traditional subsistence farming is still practised. The only programme that is likely to be effective in resolving the overstocking problem is one that provides economic incentives for pastoral farmers to reduce their stock. In this paper we investigate herd management policies which attempt to achieve increased economic returns from the cattle while simultaneously reducing stocking levels.

The low productivity of traditional African pastoral systems (Blair-Rains & Kassam, 1980; Loosli & McDowell, 1985) has resulted in numerous attempts to improve economic returns and efficiency in the use of grazing resources. Efforts to analyse management options for these systems have led to the development of a number of simulation models (Anderson & Trail, 1978; Sanders & Cartwright, 1979; Sere & Doppler, 1980; Sullivan et al, 1981; Cartwright et al, 1982; Uys et al, 1985). These models deal with the interaction between animal populations and the forage available. Due to its low data requirements the model developed by Uys et al (1985) is used as a starting point in the present analysis.

While previous model-based analyses all have the basic aim of increasing herd productivity, they differ on how to measure this. Cow reproductive performance, units of dry matter consumed by the herd per unit liveweight sold from the system, total head sold, revenue from herd sales, and total output of milk are some of the performance indices used in these models. The models identify herd management policies that maximise these performance indices. The disappointingly low rate at which these 'optimal' policies were adopted led to an investigation by Sullivan et al (1978). They found that there was a large discrepancy between the 'commercial value' of a herd and the 'traditional value' but they did not try to determine the reasons for this discrepancy. Later studies suggested that 'good' herd management strategies were directed at increasing the marketable returns from pastoral systems (Ayuko, 1981; Tapson and Rose, 1984) but failed to recognise the non-marketable benefits of the herd in a traditional African subsistence system. In such a system the value of non-marketable utilities are high compared to the value of marketable products (Colvin, 1983). Not recognising this leads to a distortion of what constitutes a 'good' policy and is a major reason for the lack of adoption of 'good' herd management practices (Horowitz, 1979; Baker, 1980; Halderman, 1985; Colvin, 1985). In a three year field study in Maputaland, Buchan (1988) tried to assess all the benefits that traditional subsistence farmers derive from their herds and it is the incorporation of these factors in our analysis which provides a point of departure from previous work.

APPROACH

A mathematical model comprising fodder, cattle and revenue for a traditional subsistence pastoral system is developed. The cattle section of this model uses the relationships given in the dynamic model formulated by Uys et al (1985). Since we are concerned with finding management policies that yield sustainable returns, an equilibrium model is empoyed here and the rates of change in the numbers of each cattle group as given by Uys, et al are set to zero.

As in the case of the work by Uys et al (1985) we consider the Maputaland area of northern Zululand. This is an overstocked semi-arid region exhibiting low levels of productivity. The offtake rates from the various herd age and sex groups are then used as parameters in an algorithm to maximise the total economic returns. This optimisation is subject to several constraints including a minimum bull to cow ratio. The results are also checked to ensure that minimum milk and draught animal requirements are met.

MODEL FORMULATION

Fodder

Detailed data on fodder production rates would normally be required for this analysis. Unfortunately, this type of data is seldom available. So we proceeded as follows: A *livestock unit* is defined as equivalent to a cow in terms of grazing impact. A younger animal would therefore represent less than one livestock unit. A *unit of fodder* can now be defined as the quantity of fodder required to maintain for one year, one livestock unit in a condition typical for the region. From estimates of head of cattle in the region (Buchan, 1988), we calculate that on average the region is supporting about 146818 livestock units. Accepting this value, the definitions imply that 146818 fodder units are produced each year. This fodder production rate will be denoted by the parameter FPN (fodder production normal).

If the stocking density in the region were reduced the increased availability of fodder per livestock unit would have important consequences for the system. In fact, the main driving variable affecting all herd population functions is fodder availability. The effect of this variable is quantified by means of the functions FDF, GF, FF and DF which are discussed later (see Figs. 1 and 2). An index of the availability of fodder is defined as follows:

$$FAI = F/FA$$

where:

FAI = fodder availability index

F = fodder units available for grazing at any given time

FA = fodder units available for grazing at any given time averaged over a typical year under traditional herd management practices.

In terms of this definition, FAI=1 corresponds to fodder availability averaged over a typical year under traditional management practices. Thus, values of FAI greater than unity indicate a greater abundance of fodder available as a result of lower stocking densities. In the event of very low stocking levels, the higher density of fodder will lead to a certain amount of intraspecific competition. This inhibiting effect on production is represented by the fodder density function, FDF (see Fig. 2). Thus, the production of fodder is determined by the equation:

$$production\ rate = FPN*FDF(FAI)$$

Fodder is grazed by the cattle at the following rate:

$$grazing\ rate = LSU*GN*GF(FAI)$$

where LSU is the number of livestock units in the regional cattle herd. The grazing normal GN is the quantity of fodder grazed by one livestock unit per year averaged over a typical year under traditional herd management practices. By our definition of fodder units, GN = 1.0 . The grazing function GF (Fig. 2) is an increasing function of FAI which reflects the increased rate of grazing possible when fodder is more abundant than usual and conversely.

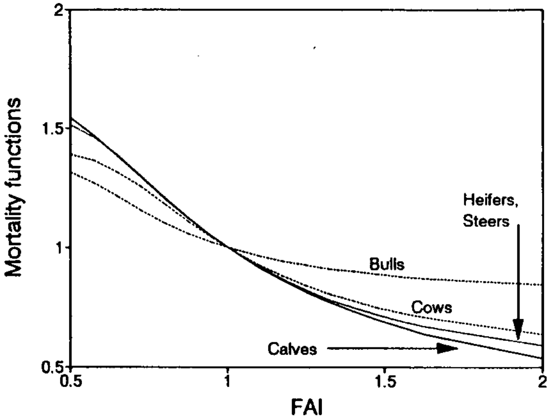

Fig. 1. Graphs of the mortality functions DF.

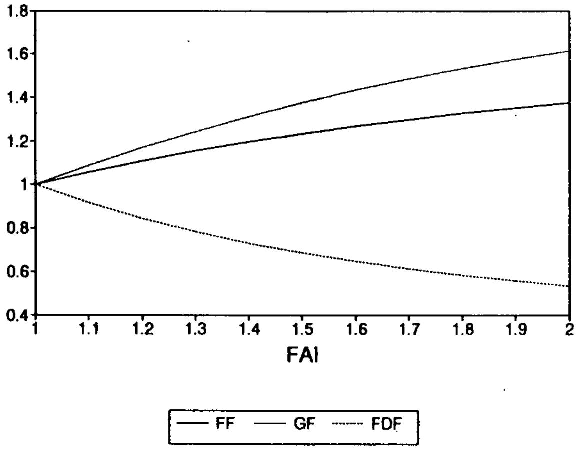

Fig. 2. Graphs of the fecundity function FF, the grazing function GF and the fodder density function FDF.

For the system to be in equilibrium we require:

production rate - grazing rate = 0, ie

$$FPN*FDF(FAI) - LSU*GN*GF(FAI) = 0 \tag{1}$$

Note that this equation implies that the total number of livestock units in the region is an implicit function of FAI.

Cattle

The cattle population is divided into the following sex and age classes: female calves, heifers, cows, male calves, steers, bulls/oxen. The population in each class in the order above is denoted by c_i, $i = 1,2,\ldots,6$. The number of livestock units in the region, LSU, is the weighted sum of the numbers in each group. ie

$$LSU = \sum_{i=1}^{6} a_i c_i \tag{2}$$

a_i is the livestock unit equivalent for an animal in group i.

For the populations in the various cattle groups to be in equilibrium there must be a balance between rates of recruitment and loss. The rates determining recruitment and loss comprise births, ageing, deaths and offtake. The equations for these rates are developed below.

Births

The birth rate of calves is determined by the following equation:

$$birth\ rate = c_3*FN*FF(FAI)$$

where FN is fraction of cows that calf in an average year under current conditions. When more fodder is available the improved condition of the cows results in increased fecundity. This effect is represented by the fecundity function FF (Fig. 2). It is assumed that male calves are born in equal proportion to females.

Deaths

The mortality rate of cattle in group i is given by:

$$deaths = c_i * DN_i * DF_i(FAI)$$

where the death normal DN_i is fractional death rate under average conditions and DF_i (Fig. 1) represents the effect of decreased mortality when fodder is more abundant (FAI>1).

Ageing

The fraction of group i that age to group i+1 per year is defined as the ageing normal, AN_i (i = 1, 2, 4, 5). Thus the rate at which individuals in group i age to group i+1 is given by:

$$ageing\ rate = c_i * AN_i \qquad (i = 1,\ 2,\ 4,\ 5)$$

Offtake

Offtake is taken to mean either the slaughter of cattle in the region or the sale of live cattle resulting in their removal from the region. The rate of offtake of cattle is determined by:

$$offtake\ rate = c_i * ON_i$$

where ON_i is the fraction of group i that are removed from the herd per year.

As inadequate infrastructure exists for importing cattle into the region, note that it is required that:

$$ON_i \geq 0 \qquad (i = 1,\ 2,\ \ldots,\ 6) \tag{3}$$

Cattle equations

Using the expressions for the above rates and the requirement for an equilibrium solution that recruitment equals loss, the following equations are obtained:

calves(f):

$$c_3 * FN * FF(FAI) - c_1 * AN_1 - c_1 * DN_1 * DF_1(FAI) - c_1 * ON_1 = 0 \tag{4}$$

heifers:

$$c_1 * AN_1 - c_2 * AN_2 - c_2 * DN_2 * DF_2(FAI) - c_2 * ON_2 = 0 \tag{5}$$

cows:

$$c_2 * AN_2 - c_3 * DN_3 * DF_3(FAI) - c_3 * ON_3 = 0 \tag{6}$$

calves(m):

$$c_3 * FN * FF(FAI) - c_4 * AN_4 - c_4 * DN_4 * DF_4(FAI) - c_4 * ON_4 = 0 \tag{7}$$

steers:

$$c_4 * AN_4 - c_5 * AN_5 - c_5 * DN_5 * DF_5(FAI) - c_5 * ON_5 = 0 \tag{8}$$

Bulls/oxen:

$$c_5 * AN_5 - c_6 * DN_6 * DF_6(FAI) - c_6 * ON_6 = 0 \tag{9}$$

Parameter values are presented in Table 1.

Revenue

Initially we shall follow the approach adopted in several earlier studies by defining revenue as financial returns resulting from the sale of live cattle to which is added the monetary value of cattle slaughtered within the region. Later a more comprehensive performance index will be defined which takes into account non-marketed utilities from the subsistence pastoral system.

This initial approach leads to the following expression for annual revenue derived from marketed products:

$$Revenue = \sum_{i=1}^{6} SP_i * c_i * ON_i * GF \tag{10}$$

where SP_i is the selling price of an animal from group i. The grazing function, GF, is included to represent the effect of changes in fodder availability on cattle condition.

TABLE 1

Livestock Parameter Estimates

Ingwavuma/Ubomba Region of Kwazulu

(Data from Buchan (1988) and Uys et al (1985))

Parameter \ Group	1	2	3	4	5	6
AN_i, ageing normal	1.0	0.5	-	1.0	0.5	-
DN_i, death normal	0.15	0.09	0.12	0.15	0.07	0.08
a_i, livestock equiv.	0.2	0.5	1.0	0.2	0.6	1.2
SP_i, selling price (R)	172	300	325	172	238	376
CP_i, carcase price (R)	169	228	258	169	167	274

FN: 0.18 calves.cow^{-1}.yr^{-1} GN: 1.0 fodder units

FPN: 146818 fodder units LSU: 146818

Milk Yield: 1328.6 l.cow^{-1}.yr^{-1} Milk Price: 0.20 Rands.l^{-1}

Draught Yield: 200 days.ox^{-1}.yr^{-1}

Draught Price: 1.25 Rand.ox^{-1}.day^{-1}

THE MATHEMATICAL PROBLEM

A mathematical problem can now be formulated with the objective of finding a stocking density, LSU, and an offtake strategy, (ON_i: i = 1, 2,..., 6) which maximises the economic returns from the regional herd. The problem is subject to the constraints represented by equations (1) - (9). In addition we need to ensure that there are sufficient bulls to service the cow population. One bull for every 20 cows is usually considered sufficient. Thus, it is also required that:

$$c_3 - 20 * c_6 \leq 0 \qquad (11)$$

As the cattle numbers, c_i, i = 1, 2,..., 6 are implicit functions of the offtake strategy, the objective function as given by equation (10), is a nonlinear function of the offtake strategy. Thus we have a nonlinear constrained optimisation problem with nonlinear constraints. While methods exist for the solution of such problems we proceeded as follows: It was anticipated that the mathematical solution would show that optimal returns from the regional herd would be obtained when stocking densities are kept at lower levels than is traditionally practised. This would have provided the necessary incentive for subsistence pastoral farmers to change their traditional practices and in the process diminish veld degradation. However, the extent of stock reductions suggested by an optimal policy might be unacceptable to the people. Therefore, it might be more useful to fix the stocking level and determine what economic returns can be achieved at that level. If this is done for a range of stocking levels a graph can be obtained which will show the trade-off between stocking levels and attainable economic returns.

According to equation (1) there is a relationship between stocking levels, LSU, and FAI. This relationship is shown in Fig.3.

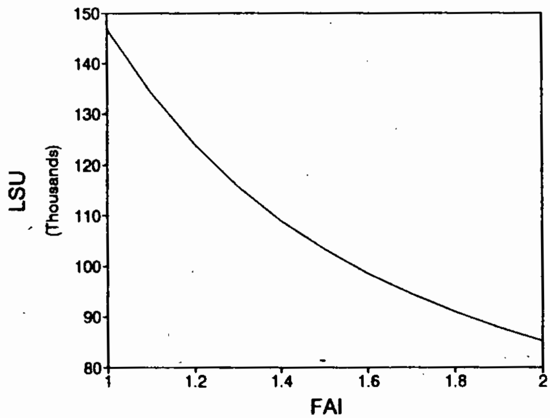

Fig. 3. The relation between LSU and FAI.

We found it more convenient to specify values of FAI rather than LSU. Current stocking levels imply that FAI is unity so FAI values greater than unity imply lower stocking levels than the current situation. The above suggestion reduces the optimisation problem from seven variables to six variables. This in itself is not a great gain. However, it will be shown that this enables the problem to be reduced to a linear programming problem. The equations (4) - (9) can be rearranged as follows:

$$c_1 * ON_1 = c_3 * FN * FF(FAI) - c_1 * AN_1 - c_1 * DN_1 * DF_1(FAI) \tag{12}$$

$$c_2 * ON_2 = c_1 * AN_1 - c_2 * AN_2 - c_2 * DN_2 * DF_2(FAI) \tag{13}$$

$$c_3 * ON_3 = c_2 * AN_2 - c_3 * DN_3 * DF_3(FAI) \tag{14}$$

$$c_4 * ON_4 = c_3 * FN * FF(FAI) - c_4 * AN_4 - c_4 * DN_4 * DF_4(FAI) \tag{15}$$

$$c_5 * ON_5 = c_4 * AN_4 - c_5 * AN_5 - c_5 * DN_5 * DF_5(FAI) \tag{16}$$

$$c_6 * ON_6 = c_5 * AN_5 - c_6 * DN_6 * DF_6(FAI)$$

As FAI is specified, the right hand side of the above equations are linear functions of c_i, $i = 1, \ldots, 6$. Equations (12) - (17) can be substituted into the objective function (10) to eliminate the ON_i. The objective function then becomes a linear function in c_i, $i = 1, \ldots, 6$. The optimisation problem can now be restated to find c_i, $i = 1, \ldots, 6$.

The constraints (4) - (9) have been rewritten as equations (12) - (17). As both c_i and ON_i ($i = 1, \ldots, 6$) are required to be nonnegative the constraints for the new problem become the requirement that the right hand side of equations (12) - (17) are nonnegative. Once the optimisation problem is solved the optimal offtake strategy can be calculated from (12) - (17).

RESULTS

Under existing stocking densities, that is FAI = 1, an optimal offtake strategy was found to be <u>ON</u> = (0,0; 0,5; 0,0; 0,0; 0,0; 22,3) where the offtake rates are expressed in units of percent per month. The high bull offtake rate is in distinct contrast with the corresponding rate with the traditional strategy given by (0,0; 0,7; 0,2; 0,0; 1,3; 1,0). It was found that this optimal strategy yields a three-fold increase in returns from sales compared to traditional practices.

As shown in Fig. 4, further substantial increases can be achieved for optimal strategies at lower stocking densities (ie at higher values of FAI). This suggests that there is sufficient motivation to lower the stocking densities.

However, criticism may be directed at this conclusion on the grounds that the objective function does not take into account all factors having economic implications. Therefore an objective function comprising the following components was considered: sales, asset appreciation and a value associated with the carcasses of animals that have died of natural causes. The last term has been included because it has been found that a significant amount of meat is recovered from these carcases (Buchan, 1988). This objective function is also a linear function of the cattle numbers so the problem can be solved easily as before.

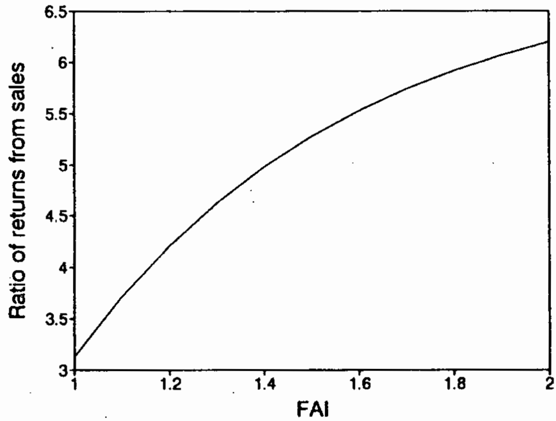

Fig. 4. Returns from offtake sales. The ratios shown are returns from offtake sales under optimal strategies for various FAI divided by the returns from sales under traditional herd management practices (where FAI = 1).

Fig. 5 shows the returns that are obtained under an optimal offtake strategy when this more comprehensive objective function is used. Note that in this case an optimal strategy achieves an increase in returns of only about 35%. When returns from offtake sales alone was considered (Fig. 4) an optimal strategy yielded an increase of over 300%. Perhaps the perception that traditional subsistence pastoral systems are badly managed is a consequence of their performance being judged according to the wrong index. Fig. 5 also shows that with a more comprehensive performance index, returns decrease with lower stocking densities. This is rather disappointing as it indicates

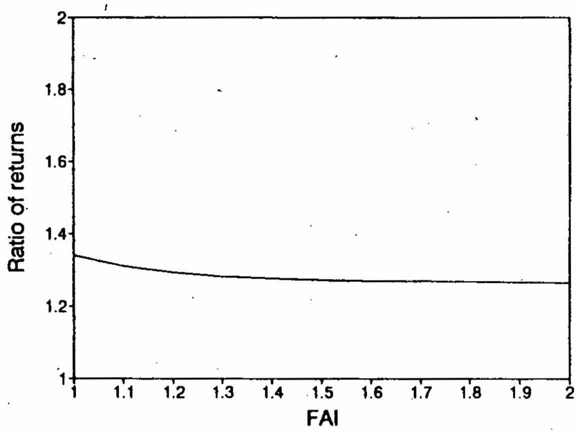

Fig. 5. Returns obtained using a comprehensive objective function. The ratios shown are returns under optimal strategies for various FAI divided by the returns under traditional herd management practices (where FAI = 1).

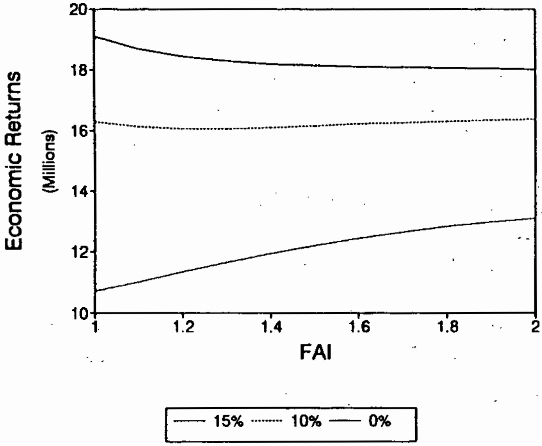

Fig. 6. Effect of inflation on returns.

that there is no economic incentive to reduce stocking levels. However, note that with an optimal strategy the economic returns at all lower stocking levels shown are still greater than those obtained under current practices.

Asset appreciation, which is included in the above objective function, depends on the current inflation rate. As this rate is variable, the effect of different rates of inflation was investigated. The results are shown in Fig. 6. As the inflation rate decreases the importance of asset appreciation diminishes until the results are similar to those obtained by considering sales alone as the objective function.

The above comprehensive objective function does not include returns from either milk or draught. It was found that in all cases there was more than sufficient of these resources to meet local requirements. There is no infrastructure in the region for marketing surplus milk. Therefore including returns from milk in the objective function would cause an unrealistic distortion in the optimal strategy. If a means for marketing surplus milk could be provided the situation would change. The effect of including returns from surplus milk in the objective function was therefore investigated for various producer prices. The results (see Fig. 7) suggest that improved returns can be achieved at lower stocking densities if the herdsmen can fetch a sufficiently high price for their milk.

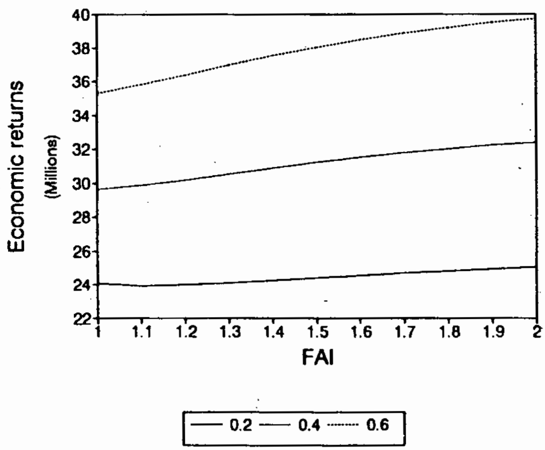

Fig. 7. Returns with milk sales included in the objective function at prices of 0.2, 0.4 and 0.6 Rand.l^{-1}.

The effect of some of the offtake strategies on the structure of the regional herd is shown in Fig. 8.

CONCLUSION

A number of optimal offtake strategies have been identified. All of these strategies yield improved economic returns compared to those obtained under traditional practices. The purpose of this study has been to investigate the possibility of providing economic motivation for reducing livestock densities in order to minimise veld degradation.

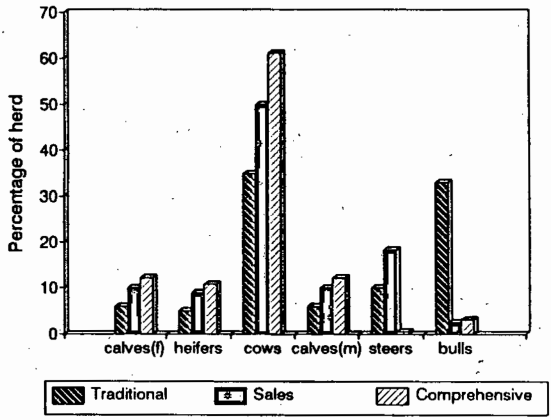

Fig. 8. The structure of the regional herd under three different offtake strategies: the traditional strategy, a strategy to optimise sales, and a strategy to optimise a comprehensive objective function which includes milk at a producer price of 0.4 (Rand.l^{-1}). The last two strategies optimise economic returns at FAI = 1,5. This represents a 30% reduction in livestock units.

A number of previous studies focussed on maximising returns from sales alone (see Buchan, 1988) and our results suggest such returns increase with reductions in livestock density. That this impression is misleading becomes apparent when the more comprehensive objective function is considered. It is then found that the optimal returns actually decrease with lower stock density although they do remain higher than that traditionally achieved.

On this basis there appears little incentive to reduce stocking densities. It has been assumed that the system under consideration is sustainable for any stocking level. This is true only over the short to medium term. As has already been discussed, present stocking levels are causing veld degradation which will eventually impact adversely on the performance of the pastoral system. The economic returns are therefore not truly sustainable at high stocking levels. However the rate at which returns are eroded appears to be too slow for this to provide enough incentive for a move away from traditional practices.

An unfortunate yet natural consequence of the traditional system of communal grazing land is that no single tribesman can reduce stocking levels unilaterally. In fact if anyone were to reduce the numbers in his personal herd, their place would be taken by cattle belonging to other tribesmen sharing the same land. His sacrifice in cattle numbers would not be compensated for by improved performance. The harsh reality is that resources he does not appropriate for his own use will be taken by others. This phenomena can only be avoided by the introduction of some system entailing personal individual responsibility for a certain tract of veld eg by way of land ownership. Under such a system each individual farmer benefits directly from any improvements he initiates. It has been shown in this paper that increased returns at lower stocking densities are feasible but that the improvements at lower densities are not spectacular. Careful management would be needed - the benefits of other breeds need to be investigated. The creation of a milk marketing infrastructure would however,provide additional incentive for stock reductions.

ACKNOWLEDGEMENTS

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