

PRODUCTION AND ECONOMICS OF ARADO AND BARKA CATTLE IN ERITREA

By

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SUBMITTED IN PARTIAL FULFILMENT OF THE
REQUIREMENTS FOR
THE DEGREE OF

MASTER OF SCIENCE IN AGRICULTURE

IN THE DISCIPLINE OF GRASSLAND SCIENCE IN THE
SCHOOL OF BIOLOGICAL AND CONSERVATION SCIENCES
FACULTY OF SCIENCE AND AGRICULTURE
UNIVERSITY OF KWAZULU-NATAL
PIETERMARITZBURG

May 2007

ABSTRACT

Grazing lands in Eritrea are degraded due to decades of overstocking and consequent overgrazing. Since the rangelands are accessible to entire village communities, organisation and coordinated decision making regarding the management of these resources is not often achieved. Farmers are not motivated enough to make investments to improve a communally owned resource due to the prevailing common access grazing systems.

A field survey was undertaken interviewing 12 farmers in the private access commercial and 80 farmers in the common access subsistence grazing using face to face interviews in the Barka and Arado cattle farming communities in four out of the six regions in Eritrea. Debub, Gash-Barka, S. Keih Bahri and Maekel regions were selected using stratified and simple random sampling methods. The regions were chosen based on various agro-ecological zones where the representatives of different grass species and the two most common cattle breeds in Eritrea (Arado and Barka) are found. The survey included the collection of data on village and household characteristics focusing on rangeland grazing management systems and additional sources of supplementary forage. The study uses several stages of analysis like principal component analysis accompanied by regression analysis together with descriptive statistics and ordination diagram.

The commercial farmers addressed grazing constraints by investing in improved grazing through planting 258 ha per farmer of drought resistant seeds and 1767 vs. 8 cactus slices per farmer and covered 75% vs. 40% of forage requirements from grazing resources compared to the subsistence farmers, respectively, during 2002. These results were achieved because 78% of the commercial farmers adopted controlled stocking rates. In common access grazing, the costs of collective action to control cattle stocking rates are high, making implementation of stocking rate controls difficult. As a consequence, 65% of the subsistence farmers were forced to migrate their cattle looking for grazing forage in the dry season during the year.

The outcomes of migration were evidenced by the results of severe overgrazing and degradation on the rangelands proximity to villages in Debub and Maekel regions and the populated area of Gash_Barka region. The increased number of animals resulting in high

grazing pressure was the consequence of migration. Ten vs. six percent of mortality rates was reported for the subsistence systems compared to the commercial systems respectively. The lower results of milk yield, calving rates and off-take rate productivity indicated in the different stages of analysis for the subsistence farmers were the consequences of the lack of the adoption of controlled stocking rates primarily constrained by the migration.

The Barka and Arado cattle farming systems are kept under common access grazing systems. Compared to the Arado cattle farming, the Barka cattle farming region had relatively better access to grazing forage. The better quality of grazing in this region is attributed to a naturally low stock density in the region.

During 2002, the Barka cattle farming had 1087 vs. 721 Lit of milk yield, 63% vs. 53% of calving productivity and 9.3% vs. 10.9% of mortality rates than the Arado cattle farming regions respectively, due to access to a wider area of grazing lands and more labour inputs. The Barka cattle area farmers are agro pastoralists and usually focus on grazing dairy cattle farming than crop farming. They increased calving rate productivity and decreased mortality rates by increasing the proportion of lactating cows and decreasing the proportion of oxen compared to the Arado cattle farming. The Arado cattle farming had higher off-take rates and income from cattle sales compared to the Barka cattle farming region. The higher off-take rate, which is an index of percentage of cattle sold, for the Arado cattle was probably linked to the shortage of grazing forage and increased herding costs.

The Barka and Arado cattle farmers had a shortage of quality and quantity crop residue winter forage during 2002. Farmers were dependent only on rain fed cropping. The application of crop rotation, fallow and chemical fertilizers were low to enhance soil nutrients. Out of the total crop residues forage produced, only 22% and 15% of legumes residue DM forage was produced for the Barka and Arado cattle farmers respectively. Agro-industrial and crop farming by-products supplementary feeds were also limited due to the shortage of feeds in the country during the year.

In general, government intervention is important to bring institutional changes to promote the adoption of controlled stocking rates to alleviate the shortage of grazing forage.

This thesis is the result of the author's original work except for assistance acknowledged, or unless specifically stated to the contrary in the text. It has not been submitted for any degree or examination at any other university or academic institution.

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ACKNOWLEDGEMENT

I wish to express my sincere thanks to all those who made this study possible, but I am particularly indebted to the following individuals and institutions.

Eritrea Ministry of Agriculture and its Human Resource Development for affording me the opportunity of this study. I am grateful for this once in a lifetime opportunity. Special thanks go to Zeba Dehub Ministry of Agriculture. Ministry of Agriculture of Four Study Regions, Gash-Barka Ministry of Regional Administration, Animal and Land Resource Departments, Asmara and Surrounding Dairy Farmers Cooperative.

Professor K P Kirkman, Chair of Grassland Science, University of KwaZulu-Natal, for his supervision, expert guidance, valuable comments, advice, encouragement, and his unlimited, appreciated efforts and patience throughout this study. I feel happy to express my gratitude to Dr S R D Ferrer, Discipline of Agricultural Economics, who co-supervised this study and whose valuable efforts I greatly appreciate.

I appreciate my wife, Gabriela, for her dedication to overcome the heavy responsibility of our family. It is she who has given me unlimited encouragement and support that enable me to carry out my study with full confidence.

Above all, the Lord God my maker and closest friend, without whom nothing would have been possible!

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CHAPTER 1

INTRODUCTION

In Eritrea, like most of the less developed countries in sub-Saharan Africa, the bulk of the population is poor and resides in rural areas. Eighty percent of Eritreans are dependant upon agriculture for their livelihoods and almost all rural communities in Eritrea are dependent upon crop-livestock integrated farming systems (FAO 2005). Despite the availability of relatively modern technology, Eritrean farming methods remain traditional and the productivity of Eritrean agriculture (including livestock agriculture) has been described as being low relative to its potential (FAO 2003; Haile 2002). On-going degradation and loss of communally owned rangelands in Eritrea, due to poor management, overgrazing and encroachment of cropping and settlements is adversely impacting on livestock productivity on this land. According to FAO (2003) the relative absence of sound rangeland management practices in Eritrea (e.g. proper grazing systems and crop rotation to improve the nutritive quality of crop residues) limits forage production and is the major constraint for cattle farming productivity in Eritrea.

The problems of on-going rangeland degradation of communally farmed rangelands and the low productivity of these rangeland systems are common to many African countries. Although numerous attempts have been made to improve economic returns and efficiency in the use of these communally owned grazing resources (Balair-Rains and Kassam 1980; Loosli and McDowell 1985), many of the livestock development programmes have been unsuccessful, and their failure has been attributed to a lack of understanding of local traditions and the socio-economic structure of the system by some researchers (Swift and Maliki 1984). These local traditions and socio-economic structure (e.g. property rights systems) and other rules governing the use of grazing land may be broadly described as institutional arrangements.

Considering that growth in per capita food production is important for long-term industrial and economic growth in less developed countries (Ghatak and Ingersent 1984), identifying policies and programmes that will improve livestock farming productivity, e.g. through improved

grazing management systems that will promote forage production, is an important objective for economic development in Eritrea. Livestock agriculture alone accounts for 10% of GDP and contributes to the Eritrean economy through a) production of food for domestic consumption and b) as an earner of foreign exchange through exports (Haile 2002; Russum 2002). The relatively large size of the smallholder cattle sector relative to the commercial cattle sector in Eritrea suggests that improved productivity of smallholder cattle farming systems will contribute significantly towards the economic development of Eritrea.

A study of cattle farming productivity in Eritrea provides opportunity to increase existing knowledge regarding the structure and functioning of the Eritrean rangeland systems and how the use and value of its rangeland resources by pastoralists is influenced by the institutional arrangements of the communal grazing system. This knowledge may be used to inform policy and programmes for rangeland and livestock management that will contribute to improving the productivity of cattle farming in Eritrea. Considering that (a) most Eritrean regions have many plant communities with composition similar to that of many other African regions with various topographic features such as highlands, lowlands and coastal region-resources (Pichi-Seremolli 1957; Vesey-Fitzgerald 1970; Fris 1992; NEMPE 1995), and (b) the socio-economic pressures in other rural African communities, e.g. those described by Boonzaier (1987) and Starr (1987) in parts of South Africa, appear to be similar to those in Eritrea; this knowledge may prove useful for the development of a policy for local livestock management and contribute to an improved understanding of managerial problems in African rangeland systems in general.

1.1 Grazing resources and livestock farming in Eritrea

The major types of livestock farmed in Eritrea are cattle, goats, sheep, camels, donkeys, horses and poultry. The relative importance of cattle to livestock farming in Eritrea is indicated in Table 1.1. The population sizes of livestock are reported in animal numbers from the survey as well as in livestock units (TLU) and it is evident that cattle are the most important type of large livestock in Eritrea. One tropical livestock unit (TLU) is 250 kg live mass or equivalent to 0.7 cattle, 0.1 sheep and goats and 1.0 Camel. The number of cattle data is sourced from the

Eritrean Ministry of Agriculture (MOA) (1997); TLU data conversion is sourced from FAO Corporate Document Repository, Agricultural Department, World Animal Review, written by Jahnke (1982), cited by De Leeuw and Rey (1995)).

Table 1.1 Livestock numbers in Eritrea

Livestock	Cattle				Sheep	Goat	Camel	Total
	Barka	Arado	Araba	Friesian				
No	1109453	778004	40000	11486	2128930	37294300	318914	41681087
Percent of cattle	(57%)	(40%)	(2%)	(1%)				
Livestock units (TLU)	776617	544603	28000	8040	212893	3729430	318914	5618497

(Source: Data adopted from MOA 1997; Jahnke 1982)

1.1.1 Agro-ecological zones in Eritrea

Rangelands comprise 49% of Eritrea and their distribution is largely restricted to certain agro-ecological zones. This section identifies the major agro-ecological zones of Eritrea and concludes by identifying the agro-ecological zones in which rangeland occurs in Eritrea. A map showing the major agro-ecological zones is provided in Figure 1.1. According to FAO (1994), Eritrea is divided into six agro-ecological zones known as:

- Central Highland Zone (CHZ) – arid Northern Midlands (NM) and moist Highlands (H) as well as Midlands
- Green Belt Zone (GBZ) - Sub Humid
- Coastal Plain Zone (CPZ) - Semi-Desert
- Western Escarpment Zone (WEZ) – Semi- Arid
- South Western Lowland Zone (SWLZ) - Moist Lowland
- North Western Lowland Zone (NWLZ) - Arid Lowland

Altitude is the major factor determining temperature and rainfall. Total annual rainfall tends to increase from north to south, from less than 200 mm at the northern to over 800 mm in a restricted area on the southern part of the country. Mean temperatures range from 16° C in the highlands to extreme highs of about 30° to 40° C along the Red Sea coast. The Danakil depression in the south-east, which is more than 130 m below sea-level in places, experiences some of the highest temperatures recorded, frequently exceeding 50° C.

The Central Highland Zone has a total area of 2.67 million ha and it is mainly constituted of disturbed high forest due to improper management and misuse of the natural resources over the past long period of time. This area consists of three sub-zones, namely the Northern Midlands which is between 1500 and 2000 m in altitude, Highlands, with an altitude of over 2000 m and Southern Midlands having an altitude between 1500 and 2000 m. The Central Highland Zone comprises moist and arid climatic conditions with over 500 mm of rainfall.

The Green Belt Zone is located on the Eastern Escarpment of the Central Highland Zone with an altitude of between 750 m and 2000 m. This zone is called the Green Belt because it gets a high rainfall ranging from 700 to more than 1000 mm. It is different from the other zones due to its capacity to produce good forage and support permanent crops such as coffee without irrigation. Cattle from the Central Highlands migrate to this zone during drought.

The Coastal Plain Zone has an area of 4.67 million ha below 600 m altitude and experiences an average of 260 mm of rainfall. The major vegetation types are *Acacia* trees and shrubs, semi-desert vegetation, riverine and mangrove species that include *Acacia tortilis*, *Acacia mellifera*, *Acacia asac*, *Acacia nubica* and *Avicennia marina*.

The Western Escarpment Zone is located between the Highlands and the Western Lowlands. It extends from 600 m to 1500 m and has a warm to hot semi-arid climate with an average rainfall of up to 500 mm.

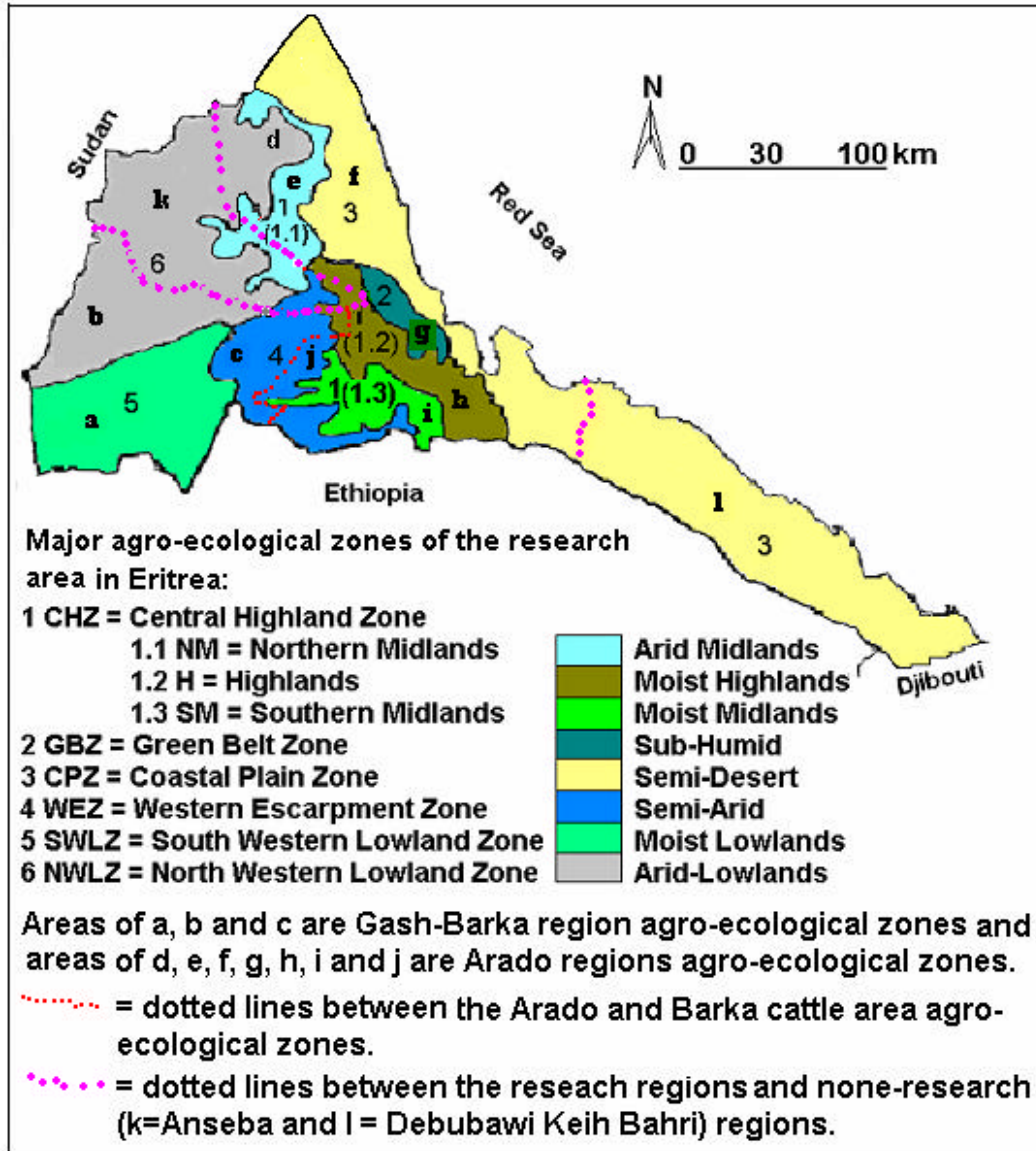


Figure 1.1 Typical six agro-ecological zones of Eritrea. (Source: MOA 1997).

The South Western Lowland Zone has an altitude of between 600 and 750 m with an annual rainfall of between 500 and 700 mm. Its area is 2.08 million ha. This zone includes woodland savanna, bushland and thicket vegetation. The dominant species in this zone are *Acacia*

tortilis, *Acacia senegal*, *Balanites aegyptiaca*, *Ziziphus spina christii* and *Boswellia papyrifera*.

The North Western Lowland Zone has an area of 3.04 million ha, with an altitude of between 400 and 1500 m asl and a hot arid climate with an average rainfall of 360 mm. Its dominant types of vegetation are *Acacia tortilis*, *Acacia mellifera*, *Balanites aegyptiaca*, *Hyphaene thebaica* and *Salvadora persica*. In NWLZ sustainable forage and crop production is difficult without irrigation.

The major rangeland zones in Eritrea are found in the Central Highlands, the Western and Southwestern Lowlands and the Eastern Coastal Plains of the country (Kayouli *et al.* 2005; MOA 1997). According to FOSA (2001), the western and south-western lowlands account for 57% of the country's grazing land and the Central Highland Zone accounts for 16% of the total.

1.1.2 Cattle farming regions in Eritrea

The main regions of the Barka and Arado cattle farming of Eritrea are found in the Western and South-western Eritrea known as Gash-Barka region (area 4 in Figure 1.2), to the South and Centre part of the Central Highlands known as Maekel and Debub regions (areas 2 and 3, respectively, in Figure 1.2) and east of the Central Highlands known as Semienawi Keih Bahri region (area 1 in Figure 1.2). The research area comprises these four regions. Anseba and Debubawi Keih Bahri regions (areas 5 and 6, respectively, in Figure 1.2) are not included in the study, owing to the cattle of Anseba region being mixed between the Arado and Barka cattle breeds and Debubawi Keih Bahri region lacks a significant number of either the Arado or Barka cattle breed. The Northern part and Northwest of the country in the Semienawi Keih Bahri and Anseba regions areas 1 and 5, respectively, in Figure 1.2 has a low population

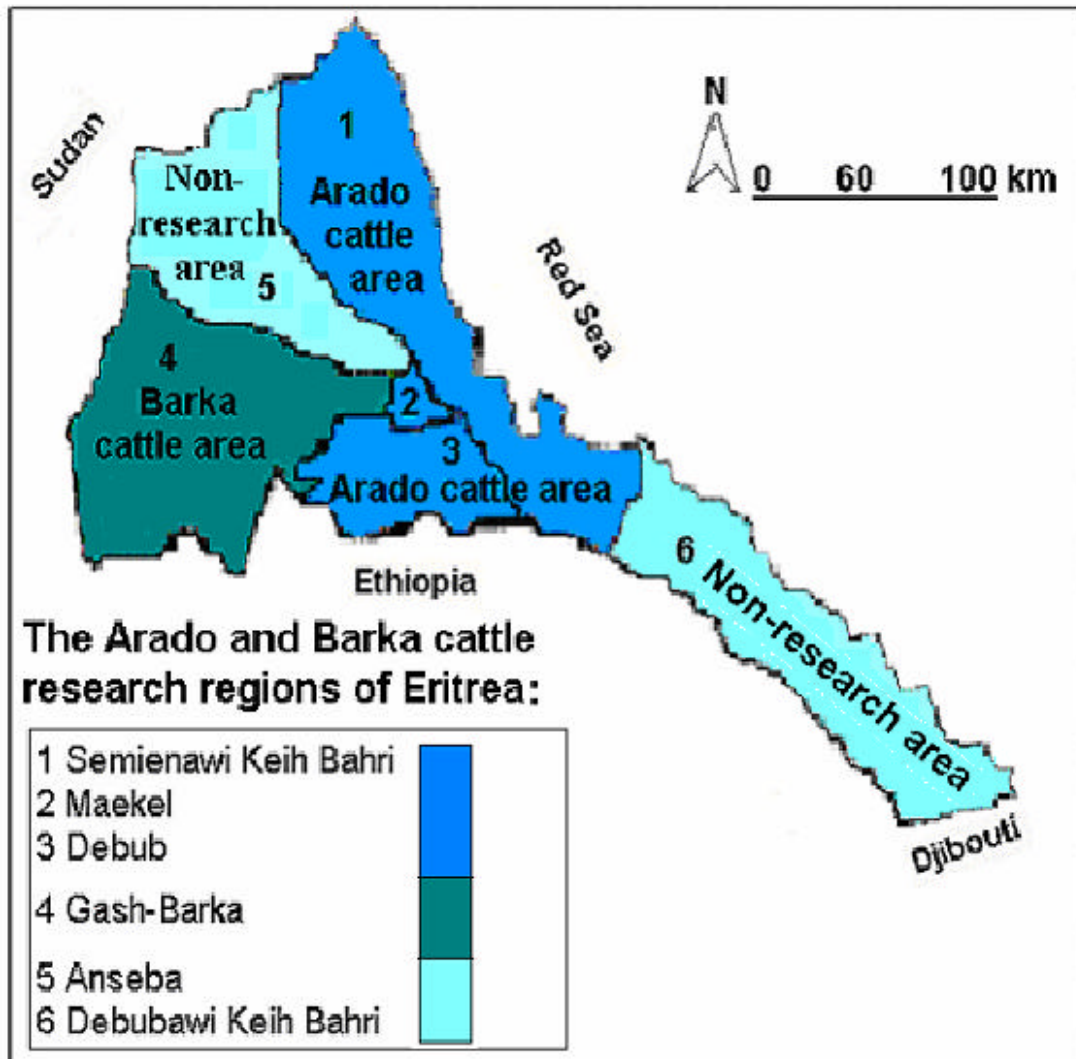


Figure 1.2 Cattle farming research areas of Eritrea. (Source: MOA 1997).

(178,532 and 218,923 head of cattle), respectively. This part of Eritrea forms the Eastern limit of the Sahelian Belt of Africa and is characterised by desert and semi-desert climatic conditions (Gebrehiwet 1995). The altitude of the region varies between 400 and 1500 m above sea level. The climate is arid and semi-arid with an average annual rainfall of less than 600 mm, mainly in the months of June to August. The vegetation consists chiefly of steppe grasslands and degraded shrubs (Caldwell 1975, cited by Konczacki 1978). Because Eritrea lies within the Sahelian climatic belt, the region is prone to drought and experiences a

relatively high evapo-transpiration rate (Gebrehiwet 1995). The country has nine big rivers flowing during summer while one river, River Tekeze Setit, is perennial. There are no natural lakes.

Mean annual rainfall in other regions of Eritrea varies between 400 and 700 mm, except in the north Western Lowlands and the Coastal area where mean annual rainfall is 360 mm and 260 mm, respectively. Figure 1.1 is a witness for better rainfall for the other regions. According to MOA (1997), the pasture resources in the Gash Barka and Semmienawi Keih Bahri regions are relatively poor and are able to support only extensive pastoralism with low levels of productivity.

The distribution of the indigenous (Barka and Arado) cattle breeds within the cattle farming regions is closely linked to the agro-ecological zones: Dehub region is found in the Central Highland Zone and Western Escarpment Zone and Maekel region is largely located in the centre (H) of the Central Highland Zone whereas Semienawi Keih Bahri region is primarily found in the Northern part of the Coastal Plain Zone, Green Belt Zone and in the Northern Midlands sub-zone where the Arado cattle are distributed in these agro-ecological zones. Gash-Barka region is largely found in the South Western Lowland Zone and North Western Lowland Zone agro-ecological zones where the Barka cattle are mainly distributed.

1.1.3 Characteristics of grazing land

In Eritrea, cattle are primarily farmed on rangeland, and during periods of good rainfall, these rangelands provide more than 80% of cattle feed (MOA 1997; FAO 2003). The quantity of forage produced in a season is dependent on a range of abiotic factors such as temperature, rainfall and soil fertility (Tainton 1981), as well as biotic factors such as the particular species composition of the sward (Grime 1997) and stocking rate (Van Poolen and Lacey 1979). Of these factors, the unfavourable spatial and temporal distribution of rainfall in Eritrea is the primary constraint to forage production. Figure 1.3 graphs the ten-year (1993 – 2002) annual rainfall distribution in the Arado cattle areas which are mainly found in the agro-ecological zones of Central Highland Zone, Western Escarpment Zone, Green Belt Zone and Coastal

Plain Zone and the Barka cattle areas largely located in the agro-ecological zones of South Western Lowland Zone and North Western Lowland Zone to indicate the variability in annual rainfall. Moreover, the seasonal rainfall distribution pattern (shown in Figure 1.4 for the four study regions during 2002) is such that the majority of rain falls between June and September, resulting in a long dry-season. Consequently, the forage producing capacity of rangeland in Eritrea is typically low.

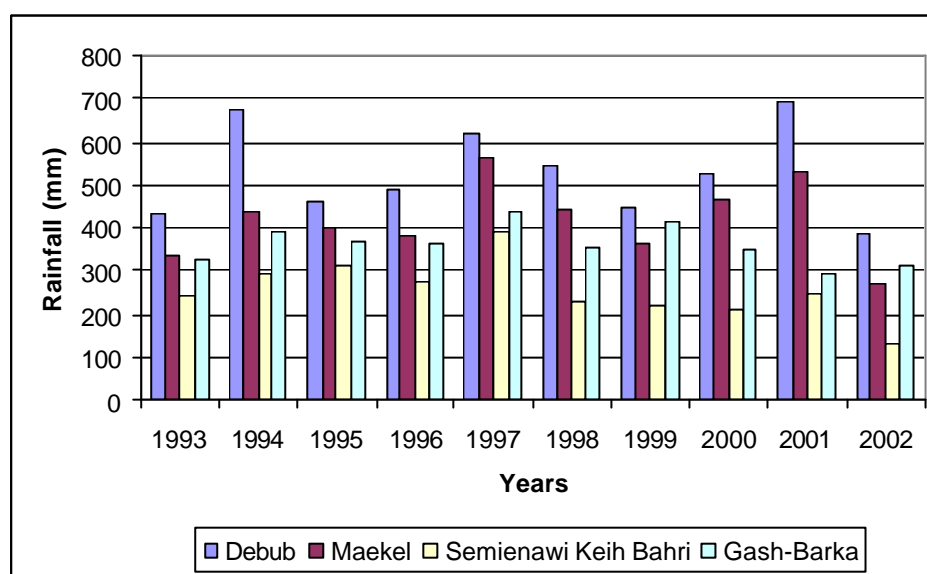


Figure 1.3 Mean annual rainfall for the four regions included in the study for the period 1993-2002. (Source: Data adopted from MOA 2002a)

Deterioration of rangelands has further reduced the forage production of rangelands in Eritrea over time (Kayouli *et al.* 2005). According to Ralphs *et al.* (1990), cited by Kirby (1993) stocking intensity in a particular season may have an effect on the peak grass biomass

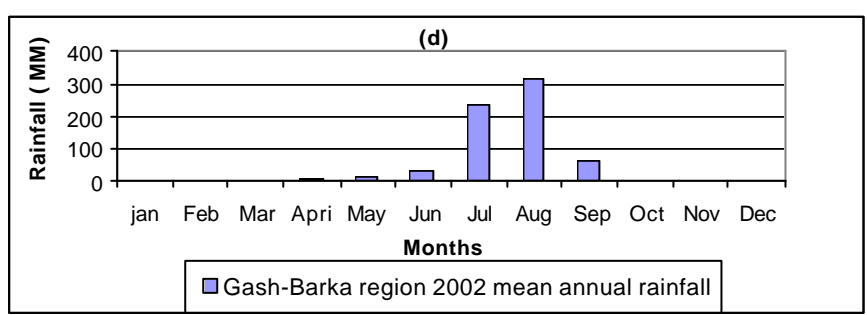
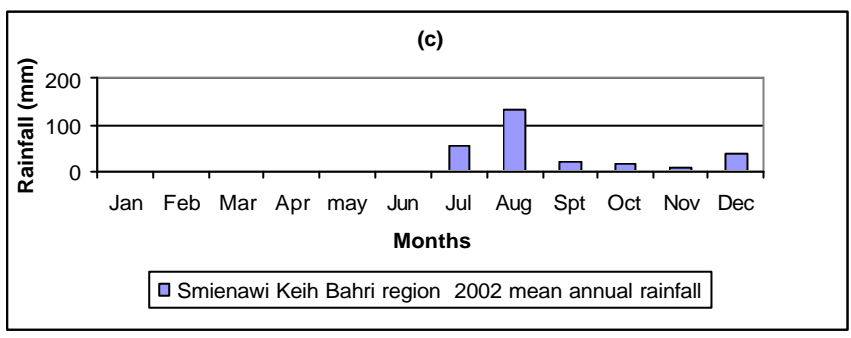
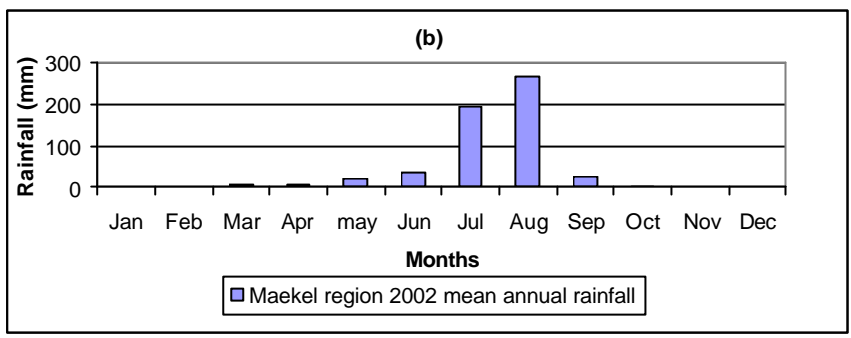
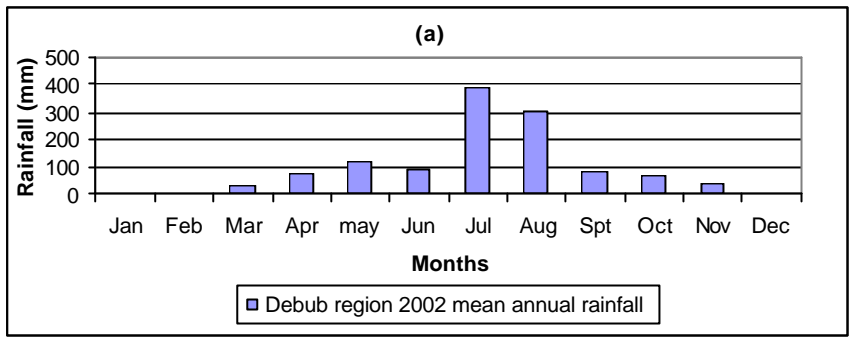


Figure 1.4 (a, b, c and d) Seasonal rainfall distribution pattern for Debu, Maekel, Semienawi Keih Bahri and Gash-Barka regions for 2002. (Source: Data adopted from MOA 2002a)

for that season. Moreover, heavy stocking rates lead to a reduction in vegetation cover, which in turn reduces water infiltration in soils, increases runoff and erosion and thereby reduces forage production of the rangeland. Rangelands under communal land tenure are typically stocked at higher stocking rates than land characterised by exclusive-use land tenure arrangements (usually commercial farmers).

Behnke and Abel (1996) attribute higher stocking rates on communally farmed rangelands to the majority of costs of cattle ranching being largely fixed (e.g. costs of own management inputs, family labour and annual land taxes). Communal farmers, therefore, have incentive to increase the size of their individual herds to spread these fixed costs and reduce their average costs per animal unit. Thus, it is expected that relative to the commercial farming regions of Eritrea, rangeland degradation is likely to be more pronounced in the smallholder farming regions.

Crop encroachment, land fragmentation and unsustainable rates of natural resource harvesting may have also contributed to reduced forage production on rangelands in Eritrea (MOA 2002b; Kayouli *et al.* 2005). For example, the area planted to cereals increased to 405 859 ha in 2003 compared to the average of 360 000 ha for 11 years from 1992 and 344 000 ha in 2002 (FAO 2003). Cleaver and Schreiber (1994) described the problem of crop encroachment on grazing lands as being a consequence of growing population pressure on rural resources resulting in increasingly marginal land being used for arable farming. According to LRCPD/MOA (1999), the Eritrean population increases 2.9% per year. Reid *et al.* (2003) established that the high degree of fragmentation of rangelands in East Africa is partly attributable to the land tenure arrangements. The negative impacts of harvesting a wide range of natural resources (cutting forest for fuel wood, making charcoal and taking lots of minerals such as nitrogen and phosphorus with grazed grass) on vegetation and forage production have been demonstrated by studies in South Africa (e.g. Twine 2005). Poverty and high population pressure in rural communities of Eritrea have resulted in high rates of wood harvesting for fuel and timber, thus exposing rangelands to soil erosion. Soil loss from a particular landscape may reduce grass productivity (Van de Koppel *et al.* 1997), and consequently may have contributed to the decline of livestock productivity in Eritrea.

Although natural rangeland is the primary source of forage for cattle in Eritrea, farmers also make use of forages from croplands as well as supplementary feeds produced as by-products of agricultural and agro-industrial processing. Forage from the croplands of smallholder farmers is made accessible for grazing by all cattle of the community during the dry season, and is, therefore, a common property resource. Crops grown in Eritrea that are used for forage purposes include sorghum, pearl-millet (*Pennisetum americanum*), maize, finger-millet, wheat, barley, teff and hamfets (a mixture of wheat and barley) (MOA 1997). Evidence from American studies (e.g. Welden and Klopfenstein (1985)) suggests that maize and sorghum (big cereals) residues are better used in forage systems than small cereal grain like teff residues due to their quality (determined by the protein and energy or digestible dry matter content). This suggests that crop residues fed to cattle in the lowland and coastal areas of Eritrea (sorghum and pearl-millet producing areas) will be of better quality than crop residues fed to cattle in the central highlands (cereal producing areas). Moreover, rural farmers feed their cattle with crop by-products during the dry season. Agro-industrial by products, e.g. wheat bran, barley bran, cotton husk, oil seed cake and by-products from beer production) are usually only fed to milking cows and draught animals during severe periods of drought (FAO 1995). According to MOA (1997), crop residues and crop by-products contribute between 10% and 20% of the total available feed supply for cattle production in rural Eritrea. Therefore, in order to promote the forage production of rangeland and croplands, the importance of flood water is discussed below.

1.1.4 Livestock migration practices of Eritrean pastoralists

The Central Highlands and the more densely populated areas of the Western Lowlands tend to experience a shortage of feed during the dry season from February to May each year. Farmers in these regions migrate some of their livestock, particularly cattle, to neighbouring areas such as Eastern Escarpments, Kerkebet, Mereb, Laellay Gash and Lower Gash every year during this period, to overcome the shortage of feed supply. Milking cows, plough oxen and small ruminants such as sheep stay behind in the villages and are grazed on the local rangelands supplemented with feeds such as agricultural by-products and conserved crop residues. This

migratory system enables these farmers to sustain larger herds than would otherwise be possible.

Overgrazing of natural rangelands remains a problem in these regions and, over time, has resulted in depletion of palatable grasses and herbs and their replacement with unpalatable forage species in these rangelands (FAO 2005). This finding is consistent with Kirkman and Carvalho's (2003) contention that the likely consequence of the provision of alternative feeds during the dry season (in this case from alternative rangelands as well as supplementary feeds) is increased growing season grazing pressure on the grazing resource. This not only reduces the quantity of forage available during the following dry season, but also reduces the production of grass seeds, especially of more palatable grass species. This indicates that the migratory system alone is not an effective substitute for rules that control stocking rates to within the sustainable carrying capacity of the resource, rather the migratory system in the absence of stocking rate controls is likely to exacerbate the problem of over-stocking.

1.1.5 Promoting grazing forage using flood water

Use of flood water to promote forage production is a practice that tends to be used by some commercial farmers but few smallholder farmers in the Western and coastal regions of Eritrea. It is therefore an important difference between the cattle production systems studied in this research. The contribution of flood water is a determinant factor to maximise grazing forage in Eritrea. Eritrea has one main rainfall season during summer (June to September) which is the main source of flood water flowing from the Highlands to Semienawi Keih Bahri region rangelands. The two other short rainfall seasons are known as Azmera (April to May) and Winter rain (October to March) that mostly includes the Eastern Coastal regions. The Summer and Azmera rainfalls include the Western Lowlands and the Central Highlands of the country (Haile 2002).

The 10-year mean annual rainfall in the study regions tends to increase from 250 mm in Semienawi Keih Bahri region (where grasses primarily depend on flood water for their growth) to 360 mm in Gash Barka region (where rivers naturally divert flood water to

surrounding rangelands during summer) and to 420 mm and 530 mm in Maekel and Debub regions (which are the source of flood water), respectively. In fact, the occurrence of rainfall below 200 mm in some places of the Coastal and Western Lowlands and above 900 mm in the Eastern Escarpments known as the Green Belt should be noted as the two extremes in the country (MOA 2002a).

Semienawi Keih Bahri region's lowlands and Gash-Barka region's Western and South Western lowlands are hotter areas getting relatively lower mean annual rainfall compared to the Highland regions (Maekel and Debub). However, the former two regions' lowlands are lucky getting abundant flood water and rivers' overflow water from the adjacent Eastern and Western Highland regions, respectively, during the rainy season. Most of Semienawi Keih Bahri region, for example, Sheeb and Ghindae sub-zobas and Ghahtelai district grazing lands grow grasses by the help of flood water coming from the adjacent Eastern Highlands. Cattle from the Highlands are grazed in the grazing lands. In Gash-Barka region, e.g. in Akurdet sub-zoba districts, rangelands grow grasses due to the flood water coming from the Barka river's overflow water every year.

In addition to flood water coming from the Highlands, there are 10 big rivers, which deliver abundant flood water from overflow water to their surrounding rangelands during the wet season in the country (Gebremedhin 1993). Beneficiary farmers and other concerned organisations therefore need to treat the rangelands around the rivers and flood waters by constructing terracing and planting different perennial grasses and leguminous plants to promote grazing resources.

1.1.6 Breeds of cattle farmed in Eritrea

Three indigenous cattle breeds can be found in Eritrea, namely Barka (Bigait), Arado and Araba breeds. The Barka breed is found in western-lowlands (Gash-Barka region) mainly with the Beni Amirs tribes. This breed is known for high quality beef, milk production and draught power. According to Sharman (1980), cited by Ghebretensaie (1995), cows have large, well developed, but pendulous udders and on average give six litres of milk a day from

normal grazing forage and 9 to 10 litres at the first stage of cross-breeding with improved dairy bulls. In well-kept dairy herds, they can give 10 to 16 litres of milk a day if they are well fed and crossed with improved dairy cattle breeds. According to Simpson and Farris (1982), the Barka breed is also called Begait because it is related to the Ingessana and Murle cattle found in East Africa. Their origin is in the southwest of Eritrea (Ghebretensaie 1995). They are of quiet disposition. Visually, they are often dissimilar in colour. Their body size is large in comparison to Arado breed, but medium in relation to other African cattle. They are long legged and have a large hump (especially the oxen). Their total number is 1 047 033 which comprise 60% of the total Eritrean cattle (MOA 1997). According to Sharman (1980), cited by Ghebretensaie (1995), the Barka cattle were crossbred with imported Friesian and Ayrshire cattle in the early 1960s with very satisfactory results.

The Barka breed of cattle are of two types, namely Erashal/Begait and Dowhen/Begait. The Erashal/Begait type of Barka are found in Gash-Barka (Talata Asher to upper Gash). Another name used by the local people for these cattle is Erashal. They have a long narrow head, with a markedly convex profile, horns and long ears. Their rump is sloping with average live body weight up to 350 kg during good seasons. The females average 230-250 kg and males average 290-310 kg. They usually have a black and white coat colour (Ghebretensaie 1995).

Typically the Dowhen type are found in Gash-Barka Administration (Sawa-River upper and lower Barka). Dowhen is their local name. They are characterised by long ears, short horn, humpless, concave back, straight head and mostly greyish brown coat colour. They have an average live weight of 420 kg. They are primarily kept for meat production, with milk production and draught power as secondary features.

The Arado breed are sanga type cattle. These cattle are primarily found in the regions of Central Highlands (Debab and Maekel), Anseba and Northern Red Sea (Semmiyaw Bahri) regions. They are characterised by a small and compact body size, short legs, dominant brown coat colour and are humped. Some are large-framed, having typical long horns and small thoracic humps with average live body weight of 250 kg. Their primary importance is for draught power. However, they also contribute significant milk (on average three litres a

day) and meat production as well as a source of cash from sales of live animals. Their total number is 833 750 which is 40% of the whole cattle population in Eritrea (MOA 1997). These cattle are drought and disease resistant and can survive harsh, adverse conditions. In comparison to other types of oxen, the Arado oxen have special importance because they contribute to agricultural production with a minimum cost despite the harsh conditions of the highland areas (MOA 1997).

The Araba are a small-sized breed of cattle. The hoof-wither height of the Araba cattle varies considerably; but they are characterised by a humped chests, long convex heads and short, fine horns. Under normal conditions the milk production of the Araba cows is between three and six litres per cow per day. By way of comparison, milk yields of between eight and ten litres per cow have been obtained under good conditions for some Araba crossbreeds. The Araba cattle currently comprise two percent of the national herd in Eritrea (Table 1.1) and their distribution is limited to the Eastern Coast of the Red Sea (Gebremedhin 1993).

Some European dairy cattle, for example the Friesian, have been introduced into Eritrea to upgrade the local cattle for milk production through crossbreeding. The use of these improved cattle is usually confined to a few large farmers and owners of commercial dairy farms. The Friesian cattle comprise about one percent of the total herd in Eritrea (Table 1.1). In Eritrea, particularly in the adjacent areas of the Arado and Barka cattle breeds and in the surrounding areas of big cities where confined dairy cattle are kept, crossbreeding has taken place between the Arado and Barka and between the Barka and Friesian cattle, respectively, and in the future, it is hopefully probable that the population of crossbreeds will improve the productivity of these three indigenous breeds of cattle in rural Eritrea (Gebremedhin 1993).

1.2 Cattle farming systems in Eritrea

The cattle farming sector in Eritrea is comprised of a subsistence smallholder sub-sector (95% of the national herd) and a commercial sub-sector (five percent of the national herd) (MOA 2000). Although all land in Eritrea is owned by the state and the rangeland resources available to these two sectors are similar, the institutional arrangements governing the use and

management of rangeland in these two sectors are very different. It is argued in this section that differences in the institutional arrangements governing the use of grazing resources across these two sectors partially explain why the two sub-sectors tend to adopt different breeds of cattle and different rangeland management practices. Other factors that may have impeded smallholder farmers changing from subsistence to commercial orientated farming practices include, according to Gebremedhin (1993), an under-supply of education, health and veterinary services to smallholder farmers due to the lack of infrastructure to access to their scattered settlements.

1.2.1 Smallholder livestock farming systems

Haile (2002) described Eritrean smallholder livestock farming systems as typically being relatively simple (low) harvesting operations of marginal resources for subsistence purposes with productivity that is well below its potential economic contribution. Smallholder farmers typically own small, multi-functional herds, which mostly consist of indigenous cattle (Arado and Barka cattle breeds) of between one and five livestock units. Cattle provide a regular source of cash income from the sale of animals and their products (milk, meat and hides). Cattle are also held as security, a store of wealth and social prestige, and they provide manure and draught power for cropping operations. Steers are usually sold at a young age to increase the supply of milk for household consumption and reduce costs of cattle feed. However, some households do keep steers as a source of liquidity to be sold when the household requires money (Ghebretenseie 1995).

According to the FAO (1994), two types of livestock production systems are used by smallholder cattle farmers in Eritrea: (a) cereal-livestock production system in the highlands (40% of cattle), and (b) pastoral and agro – pastoral livestock production systems in the lowlands (60% of cattle). In the cereal-livestock production systems cattle are kept in special communal grazing areas called *hizaati*. Oxen comprise a relatively large proportion (48%) of cattle in these systems due to their importance as a source of draught power for agricultural production. In the pastoral and agro-pastoral production systems cattle are kept primarily as a source of milk and meat.

Pastoral and agro-pastoral livestock production systems may be classified according to their objectives, strategies, needs, management styles and degree of mobility (Russum 2002). According to Russum (2002) there are categories of pastoralism amongst smallholder farmers in Eritrea: (a) nomadic pastoralism (e.g. the Afar and Rashaida pastoralists in Debubawi and Semmienawi Keih Bahri regions respectively, and the Hedareb nomadic pastoralists in Gash-Barka and Anseba regions), (b) transhumance and (c) agro-pastoralism. The first two categories are characterised by full mobility whereas the last one has little or no mobility. Because approximately 60% of Eritrean livestock are kept in nomadic and transhumance pastoral systems in extensive grazing rangeland regions (Omer and Skjerve 2000), livestock development programmes in Eritrea must take due cognisance of the local traditions and socio-economic structures that allow for nomadic and migratory grazing systems in Eritrea. The seasonal pattern of cattle management activities by smallholder farmers varies by region in accordance with the environment of each region and the breed of cattle farmed in each region (Table 1.2). In the Semmienawi Keih Bahri region from July to September and in the

Table 1.2 Seasonal cattle management calendars in different regions of Eritrea

Area	Time of year	Type of season	Major livestock activity
Semmienawi	October–March	Winter (Bahri) rainy season	Off take/selling (fair price)
Keih Bahri region (Arado cattle region)	April–June	Cool dry season	Vaccination and breeding activities
	July–September	Hot dry season	Feed shortage induced selling and purchasing
Highlands and Western Lowlands regions (Arado and Barka cattle regions respectively)	January–March	Winter dry season	Off take/selling (fair price)
	April–May	Spring (hot) dry season (Akeza /short rain)	Feed shortage induced selling and purchasing
	June–September	Summer /Wet season (Long rainy season)	Calving/milk and caves harvesting
	October–December	Autumn dry season	Vaccination and breeding activities

(Source: FAO/IFAD 1999)

highland and western lowland regions from April to June is a hot and dry season and cattle are sold at low prices due to a shortage of feed. Households with relatively better access to feed tend to purchase cattle to expand their herds during the dry season. From October to March in the Semmienawi Keih Bahri region and from January to March in the Highland and western lowland regions, the season is cool and dry. During this season, there is a high demand for livestock for use at various ceremonial occasions such as weddings, funerals and ancestral offerings. Consequently, cattle prices tend to be relatively high during that time of year, encouraging cattle selling (FAO/IFAD 1999).

1.2.2 Commercial cattle farming systems

Commercial farms in Eritrea are located in relatively close proximity to better infrastructure. Typically, single purpose herds are farmed producing either beef or milk (Gebrehiwet 1995). Although commercial farmers do not transfer the land that they farm to others through selling, they do have exclusive-use rights over their grazing land through leasehold agreements with the state for a longer period of time, usually more than 10 to 20 years duration. According to Gebrehiwet (1995), commercial farmers typically farm some indigenous crossbreeds of Arado with Barka, many pure Barka breed and some crossbreeds of exotic cattle breeds. Compared to indigenous cattle breeds (Arado and Barka cows, on average, produce three litres and six litres of milk per day on normal grazing forage, respectively (MOA 1997)), the crossbreeds tend to have higher maintenance costs but produce significantly higher daily milk yields and have a longer lactation period (Gebrehiwet 1995). Thus, compared to the smallholder sector (primarily subsistence farmers with small indigenous herds grazed on communal lands with poor grazing management systems), the commercial sub-sector (farmers with larger herds of crossbreed cattle and exclusive-use rights to grazing land) is more productive with respect to milk production. Compared to subsistence farming, in commercial orientated farming cattle are used less as a source of draught power and as a source of manure for cropping, and relatively more to generate income from milk sales (MOA 2002a).

1.3 Problem statement

In rural Eritrea, rangelands around communal villages are characteristically short of grazing forage resulting in the low level of cattle productivity and the migration of cattle to distant areas. The low level of cattle productivity is due to the low level of natural grazing rangelands caused by overgrazing, owing to the application of improper grazing management. Despite information on suitable grazing management practices being available, the innovation and adoption of appropriate grazing systems on the communally farmed rangelands remain negligible.

1.4 Objectives of the study

The objectives of this study are:

- To investigate the production systems practiced, particularly in relation to forage production, by smallholder farmers in the Arado and Barka regions of Eritrea and to compare them against production systems of commercial livestock farmers in Eritrea;
- To evaluate management practices applied on rangelands by smallholder cattle farmers in the Arado and Barka cattle regions of Eritrea with respect to how they are geared towards improving herd productivity;
- To compare the performance of smallholder cattle farming systems relative to commercial farming systems in Eritrea. To analyse the productivity of smallholder cattle farming systems in Eritrea from physical production and economic perspectives;
- To identify factors that currently constrain the performance of smallholder cattle farming in Eritrea and to recommend policies and programmes that will contribute towards alleviating these constraints.

1.5 Outline of this dissertation

Chapter two of this dissertation presents a review of literature on smallholder cattle farming productivity in Eritrea. This review is used to consider how the productivity of smallholder cattle farming may be measured and to identify suitable approaches for contrasting the forage

and herd management practices used by smallholder farmers in the Arado and Barka regions of Eritrea and for comparing the relative productivity of their farming systems. Chapter 3 outlines the research methodology used in this study, including the survey and sampling techniques used to collect data and the statistical techniques used to analyse the data. Results are presented and discussed in Chapter 4, followed by a closing chapter 5 that presents the conclusions and recommendations that stem from this research.

CHAPTER 2

LITERATURE REVIEW

This chapter presents a review of literature on factors affecting the productivity of rangelands with a particular emphasis on the grazing systems, the availability and use of forage in cattle farming systems and the institutional arrangements governing the use of grazing resources. Seven categories of factors expected to determine the productivity of rangelands and cattle farming systems in Eritrea are categorised in Figure 2.1. They are: a) Rangeland grazing management (i.e. stocking rates, rotational grazing and fencing as to maximize the availability and use of rangeland forage resources), b) Forage from crop residues (i.e. type, amount and quality of crop residue DM), c) Supplementary feeds e.g. agricultural and industrial by-products, d) Herd characteristics e.g. herd breed size and composition, e) Institutional arrangements e.g. farmers property rights to grazing and water resources, f) Household resources e.g. skills and availability of household labour and g) Access to input and product markets e.g. access to credit, proximity to product markets, etc. These seven categories of factors are reviewed in sections 2.1 through 2.7 respectively. The chapter is concluded with a discussion on the causes of rangeland degradation in Eritrea.

2.1 Rangeland management in Eritrea

Because the quantity and quality of natural grazing forage in the rangelands available for livestock varies according to land-use management practices such as cropping intensity, the grazing systems applied and the harvesting of various rangeland resources, sound rangeland management is central to realizing the forage production potential of natural rangelands. This section reviews existing literature on the forage production capacity of rangelands in Eritrea and rangeland management in Eritrea.

2.1.1 Species composition of the natural pastures of rangeland in Eritrea

The natural rangelands on which livestock graze and browse in Eritrea comprise fast maturing species of grasses, various shrubs and trees. In addition to indigenous plant species,

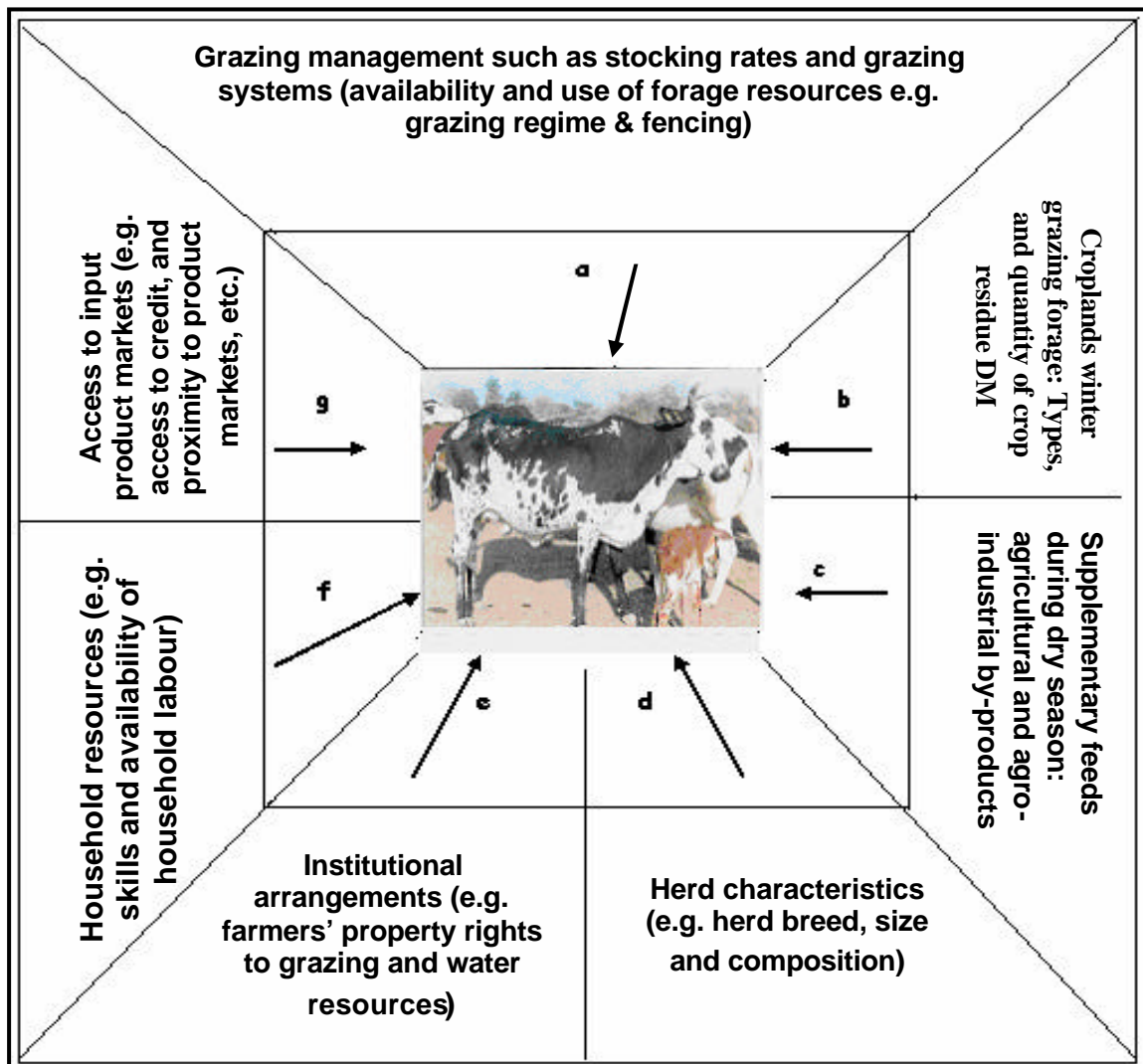


Figure 2.1 Factors hypothesized to affect rangeland and cattle productivity in Eritrea.

some exotic plant species, especially spineless cactus species (*Opuntia ficus-indica*) have become important constituents of the vegetation of natural rangelands in Eritrea. *Opuntia* spp. is well known as an emergency drought feed for cattle though it has an invasive nature in restraining other plants (Bein *et al.* 1996).

Tree species of the Eritrean rangelands include *Acacia* spp., *Balanites aegyptica*, *Terminalia brownie*, *Capparis decidua*, *Diospyros abyssinica*, *Ziziphus spina-christi* and *Albizia lebeck*. Forage produced by these trees is available during the rainy season (FAO 1995). In

Semmienawi Keih Bahri region (Arado area), surrounding Gahtelay and towards Shieb plain, only short Acacia species are available due to low precipitation in this region. Cattle owners in the western part of this region depend on floods from the adjacent highlands of Maekel region for their forage and crop cultivation. In Debub region (Arado area), in Gezamedebai towards Mereb plain, *Ziziphus spina-christi* (Gaba) tree species are dominant. In Gash Barka region (Barka cattle area) towards Akurdet, Mogolo and Barentu Sub-zobas, remnants of *Hypheane thebiaca* (Arkokobay) tree species are left (FAO 1995). In all regions of the study areas, the problem of substantial deforestation without replacement planting is prevalent (Kayouli *et al.* 2005).

The grass species composition of the natural pastures of rangelands in Eritrea also varies by region. Some of the natural grasses found in the rangelands of the Central Highland Zone are *Pennisetum clandestinum*, *Digitaria abyssinica*, *Setaria sphacelata*, *Cenchrus mitis*, *Eragrostis* spp., *Andropogon* spp. and *Themeda triandra* (Gose 1998). The Western Lowland rangelands are comprised of the Southwestern and Northwestern Lowlands. This zone represents a wide variety of vegetation types and is called Semi-Arid Tropical. The Northwestern Lowland rangelands, found at altitudes between 400 to 1500m, are dry and their grass cover is relatively low compared to the rangelands of the Southwestern region. In general, the dominant grasses available in this zone are *Andropogon dumeri*, *Digitaria diagonalis*, *Setaria sphacelata*, *Eragrostis* spp. and *Aristida mutabilis*. The Eastern Lowland Plain rangelands are found in a relatively hot, arid region, resulting in low productivity of its pasture. Some of the grass species that occur naturally in this zone include *Cynodon* spp., *Cenchrus prieuri*, *Eragrostis* spp., *Aristida mutabili*, *Elytrophorus spicatus*, *Panicum triticeum* and *Paspalidium gemminatum* (Gose 1998). Due to the low level of moisture management and, particularly in the highlands, overstocking, grass and legume leaves are relatively scarce in Eritrean rangelands (Kayouli *et al.* 2005).

Eritrean cattle owners have developed the system of planting exotic spineless cactus species (*Opuntia ficus-indica*) in the marginal land around their homesteads. The *Opuntia* species not only provide an important source of livestock fodder during the dry season, but also fruit for human use, bee forage, live fences and windbreaks, and they may be used to control soil

erosion (Kayouli *et al.* 2005). This plant species is well adapted to the arid rocky shallow infertile soil as it has the ability of growing under very adverse conditions unfavourable to many other plants (De Koch 1980). MOA (1997) estimated that approximately 500 000 cactus trees have been planted in Debub region, and farmers in Maekel region planted more than 30 000 cactus seedlings in the eroded hills.

2.1.2 Livestock capacities of rangelands in Eritrea

Estimates of potential forage production and associated livestock carrying capacities of Eritrean rangelands by FAO (1995) are reported in Table 2.1. These estimate are based primarily on annual rainfall, which is considered to be the primary determinant of forage production in the Eritrean rangelands. Forage production is measured in terms of the quantity of livestock feed per hectare on a dry matter basis (DM kg/ha), and the associated livestock carrying capacities are measured as the area required per Tropical Livestock Unit (ha/Tropical Livestock Unit).

Table 2.1 Estimated DM production and carrying capacity of rangeland in Eritrea

Rainfall (mm)	Total above ground DM production (kg/ha)	Carrying capacity (ha/TLU)
100	n.a.	Over 20
200	450	17
300	675	10
400	900	7
500	1125	6
600	1130	4

(Source: FAO 1995)

The carrying capacity of the grasses of three rangeland zones may be estimated using Table 2.1 and mean rainfall data reported in MOA (2002b):

- The Central Highland Zone receives a mean annual rainfall in the region of 600mm, and therefore has a livestock carrying capacity of approximately 4ha/TLU;
- The South Western Lowland rangelands, with average annual rainfall between 500 and 700 mm, have an estimated livestock carrying capacity of less than 6ha/TLU and in some areas less than 4ha/TLU.
- The North-western Lowland rangelands, which receive an average of less than 300 mm of rainfall per annum, have a livestock carrying capacity of approximately 10ha/TLU and
- The Eastern Lowland Plain rangelands, which receive an average rainfall of 200 mm per annum have an estimated livestock carrying capacity of 17ha/TLU.

2.1.3 Rangeland management practices in Eritrea

Tainton (1981) stated that grazing management is directed towards improvement of the quantity and quality of the forage produced and the application of stocking rate and different grazing systems. Furthermore, he said that these systems depend on the owner's understanding of the relationships between pasture growth, grazing and animal production. This section describes the current grazing management systems and the current condition of natural rangelands in Eritrean rangelands by region. This is followed by a brief description of the practice of herd migration by pastoralists in Eritrea in Section 2.1.4.

The Central Highland Zone

Although the Central Highland Zone accounts for only 16% of the total area of rangelands in Eritrea, it is of particular importance because 56% of Eritrea's human population and 40% of Eritrea's livestock population are located in the Central Highland Zone (MOA 2000). Agriculture in this zone is characterized by sedentary mixed-farming (crop-livestock farming) and the grazing management system applied is best described as continuous, uncontrolled grazing (FAO 2003). The high human and livestock population density of the region in conjunction with the steep and rugged topography of the region, the absence of good grazing management systems, and increasing crop encroachment on natural rangelands have resulted in overgrazing, improper utilization of water resources and deforestation of rangelands.

The Western Lowlands

The Western Lowland rangelands are comprised of the Southwestern and Northwestern Lowlands. In these pasturelands, nomadic pastoralism, semi-sedentary agro-pastoralism and commercial farming production systems are practiced. The rangelands are relatively in a better condition compared to the Central Highland rangelands. Reasons for the better state of rangelands include:

- Some commercial farmers apply realistic or conservative stocking rates that can help to match the herd sizes with the availability of the region's forage potential to allow the removable of forage without limiting the plant's future production and
- Although the grazing of smallholder farmers is relatively uncontrolled, due to the availability of wider grazing area compared to the number of the livestock depending on it, the Western Lowland rangelands generally have enough forage (Kayouli *et al.* 2005).

The Eastern Lowland Plain

Agro-pastoralist and nomadic pastoralist production systems are found in the Eastern Lowlands Plains. Because this region has relatively reliable grazing forage and water points during the dry season, nomadic pastoralists from neighbouring regions (especially the Central Highlands) tend to graze their herds in this region during the dry season (February – May), increasing the livestock pressure on the grazing resource, which has a relatively low productivity owing to the hot, arid climate of the region. As a result, the region tends to be overstocked during the dry season and the rangeland has become severely degraded. In particular, because the water holding capacity of the degraded soils is reduced, gully erosion is common (MOA 2002b).

2.1.4 Improved grazing systems

Almost all the rural communities in Eritrea are dependent on crop-livestock integrated farming systems (FAO 2005). The previous section indicated that grazing management systems applied by smallholder farmers are typically overstocking or uncontrolled grazing. The

application of better grazing management is expected to promote increased forage production and, therefore, improve cattle farming productivity. Indeed, the MOA (2002b) has recognised that the promotion and implementation of better grazing management in Eritrea needs to be given greater priority in future. Generally, grazing management is defined as the manipulation of animal grazing to achieve optimum and sustained animal, plant and land economic results while ensuring a continuous supply of forage to grazing animals, and its purpose is to maintain productive pasture and ensure full productive potential of rangelands. Practically, this includes the application of continuous and rotational grazing systems and stocking rates on rangelands (Vallentine 2001). This section reviews the principles of grazing systems (continuous and rotational) and controlled stocking rates, the role of fencing in grazing management and other principles for curbing degradation on Eritrean rangelands. Some of the practical constraints to adoption of these principles by smallholder farmers in Eritrea are identified in other sections of this dissertation.

2.1.4.1 Controlled stocking rates

Stocking rate can be defined as the number of animals of a particular class (i.e. cattle, sheep, etc.) allocated to a unit area of land for a specific period of time (Bartholomew 1991). Conservative (medium) stocking rates improve animal production and maintain long-term ability of rangeland resources whereas overstocking results in rangeland degradation, which consequently results in decreased animal production (O'Reagain and Turner 1992). However, so long as users try to suite stocking rate according to their farming strategy, optimal stocking rate depends on the livestock production strategy. Production strategies vary according to the objectives of the production system. For example, farmers may aim to maximise their cattle production per hectare by stocking as many animals as possible. Alternatively, farmers will stock cattle at lower densities if their objective is to maximise production per animal unit (Morris *et al.* 2000; Behnke and Abel 1996).

Maximum economic return can be obtained at a stocking rate intermediate between that which gives maximum production per animal and that which gives maximum production per hectare. However, in communal grazing systems, the aim is to maintain maximum number of livestock

regardless of the productivity of the individual animals (Mentis 1984; Hardy and Mentis 1986). In such systems, non-consumptive products of livestock (draught, fuel, manure, ceremonial purposes, etc.) may be more important than saleable products (meat, milk, etc.) and the system is stocked close to ecological carrying capacity in which animals are near maintenance (Morris *et al.* 2000). Though Morris *et al.* (2000) review different situations of climate, vegetation, animals, etc. certain principles may apply to Eritrean rangelands. Under the circumstances of the objectives of livestock systems aiming to maximise production per hectare by running as many cattle as possible, Eritrean grazing management may be related to the review by Morris *et al.* (2000) of South Africa covering high stocking rates. Eritrean rangelands are severely and frequently grazed for long periods of time that result in overgrazing and declining productivity of the cattle depending on it (FAO 2005).

Despite a clear need for destocking the Eritrean rangelands to within their sustainable carrying capacities, FAO (2005) expressed the opinion that the effective control of stocking rates is beyond the scope of Eritrean communities with communally managed grazing systems. Reasons for this problem are explored in section 2.5.

2.1.4.2 Continuous and rotational grazing systems

Continuous grazing is an extensive system of grazing in which livestock remain on the same pasture area throughout the growing season or year. An extensive space is required to support the stock all year round. So long as sufficient forage is available, continuous grazing results in higher per animal gains than other grazing systems (Alice 2004). Unlike continuous grazing, rotational grazing involves periodically moving livestock from paddock to paddock (fenced grazing area) to allow grasses to grow or to recover between the successive periods of use. The stock grazes a paddock for a specific time then moves to another paddock, returning to previously grazed plots when they recover during rest (Charray *et al.* 1992), cited by (Ibrahim and Olaloku 2000). In this case, there must be clear understanding between rotational grazing and rotational resting. Rotational grazing is carried out in fenced land having many paddocks and the rest between two successive grazing periods is short and limited to recovery period to recover only some of the vigour of the plants. Rotational resting has long period, usually a full

season, enough for the plants to recover vigour, flower, set seeds and for the seeds to mature for the next germination (Du Toit 2001). In rural Eritrean communal grazing regimes rotational grazing is seldom practical. Grazing land is used under the state of communal grazing management based on village level. For rotational grazing to be successful, a well-organised arrangement of herding systems is required. All livestock of the village needs to be herded under one herding guidance. In rotational grazing, a uniformity of numbers and types of animals is helpful to determine the grazing length of time and supervise the condition of animals and grazing area (Kristensen 1988; Colino and Duru 1999). Moreover, the availability of fenced rangelands and the readiness of farmers are necessary to promote rotational grazing. In Eritrea, farmers usually herd their livestock near their crop farming areas as most herders are family labourers that simultaneously help their parents in crop farming. Different types of animals usually graze together in an unfenced rangeland. Some of the reasons are the shortage of grazing area and labour for herding, lack of finance and individual property rights to fence rangelands individually. Hence, rangelands become overgrazed and degraded due to the lack of proper grazing management and greater livestock numbers (UOA and MOA 1998).

In general, according to Rayburn (1992), grazing system is the combination of pasture, livestock, fences and management used to control forage production and harvest. The development of a grazing system should be flexible and dependent on the livestock producer's goals and resources. Grazing systems are important to animal production because they help minimise costs that would be incurred or spent for producing planted forages or purchasing grain feeds. Grazing systems are divided into continuous and rotational stocked systems. However, these two grazing systems need to be incorporated with controlled stocking rates to avoid overstocking and its consequences (O'Reagain and Turner 1992).

2.1.4.2.1 Merits of continuous grazing systems

Unlike rotational grazing systems, continuous grazing systems have the merits of saving on costs for fencing and moving animals from paddock to paddock since livestock remains on the same pasture throughout the grazing season. Good production per animal can be obtained if

continuous grazing systems are applied in conjunction with controlled stocking rates. Compared to rotational grazing systems, greater daily gains of cattle are obtained from continuous grazing systems (O'Donovan *et al.* 2005).

The resistance of severe drops in composition and forage quality and quantity after grazing is greater on continuous grazing systems when compared to rotational grazing. The retrieving period of forage status of rangelands is quicker in continuous grazing systems (Bertelsen *et al.* 1993). This is reinforced by Hart *et al.* (1988) and Ralph *et al.* (1990), both cited by Kirby (1993), stating that the disappearance of herbage is less under continuous grazing than in rotational grazing systems.

2.1.4.2.2 Demerits of continuous grazing systems

Continuous grazing systems are less convenient for rationing to give priority of grazing to productive animals such as milking and pregnant cows as grazing is easily accessible. Moreover, there is more energy loss as grazing competition is increased and cattle walk more to graze.

In Eritrea, almost all the communal grazing farmers use continuous grazing systems accompanied by heavy stocking rates. Due to the nature of common access grazing systems, the application of controlled stocking rates is constrained and the rangeland productivity decreases as the pressure of heavy stocking rates increases (Kayouli *et al.* 2005). Hence, though the merits and demerits occurred are called under the names of the grazing systems, the determinant factors for these results are the stocking rates applied in the grazing systems.

2.1.4.2.3 Merits of rotational grazing systems

As it is evidenced by different reviews, the merits of rotational grazing is realised when it is incorporated with controlled stocking rates. In addition, rotational grazing has insignificant differences when compared to continuous grazing. After examining over 50 grazing experiments conducted in southern Africa, O'Reagain and Turner (1992) found that stocking

rate is a major determinant of both range condition and animal production. It is also the most important management variable of any other grazing systems such as continuous and rotational grazing when it is applied under the direct control of the grazer. Moreover, when Fynn and O'Connor (2000) examined the behaviour of plant and animal relationships in semi-arid rangelands, they applied stocking rates for the evaluation of the influences of rainfall and grazing on animal and vegetation dynamics. This indicates that, stocking rate is a more important factor than grazing systems (continuous and rotational) in changing botanical compositions, primary production and live weight gain per animal and per hectare.

2.1.4.2.4 Demerits of rotational grazing systems

Many demerits of rotational grazing systems are stated by different authors. O'Reagain and Turner (1992) stated that unlike continuous grazing, non-selective grazing used by rotational grazing systems leads to range degradation. This negative impact occurs when animals are grazed in confined grazing areas (paddocks), they cause severe damages on the grasses and soils, which are consequently being exposed to adverse conditions. Costs incurred for multi-camp fencing are unproductive and wasteful if there is no significant ecological or economical importance of the multi-paddock fencing systems (used in rotational grazing systems) over pauci-paddock systems. This finding is supported by the review of Hart *et al.* (1988) in USA, cited by Kirby (1993) saying that a decreased performance by livestock was caused by increased grazing pressure regardless of grazing systems. This emphasises that grazing systems like rotational grazing contribute little to the improvement of livestock performance if they are not accompanied by controlled stocking rates. Cattle grazed in more confined places feel more stress and cause more damage than those grazed in free place. Moreover, unlike continuous grazing, in rotational grazing more time is spent checking and moving livestock from one fence to another and more effort may be required to make water available to the animals (Kirby 1993).

2.1.4.2.5 Discussion: grazing management

As one of the purposes of improved grazing management is to ensure a continuous supply of forage to grazing animals, it also primarily focuses on maintaining the productive potential of rangelands since this potential is the only means to ensure the availability of forage resources to grazing animals.

To point out the possibility of improved grazing management, O'Reagain and Turner (1992) stated that in rangeland management, stocking rates, particularly conservative stocking is the major importance to maintain rangeland resources and improve animal production whereas grazing systems which are basically classified as either continuous or rotational grazing have little importance relative to stocking rates. The comparison between continuous and rotational grazing systems indicates that neither grazing system is superior, nor is inferior to the other in real practices. The authors backed up their arguments with evidence relative to animal production that out of 23 trials conducted on a variety of veld types, continuous grazing was superior to rotational grazing in nine trials whereas rotational grazing was superior in seven trials and there was no difference in seven trials. Both grazing systems have merits and demerits. To exploit the merits and avoid the demerits of both grazing systems, the application of conservative stocking rates is a major determining factor to promote both range condition and animal production.

With regard to paddocks or fencing, pauci-paddock (fencing round grazing land) mostly used in continuous grazing systems appear to be equal to multi-paddock systems usually used in rotational grazing and there appears to be little ecological or economic justification for applying the latter (multi-paddock) systems. Therefore, to achieve long-term maintained range condition and stable animal production, applying simple rotational-resting or pauci-paddock systems is advisable (O'Reagain and Turner 1992).

However, according to Morris *et al.* (2000), the underlying problem is that farmers use stocking rates according to their farming strategy not according to the beneficial (conservative) stocking. For example, in Eritrea, the communal grazing farmers do not limit

their animal numbers to match the potential of forages available in the rangelands. Despite having overgrazed and degraded rangelands, the farmers are still keeping as many animals as possible whereas in the commercial cattle farming, most of the farmers use conservative stocking and save their rangelands from overgrazing and degradation. What causes overgrazing in the communal farmers rangelands is the lack of control of animal numbers (Gose 1998).

2.1.5 Introducing forage grasses and legumes to Eritrean rangelands

Good grazing management maintains the veld with required botanical composition containing more palatable grasses and shrubs and vigour as well as increases its productivity, while bad management inevitably leads to the deterioration of the palatable grasses and vigour of the veld and consequently of its productive capacity. Fortunately, appropriate interventions are able halt this process of deterioration and to reverse it (Tainton *et al.* 2000).

Rangelands can be improved by introducing suitable forage grasses and legumes. Accordingly, the Eritrean Department of Agricultural Research and Human Resources Development has several research units centred at Halhale Research Station that are investigating the introduction of exotic annual and perennial grasses to increase pasture production of Eritrean rangelands. The Livestock Research Unit has established mixed grass-legume pastures such as oats, Columbus grass and Sudan grass with vetch; Rhodes grass with *Setaria* and *Desmodium*, and sorghum with Lablab and cowpeas on enclosed land and in the integrated livestock/crop production systems in the highland and lowland areas (Kayouli *et al.* 2005). It is also conducting an adaptive trial for five legume forages and three grasses at Halhale Station. The grasses are oats (*Avena sativa*), Sudan grass (*Sorghum sudanese*) Rhodes grass (*Chloris gayana*) and elephant grass (*Pennisetum purpureum*). The objective of the field and laboratory trials is to determine which of these exotic plant species should be introduced into Eritrean rangelands to improve forage supply. Specifically the trials aim to: evaluate the adaptability of the imported forage plants in Eritrean environmental and soil conditions, assess the biomass productivity of these plants under rain fed conditions, assess the seed production ability of the plants, and evaluate the plants' tolerance to diseases and pests.

Although the initial six-month trial was supposed to be executed under rain fed conditions, due to early cessation of rain, irrigation was applied three times at three-week intervals (MOA 2002b). The results of this initial trial (reported in Table 2.2) suggest that *Sorghum almum* (Columbus grass) is well adapted to Eritrean highland climates and soil types. Less suitable species include *Trifolium semipilusum* (very poor germination rates, possibly attributable to soil characteristics of the trial site), *Medicago sativa* (prone to rust (fungal disease) infections), and *Desmodium introtum* (very low field population density).

Table 2.2 Legumes and grasses adaptive trial at Halhale Research Station: A summary of findings

Species name	Germination rate (%)	Emergency rate(%)	DM yield (kg/ha)	Seed yield (kg/ha)	Incidence of	
					Diseases	Pests
<i>Trifolium semipilusum</i>	10	1.06	-	-	-	-
<i>Dolichos lablab</i>	96	64.16	2754±745	-	I.Helianthus armiger (African boll worm) 2.Leaf miner	White fly
<i>Vigna unguiculata</i>	98	65.6	2203±432	-	Mosaic (Yellow mosaic virus)*	White fly, foliage beetle, and variegated grasshopper
<i>Medicago sativa</i>	95	85.2	-	-	Rust (uromyccs-foliage)**	-
<i>Desmodium intortum</i>	92	5.96	-	-	-	-
<i>Avena sativa</i>	96	54.8	2609±906	1041±344	-	Variegated grasshopper
<i>Sorghum almun</i>	58	70.4	8735±2735	1594±40	-	Variegated grasshopper

(Source: Adopted from MOA 2002b)

*= type of virus disease that attacks *Vigna unguiculata* species

**= type of rust disease that attacks *Medicago sativa* species.

2.1.6 Forage quality

Like forage yield and utilization, forage quality is primarily used as a principal parameter to evaluate the vegetation resources of rangelands for livestock production (FAO 2000). The important indices of forage nutritive quality are energy and protein contents. The author includes that the dynamics (unpredictability) of the energy and protein contents, for each forage type, give important insights into the limitation of livestock production. When the quality of forage varies in its energy and protein content, the productivity of livestock depending on it varies in a similar pattern. Factors influencing forage quality are complex and interrelated. Soil fertility is among the factors influencing forage quality. Soil nitrogen level directly affects forage crude protein (forage quality) level in grasses. Therefore, more nitrogen in the soil improves forage quality whereas the depletion of nutrients from grazing lands causes negative impacts on forage quality and leads to a reduction in animal production (Annicchiarico and Berardo /FAO 1991). The situation can be reversed by planting legume plants such as *Lablab purpureus*, which is drought resistant species. Forage quality can be improved by *Lablab purpureus* due to its characteristics of enhancing the nutritive value of soil, being a good source of protein and growing in a diverse range of environmental conditions producing more than 6 tons of dry matter per hectare (Murphy and Colucci 1999).

The production of legume plants is also carried out by some individual Eritrean farmers getting seeds from Halhale Research Station. After conducting the adaptive trials of legume and grass varieties like in Table 2.2, the Research Station distributes improved forage seeds to voluntary individual farmers to produce green forage on their irrigable or rain fed lands. However, some farmers are trying to improve the forage quality by producing green forage on their plots, the forage quality improvement programme is not accelerated due to the shortage of access to irrigable land (Kayouli *et al.* 2005).

As one of the programmes is to carry out research on animal nutrition, Halhale Research Station imports exotic annual and perennial grasses such as oats (*Avena sativa*), Sudan grass (*Sorghum Sudanese*), elephant grass (*Pennisetum purpureum*) and plants them on its research experimental plots with legumes to evaluate the nutritive (protein) content of the forage and

the feeds' digestibility as the quality of feed lies mainly on its digestibility which determines the availability of nutrients for growth, reproduction, etc. Methods such as *in vivo* and *in vitro* Measurements for measuring digestibility are used to evaluate and calculate the digestibility values of feeds (Kayouli *et al.* 2005).

For feed quality improvements, legume forage plays a great role to increase the forage nutrient quality. When crop residue forage is used mixed with legume forage, the nutritive quality, digestibility and intake of the forage increases. Adding supplements of energy, protein and minerals gives an adequate supply of nutrients to animals. Research carried out by Girma *et al.* (1994) and Umunna *et al.* (1995) at International Livestock Research Institution (ILRI) has shown that supplementation with forage legumes is a sustainable way of improving feed quality. *Stylosanthes guianensis*, *Lablab purpureus* and *Sesbania sesban* were useful as supplements for livestock. When feeds of maize-lablab forage were supplemented to cattle on a wheat middling diet, the daily mean organic matter intake was increased resulting in increase in milk yield (Khalili *et al.* 1994).

2.1.7 Fencing

Fencing is an important aid to grazing management especially for controlling stocking rates and rotational grazing systems. Fencing can prevent under or over utilization of particular areas of rangeland and help badly degraded rangeland to rest and recover, thus accelerating growth resulting in better returns of grazing patches and increasing the frequency of rotations per grazing season. Therefore effective use of fencing can increase rangeland productivity (William 2000; Gay *et al.* 2003). According to MOA (1997), Halhale Research Station in Eritrea has used fencing effectively to protect its cultivated pastures from unplanned grazing, and many commercial farmers apply fencing widely on the natural grazing and cultivated forage lands to exclude other farmers' livestock from their exclusive-use grazing areas. MOA (2002a) acknowledged that fencing can be advantageous in grazing management systems that aim to improve rangeland productivity.

Nevertheless, according to the global review of Kirkman and Carvalho (2003), fencing has restricting influences on using rangelands by limiting animal movements resulting in the greatest impacts on seasonal feed provision and rangeland condition. The limitation of animal movement causes a declined dry season animal production due to less quality and quantity feeds in humid and arid rangelands respectively. Although Gay *et al.* (2003) are of the opinion that fencing may help to avoid potentially damaging disputes between neighbours, because fencing inhibits the mobility of nomadic and transhumance pastoralists, it is more likely to cause disputes between pastoralists in Eritrea. The extent to which fencing of rangelands is unacceptable to communities of farmers in Eritrea poses a serious constraint to encouraging improved rangeland management practices that require fencing. The high capital costs of fencing may also partially explain the relative absence of fencing in rangelands in Eritrea (MOA 2002a).

Section 2.1 has reviewed factors influencing the quantity of forage produced by natural rangelands in Eritrea. The next two sections review supplementary sources of livestock feed available to Eritrean Pastoralists. These supplementary feeds are important for Eritrean pastoralists for sustaining their livestock during the dry periods.

2.2 Contribution of crop residues as winter grazing forage

Crop residues are the fibrous remnants from crop harvests with highly variable quality depending on the crop species and growing conditions (Smith 1993). The quantity of crude protein in the residues of fertilized crops can be two or three times higher than those available from native pasture, hence, crop residues could be allocated as a winter grazing forage reserve to alleviate the shortfall in crude protein in the natural winter forage (Thomas and Barton 1995). The review of Trytsman and Mappledoram (2003) in South Africa indicated that an integrated cropping system is a viable land use option practiced by up to 60% of rural farmers to improve the nutritional value of crop residue. In addition, by intercropping with legumes and perennial forage legumes in the tropics between 20 and 180 kg N/ha can be fixed per year.

2.2.1 Type and quantity of crop residues

About nine types of major rain fed crops that are grown in Eritrea produce a considerable quantity of crop residues. However, during the dry period, there is still a shortage of crop residues that cannot meet maintenance requirements of livestock for several months. The larger number of livestock compared to the forage availability and the lack of necessary inputs like improved seeds, fertilisers and the limited practical skills of smallholders are the basic reasons for the shortage. The management practices of farmers are very traditional, limited only to local inputs. The farmers are not literate, hence are constrained to participate in workshops and gain knowledge from exposure to science and technology. Moreover, the extension services available are limited, owing to a shortage of qualified extension people and extension supplies (Kayouli *et al.* 2005).

To outline the condition of croplands forage in Eritrea, the crop residues of 2003 are reviewed in detail. From the large grain cereals, sorghum, pearl-millet and maize croplands produced 45%, eight percent and three percent of the crop residue dry matter (DM) respectively, which covered 56% of the crop residue DM in the country (Table 2.3a). These crop residues were primarily produced in the Western and Eastern Coastal Lowlands largely in Gash Barka region where 52% of the total crop residues were produced (Table 2.3b). From the small grain cereals, barley, teff, finger-millet, wheat and hanfets croplands covered 26 percent of the total crop residues in the country. Most of these crop residues were produced in the Highlands, largely in Debub region where 34 percent of the total crop residues were produced. In addition, legume crops like oil crops of sesame largely grown in Gash Barka region (ten percent) and pulse crops of chickpeas cultivated in the Highlands, particularly in Debub region (eight percent) covered 18% of crop residue DM in the country (Table 2.3b). While the other three regions did not plant legume crops due to certain reasons. The shortage of land for Maekel and the agro-pastoral farming nature focusing primarily on livestock for Semienawi Keih Bahri region were the main reasons. Anseba region farming type concentrates largely on horticulture pearl-millet crops. Maekel region produced five percent of the total crop residue largely from the small grain cereals of barley and wheat and Anseba region produced five

Table 2.3a Type and quantity of crop residues in Eritrea, 2003

Crops	Total Area (ha)	Total crop prod (ton)	Total crop residue DM* forage (ton)	% of total crop residue DM Produced
Sorghum	200933	64061	64061	45
P-millet**	64481	11748	11748	8
Maize	13362	4456	4456	3
F- millet***	27734	5187	7677	5
Wheat	19156	3442	5094	4
Barley	43965	8576	12692	9
Teff	31456	7161	10598	7
Hanfets****	4772	1313	1943	1
Legumes	63023	17228	25497	18
Total	468882	123172	143767	100

(Source: FAO 2003)

*Crop residues dry matter (DM) is calculated based on Verjux (1988) and Bekele (1991) using a medium growth situation of forage/ha for large grain cereals and an average grain-straw ratio of 0.67 and thus a multiplier of 1.48 for small grain cereals. Following Verjux (1988), a multiplier is not used to compute the crop residues of large grain cereals and computations are based on a medium growth scenario.

** Pearl-millet (*Pennisetum americanum*)

*** Finger-millet (*Eleusine coracana*)

**** Hanfets = is a mixture of wheat and barley grain cereals sown, grown and harvested together. The grain is used for human consumption in Eritrea.

Table 2.3b A regional breakdown of crop residues in Eritrea, 2003

Region	Area (ha)	crop production (ton)	Crop residue DM Forage* (ton)	Legume residue DM forage (%)
Gash Barka	215345	70458	75442	10
Debub	169244	35078	48229	8
S. K. Bahri	13990	6810	6985	-
Anseba	45303	6795	71545	-
Maekel	25000	4031	5957	-
D.K. Bahri**	-	-	-	-
Total	468882	123172	143767	18

(Source : FAO 2003)

*The importance of the DM forage figures in Table 2.3b is to show the availability of crop residue DM forage in each region in a summarised form.

** There is no significant crop farming activity in Debubawi Keih Bahri region, owing to unfavourable climate.

percent of the total crop residues mainly from the large grain cereals of pearl-millet and sorghum. Semmienawi Keih Bahri region produced five percent of the crop residues primarily from sorghum and maize croplands (Table 2.3b). In Maekel region lack of arable land, in Anseba region shortage of moisture and in Semmienawi Keih Bahri region due to the unsettled agro-pastoral farming nature where some of the constraints in addition to the shortage of inputs like fertilizers and low level of crop rotation practices and application of manure (FAO 2003; Kayouli *et al.* 2005).

2.2.2 Quality of crop residues

Quality of crop residues can be influenced by the management (the intensity of added inputs such as manure, chemical fertilisers, practices of crop rotation, length of fallow, timely weeding, etc) of the croplands and the process of collecting and conserving it. There are several factors that promote the nutrient quality of crop residues. Crop rotations and the application of manure are the most essential local practices carried out at cheaper costs relative to the costs of chemical fertilisers. Fallow systems are also very important

exercises to promote the nutritive quality and quantity of crop residues so long as the indirect costs for an extended time of unproductive land do not exceed the benefits obtained from the forage. The application of chemical fertilisers also contributes to enhance the quality of crop residues if the first two preceding options are not possible (Bojo 1996), cited by MOA (2002b).

The crop rotation of oil crops with large grain cereals like sorghum in Gash Barka region and pulse crops with small cereals of barley and finger-millet in Debub region are common practices compared to the other regions' (Semienawi Keih Bahri, Maekel and Anseba) farmers. However, due to the shortage of land, particularly in the Central Highlands, the decreasing frequency and regularity of fallow systems and crop rotation between good and bad years causes a nutrient loss.

When forage is consumed by livestock, soil nutrients such as nitrogen and phosphorus are taken through the forage. Dung from livestock, which is expected to replace lost soil nutrients, is used for fuel due to the lack of fuel wood and electricity in rural Eritrea. Hence, one of the options left to compensate the lost nutrients is the practice of crop rotation. However, since crop rotation practices need sufficient moisture, it is advisable to plant more legumes in good years and fewer legumes in poor years in order to recover the nutrient contents (Bojo 1996), cited by MOA (2002b). Nevertheless, to practically predict whether the coming year would be a good or bad one is difficult in Eritrea. The information of rainfall obtained from metrology office is the only source available and distributed to farmers through MOA in different media. Another important point is that most legume crops such as chickpea are planted in late summer so that the farmers can have ideas about the rainfall potential of the year.

2.3 Supplementary feeds as a dry season feeding strategy

Better feed and feeding management contributes to promote milk production. Pasturelands can be the major sources of feed for milking cows but there are limitations to their use. Pastures in the highlands are infertile and fragile under continuous uncontrolled grazing regimes. The grazing area has been shrinking over the years because of over-grazing, extensive cultivation and improper utilization of water resources. In the Western Lowlands, particularly in the drier Northern part of the Lowlands, grasses become

relatively scarcer. In the Eastern Coastal Lowlands, the region is arid with temperatures from 28°C to 38°C with little seasonal variation. Some of the grasses found in Eritrea grazing areas are *Chloris gayana*, *Digitaria abyssinica*, *Eragrostis cilianensis*, *Eragrostis superba* etc. in the Central highlands, *Cynodon* spp, *Eragrostis cylindriflora* and shrubs like *Atriplex* spp. in the Eastern Coastal Lowlands and *Andropogon dummeri*, *Aristida adscensionis* and *Eragrostis* spp. and others in the Western Lowlands are in bad condition and not readily available for grazing during the dry season in terms of ground cover, grasses are more scarce and browses are limited specially in the North Western and Eastern Coastal Plain Lowlands (Gose 1998).

2.3.1 Sources of supplementary feeds in Eritrea

Croplands are primarily the sources of supplementary feeds producing crop residues. However, poor management like continuous cropping and overgrazing causes the depletion of soil nutrients and a decline of water retention (Blench and Marriage 1999). In Eritrea, according to Kayouli *et al.* (2005), most of the communal farmers are not observed applying chemical fertilizers to promote soil fertility despite their implementation of continuous farming. Recent surveys showed that from 1997 up to 2003, on average, the amount of chemical fertilizers used was only 8.8 kg/ha per cropping season (FAO 2003). The application of manure was one of the means to promote soil fertility of croplands in the country. However, due to the lack of fuel in the rural areas, most of the animal dung is used for domestic fuel. For example, due to the consumption of 273,000 tons/year of animal dung for fuel, 756 tons/year of nitrogen and 702 tons/year of phosphorus are lost every year (Bojo 1996), cited by MOA (2002b). When the croplands of 2003 in particular and the crop production of 1997-2003 in general are observed with regard to crop rotation, on average, only 13% of the croplands comprised legumes and 87% of the croplands comprised grain cereals (Table 2.3a). On the other hand, growing sorghum removes approximately 30 kg/ha/year of nitrogen and 12.5 kg/ha/year of phosphorus (FAO 2003). When the removal of nitrogen and phosphorus through growing cereal crops is compared to the replacement through the application of fertilizers and crop rotation practices, the replacement is insignificant indicating that the decline in the nutritive value of crop residues worsens from time to time.

2.3.2 Agricultural and industrial by-products as supplementary feeds

Due to the shortage of grazing forage, farmers from the Highlands store straw of barley, teff and wheat whereas in the Lowlands sorghum and pearl-millet stover are conserved every year to supplement the cattle during the dry period. The quality and quantity of crop residues stored varies from year to year depending on the distribution of rainfall, application of inputs on the croplands and availability of the crop residues (Kayouli *et al.* 2005). However, since the stock of crop residues does not sustain the cattle long, farmers need to supplement their cattle with agro-industrial by-products such as barley and wheat bran, oil-seed cakes, and brewers grain. The total products in the country are 15000 tons of bran, 6000 tons of oil-seed cake and 10000 tons of brewers grain per year and priority of access is usually given to commercial farmers. Industrial by-products for communal farmers are therefore rarely available (FAO 1995).

In the Central Highlands and Lowlands of Eritrea where rainfall is up to 600 mm, legume trees such as *Leucaena leucocephala*, *Sesbania sesban* and shrubs of *Cajanus cajan* (Pigeon pea) have been used as green supplementary feeds. Moreover, Cactus pear (*Opuntia ficus-indica*.) is widely used as an emergency drought feed for cattle where there is a shortage of grass forage in the Highlands. In addition, in the area where annual rainfall is below 500 mm, the introduction of leguminous forage plants (*Leucaena leucocephala* and *Sesbania sesban*) into natural grazing areas has been given priority as the plants are drought resistant and have a minimum of 50% increase in productivity compared to the non-legume plants like *Atriplex nummularia* in dry matter yields (Kayouli *et al.* 2005).

Conserved crop residue/ by-product used as supplementary feeds for the dry season are collected largely from large grain cereals like sorghum, pearl-millet and maize in Gash-Barka, Anseba and Semienawi Keih Bahri regions. In the highland regions, small grain cereals like barley, teff, wheat and finger-millet are the main sources of crop residues for the winter dry season in the Dehub and Maekel regions. There is only one primary source of agro-industrial by-product used as supplementary feeds in the country, Asmara, which distributes to all regions. Government agro-industrial mills are the main sources of bran of wheat and barley, cotton seeds, oilseeds, wet brewer grain, cotton husk, meat meal, bone meal and dairy meal. These feeds are not easily accessible to the smallholder cattle farmers. Green trees and shrubs are other sources of supplementary feeds for the dry

season forage. Legume trees and cactus are the main sources of green forage producing *Leucaena*, *Sesbania* and *Cajanus cajan* in the Highlands and Western Lowlands and spiny and spine-less cactus in the Highlands (Gose 1998).

2.3.3 Urea treatments in Eritrea Central Highlands

The improvement of supplementary feeds in digestibility, palatability and nutritional quality as well as to increase intake of fibrous residues is necessitated in order to promote feed and feeding management in Eritrea. Therefore, one of the practical actions that Halhale Research Station has established is urea treated straw and the manufacture and utilization of feed blocks in the highlands. Consequently, straw intake was increased by 15% and 35% when animals were supplemented with feed blocks and when straw was treated with urea respectively (Kayouli and Assefaw 2000). Increases in crude protein (CP) content in urea treated teff (*Eragrostis teff*) and barley straws were observed to be 134 percent and 85% compared to their initial nutrient content of 3.8% and 5.5% of CP respectively. In addition to improved intake, about 70% of the treated crop residues were edible compared to 40% for the untreated ones. Moreover, feeding urea treated crop residues to dairy cows also increased milk yield from 150 litres to 355 litres per cow over a period of a month (Kayouli 1996).

2.4 Herd breed, size and composition

Cattle herd characteristics such as breed (genetics), size and composition are important determinants of cattle farming productivity, where cattle farming productivity refers to various products (e.g. meat, leather, milk and manure) and services (draught power) produced by cattle. Cattle breed and genetics are clear determinants of the production potential of cattle, and the relative productivity of the indigenous cattle breeds farmed in Eritrea was briefly discussed in Chapter 1. According to Simpson and Farris (1982) although all east African indigenous cattle are well adapted to the conditions prevailing in the tropics, they are late maturing, their dairy potential is relatively poor, and usually they do not let down milk unless stimulated by the sucking of the calf. Thus one of the many constraints of milk production in Eritrea is the poor genetic potential of the indigenous animals.

According to Syrstad (1996), crossbreeding of tropical cattle with cattle of European-type breeds has shown a dramatic increase in milk yield in the first crossed generation (F1), compared with local stock. He added that the crossed females calved at a much younger age than native animals, produced two to three times more milk and had longer lactations, shorter dry periods and shorter calving intervals, but that mortality and susceptibility to disease were only slightly higher than in native cattle. However, Syrstad (1996) found that these favourable results didn't always result in the expected further improvements from backcrossing to exotic bulls and in many cases a decline in performance was observed, with increased mortality and reduced fertility as the level of exotic inheritance increased towards 100%. At a low and intermediate level of production, backcrosses show an average increment in milk yield per lactation by 118 kg and 40 kg respectively (Table 2.4). However, at high production levels backcrosses show a decline in the average milk yield of 100 kg, demonstrating the success of the first crossbred generation (F1) and the deterioration in the next generation (F2), and supporting the hybrid vigour (heterosis) in crosses, like zebu x European-type cattle because of the wide genetic distance between the two types (Cunningham and Syrstad 1987).

Table 2.4 Comparison of F1 and backcrosses (1/2 and 3/4 European inheritance)

Production level	Average milk yield (kg)	
	F1	Backcrosses (1/2 and 3/4)
Low (<2000 kg)	1487	1605
Intermediate (2000 – 2405 kg)	2175	2218
High (> 2405 kg)	2798	2698

(Source: Syrstad 1996)

In rural Eritrea, access to buy dairy Friesian cattle is difficult and very expensive. To overcome such constraints, farmers near the urban areas use artificial insemination, while farmers living in the rural areas use crossbreeding. The crossbreeding has been carried out between the Arado breed females and the Barka breed bulls with the female offspring crossed with Friesians (MOA 1997). This program has usually been more successful in increasing milk productivity and improving the breeds rather than keeping pure Arado or/ and Barka breeds. The Arado farmers from the Central Highlands adjacent to the Barka breed area practice crossbreeding of the Barka type bulls with their local Arado cows. The

crossbreed is well built and hardy like the Barka cattle and, like the Arado cattle, resistant to feed shortage stress in the Highlands (UOA and MOA 1998). However, Syrstad (1996) stated that genetic improvement alone might not result in drastic increases of milk production in the tropics, but it is a prerequisite for such increases. According to Syrstad (1996), the performance of an animal is the result of the joint action of its genotype and the non-genetic effects to which it is exposed. The non-genetic factors are often collectively termed the environment. Genetically improved animals are more productive and also most responsive to improved feeding and management (Syrstad 1996).

The cattle herd composition also impacts its productivity. For example, it is noted in Section 1.1 that agro-pastoralists in Eritrea tend to keep a relatively high proportion of oxen in their herds as a source of draught power for cropping. Herd size may also have a bearing on the management practices used to farm cattle. For example, smallholder farmers with relatively larger herd sizes may have better access to veterinary services.

2.5 Institutional arrangements governing the use of grazing resources in Eritrea

In chapter one an argument was presented that despite the existence of well defined property rights for groups of smallholder farmers at the village level, this is not sufficient to guarantee that grazing resources will be managed as well as if farmers each had exclusive-use rights over their grazing resources (e.g. as per optimal stocking rates shown in Figure 2.2). In particular, it was argued that if groups of farmers are unable to enforce their property rights (i.e. exclude outsiders) or if high costs of collective action limit the extent to which farmers co-operate and implement grazing management, then the outcome may be similar to that of open access. This section reviews the problem of common property grazing under open-access and why “the tragedy of the commons” may result. It is important with respect to understanding why few groups of smallholder farmers in Eritrea have adopted sound grazing management practices, and further, why they appear to pursue a survival or subsistence strategy rather than a commercial farming strategy.

2.5.1 “The tragedy of the commons”

Gordon (1954) explained the common property problem under open access. The profit maximising rule is to stock cattle such that the value of the marginal product of cattle

(VMP) is equal to the cost of keeping an additional head of cattle (P_x). At this point, returns (rents) are maximised. Assuming that the stockowner's time preferences are consistent with those of society as a whole (i.e. a positive discount rate), then the optimal stocking rate will be less than or equal to the maximum long-term stocking rate of the land, which is where the VMP is equal to zero. Thus, this stocking rate prevents land degradation (Gordon 1954).

However, if the grazing land is under open-access grazing, the land will be stocked such that the value of the average product (VAP) is equal to the cost of keeping an additional cow (P_x). This equilibrium arises because under conditions of open-access stockowners only consider their own private costs and returns when deciding whether or not to make use of the commons. They do not consider the total costs and total returns of all the stockowners who use the land. In this situation there is no incentive for stockowners to 'stint on the commons' as rents would accrue to others - the free riders. The net result is that returns to cattle farming will be zero. What is more, it is possible that the stocking rate

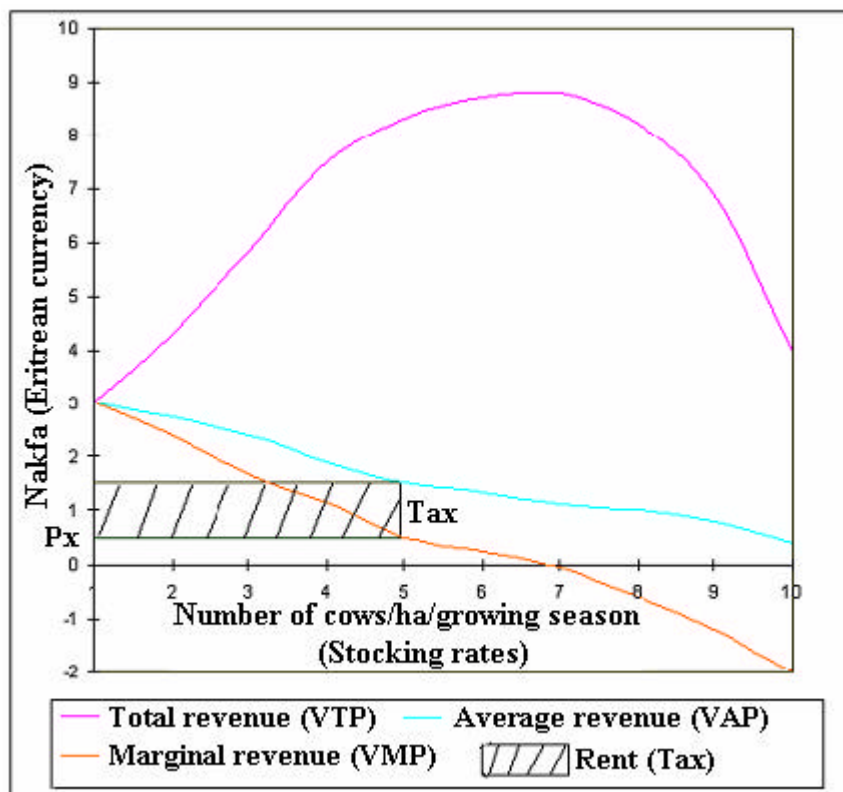


Figure 2.2 Total, average and marginal value product curves (Gordon 1954).

VTP = Value of total products, VAP = Value of average products,

VMP = Value of marginal products.

under conditions of open-access may exceed the maximum sustainable stocking rate of the land. Thus conditions of open-access may lead to land degradation, although this is not a necessary condition of open-access. Land degradation will tend to result in an increase in P_x due to increased mortality rates, which will temper stocking rates on degraded rangelands if the input-output price ratio (P_x/P_y) remains unchanged (Gordon 1954).

Gordon's (1954) theory of the tragedy of the commons is illustrated in Figure 2.2. In this graph, economic rents will be maximised at a stocking rate of 5 cattle ($VMP = P_x$), however, under conditions of open-access the land will be stocked at a rate of 10 cattle ($VAP = P_x$) and rents are zero. In this example, the maximum sustainable stocking rate is equal to 7 cattle, thus under conditions of open-access the land will be over-stocked and is likely to become degraded.

2.5.2 Open-access versus communal access

If a group of farmers collectively have exclusive use-rights to a grazing resource and the group can exclude outsiders from using their grazing, then the land is not under conditions of open-access but is under conditions of communal access. Clearly, the tragedy of the commons may be averted if the group of stockowners choose to cooperate and agree to stock the land at a level that is within the carrying capacity of the land, and preferably at the level where $VMP = P_x$. High costs of collective action may limit the ability of a group of farmers to effectively cooperate, thus land farmed communally by a well defined group of farmers may suffer from the tragedy of the commons (World Resources 2005).

Collective action by groups of farmers is necessary not only for reducing stocking rates to optimal levels, but also for investing in improvements to the land (such as improving pastures, water points or green feeds). Thus it is important that the institutional arrangements that govern the use of communally farmed rangelands must be strong (i.e. ability to exclude outsiders and to enforce rules amongst the group) and they must be conducive to effective collective action by the group if the tragedy of the commons is to be averted (World Resources 2005).

2.6 Household resources

The household resource characteristics are important factors affecting cattle productivity as they determine the quality of rangeland and herd management, the quantity of available household labour and the on-farm consumption requirements of the household.

2.6.1 Education

Increased levels of literacy and education help to reduce the economic costs of securing and using information. With literate and better-educated farmers, appropriate livestock and natural resource management may be better understood (UOA and MOA 1998)

2.6.2 Household income

Low household liquidity may impact on cattle farming productivity because cash may be required for the hiring of labour to herd cattle, purchase supplementary feeds during dry periods, purchase new animals to improve herd genetics, invest in fixed improvements such as fencing, and to pay for veterinary services, amongst others. In general, cattle are a relatively liquid asset, however, during dry periods when cattle prices tend to be low, farmers may prefer not to liquidate part of their herd and rather support their herd using purchased supplementary feeds (UOA and MOA 1998).

Eritrean rural households' main source of income is from livestock and crop cultivation, which is mainly rain fed. The income from livestock is from sales of live animals, milk and meat. MOA (2000) stated that the demand for livestock products increases resulting in an increase in the income of households. In the Central Highlands, the Arado cattle area, where human population is dense, milk, meat and live animal prices are higher on average by 20% than the Barka cattle area (FAO 1994). Households from Gash-Barka, the Central Highlands (Debub and Maekel regions) and Semienawi Keih Bahri regions get, on average, between 1138 and 2456 Nakfa per year from each of both the sale of live animals and crop yields. When assessed in detail, Gash-Barka, the Central Highlands and Semienawi Keih Bahri regions got 20%, 16%, and 17% of income obtained from the sale of live animals whereas 12%, 19% and 19% of income from crop yields respectively during 1993 and 1994 (UOA and MOA 1998).

2.6.3 Household structure

Cattle owners' age and gender has a great influence on cattle farming development. In Eritrea, most livestock production operations are carried out by men. Eighty-five percent of Eritrean population live in rural areas and depend on livestock and crop farming activities. Generally, 50% of the 85% are considered as able bodied which are between 15 and 64 years old (FAO 1994). There is not any population difference between male and female. However, as evident in the three sampled-districts, Debubawi Anseba (in Gash-Barka region) 46%, Egelahatzin (in Debub region) 36% and Gahtekay (in Semienawi Keih Bahri region) five percent were female-headed households (UOA and MOA 1998). The large size of female-headed households has two implications with respect to Eritrean community. The first implication, which is cultural, is that it creates the dependency of females on their male relatives or share-herders or share-croppers in cattle herding and crop farming activities. During dry period, when a migration of livestock is needed for better access to forage and water supply, ladies usually face difficulty to look after the livestock out of their homesteads as they are more responsible to look after their children. The other important implication is that family leading responsibility creates an exposure of favourable circumstances to ladies that they can gain a lot of experience in cattle and crop farming management to generate their income independently (UOA and MOA 1998).

2.7 Access to input and product markets

In Eritrea, smallholder cattle owners with poor infrastructure such as shortage of transport and other means of communication suffer due to high transaction costs to input-output market. For example, dairy farms need immediate market access for their products because dairy products like milk and milk products are perishable if they are not marketed immediately. Similarly, as the income of smallholder farmers is very little, they have financial constraints to fund their farms. Institutional markets of supply of credit do not readily give a significant amount of funds to the rural smallholder cattle owners due to the lack of collateral (NFIS 2005).

2.7.1 Location

Location impacts on transaction costs in input and product markets. The growth of smallholder dairy is limited by high transaction costs for both production and marketing. This in turn causes most commercial cattle production farms to be crowded around the urban areas to escape from pressure of high transaction costs caused by long distance to market and shortage of inputs around and suggesting that in peri-urban areas, dairy and fattening offer high potential as a smallholder diversification activity (FOSA 2001). Moreover, infrastructure in rural Eritrea is another constraint impeding the development of smallholder livestock keepers in the country. The Western and North West Lowlands of Eritrea are forced to have a regional market economy with proximate neighbouring countries due to the very long distance and a lack of infrastructure to the marketing centres of the country. However, the newly constructed infrastructure which connects Gash-Barka and Debub regions helps the livestock owners particularly cattle herders in the Upper Gash and Shambuko from the South-West Lowlands to have a better access to the central part of the country such as Asmara and other cities (FAO/IFD 1999).

2.7.2 Access to credit

Smallholder rural farmers in Eritrea are not able to escape their poverty and improve their cattle farming productivity. Constraints for this are that the grazing lands do not contain enough forage mainly due to improper grazing systems. The herds kept for breeding are not productive by the fact that they are not well fed and not exposed to cross breeding with improved dairy herds. To alleviate such constraints, the intervention of institutional organisations with supply of credit is important (MOA 2002a). There are some credit organisations such as the Associations for Co-operation and Research in Development (ACORD), the Eritrean Community Development Fund (ECDF) which is under the Ministry of Local Government and the Ministry of Agriculture (MOA). Even though the credit organisations assist farmers by giving loans, the cattle owners are not full beneficiaries from these credit providers. ACORD (a non-government organisation) is likely to give loans based on a group liability for a short-term. According to ACORD regulation, people, on average not more than 5, organise themselves as a group and take loans individually. If any member of the group does not repay back the loan, the group is responsible to pay. Farmers who want to take a large loan for a long period of time are

often discouraged by other group members who fear accepting responsibility for repayment of the loan. While ECDF gives credit to farmers, it mostly places emphasis on social needs based on a village population. MOA distributes about two million dollars credit per year to poor farmers but 75% of this is targeted to draught oxen and 25% for water pumps or tractors focusing on crop farming activities. However, the credit organisations' individual programmes are supported, their capital potential may not be compatible to respond the credit needs of the smallholders. Therefore, the smallholder cattle owners have little chance to be beneficiaries from such credit programmes (MOA 2002a; NFIS 2005).

Eritrea is one of the less developed countries that require improved access to credit and other inputs to remove or reduce up-stream constraints (shortage of credit supply) and require market access to remove or reduce down-stream constraints (shortage of market access). In this case, credit helps to build and make equipped the farms with necessary inputs to improve productivity whereas market access is important to purchase quality inputs at fair prices to capture high output prices. Hence, it needs to include any capacity building and/or institutional strengthening (IFAD 2001).

Moreover, farmers adjacent to urban areas have a better chance to get involved with off-farm activities to maximise their off-farm incomes. The off-farm employment opportunities have positive influence on the livestock farming development in supplying liquid money to purchase necessary inputs for the farms (NFIS 2005).

2.8 Discussion: Causes of overgrazing and degradation of Eritrean rangelands

Overgrazing and degradation of rangelands are potential causes of low cattle productivity in the communally farmed rangelands of Eritrea. In this chapter, a possible underlying cause of this overgrazing and degradation of rangelands is traced to a possible lack of effective collective action by communities of farmers. This lack of collective action is a constraint not only to reducing stocking rates, but also a constraint to the adoption of innovative grazing systems and investments that improve the grazing resource. In other words, institutional innovation may be required as a pre-cursor to technological innovation.

Another possible underlying cause of the overgrazing and degradation of rangelands is the use of supplementary feeds by Eritrean livestock farmers to support their herds during the dry periods. In this context, the migration of livestock to alternative sources of forage during the dry season is also a type of supplementary feed. The consequence is that when the use of supplementary feeds ceases (or livestock return to rangelands in close proximity to farmers' villages) at the start of the next wet season, the stocking rate will be higher than that possible without the use of supplementary feeding (herd migration). According to Kirkman and Carvalho (2003), high wet season grazing pressure constrains the grasses from producing seed for the following growing season, thus resulting in rangeland degradation, especially the depletion of palatable grass and herb species. Although Kirkman and Carvalho's (2003) review paper is universal, its observation that high wet season grazing pressure leads to deterioration of rangelands is expected to hold true in the rangelands of Eritrea.

CHAPTER 3

RESEARCH METHODOLOGY AND DATA COLLECTION

3.1 Introduction

The primary objective of this chapter is to outline the statistical techniques used to analyse the characteristics of commercial and smallholder cattle production systems in the Arado and the Barka cattle farming regions of Eritrea. The study is designed to analyse characteristics that describe forage production in these systems and to relate these to the productivity of cattle farmed in these systems. The analysis of forage production focuses on examining farmers' management of their grazing resources (e.g. control of stocking rates and investments in grazing and water resources essential to facilitate forage production systems) and their use of rangeland and cropland forage and various supplementary feeds to sustain their livestock. The design of this analysis is detailed in Section 3.3. The analysis of cattle productivity incorporates several aspects to cattle productivity, namely milk productivity, calving rates, off-take rates (sale of livestock) and herd mortality rates. The specification of this section of the analysis and an explanation of the statistical techniques used for the analysis are presented in Section 3.4. First, however, the methodology used to collect data for these analyses is described in Section 3.2.

3.2 Data collection

Four sets of data were collected for this study. The first set of data is comprised of secondary data obtained from Farmers' Associations in Eritrea. The data collected and the methodology used to collect the data is described in Section 3.2.3. The second set of data was obtained through face-to-face-interview surveys of a sample of 12 commercial cattle farmers in Eritrea. The sampling approach and survey methodology used for this survey are explained in Section 3.2.4. The third set of data was elicited through face-to-face-interview of a stratified random sample of 40 smallholder farmers from the Barka cattle region and 40 smallholder cattle farmers from the Arado cattle region. The sampling approach and survey methodology used for this survey are explained in Section 3.2.5. The final set of data was obtained through a series of group discussions held with commercial and smallholder cattle farmers to discuss factors that constrain cattle farming by smallholder farmers in Eritrea from becoming more commercially orientated. The

approach used for these group-discussions is explained in section 3.2.6. First, however, section 3.2.1 explains the concepts of random sampling and stratified-random sampling and Section 3.2.2 explains the method used for face-to-face interviews conducted in this study

3.2.1 Random sampling and stratified random sampling techniques

The issue of sampling is important because it is rarely the case that there has been sufficient time and resources to conduct research on all of those individuals who could potentially be included in the study. Without implementation of sampling it is seldom possible to carry out complete enumeration and is impractical for financial, manpower or logistic reasons (Bright 1991, Haining 2003). In addition, this method is necessary because different units within populations (e.g. households, cattle, survey areas, etc) vary in their individual characteristics.

In this study both simple random sampling and stratified random sampling were implemented. Simple random sampling is a sampling procedure that assures that each element in the population has an equal chance of being selected. Stratified random sampling specifies that the target population to be estimated be divided into different strata usually chosen along geographical lines and/or for other administrative reasons. Barnett (1991) stated that the advantage of stratified random sampling is that it helps to avoid the problem of insufficient variation in the target population. Provided the variance within the stratum is less than the variance between the strata, the technique will yield a representative sample with less variance than with simple random sampling (Barnett 1991).

In this study a simple random sample was used to survey the populations of commercial farmers in Eritrea because there are no clear strata within this population of farmers. A stratified random sample was used to survey the population of smallholder cattle farmers because this population is easily partitioned into strata according to the administrative region in which they farm. Because there is considerable climatic variation across Eritrea there is sound reason to expect significant differences between these strata of smallholder farmers. Consequently, stratified random sampling is an appropriate sampling methodology in this case.

3.2.2 The survey interview technique

Because the main household data collecting medium was through survey questionnaires, it was necessary to conduct survey interviews with farmers selected in the study samples. The respondents were interviewed personally one at a time with the aid of interpreters in order to exclude the possible bias that could be introduced by the use of different enumerators. According to Sudman and Bradburn (1982), advantages of personal interviews are that quantitative analysis is possible, and the interview is flexible and answers are spontaneous. Moreover, Selltitz *et al.* (1961) emphasised that the interviewer can rephrase or adjust questions where necessary. However, limitations include the dependence on the interviewee's memory (Murphy and Sprey 1982) and the possibility of intentional or unintentional bias (Sudman and Bradburn 1982).

3.2.3 Collection of secondary information from farmers' associations

The researcher collected secondary information from the farmers' association offices on village level and from the ministry of agriculture (MOA) offices on districts level before collecting the primary data from the individual households. The purpose of the secondary information was to gain insight about the surveyed villages general resources. Another purpose of the secondary information was to help the researcher save time and cost during the survey of the primary data. Moreover, the secondary information obtained from both offices was about the relationships between the commercial and the communal farmers with regard to the past and current grazing management activities. To approach households with a good system of interviews, information about the availability of forage and stocking rate was dealt in its general sense. The availability of rangelands and the forage potential of the sampled villages were also observed. However, as Crawford/FAO (1997) faced problems from secondary data in different African countries, the secondary information is to be carefully handled that some might be outdated and others might be too general and may not include the present research area. Therefore, it needs careful analysis as it was collected for purposes other than that of this particular research study.

3.2.4 The survey of commercial cattle farmers

Commercial farmers were studied to learn about rangeland management applied in commercially orientated farming systems in Eritrea.

Thirty-two commercial dairy farmers that were primarily dependent on grazing forage were identified from the MOA office. Out of the 32 commercial dairy farmers, 12 farmers were selected using a simple random sampling method (Table 3.2). Although the number of commercial farmers surveyed is small relative to the number of smallholder farmers surveyed, mean statistics of the two groups can be compared using appropriate *t*-tests (Strum and Donald, 1988).

The survey questionnaire for commercial farmers was designed to obtain information about farmers' grazing management practices (e.g. control of stocking rates, grazing regimes and flood water diverting practices), and their use of cropland forage and supplementary feeds to sustain their Barka-breed dominated cattle.

3.2.5 The survey of subsistence cattle farmers

The population of smallholder cattle farmers in Eritrea are found in diverse areas that vary according to geographical location, average annual rainfall and rangeland productivity. Although it can be easily stratified according to the administrative regional (provincial) level, in this study it is primarily stratified according to the breed of cattle farmed by smallholder farmers in the region. The Debub, Semmienawi Keih Bahri and Maekel regions were selected because the Arado cattle breed is farmed in these regions. The Gash-Barka region was selected as the Barka breed is farmed in this region. These strata are further sub-stratified according to the climatic region in which they are situated (i.e. lowland, highland, arid, and semiarid areas).

Lists of all villages in each sample district were obtained from the MOA and Ministry of Local Administrative (MOLA) offices. Lists of individuals who own cattle in each of these villages were obtained from the village administration offices. Since the lists of villages and individuals represented different administrative regions containing various climates and vegetation types, etc, first a stratified random sampling technique was used to

divide the target population into different strata in order to keep sufficient variation in the target population. Then simple random sampling method was applied to choose the individuals from each stratum (Table 3.1).

As indicated in Table 3.1, in Debub region, districts were stratified into the lowland and highland strata. Unlike Debub, Gash-Barka was stratified into lowland and midland strata. Though the latter region is known as lowland, its Eastern and Southeast parts are Midland areas, which have clear differences in altitude and rainfall as well as type of vegetation with the Lowland areas. In these two Zobas (Regions), within the strata, in MOLA and MOA offices, lists of villages' populations were available from which sampled villages were drawn using the simple random sampling statistical techniques. Similarly, in the village administrative offices, there were lists of household populations from which stratified simple randomly sampled cattle owner households were drawn. However, in Maekel and Semmieniawi Keih Bahri regions, the stratification technique was not applied. Maekel region is found in the Highland area having similar types of vegetation and feeding management. The altitude and rainfall distribution of the region have the same influence on the vegetation and feeding management throughout the largest part of the region. Semmieniawi Keih Bahri region is located in the Eastern Coastal lowlands with the characteristics of the same geographical area having similar altitude, temperature and rainfall distribution resulting in the same types of vegetation with similar feeding management. Debub and Gash-Barka regions have the characteristics of semi-lowland and semi highland, fully lowland, midland and highland nature of districts. Accordingly, the characteristics of the target population were measured using stratified and simple random sampling techniques (Table 3.1).

A survey questionnaire was designed to elicit information from the sample of farmers about the rules governing the use of communal grazing available to their villages and the management practices applied to these rangelands and the impacts of the practice of cattle during the dry season. The survey also collected information on farmers' use of cropland forage and supplementary feeds to sustain their cattle and the physical and economic productivity of their cattle herds. Physical cattle productivity information elicited included information on off-take rates and milk yield. Income (defined as income from milk and animal sales plus the value of on-farm consumption) and costs information was collected

for the computation of economic productivity indicators such as farmers' gross margins and the total annual cost of variable inputs.

Table 3.1 Smallholders stratified and simple random sampled villages and households

Stratified and simple random Samples	Arado breed regions			Barka breed region			Total
	Dehub*		Maekel	Sem Keih Bahr	Gash-Barka*		
	Lowland Stratum	Highland Stratum			Lowland Stratum	Midland Stratum	
Number of villages	52	78	20	28	129	22	329
Randomly selected villages	2	2	2	2	6	2	16
Number of households	8,602	12,122	6,698	7,573	18,655	6,382	60,032
Randomly selected households	10	10	10	10	30	10	80

(Source: Population data from MOLA and MOA Offices 2001)

* = Regions in which stratification techniques are applied.

Table 3.2 Commercial simple random sampled villages and households

Simple Random samples	Arado breed regions				Barka breed region		Total
	Dehub	Maekel	Sem Keih Bahri	Gash-Barka			
Number of villages	11	4	2	6		23	
Randomly selected villages	4	2	1	3		10	
Number of households	16	6	2	8		32	
Randomly selected households	5	2	1	4		12	

(Source: Population data from MOLA and MOA Offices 2001).

3.2.6 Group discussions

Group discussions were held to encourage farmers to provide additional information that they may have been reluctant to provide during individual survey interviews. In particular, these discussions were focused to establish reasons for the decline in the productivity of rangelands over time and why smallholder cattle farming has remained subsistence orientated. The group discussions were structured as semiformal meetings at MOA offices. Participants at the meetings included cattle owners and village administration members. Tapson and Rose (1984) stated that this technique of qualitative information provides a cross reference for information obtained in private interviews by allowing stockmen to give their views on management and benefits without having to answer personal questions. In addition, the author visited the grazing areas and the cattle, while they were grazing, to relate the environmental situations with the information given by the respondents during the interviews.

In summary, the four components of the data collection process used in this study were designed to:

- To collect data for analysis of forage production and economics of production systems traditionally used in Eritrea for the Barka and the Arado cattle in the communal grazing systems;
- To identify feed and feeding problems experienced by cattle owners in relation to applying modern systems of forage development like green feeds, agricultural and agro-industrial by-products;
- To determine the basic constraints of grazing land improvement;
- To determine the cattle owners' opinions of alternative management systems with regard to herd improvement;
- To determine the cattle owners' problems regarding credit, market and marketing conditions;
- To document the cattle owners' suggested solutions.

3.3 The statistical methodology used to analyse cattle farming systems in Eritrea

To achieve the objectives of investigating the foraging methods and assessing the performance of smallholder cattle farming systems against the commercial cattle farming systems foraging and performance, descriptive statistics were applied in examining the grazing management, fencing, croplands and supplementary feeds. In addition, t-test analysis was also applied to determine the significant differences between the smallholder communal farmers of the Arado and Barka cattle and the commercial cattle farmers (Statistical Product and Service Solutions (SPSS) 1990).

To achieve the objectives of appraising management practices applied by the smallholder cattle farmers in the Arado and the Barka cattle regions and analysing the productivity of smallholder cattle farming systems in the country from a physical production and economic perspectives, physical production measurements and the gross margins of the Arado and Barka cattle in Eritrea were computed using an approach used by Barnard and Nix (1979) for farms in UK.

To achieve the objectives of identifying factors that constrain the performance of smallholder cattle farming, descriptive statistics were used with the application of t-test analyses to calculate the significant differences between the Arado cattle and the Barka cattle areas.

3.4 The statistical methodology used to analyse cattle productivity

Measurements of physical and economic production performance have been included in a principal component analysis (PCA) to examine heterogeneity in cattle performance across smallholder and commercial cattle farmers. The analysis of cattle production farms in Eritrea is also carried out using principal component analysis (PCA) to apply the techniques of rotated factor loadings of factor scores analysis. Moreover, to achieve the objectives of cattle farming analysis, factor scores, regression analysis and t-test analysis were also applied to analyse the surveyed data of the Barka and Arado cattle areas. In this research assessment, 40 households from each breed, totalling 80 households from the smallholder cattle owners and 12 households from commercial farmers found in the two

breed areas were randomly surveyed and different data concerning forage production activities were collected.

3.4.1 Methods of principal components analysis (PCA)

Data were collected from the Arado and Barka cattle breeds located in different agro-ecological zones. Two analytical methods of principal component analysis (PCA) were applied to data. The first method is the PCA factor analysis in which factoring is carried out using a correlation matrix which helps to standardise data because the units of the variables entered in the analysis differ (SPSS 1990). The main application of PCA is to identify a relatively small number of factors that can be used to represent relationships among sets of many interrelated variables (SPSS 1990; Cattell 1973). It estimates a linear combination of variables such that the maximum amount of variance is extracted from the variables. It seeks a second linear combination which explains the maximum proportion of the remaining variance, and so on. This method of extraction results in orthogonal (uncorrelated) factors. PCA is both simple and interpretable when it passes through the steps of correlation matrix, factor extraction, and rotation and factor scores. Its goal is to describe the factors not directly observable based on a set of observable variables (SPSS 1990). In addition, in order to evaluate results, factor score analysis is also applied.

The second analytical method of PCA is the PCA Ordination Plot. PCA ordination technique plot helps to represent variables by arrows in the ordination diagram along the gradients indicating the relationships between the samples and variables as well as among the variables (Palmer 2006).

For the basic objectives, ordination plot techniques aim at ordering samples and/or species along a few axes that represent the main compositional gradients (structural levels or positions) in the data sets using abundance data for the specific species in the particular sample plots (Carleton 1984). Gauch (1982) says that ordination endeavours characterise sample and species relationships in a low dimensional space (i.e. along a few factors) for the purpose of saving time by analysing a single multivariate analysis than to analyse each species. It is interpretable and easy to enhance statistical power on species or samples when necessary. Ordination techniques have the ability of determining the relative importance of different gradients providing an optimal linear combination of dependent

variables virtually impossible with univariate techniques which utilise only a single dependent variable (Wendorf 2004; SPSS 1990).

Users can determine the management and productivity of variables from the relationships that can be illustrated in PCA ordination results. PCA ordination technique is applied in the study to show the distribution of the samples and variables and the relationships between them when comparing the cattle farming productivity between the commercial and subsistence as well as within the subsistence farming between the Arado and Barka cattle farmers in Eritrea using PCA ordination Biplots. The ordination analysis is important to present the relationships between the cattle farming variables and samples (commercial and subsistence as well as the Barka and Arado cattle farming area farmers) entered through PCA ordination plot. The relationships are helpful as an introduction to give information of over all structure of the cattle farming data that can assist to simplify the interpretation of principal component analysis.

3.4.2 Cattle farming variables and equations

Fifteen variables and their abbreviations are set out in Table 3.3 for the purpose of describing and evaluating the grazing (forage) and cattle management of the Arado and Barka smallholder cattle farming as well as for comparing the smallholder with commercial cattle farming in Eritrea.

GM (grazing management) comprises stocking rates and grazing systems such as continuous and rotational grazing. Proper grazing management like the application of controlled stocking rates ensures maximising forage production. FCM = feed & cattle management is the management activity carried out on feed producing and cattle rearing tasks that are essential to promote the productivity of cattle farming. LU = livestock unit which is used to determine the size (number) of cattle in relation to the tropical livestock unit. In Eritrea, 0.7 LU equals one head of cattle of, on average, 250 kg body weight.

Table 3.3 Variables used to describe cattle farming systems in this study

Grazing Management (GM)	Feed & cattle management (FCM)	Livestock Unit (LU)	Occupation: (O) Own farming	Cattle production (CP)
Body live weight (BL)	Carcass weight (CW)	Household education (HE)	Heart girth index (HGI)	Productivity index / cow (Pi)
Off take rate (OT)	Calving rates (CR)	Mortality Rates (MR)	Milk yield (MY)	Productivity indicators (PI)

O = occupation of own crop farming that cattle owners carry out to generate supplementary or main income which can likely contribute to promote their cattle farming. CP = cattle production is used to indicate cattle farming outputs like milk yield, live weight gain, etc. BL = body live weight is used to indicate body mass of cattle in kg. CW = carcass weight is the weight of the edible flesh of cattle. HE = household education is that of formal education obtained by the cattle owners and likely has an influence to promote the cattle farming. HGI = heart girth is one of the measurements used for cattle around their heart girth to determine their body weight. Pi = productivity index/cow is used to indicate the output of milk produced per milking cow per day or per lactation. Index may be of type numeric used as a key or guidance for measuring milk productivity. In general, index in this study is used as a code or guide that facilitates references to measure the performance of the cattle farming. Off-take rates (OT), calving rates (CR) and mortality rates (MR), MY = milk yield, are used among the factors to measure the productivity of the cattle farming. PI = productive indicators are factors like the quantity and quality and type of forage production, that are used to show the productivity of rangelands and cattle farming.

The cattle productivity variables in Table 3.3 may be described in terms of common factors. In this representation any Q variable drawn from the sample (i.e. the study) is described by the linear combination of the orthogonal components (unrelated factors). Therefore, the model for the i^{th} standardised variable is stated as:

$$Q_i = d_{i1}K_1 + d_{i2}K_2 + \dots + d_{iz}K_z + U_i \quad \dots \text{Equation 1}$$

where the K's are the common factors, the U represents the unique factor error. The d's are the constants used to combine the z factors. The unique factors are expected to be uncorrelated with each other and with the common factors. The factors inferred from the observed variables are estimated as linear combinations (SPSS 1990). Similarly, the grazing and cattle management factor inferred from the sampled (observed) variables is expressed as:

$$\text{GRAZING and CATTLE MANAGEMENT} = L_1(X_1) + L_2(X_2) + \dots + L_N(X_N)$$

Where :

X_i = the i^{th} variable hypothesised to describe cattle farming systems (Table 3.3)

L_i = the factor loading of the i^{th} variable, $i = 1, \dots, N$

...Equation 2

In this case, relating with equation 2, the Grazing and Cattle Management factor is estimated as a linear combination of the observed variables (ex. OT, MR and MY) characterising the factor by their large (L) coefficients. In algebraic form, the general expression for the estimate of the j th factor K_j is:

$$K_j = \sum_{i=1}^n p_{ji} Q_i = p_{j1} Q_1 + p_{j2} Q_2 + \dots + p_{jn} Q_n$$

...Equation 3

where the P_i 's are known as factor score coefficients and n is the number of variables. These equations and models are implemented in the following chapters' data interpretation according to their relevant context.

3.4.3 Factor scores

Factor scores (component scores in PCA) are linear combinations of variables, which are used to estimate the cases' scores on factors or components. They are the scores of each case (row) on each factor (column). To derive the factor scores for comparing results between cases (for example, results between the Barka and Arado cattle farming areas), the variables under the cases (for example, the variables under the Barka and Arado cattle

farming areas) need to be standardised in order to scale the variables and have a mean of zero and variance of one. The standardisation process can be computed by subtracting off the mean from each original variable's data and then divide by the standard deviation (SPSS 1990; Tucker 1971; Harman 1967).

Based on the preceding derivation, factor scores for the variables of one particular case or project considered (for example, in the Barka and Arado cattle farming areas) can be obtained by multiplying the case's standardised values by the corresponding variables factor score coefficients (for example, under factor or component one) and then adding them up. By computing the factor scores for the rest of the factors (components) in the same manner, factor score coefficients for the sample data can be obtained. The general expression for case z, the score for jth factor can be estimated as:

$$K_{jz} = \sum_{i=1}^n d_{ji} Q_{iz} \quad \dots \text{Equation 4}$$

where Q_{iz} is the standardized value of the i th variable for case z and d_{ji} is the factor score coefficient for the j th factor and the i th variable.

Equation 4 is demonstrated in Equation 5 in detail to indicate the computation of the sampled areas' factor scores. For example, for the grazing project of the Barka and Arado cattle area, factor scores can be computed by multiplying the case's standardised values (Q_{iz}) by the corresponding original n variables' (A, B, \dots, n) coefficients on factor one and adding them up. Applying a similar computation for the rest of the factors or components, factor scores for the sampled areas can be computed. The case z values and corresponding n variables on factor 1, i.e. K_{1z} is shown as:

$$K_{1z} = (A \times Q_{1z}) + (B \times Q_{2z}) + \dots + (n \times Q_{iz}) = \sum[(A \times Q_{1z}) + (B \times Q_{2z}) + \dots + (n \times Q_{iz})] \quad \dots \text{Equation 5}$$

3.4.4 Regression analysis

Regression analysis is used to explain the relationships between dependent and independent variables entered into the analysis. The importance of regression analysis is

that it helps to respond to the questions stated by the hypothesis by determining the associations between the independent and dependent variables in the analysis (SPSS 1990). In the study, regression analysis is applied to explain the relationships between various variables such as grazing, herding and milking costs, supplementary feeds, etc to assess the influences on the cattle farming productivity indicators like milk yield, off-take rate and calving rate.

As the information of both the explanatory and responsive variables are loaded, regression analysis interestingly determines the influences of independent variables over dependent variables and expresses the magnitude of the influences on its standardised coefficients Beta-column. An equation can be derived from the unstandardised regression coefficients and constant in B-column which predicts the values of dependent variables. The regression equation is written as:

$$Y = a + bX + e, \text{ (for multiple regression there can be many X- variables)}$$

where Y = the value of dependent variable that is being predicted; a = constant, equals the value of Y when the value of x is 0; b = is the coefficient of X, the slope of the regression line, which is how much Y changes for each one unit change in X; X = the value of independent variable, what is predicting the value of Y (SPSS 1990)

In addition, the measures of association and measures of statistical significance used with regression equation help to discern the degree goodness of the equation in predicting the values of Y for given values of X. So, a regression equation includes the R-square (R^2) and F for a measure of association and for a statistical significance of the regression equation, respectively (SPSS 1990; Portillo 2001).

The techniques of regression analysis described in the preceding paragraphs are important to explain the cattle farming variables and in investigating the relationships between the explanatory variables such as grazing private vs. commons, herding, supplementary feeds, herd size, etc and the responsive variables such as milk yield, calving rate and off-take rate. The analysis is carried out to examine the characteristics between the commercial and subsistence cattle production systems as well as between the Barka and Arado cattle

production systems in Eritrea. It is designed to analyse the characteristics that describe forage production in these systems.

CHAPTER 4
GRAZING MANAGEMENT AND FORAGE PRODUCTION IN
ERITREA: RESEARCH FINDINGS

4.1 Introduction

This chapter presents the results of analyses that investigate grazing management and forage production of the rangelands in Eritrea and compare the productivity of commercial and subsistence livestock farming systems found in the same environments in the Barka and Arado cattle farming regions of Eritrea. Section 4.2 to 4.4 present statistics describing commercial and subsistence livestock grazing systems in Eritrea. Section 4.5 presents a statistical analysis of livestock productivity indicators, including milk yield productivity, calving rate, off-take rate, and mortality rate. This is followed in Section 4.6 by the results of regression analysis used to explore the empirical relationships between dimensions of livestock productivity and grazing management variables. Section 4.7 presents the findings of focus group discussions held with Eritrean farmers to identify factors that constrain farmers from adopting improved grazing management systems and other tasks that are likely to promote forage production.

4.2 Grazing systems and forage production in the Eritrean livestock farming systems

The surveys described in Chapter 3 of this dissertation were designed to compare the livestock production systems used by communal farmers using common access grazing systems and the lease landholding commercial farmers using private access grazing systems. Results indicate that although both the commercial and communal production systems primarily relied on grazing forage to maximise their cattle farming products, there are significant differences between the two types of cattle production systems. Descriptive statistics comparing the grazing systems used by commercial and subsistence farmers surveyed in this study are presented in Table 4.1. The t-Test used to compare group means is the Strum and Donald (1988) formula which assumes unequal group variances:

$$t' = \frac{\bar{x} - \bar{y} - \Delta_0}{\sqrt{\frac{S_1^2}{m} + \frac{S_2^2}{n}}}$$

Table 4.1 A comparison of the livestock production systems used by commercial and subsistence cattle farmers in Eritrea, 2002

Variables	Unit	Commercial	Subsistence	t-value
		farmers (n = 12), Cattle (n1 = 207)	farmers (n = 80), Cattle (n1 = 933)	
➤Activities used to produce outputs:				
Exclusive use grazing systems	%	100	0	
Common access grazing systems	%	0	96	
Controlled stocking rate	%	78	0	
Fenced grazing land	%	100	0	
Mean area of fenced grazing land	ha	25.8	0	
Positive attitude towards fencing of grazing land	%	100	43	4.338**
Planting cactus per farmer	No	1767	8	7.03**
Planting leguminous plants per farmer	ha	1.57	0	
Grazing costs/ livestock unit (LU) in 2002	Nk	131	85	2.17*
Farmers diverting flood water and introducing water points in grazing area	%	65	0	
Variable costs per farmer in 2002	Nk	3562	2505	2.239*
Costs of production ¹	Nk/Lit	1.9	2.8	-2.697**
Farmers using hired (additional) labour	%	91	27	8.85**
Farmers migrating during the dry period	%	0	65	
➤Outputs obtained from the tasks carried outs:				
Forage requirements used from grazing area	%	75	40	5.33**
Milk yield (MY) per lactation per in 2002	Lit	1945	904	4.934**
Calving rate (CR)	%	65	58	2.9*
Off-take rate (OT)	LU	4.9	2.5	2.9*
Milk income (IM) per lactation in 2002	Nk	17797	8281	1.498^
Mortality rate (MR)	%	6	10	-4.378**

Note: ** = difference is statistically significant at more than the 95 % confidence level.

*** = difference is statistically significant at more than the 85% confidence level.**

^ = milk income shows insignificant t-value despite the large differences in milk yield between the two production systems.

1 = on average, costs incurred to produce one litre of milk during 2002.

According to the survey findings, the commercial cattle farming systems are characterised by exclusive access to grazing resources, whereas the subsistence cattle farming systems are largely characterised by common access to grazing resources. Three subsistence farmers in the eastern coastal region (part of the Arado area) indicated that they had *de facto* exclusive use rights over grazing resources, although they appear to have weak security of tenure compared to the commercial farmers. As a consequence, cattle stocking rates tend to be controlled in commercial systems (78%) but not in subsistence systems because the costs of collective action to control cattle stocking rates in common access systems are high, making implementation of stocking rate controls difficult. For the same reason, all communal systems use higher stocking rates (0.922 TLU/ha) compared to stocking rates in commercial farms (0.63TLU/ha) which enable farmers to provide preferential grazing to their relatively more productive animals such as pregnant and milking cows. The consequence is that compared to subsistence farming systems a significantly greater percentage of forage requirements are provided from grazing resources in commercial farming systems (75%) compared to communal systems (40%). A relatively large proportion of subsistence farmers (65%) compared to commercial farmers relying on cattle migration during the dry period. Perhaps it is due to this reliance on cattle migration that only 40% of subsistence farmers surveyed support the concept of fencing in grazing land.

Furthermore, results support expectations that free-rider problems in communal farming systems discourage investments that improve the grazing resource, whereas farmers with exclusive use rights to grazing resources are more likely to invest in improving their grazing resource. This is demonstrated by the findings that compared to communal grazing systems commercial farmers are relatively more likely to invest in fencing (100%) around an average of 25.8 ha grazing land, divert flood water and establish water-points (65%), and improved grazing through planting leguminous plants (an average of 1.57 ha per farmer) and improved grazing through planting cactus (averages of 8 slices per farmer in communal areas versus 1767 slices per commercial farmer). The two cattle production systems further differed in that commercial cattle systems tend to incur greater expenditure on variable inputs, grazing costs, labour and attain lower costs of production.

It was noted that the use of better grazing systems in commercial farming systems results in relatively higher productivity compared to communal grazing systems. The analysis

presented in Table 4.1 shows that compared to communal grazing systems, commercial farmers, on average, covered a greater percentage of forage requirements from grazing (75% versus 40%), achieved higher average milk yields per lactation (1945 litres versus 904 litres), achieved higher calving rates (65% versus 58%) and higher off-take rates (4.9% versus 2.5%), and experienced lower cattle mortality rates (6% versus 10%). (The finding that income from milk sales is not statistically different for the two livestock systems reflects that subsistence farmers tend to engage in value-adding production and tend to sell milk products such as butter, whereas commercial farmers tend to sell fresh milk. Therefore, this finding does not imply that forage production is similar across the two production systems.

In summary, when the productivity of the two production systems is compared, the productivity of the communal farming system is found to be relatively low. The differences between the two systems imply differences in efficiency of the two categories of grazing systems. Forage availability influences milk yield in particular: higher forage density (high carrying capacity area) is positively related to milk yield because there is less energy loss as grazing competition is reduced and cattle walk less distance to graze. Forage in systems with controlled stocking rates (i.e. commercial livestock farming) are therefore likely to produce greater milk yields than forage systems with common access (i.e. subsistence farming systems).

Relatively low productivity of communal grazing systems is not attributed to relatively low effort by subsistence farmers. Rather, higher productivity achieved by commercial farmers is the result of improved forage and the use of improved management (controlled stocking rates). Further, unlike the communal farmers, the commercial farmers didn't depend only on natural grazing forage; to solve the problem of feed shortage, they put their inputs on permanent investment like promoting planted grazing forage. Planting exotic and indigenous leguminous plants (1.57 ha) per farmer and cactus plants in the pasture was relatively higher in the private access grazing lands than in communal pastures. High calving rates, high off-take rates, and low mortality rates are all indicative of good herd conditions, and therefore of good feeding management. Descriptive statistics thus suggest better use of forage under livestock systems with controlled stocking rate compared to those characterised by common access grazing.

Farmers also address grazing constraints through purchasing substitute inputs (e.g. feed supplements), producing green feeds on arable land, and hiring labour to herd their cattle in better grazing areas. Survey findings indicate that although on average commercial farmers spend more on variable inputs per farmer and grazing costs per LU than do subsistence farmers (Nk3562 vs. Nk2505 and Nk131 vs. Nk85 respectively, during 2002 – a drought year), the difference is not statistically significant. This finding highlights that subsistence farmers are willing to invest in inputs over which they have exclusive use (e.g. supplementary feeds) and are therefore not prone to free-rider problems. In other words, they invest in their cattle, over which they have exclusive use rights, but they do not seek to improve the grazing resource, over which they do not have exclusive use rights. (Note that subsistence farmers' purchases of these inputs are typically subject to stringent liquidity constraints).

The temporal variation of rainfall distribution is a significant constraint to forage production in Eritrea. Sixty-five percent of commercial farmers surveyed have invested in diverting flood water and establishing water points, i.e. wells, ponds, water tanks, reservoirs, dams and motor pumps, however, investments to address water constraints were found to be absent on communal grazing land.

This section has provided and discussed descriptive statistics describing commercial and subsistence cattle farming systems in Eritrea. A more detailed analysis of livestock farming productivity in Eritrea is presented in section 4.5 of this chapter. This subsequent analysis identifies empirical relationships between livestock productivity and explanatory variables such as grazing, cost allocation, herd quality, roughage supplementary feeds, amongst others.

4.2.1 Constraints to the adoption of improved grazing systems in common access grazing systems

Heavy stocking rates are a serious constraint to forage production in livestock systems characterised by common access grazing. This presents a primary bottleneck to promoting rangeland productivity in Eritrea. The scarcity of grazing forage results in an increase in the costs of forage. Farmers facing a shortage of grazing forage are likely to incur more costs for purchasing additional supplementary feeds or produce planted forage to maintain

cattle productivity. Otherwise, the productivity indices such as calving rate, off-take rate and milk yields would decline and mortality rate would increase.

The practice of cattle migration during dry periods is a constraint to the adoption of controlled stocking rate by communities of subsistence farmers in Eritrea. The practice of cattle migration enables farmers to hold larger cattle herds than would otherwise be possible. Survey findings indicate that, on average, 65% of the cattle owned by subsistence farmers in communal grazing systems in Maekel and Dehub regions and in the sub-zobas of Barentu, Mogolo, Akurdet in Gash-Barka region migrate during the dry season (March-May). When these cattle return to their village rangelands, rangelands in these regions tend to be overstocked. Despite having overgrazed rangelands, farmers still indicate a tendency to increase their herd sizes. Clearly the consequence of cattle migration during the dry season is an obstacle to the adoption of controlled stocking rates during the growing season.

A second constraint to the adoption of controlled stocking rates is the system of communal grazing used by communities of subsistence farmers in Eritrea. The crux of the problem is that collective action by groups of farmers is difficult as long as there remains the potential for farmers to free-ride. Although farmers depend upon village rangelands and farmers would prefer lower stocking rates on these rangelands, each farmer is reluctant to reduce his own herd size to contribute towards reducing stocking rates because they are unable to fully internalize the benefits of their actions. Consequently, obtaining agreement from individual farmers in a community to control stocking and subsequently enforce those rules is problematic for communities of farmers. A similar argument explains why individual farmers have little incentive to invest in improving a common access grazing resource.

The above argument is supported by the findings presented in section 4.1 of this chapter. It was noted that whereas controlled stocking practices are absent from communal access grazing in Eritrea, controlled stocking is the norm for commercial cattle farmers. Likewise, whereas investments that improve the grazing resource are rare for common access rangelands, most commercial farmers invest in improvements to their grazing lands. The findings of this study therefore suggest that some degree of institutional change is required in order to promote the adoption of controlled stocking rates in Eritrea. Examples

of such institutional change include an expansion of the lease land holding system and findings ways to implement and enforce rules for common access rangelands.

4.3 Forage Requirements

Grazing resources contribute forage requirements in the Barka and Arado cattle farming areas in Eritrea. In addition, cropland residues as winter forage and agricultural and agro-industrial by-products are used as supplementary feeds during the dry season.

4.3.1 Grazing resources available in the Barka and Arado cattle study regions

Grazing is a primary source of forage for cattle in Eritrea. The Barka and Arado cattle farming productivity is therefore based on grazing resources. Forage vegetations examined from the study regions particularly from the surveyed villages are presented in Table 4.2. According to the data collected from the surveyed households, the Barka cattle study region had more of bush land savannah (55%), indicating a better grazing grass resources than the Arado cattle grazing regions (7%). On the other hand, the Arado cattle grazing regions had more shrubby area (39%) for browsing forage compared to the Barka cattle shrubby area (24%). However, adding the shrubby and savannah grazing areas together, the Barka cattle region still had more area covered grazing resources than the Arado cattle regions (79% vs. 46%) respectively. In addition, the Arado cattle grazing area had 28% of semi-desert influenced area whereas such incidence was not seen in the Barka cattle grazing area.

Table 4.2 Different vegetation areas available in the Barka and Arado cattle study regions

Type of vegetations	Barka cattle region (%)	Arado cattle regions (%)
Grasslands	21	21
Shrubs	24	39
Bushlands	-	5
Bushland Savanna	55	7
Semi-desert	-	28
Total	100	100

In Eritrea, due to heavy grazing incidence in the common access grazing, current forage vegetation is remained remnant. Among the remnant of the indigenous and exotic forage trees and grasses observed during the survey: Arkokobay (*Hypheane the biaca*) in the planes of Barentu, Mogolo and Akurdet sub-zobas in Gash-Barka region; Belles (*Opinta specious*) (exotic forage trees) in Segheneiti sub-zoba in Debub region and in Maekel region and Gaba (*Ziziphus spina christi*) in Debub region in Adiquala sub-zoba; Taftafo grasses (variety of wild teff) (*Eragrostis* spp.) which looks like cultivated teff, found in plane clay soil in Gash-Barka, Debub and Maekel regions grazing areas. Due to the deterioration of natural grazing forage, farmers focus on crop residues for feeding cattle.

4.3.2 Croplands forage

Croplands are the main sources of feed supply during winter for cattle in rural Eritrea. It is important to note that traditional rules applied in the subsistence farming regions decree that after the harvest period, cropland residues that have not been collected and conserved for use as supplementary feed are a common access forage resource. Consequently, access to cropland residues for forage cannot be assessed on a per farmer basis for subsistence farmers in Eritrea. Instead, Farmers' Associations in the Barka and Arado cattle regions of Eritrea were visited to obtain relevant information on cropping activities and cattle numbers for each village of subsistence farmers in the study region. Information regarding the various types of crop residues, their areas, and the estimated dry matter (DM) of crop residues in each breed area were computed from this information and are reported in Table 4.3.

For calculating the DM of crop residues, the cropland residues are examined into two parts, namely the large grain crops which include sorghum, pearl-millet and maize and the small grain crops that include barley, wheat, hanfets, teff and finger-millet. The calculation is carried out using the principles of Verjux (1988) and Bekele (1991). For the large grain, from the three situations of growth (low, medium and high), a medium growth is assumed to represent the majority of farm situations. This medium growth of crop production is considered as a medium growth of crop residue DM forage without using any multiplier (Verjux 1988). According to Bekele (1991), for the small grain crops, an average grain-straw ratio of 0.67 and thus a multiplier of 1.48 is used. The amount of crop residue DM forage is obtained by multiplying the crop production/ha by the multiplier (1.48). Legume

crops like chick-peas, vetch, linseed and sesame are considered as small grain crops as their stems and leaves are similar in size to small grain crops. The legume crops were grown in both the Arado and Barka cattle areas where the practices of crop rotation and fallow were carried out to promote the fertility of soil to increase the quantity and quality of crops and crop residues. The analysis of t-Test is undertaken to back up the descriptive analysis in assessing the statistically significant differences in crop residue DM forage between the two breed areas.

4.3.2.1 Type and quantity of crop residues

Crops produced in the study areas were found to differ from the Barka cattle region to the Arado cattle region in type and quantity. Sorghum and pearl-millet were primarily produced in the Western Lowlands of the Barka cattle area in Gash-Barka region. Unlike the Barka cattle area, in the Arado cattle area, barley and teff are mainly produced in the Central Highlands of Dehub and Maekel regions. However, in the Arado cattle area, Maize was also the main product in Semienawi Keih Bahri and Dehub regions. Moreover, in all the study regions, maize was grown contributing a variety or mixture of crop residues because farmers found it very important forage to use alongside with other feeds. Wheat and hanfets were also produced as the main sources of winter forage in the Arado cattle area. Legume crop was grown in both the Barka and Arado cattle area. Hence, the total crop residue DM forage produced in the Barka cattle area was, on average, 0.22 tons per ha while 0.29 tons per ha were produced in the Arado cattle area. Of the total crop residue DM forage available in the country, 45% was produced in the Barka cattle area in Gash-Barka region and 55% was produced in the three regions (Dehub, Maekel and Semienawi Keih Bahri) of the Arado cattle area. Farmers in the study regions were focussing on particular crops that suited to the environment in order to maximise the crop residue forage for their cattle. In this respect, of the total crop residue DM forage produced, the primary sources of winter crop residue were sorghum 56% and legume crops 22% in the Barka cattle (Gash-Barka) region, and barley 36%, teff 18% and legume 14% in the Arado cattle regions. Maize was produced almost on equal magnitude (10% and 12%) in the Barka and Arado cattle areas respectively. Moreover, pear-millet (10%) for the Barka cattle area and both wheat and hanfets (14%) for the Arado cattle area were also considerably produced as feed (Table 4.3).

Table 4.3 Type and quantity of crop residue DM[^] forage as sources of winter forage for subsistence farmers in two breed cattle regions of Eritrea, 2002

Crop residues	The Barka cattle breed area (Gash-Barka region)				The Arado cattle area (Dejub, Maekel and Semmienawi Keih Bahri regions)			
	Area (ha)	Crop production (ton)	crop residues DM [^] forage (ton/ha)	Total crop residue DM forage of each crop (%)	Area (ha)	Crop production (ton)	crop residues DM [^] forage (ton/ha)	Total crop residue DM forage of each crop (%)
Sorghum	58295	8955	0.15	56	3651	529	0.15	2
Sorghum*	7205	1428	0.20					
P-millet ¹	8274	1311	0.16	10	668	97	0.15	1
P-millet**	2068	393	0.19					
Maize*	1551	356	0.23	10				
Maize	7067	1374	0.19		8758	2172	0.25	12
Maize**					1937	600	0.31	
F-millet ²	1724	273	0.23	2	2948	443	0.22	3
Legume	9050	2700	0.44	22	7966	2098	0.39	14
Teff					10705	2261	0.31	18
Teff*					1785	437	0.36	
Barley					22421	5123	0.34	36
Barley*					944	298	0.47	
Wheat					7292	1340	0.27	9
Hanfets ³					4686	777	0.25	5
Total	95234	16790	1.79	100	73761	16160	3.47	100
Average yield per ha			0.22				0.29	
Total crop residue DM forage			18033				22361	

[^] Crop residues dry matter (DM) is calculated based on Verjux (1988) and Bekele (1991) using a medium growth situation of forage/ha for large grain cereals and an average grain-straw ratio of 0.67 and thus a multiplier of 1.48 for small grain cereals respectively.

*=crop residues produced after crop rotation;

**=crop residues produced after fallow.

P-millet¹ = Pearl-millet which looks like sorghum but different variety;

F-millet² = Finger-millet;

Hanfets³ = A mixture of wheat and barley.

4.3.2.2 Crop rotation and fallow

The cultivation of legume crops enabled the farmers to carry out the management of crop rotation. In the Barka cattle region, leguminous crops like sesame and linseed were rotated with sorghum and maize. Similarly, in the Arado cattle regions, chick-peas, vetch and linseed legumes were primarily cropped on the croplands of barley and teff to promote soil quality and improve the productivity and nutritive value of crop residues. Accordingly, the Barka cattle farmers showed better improvements of yields of crop residue DM forage in the rotated sorghum and maize croplands than those unrotated croplands of same type of crop residues (0.20 ton and 0.23 ton DM forage per ha) vs. (0.15 ton and 0.19 ton DM forage per ha) respectively. Similarly, the Arado cattle farmers harvested better yields of crop residue DM forage from the rotated teff and barley croplands (0.36 ton and 0.47 ton DM forage per ha) than unrotated ones (0.31 ton and 0.34 ton DM forage per ha) respectively (Table 4.3). This extra production may be due to the crop rotation practices undertaken in both breed areas. However, when comparing the extra production with the opportunity costs (the forgone opportunities that could have been obtained from continuous crops) the differences are statistically insignificant. The reason may be that the crop rotation practices were not used at depth (the rotation time interval may be too long to retrieve the lost nutrients).

In addition to crop rotation, fallow was used by cattle owners in the Barka and Arado cattle areas to restore the fertility of croplands. The cattle owners in these two cattle breed areas were fully dependent on crop residues for winter forage. Farmers in the Barka cattle area produced pearl-millet and those from Arado cattle area produced maize from the fallowed croplands. In the former cattle breed area, the fallowed pearl-millet croplands produced 0.19 ton DM forage per ha and the unfallowed corresponding croplands produced 0.16 ton DM forage per ha whereas in the latter cattle breed area, the fallowed maize croplands produced 0.31 ton DM forage per ha and the unfallowed corresponding croplands produced 0.25 ton DM forage per ha. Therefore, the fallowed croplands produced better DM forages per ha for pearl-millet and maize. However, the fallow practices compete with lands used for cropping. Such practices are creating opportunity costs to those who have a shortage of arable lands and can cause negative impacts on the total production. Hence, the extra production obtained from this practice may not off-set the forgone opportunities (i.e. that could have been produced if the decision had been made). Fallow practices probably

have more impacts on total production in the Arado cattle area where there is a shortage of arable lands than at the Barka cattle area.

It is easier for land-rich farmers to adopt different farming practices than those who are constrained of land. Farmers who have better access to arable land can allocate some of it to crop rotation, fallow, etc. while still producing some other crops like cereal grain crops, etc. In the study area, farmers in the Barka breed area have relatively better access to land than those in the Arado breed area. In this respect, the opportunity costs of farming practices such as crop rotation and fallow are expected to be relatively lower in the former than the latter cattle breed area. Accordingly, the impacts of the farming practices on the total production are expected to be lower in the Barka breed area than in the Arado breed area. However, farmers in the Arado breed region tend to show more total production of forage of crop residues (22361 tons vs. 18033 tons) but a lower percent of leguminous crops (14% vs. 22%) from the total cultivated area surveyed (73761 ha vs. 95234 ha) than farmers in the Barka breed region (Table 4.3). The differences in the forage yields between rotated and unrotated sorghum and maize in the Barka cattle area and between teff and barley in the Arado cattle area are statistically insignificant at the 95% level of statistical confidence ($t = 1.547$) and ($t = 1.510$) respectively.

The preceding results insight the farmers to reconsider their decisions to raise the size of crop rotation practices and reduce continuous crops in order to reduce the opportunity costs. In Eritrea, unlike fallow practices, crop rotation practices have double advantages. In addition to improving soil fertility, the products of legume crops are used as cash crops having better market prices than cereal grains. Fallow practices with a shortage of arable lands may cause impacts on the total production. Long time intervals between two rotations can result to low yields in quantity and quality of crop residues.

An analysis of crop residue DM forage used for livestock forage should account for quality (i.e. nutritive content) as well as quantity. Improved forage availability through the application of crop rotation and fallow is expected to reflect positively on milk production and butter fat content. Anecdotal information provided by farmers surveyed during this study agrees with this hypothesis. According to these farmers, on average, 18 litres of milk produced by a cow fed rotated and fallowed crop residue forage is required to produce one litre of butter whereas more than 20 litres of milk from cows fed unrotated crop residue

forage is required to make the same quantity of butter. This reflects that crop rotation and fallow practices on croplands have a significant contribution to promote the nutrient content of crop residue forage. Scientific research is, however, required to verify this hypothesis. Preston and Leng (1987) stated that the feeding value of straws and stalks of various species of grain crops depend on their intake and digestibility and they were observed to be highly variable in the vitro digestibility and the crude protein was always low. From the large and small grain crops, sorghum, maize, barley and wheat contain in vitro organic matter digestibility and nitrogen content of 35-78% and 0.5-0.8% DM, 31-50 and 0.5-1.2, 34-61 and 0.4-1.0 & 28-58 and 0.4-1.0, respectively (Preston and Leng 1987).

4.3.2.3 Discussion

Despite the production of relatively more legume crop residues DM forage (22% vs. 14%), the average crop residue forage is relatively less (0.22 ton DM/ha vs. 0.29 ton DM/ha) for the Barka cattle farmers compared to the Arado cattle farmers. Among the reasons, in the Barka cattle farmers, the percentage of land used for crop rotation and fallow farming practices is relatively lower (10% and 2% vs. 11% and 3%) compared to the Arado cattle farmers respectively. Perhaps this may be one of the reasons why the Barka cattle area farmers produced lower total percent of crop residues (45% DM) than that of the Arado cattle farmers (55% DM).

Among the reasons for the relatively lower results in the Barka cattle area is that the Barka cattle farmers focus more on the pastoral and agro pastoral cattle farming activities because it is the primary task from which they earn their main income. On the other hand, the Arado cattle farmers focus relatively more on crop farming because they practice sedentary mixed farming. It is their major task as well as their primary source of income compared to the Barka cattle farmers.

Nevertheless, the results of the total crop residue and the productivity per ha for the two cattle farming areas differed statistically. Differences in the application of crop rotation and fallow farming practices between the two cattle production farmers are also statistically insignificant. Lower crop farming practices in the smallholder Barka cattle farmers and the shortage of croplands in the Arado cattle smallholder farmers are among the main reasons why no significant difference is observed.

Croplands forage helps to solve problems of shortage of winter forage. Because farmers have exclusive use rights to their cropland residues, but only communal access to rangeland resources, they are more likely to invest in their cropland and less likely to invest in improving rangelands. Expansion of cropping activities over time has encroached on rangeland resources, thus reducing the area of common access rangeland and increasing grazing pressure on rangelands. It has also resulted in increased fragmentation of rangelands with small partitions of rangeland surrounded by cropland. Increased fragmentation makes herding increasingly difficult, which increases likelihood of some fragments becoming over-grazed. Further, farmers are less likely to invest in fragmented areas of rangeland that are difficult to access (due to barriers created by cropland). These impacts make determination of appropriate stocking rates difficult. Therefore communities of Eritrean farmers must be encouraged to practice holistic land-use planning that takes into consideration the tradeoffs of cropland encroachment on rangelands. Anecdotal evidence of the negative effect of cropland encroachment on rangelands was provided by several of the surveyed subsistence farmers, particularly farmers in the Highlands of the Arado cattle farming regions and in the populated areas of the Western Lowlands Barka cattle region.

4.3.3 Supplementary feeds

Supplementary feeds are important sources of cattle feed in Eritrea, especially during the hot dry period (mostly March to May) in Eritrea. These supplementary feeds are primarily produced by the crop farms and agro-industrial businesses. The survey of 80 subsistence livestock farmers conducted in this study found that between 33 and 57% of Barka cattle farmers and between 23 and 62% of Arado cattle farmers fed supplementary feeds derived from crop farming by-products to their cattle during 2002. Further, 38 and 43% of the Arado and the Barka cattle farmers, respectively, fed agro-industrial by-products to their cattle during the same year (Tables 4.4 and 4.5).

4.3.3.1 Crop farm by-products

The Arado and the Barka cattle farmers used different types and quantity of agricultural supplementary feeds. The use of various types of conserved crop residues as supplementary cattle forage by the samples of 40 Barka cattle region subsistence farmers

and the 40 Arado cattle region subsistence farmers is detailed in Table 4.4. The table indicates the total utilization of each type of conserved crop residue and the number of farmers that utilized it. Sorghum and pearl millet stalks were the most commonly used type of conserved cropland residue in the sample of Barka cattle farmers with 13 out of 40 farmers using a total of 13.8 tons during 2002. Teff, wheat and barley straws were the most commonly used conserved crop residues by farmers in the sample of Arado cattle farmers with 9 out of 40 farmers using a total of 12.7 tons of residues. In total, the

Table 4.4 Total use of supplementary cropland forage feeds by a sample of 80 subsistence livestock farmers from two breed cattle regions of Eritrea, 2002

Agricultural by-product supplementary feeds	From the sampled cattle owners in					
	Barka cattle area			Arado cattle area		
	No (n = 40)	House holds (%)	Supplementary feeds (tons)	No (n=40)	House holds (%)	Supplementary feeds (ton)
Green feed	1	2	3.0	2	5	4.4
Maize stalks	2	5	13.8	4	10	10.4
Sorghum and pearl millet Stalks	13	33	13.8	-	-	-
Crush grain of sorghum	5	12	5.3	-	-	-
Finger millet Straw	2	5	10.4	1	2	13.5
Teff**, wheat and barley straws	-	-	-	9	23	12.7
Hay***	-	-	-	4	10	11.9
Urea treatment****	-	-	-	5	12	0.8
Total	13-23*	33-57*	46.3	9-25*	23-62*	53.7

*= Due to the possibility of repetition of farmers taking more than one type of by- product feeds their total is written in range.

Teff** = Eragrostis grass cultivated and Eragrostis teff grain is used as a staple food by Eritrean society; Hay*** = feed of grasses and legumes leaves harvested at a stage of 25% moisture content; Urea treatments**** = feed prepared from any dry straw forage treated with urea to improve the nutritive value of the forage.

40 subsistence farmers surveyed in the Barka cattle area fed a total of 46.3 tons of cropland forage to their cattle (a mean of 1.16 tons of cropland forage per farmer, or 0.086 tons of cropland forage per LU). The 40 subsistence farmers surveyed in the Arado cattle fed a total of 53.7 tons of cropland forage to their cattle (a mean of 1.34 tons of cropland forage per farmer, or 0.135 tons of cropland forage per LU). However, there is considerable

variability in farmers' access to cropland forage as a supplementary feed: in the Barka cattle region at least 32% but fewer than 58% of farmers surveyed fed cropland forage to their cattle and in the Arado cattle region at least 23% but fewer than 63% of farmers surveyed fed cropland forage to their cattle.

The Halhale Research Station has introduced a new urea treatment process in the Arado cattle Central Highland regions to improve the nutritive quality of agricultural by-product supplementary feeds and promote a better utilization of locally available feed resources. Research reported by the FAO (2003) found that this treatment increases nutritive values of the supplementary feeds by 12%. It was also found to increase feed palatability, resulting in an increase in feed consumption of 35%. During the time of the survey this supplementary feed was available for purchase by some farmers in areas of feed shortage. The survey did not collect data on the extent to which these supplementary feeds were used by farmers surveyed in this study.

4.3.3.2 Agro-industry by-products

The findings further indicate that the cattle farming smallholder farmers had an access problem to agro-industry supplementary feeds. This access problem is due to a relative shortage of agro-industry supplementary feeds in the market, resulting in prices that most subsistence farmers cannot afford. Further, there is a common perception amongst subsistence farmers that this source of feed is largely reserved for purchase by commercial farmers. Consequently, out of the 80 farmers of the sampled study areas, a range of 8-17 farmers from the Barka cattle area and 6-15 from the Arado cattle area (totalling a range of 14 to 32 farmers) were able to get access to the agro-industry by-product feeds. Therefore, 2% of the farmers from the Barka cattle region and 8% from the Arado cattle regions supplied their cattle with, on average, 3.0 tons and 0.73 tons of bone and meat meal by-products respectively. Thirteen percent of the farmers from the Barka cattle region and 10% from the Arado cattle regions supplied their cattle with 7.41 tons and 8.0 tons of bran supplementary feeds, respectively. As Gash-Barka region has been rich in sesame (legume oilseed) crop production, 8% and 20% of the Barka cattle farmers fed their cattle with 6.0 tons of oilseed cake and 1.9 tons of sesame cake, respectively. Similarly, 5% of the Arado cattle farmers fed their cattle with 7.6 tons of oilseed cake and 15% of the farmers from the same breed area got 1.83 tons of brewery supplementary feed. Therefore, only a range of

20 to 43% of farmers from the Barka cattle region and a range of 15 to 38% of farmers from the Arado cattle regions were able to get access to the agro-industry by-product supplementary feeds to maintain the milk production during the hot dry period (March to May) (Table 4.5).

The differences in the industrial by-product feeds per farmer offered between the Barka and Arado cattle areas (7.3 tons and 7.2 tons) were not statistically significant at the 95% level of statistical confidence (t-value = 0.014).

When computing the feed rations per LU for the three-month dry season using the information of 535 LU of the Barka cattle and 398 LU of the Arado cattle data surveyed, the average ration was: 535 LU/40 households = 13.4 LU/household, then 7.3 tons per

Table 4.5 Supplementary feeds used during the dry season in two breed cattle regions in Eritrea, 2002

Agro-industry by-products	Barka cattle area			Arado cattle area		
	Farmers		Feed per farmer (ton)	Farmers		Feed per farmer (ton)
	No (n=40)	%		No (n=40)	%	
Bone and meat meal	1	2	3.0	3	8	0.73
Bran	5	13	7.41	4	10	8.0
Oilseed cake	3	8	6.0	2	5	7.55
Sesame cake	8	20	1.85	-	-	-
Brewery	-	-	-	6	15	1.83
Total	8-17*	20-43*	18.26	6-15*	15-38*	8.11

*= Due to the possibility of repetition of farmers taking more than one type of by-product feeds their total is written in range.

household /13.4 LU = 0.54 ton/LU for the Barka cattle area. The calculation for the Arado cattle area that the 398 LU/40 households = 10.0 LU/household, then 7.2 ton per household /10.0 LU = 0.72 ton/LU. This result indicates that like the agricultural by-products, the industrial by-products were also scarce during the 2002 dry season and both the Barka and Arado cattle area farmers had similar constraints in accessing the industrial by-products. The major reason for the constraints was that priority of agro-industrial by-products was

given to urban beef and dairy producers who were believed lacking any other options of feed sources but bringing more livestock products to market. (

This may not reflect official policy, but rather reflect that these farmers who frequently sell products at urban markets have relatively better access to these input markets.) Though some amounts of industrial by-products were released to market, because of their high prices, except some rich farmers the ordinary subsistence farmers were able to afford them.

4.3.3.3 Discussion

The results presented in this section indicate that in Eritrea supplementary feeding of cattle is important to maintain animal productivity during the dry season. However, there were two controversial ideas resulting in negative outcomes. Farmers insisted on the application of supplementary feeds during the dry season to generate the livestock income in the season. This income encouraged the farmers to retain large number of animals resulting in overgrazing. These opposite circumstances occurred due to the management failures of the farmers to limit their animal numbers during the wet season. If attention is not given to incorporate controlled stocking rates during the wet season with the provision of supplementary feeds during the dry season, as the universal review paper of Kirkman and Carvalho (2003) mentioned, the negative consequence of the provision of supplementary feeds on the rangelands would be aggravated. Grazing forage from migration in the dry season or supplementation of conserved crop residues or industrial by-products can not be a solution without adopting reduced stocking rates during the growing season.

4.4 An analysis of the productivity of Arado and Barka cattle in Eritrea

The rationale behind the analysis of cattle productivity indicators presented in this section is that rangeland productivity is an important determinant of cattle productivity in Eritrea. The productivity of rangelands is partially determined by characteristics of the grazing systems, e.g. whether or not stocking rates are controlled. By relating dimensions of livestock productivity to characteristics of farming systems an insight is provided to the partial contributions of various factors to variation in cattle productivity of farmers surveyed in this study.

The analysis presented in Section 4.2 compared the mean productivity of cattle in commercial and subsistence farming systems in Eritrea. Besides using standard deviations of productivity measures to compute t-statistics (besides examining the dispersion of sampled data used for productivity measures to compute t-statistics), the analysis presented masks the heterogeneity that exists within categories of commercial and subsistence livestock farming systems. Analysis of the variance of measures (analysis of the distribution of the sample data) of livestock productivity lends additional insight to the productivity of livestock farming systems. For example, it is important to understand the factors that affect the relative productivity of farmers that farm in the same natural and institutional environment and using the same breed of cattle. Analysis of the co-variation (analysis of the interaction) between various measures of livestock productivity provides further insight into trade-offs and complementary relationships between various dimensions of livestock productivity. For example, it may be expected that an increase in use of cattle for draft power will reduce milk yield, *ceteris paribus*. On the other hand, an increase in the calving rate is expected to be associated with an increase in milk yield per LU because as more cows calve, the production of more milk is expected. This indicates that there exists a linear relationship between milk yield and calving rate.

This section includes use of principal components analyses (PCA) to analyse the productivity of smallholder and commercial cattle farming systems in Eritrea. As discussed in chapter 3, there are several dimensions to the concept of livestock productivity and various measurements of livestock productivity may be related. If these measurements are indeed collinear, PCA may be used to obtain principal components that are orthogonal (independent) variables that account for the variability in the original variables (various measurements of livestock productivity). As such the principal components are indices of livestock productivity that are statistically unrelated to each other. The elicited principal components can be used as dependent variables in regression analyses to investigate factors that affect each dimension of cattle productivity. Alternatively, if the initial measurements of livestock productivity are not collinear, the initial measurements can be used as the dependent variables in the regression analysis.

In this study, significant collinearity was present between the measurements of cattle productivity collected for the sample of 80 smallholder farmers (40 farmers from the Arado area and 40 farmers from the Barka area). Results of an Ordination diagram

analysis of this data is presented in section 4.4.5, and the PCA of this data is presented in section 4.4.6. The subsequent regression analysis of factors affecting the productivity of smallholder farmers is presented in section 4.4.7. These analyses are useful for comparing the productivity of Arado and Barka cattle in smallholder livestock production systems in Eritrea.

A smaller set of cattle productivity indicators was collected for the 12 commercial farmers. When the two data sets (for the 80 smallholder and 12 commercial farmers, respectively) were pooled, the set of three cattle productivity indicators common to both data sets were not statistically collinear, hence use of PCA was not warranted to obtain orthogonal indices of cattle farming productivity. An ordination diagram analysis of this data is presented in Section 4.4.2. The regression analyses of factors affecting cattle farming productivity using this pooled data set is presented in section 4.4.4. These analyses are useful for comparing the productivity of cattle farming in commercial and smallholder farming systems. This section is concluded with a discussion of results that incorporates the findings of the focus group discussions held with some of the smallholder and commercial farmers surveyed in this study.

4.4.1 Measurements of livestock productivity used in the analysis

Important indicators used to describe the productivity of cattle farming production systems include (a) production of milk, (b) production of calves, (c) production of manure for use as organic fertilizers, (d) production of draft power for cropping activities and (e) production of cattle for sale at markets (off-take). Because neither the survey of subsistence farmers nor the survey of commercial farmers elicited information about manure production of cattle or the extent to which cattle were used for draft power by sampled farmers, these productivity dimensions were excluded from the PC analyses. The set of variables measuring various aspects of cattle productivity used in this analysis are presented in Table 4.6.

Milk productivity was defined as milk yield per cow per lactation (MY) and was measured in litres. Income from milk and dairy product sales per LU can be considered as measures of milk yield productivity, but was rejected because this indicator of milk yield productivity is distorted by on-farm consumption of dairy products and value-adding

processing of dairy products prior to sale. Production of calves was measured using the calving rate (CR), defined as the mean percentage of cows that produced calves in 2002 to reflect the quantity of calves produced and the average weight of calves produced to reflect the quality of calves produced. Cattle off-take productivity was measured using as income from sale of live animals per LU as well as by using the off-take rate (OT), which was defined as the number of animals sold or used for household consumption during 2002. Two additional general herd performance measures were included in the analysis: (a) The mean body live weight of the herd¹ was included to reflect the physical condition of the herd as heavier cattle tend to be relatively more healthy, and (b) the herd mortality rate

Table 4.6 Seven indicators of cattle productivity used in the PCA of the Barka and Arado cattle farming

Variable	Unit	Description	Relationship with cattle productivity
Milk yield (MY)	Lit	Milk yield per lactation per lactating cow	+
Income from sale of live animals (MI)	Nk*	Income from cattle sold per LU	+
Body live weight (BW)	Kg	Average mean weight of cattle in 2002	+
Weight of calves at birth (Wb)	Kg	Average weight for calves at birth	+
Off-take rate (OT)	No	Cattle off-take in 2002	+
Calving rate (CR)	%	Mean percentage of cows calving from the total number of cows	+
Mortality rate (MR)	%	Cattle deaths as a percentage of herd size in 2002	-

*= Eritrean currency, 15 Nakfa (Nk) = \$1.00 (in 2002)

(MR) was included to reflect that relatively higher cattle mortality is associated with poor herd productivity.

Mean milk yield and calving rates of the cattle owned by the commercial and subsistence farmers surveyed in this study are reported in Table 4.7. On average, cattle in commercial

¹ Because this study was conducted at the same time as the Animal Weight Campaign in Eritrea during 2002, the researcher had access to scales for weighing cattle of surveyed farmers.

farming systems are more productive with respect to both milk yield and calving rate when compared to cattle in subsistence farming systems. A comparison of group means for subsistence farmers indicates that in the subsistence farming systems the Barka cattle tend to achieve higher milk yields and greater calving rates than Arado cattle.

Table 4.7 Milk yield and calving rates in commercial and subsistence cattle farming systems in Eritrea, 2002

Variables	Mean milk yield per cow per lactation (Litres)	Mean Calving rate (%)
Commercial farming systems (n = 12)	1944	64
Subsistence farming systems (n = 80)	904	58
Subsistence farming systems in the Arado cattle region (n = 40)	721	53
Subsistence farming systems in the Barka cattle region (n = 40)	1087	63

Summary statistics describing the productivity of subsistence cattle farming systems are presented in Table 4.8. Despite the higher cattle population in the Barka cattle area compared to the Arado cattle area (1109453 vs. 778004 in number, respectively), grazing shortage resulted in Arado cattle farmers facing cattle feed shortages and consequently selling relatively large proportions of their cattle during 2002. Consequently, income from cattle sales of Arado cattle farmers in 2002 overstated the average value. Barka cattle farmers, however, had relatively better access to grazing forage, especially in South Western Lowlands region. The better quality of grazing in this region is attributed to a naturally low stock density in the region. Therefore, when the two breed cattle productivity indicators results are brought to the t-Test analysis, regardless of the difference between the weight of the two cattle populations, based on the differences of the forage access attributions of the Barka breed and Arado breed cattle, the results show statistically insignificant ($P>0.05$) differences in income from sale animals (Nk 13816 vs. NK 11680) and in off-take rates (3.75 vs. 3.28 in number), respectively.

Table 4.8 Cattle productivity indicators in subsistence cattle farming systems in Eritrea, 2002

Variable	unit	Average (n = 80)	Barka cattle Region (n = 40)	Arado cattle Region (n = 40)	t-Test
Milk yield (MY)	lit	904	1087	721	11.58*
Income from cattle sales (MI)	Nk**	12748	13816	11680	1.1
Body live weight (BW)	kg	287	323	251	5.53*
Weight at birth (Wb)	kg	17	18.7	16.6	5.16*
Off-take (OT)	no	3.5	3.75	3.28	1.01
Calving rate (CR)	%	58	63	53	2.12
Mortality rate (MR)	%	10	9.3	10.87	-2.56

Note: * = difference is statistically significant at more than the 95% confidence level.

** = Eritrean currency, 15 Nakfa (Nk) = \$1.00 (in 2002)

4.4.2 Ordination diagram analysis for commercial and subsistence farmers

The ordination diagram in Figure 4.1 analyses nine variables included in the analysis as a measure of cattle farming production systems for 12 commercial and 80 subsistence cattle farmers. The eigenvalues for axes 1 and 2 are 0.305 and 0.200, representing 30.5% and 20.0% of the total variance, respectively. The aim of the ordination diagram analysis is to allow for interpretation of the principal component analysis in section 4.4.3.

A correlation matrix table for these variables (Appendix A Table A1) is also included to indicate relationships computed among the variables entered in the ordination diagram analysis. Its objective is to show the significance of the relationships and influence of the variable costs per farmers (varc_far) and grazing costs per livestock unit (grac_lu) on the productivity indicators such as milk yield per lactation (my_lc), lactating cows (lc),

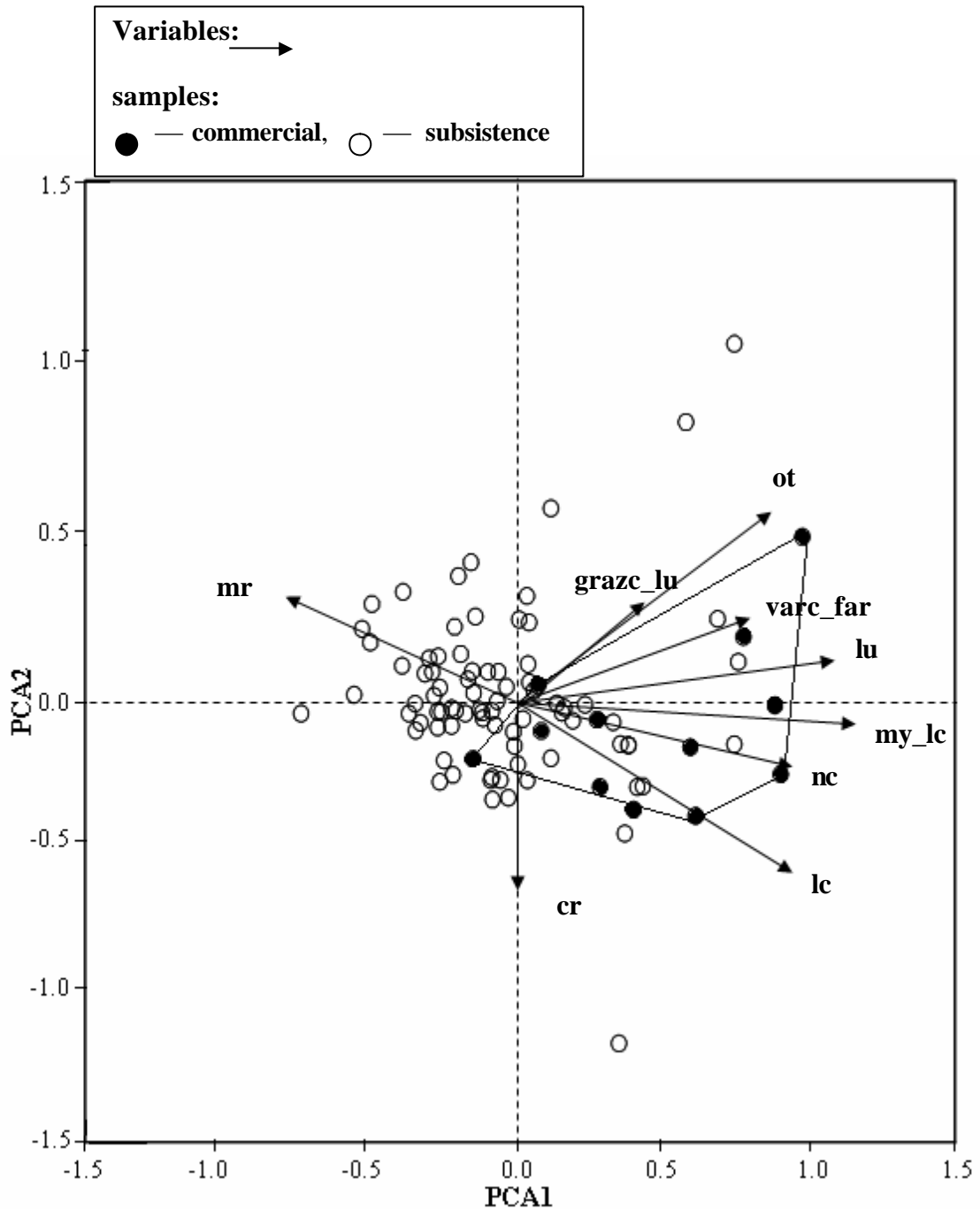


Figure 4.1 Ordination biplot diagram of the commercial and subsistence cattle farming. First two axes of a standardized and centered principal component analysis (PCA) of cattle farming variables (arrows) for the commercial (filled circles) and subsistence cattle farming (empty circles) regions.

➤ Variable names are: grazc_lu = grazing costs per livestock unit; ot = off-take rate; varc_far = variable costs per farmer; lu = livestock unit (herd size); my_lc = milk yield per lactation; nc = number of cows; lc = lactating cows; cr = calving rate; mr = mortality rate. calving rate (cr) productivity and livestock unit (lu) in the analysis. The correlation coefficients show that that variable costs and grazing costs are positively ($P < 0.05$) related to milk yield and off take rate (ot) productivity. Calving rate productivity is positively related to the number of lactating cows in the herd but negatively related to herd size.

The ordination diagram indicates the distributions of samples and variables and the observable relationships between the samples and variables as well as within the variables entered in the analysis. Results indicate that, in general, the surveyed commercial cattle farmers outperform the surveyed smallholder farmers for all cattle productivity indicators considered in the analysis. Some smallholder farmers are amongst the cluster of commercial farmers in the ordination diagram, indicating that some subsistence farmers achieve relatively good cattle productivity. The relatively high cattle mortality rates incurred by a large proportion of smallholder farmers probably reflect the shortage of forage grazing faced by these farmers. A shortage of grazing is indicative of poor rangeland management (e.g. over-stocking and insufficient investment in improving the productivity of the resource).

4.4.3 Results of principal component analysis (PCA1) of indication of herd size and composition in commercial and subsistence cattle production systems

Herd size and composition are hypothesised to be important determinants of cattle productivity. The data set comprised of the 80 subsistence farmers and the 12 commercial farmers revealed high collinearity amongst three variables that describe herd size and composition, i.e. herd size (LU), numbers of cows (NC) and number of lactating cows (LC). Principal component analysis (PCA1) was applied to extract three orthogonal principal components (PCs) that describe herd size and composition. The loadings of the elicited principal components are presented in Table 4.9. The elicited principal components (PC1.1, PC1.2 and PC1.3) are used as explanatory variables in a subsequent regression analysis of factors affecting cattle productivity of commercial and subsistence cattle farmers in Eritrea (section 4.4.4).

Principal component one (PC1.1) explains the size of herds and accounts 60.5% of the total variance in the three variables used for the measurement of calving rate productivity. It is positively related to all the three variables (LU, NC and LC). The mean value of PC1.1 for the commercial cattle farming is 0.92930 and for the subsistence cattle farming is -0.13939, indicating that, on average, commercial farmers own more cattle than subsistence farmers.

Principal component two (PC1.2) accounts for 26.2% of the total variation in the three variables and is interpreted as being an index of the proportion of cows in herd. Farmers with a relatively large proportion of cows in their herds (e.g. dairy farmers) will score relatively low values for PC1.2. The mean value of PC1.2 for the commercial cattle farming is -0.04386 and for the subsistence cattle farming is 0.00658 emphasising that the group average of the 12 commercial farmers for PC1.2 is not significantly different to the group average for the 80 subsistence farmers.

Table 4.9 Principal component analysis describing cattle herd size and composition for commercial and subsistence cattle farmers in Eritrea

Principal components (PCs)*	PC1.1	PC1.2	PC1.3
Percentage of variance explained	60.5	26.2	13.2
Eigenvalue	1.8	0.8	0.4
Variables:	Herd Size	Proportion of cows in HS	Index of proportion of lactating cows
Lactating cows (LC)	0.862	-0.208	-0.462
Livestock unit (LU)	0.623	0.779	0.018
Number of cows (CN)	0.827	-0.370	0.423
The mean values of PCs for :			
Commercial farmers	0.92930	- 0.04386	-0.24045
Subsistence farmers	-0.13939	0.00658	0.03606

* A factor extraction method used to form uncorrelated linear combinations of the observed variables. The first component has maximum variance. Successive components explain progressively smaller portions of the variance and are all uncorrelated with each other.

Principal component three (PC1.3) accounts for 13.2% of the variation in the three variables. It is an index that is negatively related to the proportion of cows that are lactating. Assuming that relatively well managed herds will tend to have fewer cows that are not lactating, PC1.3 is interpreted as being an index of cattle management quality.

The mean value of PC1.3 for the 12 commercial cattle farmers is -0.24045 and 0.03606 for the 80 subsistence farmers, indicating that commercial farmers tend to apply a higher standard of herd management than the subsistence farmers.

4.4.4 Factors affecting cattle productivity of commercial and subsistence cattle farmers in Eritrea

This section reports the regression analyses used to identify factors affecting cattle farming productivity using the pooled data set (80 subsistence farmers and 12 commercial farmers). As noted in the introductory section to section 4.4, only two cattle productivity measurements (milk yield (MY) and calving rate (CR)) were obtained for both the commercial and subsistence farmers, and these variables were not found to be significantly collinear and seem to measure independent dimensions of cattle productivity. Consequently, regression analyses were conducted to explain observed variation in MY and CR. Section 4.4.4.1 specifies the estimated regression models and the estimated regression equations are reported in section 4.4.4.2.

4.4.4.1 Specification of the regression models

The dependent variables in the regression models, MY and CR were previously defined in Table 4.6. The explanatory variables used in the analysis are presented in Table 4.10. In general, the explanatory variables were selected to relate characteristics of the cattle farming systems to achieve cattle productivity.

“**Grazing**” is a dummy variable that takes a value of 1 if the farmer has exclusive use rights over grazing and zero if the farmer grazes cattle on common access rangelands. The literature reviewed in Chapter 2 argued that compared to farmers with common access to grazing, farmers with exclusive use rights over grazing resources have more incentive to invest in improvements to the grazing resource. Further, unless farmers with communal access to grazing resources engage in successful collective action to control livestock stocking rates, it is likely that communally owned grazing resources will be over-stocked relative to the profit maximizing stocking rates. Farmers with exclusive use rights over grazing resources are expected to limit stocking rates to profit maximising levels. Therefore, cattle productivity is expected to be positively related to “Grazing”.

“**Breed**” is also a dummy variable equal to 1 if the breed of cattle farmed is predominantly Barka, otherwise zero. The variable is highly collinear with the Arado and Barka regions, and therefore ill capture not only differences between the two breeds, but also climatic

(and other) differences between the two regions. Considering that Barka is a dairy breed of cattle whereas the Arado breed is dual purpose, “Breed” is expected to be positively related to MY. The expected relationship between CR and breed is uncertain.

“**Total Costs**” is a variable that reflects total annual expenditure on improving grazing resources, herding, feed supplements and other variable inputs to improve cattle performance. Therefore, “Costs far” is expected to be positively related to both MY and CR. “Average costs” is defined as total costs per litre of milk produced. Both of these variables are measured in Nakfa (Nk). The relationship between average costs and productivity is uncertain because although higher average variable costs per LU is expected to be associated with increased productivity, average fixed costs will decline with size.

Although the two cost variables do include the cost of hired labour, neither of them includes the implicit cost of household labour used in cattle production, Consequently, the variable ‘**labour**’ is defined as the number of labour (hired plus own household) that are primarily employed in the household’s cattle production activities. Likewise, the two cost variables do not reflect the implicit cost of supplementary feeds that are not purchased.

Therefore, two variables are defined to capture the effect of supplementary feeding: “**Concentrate**” and “**Roughage**” are defined as the respective quantities of feed concentrates and roughage per LU fed to cattle by each farmer during 2002. Although supplementary feeding is expected to have a positive effect on cattle productivity, supplementary feeding may be used by some farmers to sustain cattle during periods of inadequate natural grazing rather than to enhance cattle productivity. Consequently, use of supplementary feeding may be associated with relatively low cattle productivity rather than with relatively high cattle productivity.

PC1.1, PC1.2 and PC1.3 are indices that reflect various dimensions of herd size and composition (refer to section .4.4.3). PC1.1 is positively related to herd size, PC1.2 is negatively related to the proportion of cows in the herd, and PC1.3 is an index negatively related to the quality of herd management.

Finally, three variables are included to reflect the farmer's skills, knowledge and propensity to adopt "new" approaches to farming. Cattle productivity is expected to be positively related to the farmers level of education and experience with cattle farming. On the other hand, it is expected that older farmers may be relatively more reluctant to adopt

Table 4.10 Explanatory variables included in regression analyses for MY and CR using the pooled data set (12 commercial farmers and 80 subsistence farmers)

Variables	Description	Measurement
Grazing	private access grazing for commercial and common access for subsistence farmers	Dichotomous (commercial = 1, communal = 0)
Breed	The predominant breed of cattle in the farmers' herd	Dichotomous (Barka = 1, Arado = 0)
Total Costs	Costs attributable to cattle farming in 2002	Nk
Average Costs	Costs incurred to produce one litre of milk in 2002	Nk/Lit
Concentrates	Concentrates fed as supplementary feed per LU	Kg
Roughage	Roughage fed as supplementary feed per LU	kg
PC1.1	Index positively related to herd size	Index
PC1.2	Index negatively related to the proportion of cows in the herd	Index
PC1.3	Index negatively related to the number of lactating cows as a proportion of total cows	index
Lact days	Length of lactation days	Day/month
Labour	Total family and hired labour	Number
Education	People who can write, read and further formal school level	Dichotomous (literate = 1, Illiterate = 0)
Experience	length of time farmers dealing with cattle farming activities	year
Age	Cattle owner's age	year

modern farming practices, which will have a negative effect on productivity. Several of the variables in Table 4.10 are expected to be collinear. For example, PC1.1, labour and total costs are all expected to be positively related to the size of the herd. Likewise, farmer's age and experience are expected to be positively related. Consequently, the statistical modelling exercise did not force all of the variables into each of the regression models. But rather sought parsimonious models that did not display symptoms of multicollinearity.

4.4.4.2 Results of the regression analysis on milk yield productivity

The estimated regression equation of factors explaining observed variation in milk productivity is presented in Table 4.11. It accounts for 66.9% of observed variation in MY and is statistically significant at the 99% level of confidence. The estimated regression coefficients (the values under the B column) indicate that milk productivity tends to be higher for farmers with exclusive use rights over grazing land. This relationship is consistent with *a priori* expectations. Results of the ordination diagram presented in Figure 4.1 suggest that farmers who farm with a specialist dairy breed (the Barka breed) rather than a dual purpose breed (the Arado breed) tend to obtain relatively higher milk yields. Although the sign of the estimated regression coefficient for the Breed variable in the regression analysis is consistent with this argument, it is not statistically significant from zero at a high level of statistical confidence. The finding that milk productivity

Table 4.11 Estimated regression coefficients for the regression on Milk yield using data for a sample of 12 commercial farmers and 80 subsistence farmers

Variables	B	Beta	t-value	Sig
(Constant)	823.483		9.275	.000
Grazing private vs. commons	508.811	.356	4.453	.000
Breed	112.405	.116	1.406	.163
Total Costs	0.250	.551	4.566	.000
Average Costs	-211.161	-.498	-4.304	.000
Summary of the regression model i.e. R square (R²) =.669				
F-value = 59.2, significance (Sig) =.000				

Dependent variable: Milk yield.

increases with total costs but declines as average costs per LU rise is difficult to explain because expenditure on inputs may be used to sustain cattle during periods of inadequate grazing rather than to enhance productivity.

4.4.4.3 Results of the regression analysis on calving rate productivity

The estimated regression equation of factors explaining observed variation in calving rates is presented in Table 4.12. It accounts for only 37.8% of observed variation in CR,

however the F statistic indicates that the regression equation is nonetheless significant at the 99% level of confidence. The estimated regression coefficients indicate that CR increases as the proportion of cows in the herd increases, as the quality of herd management increases, and as provision of supplementary roughage feed increases. CR tends to be higher for the Barka breed of cattle than the Arado breed. Farmers with exclusive use rights to grazing land, on average, obtain higher calving rates than farmers with common access to rangeland resources. This result is contrary to a priori expectations because grazing is the primary source of forage in Eritrea.

Table 4.12 Estimated regression coefficients for the regression on Calving Rates using data for a sample of 12 commercial farmers and 80 subsistence farmers

Variables	B	Beta	t-value	Sig
(Constant)	50.866		17.338	.000
PC1.2*	-6.200	-.292	-3.421	.001
PC1.3*	-9.730	-.459	-5.355	.000
Breed	10.767	.253	2.781	.007
Roughage (ROU)	1.243	.177	1.841	.069
Grazing private vs. commons	-7.895	-.126	-1.264	.210
Summary of the regression model i.e. R square (R^2) =.378				
F-value = 10.46, significance (Sig) =.000				

Dependent variable: Calving rate.

***= PCs are used as explanatory variables in regression models to obtain parameter estimates and to minimize the effect of multicollinearity (Esbensen 2006).**

4.4.4.4 Discussion

In general, the explanatory power of the estimated regression equations is not particularly high as they explain only 67% (i.e. $R^2 = .669$, F-statistics = 59) of observed variation in milk productivity and 38% (i.e. $R^2 = .378$, F-statistics = 10.46) of observed variation in calving rates. One possible reason for this is that good record keeping is not practiced by many of the surveyed households, thus reducing the reliability of cattle productivity data

collected from these households. Nonetheless, results do indicate that land tenure arrangements are important determinants of milk yield productivity.

4.4.5 Ordination diagram analysis of Barka and Arado subsistence cattle farming

The ordination diagram analysis in Figure 4.2 presents the distributions of 80 households' samples and 10 cattle farming variables entered the analysis. The eigenvalues for axes 1 and 2 are 0.261 and 0.211, representing 26.1% and 21.1% of the total variance, respectively. The ordination diagram analysis indicates the relationships between the samples and variables and within the variables in the distribution.

The primary purpose of this ordination diagram analysis is to allow for interpretation of the principal component analysis (PCA2) in the following section. The observable distributions and relationships between the samples and variables as well as within the variables in the ordination diagram are the main points for interpretation of corresponding samples and variables entered in the PCA. Computed correlation matrix (Appendix A Table A2) is also included to confirm the relationships between the variables entered in the ordination analysis.

In the ordination diagram, grazing costs (graz_cos), off-take rates (ot_avg), income from cattle sale (isa (avg) and mortality rates (Mortality)) are presented in the Arado cattle area. Milk yield (milkyield), body live weight (liveweight), weight at birth (wtbirth), calving rates (cr), feed costs (feed_c) and milk income im_lc) are presented in the Barka cattle sample area. The computed correlation matrix table (Appendix A Table A2) for the ordination diagram indicates that increased grazing costs result in increased off-take rates although its influence is low. Farmers that had higher grazing costs accompanied by higher mortality rates also had higher shortage of forage. On the other hand, feed costs are

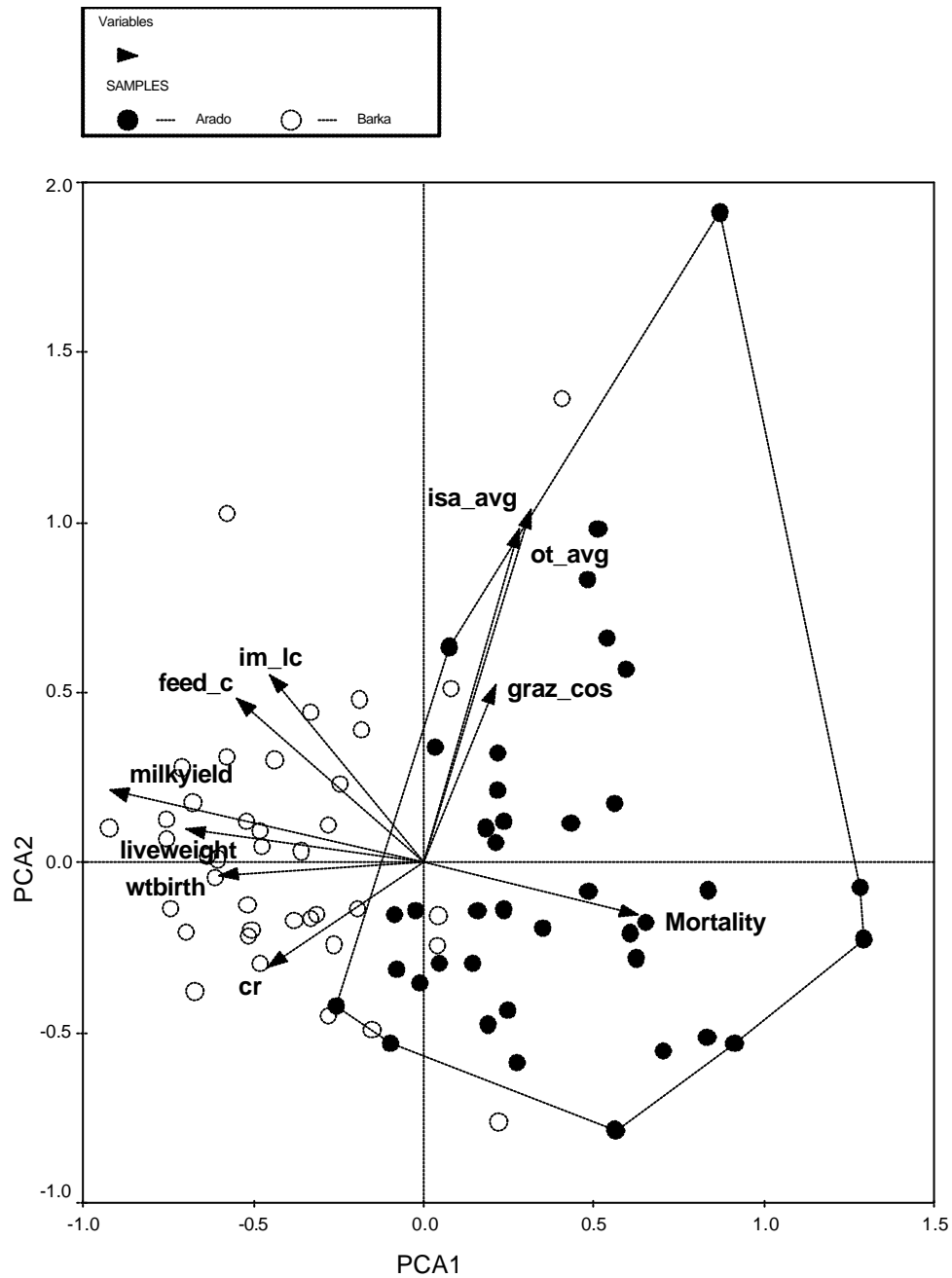


Figure 4.2 Ordination biplot diagram. First two axes of a standardized and centered PCA of cattle farming variables (arrows) from the Arado (filled circles) and Barka (empty circles) cattle regions.

➤ Variable names are: milkyield = milk yield; cr = calving rate; liveweight = body live weight; wtbirth = calf weight at birth; feed_c = feed costs; im_lc = milk income per lactation; mortality = mortality rates; graz_cos = grazing costs; ot_avg = off-take rates; isa_avg = income from sale of live animals.

higher in the Barka cattle area and have positively ($P < 0.05$) influences on milk yield than in the Arado cattle area.

In the ordination diagram, grazing costs (graz_cos), off-take rates (ot_avg), income from cattle sale (isa (avg) and mortality rates (Mortality)) are presented in the Arado cattle area. Milk yield (milkyield), live weight (liveweight), weight at birth (wtbirth), calving rates (cr), feed costs (feed_c) and milk income im_lc) are presented in the Barka cattle sample area. The computed correlation matrix table (Appendix A Table A2) for the ordination diagram indicates that increased grazing costs result in increased off-take rates although its influence is low. Farmers that had higher grazing costs accompanied by higher mortality rates also had higher shortage of forage. On the other hand, feed costs are higher in the Barka cattle area and have positively ($P < 0.05$) influences on milk yield than in the Arado cattle area.

The ordination diagram shows that the groupings of subsistence cattle farming systems in the Barka region are fairly distinct from the grouping of subsistence cattle farming systems from the Arado region. The arrows indicate that, compared to cattle production in the Arado region, cattle production in the Barka region is typically associated with higher milk yields and higher income from milk sales, higher calving rates, larger cattle (higher birth weights and liveweights of adults), and higher feed costs. Arado cattle production systems are, on the other hand, associated with relatively higher mortality rates. Higher dairy cattle production in the Barka cattle region is due to the availability of relatively higher grazing resources compared to the Arado cattle regions (section 4.3, Table 4.2). The arrows for off-take rates, income from cattle sales and grazing costs point between the two groups, indicating that farming region is not closely associated with these traits.

4.4.6 An analysis of the productivity of Arado and Barka cattle in smallholder production systems in Eritrea.

The cattle productivity of the sample of 80 subsistence farmers in the Arado and Barka cattle area was examined using a set of measurements of various dimensions of cattle productivity. Because significant collinearity was detected amongst these variables, a PCA of these variables was conducted to convert the set of related productivity measurements into an index of unrelated (orthogonal) principal components that describe various

dimensions of cattle productivity. The PCA was based on the correlation matrix rather than the covariance matrix because the units of the variables included in the analysis differ (SPSS 1990). A varimax rotation (an orthogonal or unrelated criterion) was used because this type of rotation produced orthogonal principal components and simplifies the interpretation of the principal components (SPSS 1990).

The PCA produced three principal components with eigenvalues of one or greater. Together, these three components account for 73% of the variation in the original seven livestock productivity indicators that were included in the analysis. The loadings of these principal components are presented in Table 4.13 and are used to “interpret” the dimension of cattle productivity contained in each of the three components. The results of these three components are consistent with the results observed in the ordination diagram in Figure 4.2.

PC2.1 (Principal component one of this analysis) accounts for 35% of total variance in the seven productivity measurements. It is positively related to both income from sale of live animals (ISA) per livestock unit (LU) and off-take rate (OT)/LU and is therefore interpreted as an index of ‘livestock off-take’ productivity. The mean value of PC2.1 for the Arado breed area is 0.13329, and PC2.1 for the Barka breed area is -0.13329. The mean value of PC2.1 indicates that the Arado breed area has a higher OT productivity resulting in a higher income from the sale of live animals than the Barka cattle area. Farmers with high value for PC2.1 have high livestock off-take productivity and farmers with low value for PC2.1 have low livestock off-take productivity, which seems to indicate differences in livestock off-take productivity between the Arado and Barka cattle production systems.

The negative sign for the mean value of the Barka breed area under PC2.1 was unexpected because Barka cattle are dominant in the Eritrean livestock markets and the most numerous breed of cattle in Eritrea. However, careful interpretation of the principal component reveals that the component is an index of the percentage of cattle sold, not the absolute number of cattle sold by each farmer. Results therefore reflect that cattle farming systems in Arado cattle regions, on average, had higher off-take rates than did cattle farming systems in Barka cattle regions during 2002. The high off-take rates of the Arado cattle may be linked to the fact that a shortage of grazing forage induced sales during the dry season. This is evidenced by the ordination diagram in section 4.4.5 that farmers in the

Arado cattle area had higher grazing costs, which emphasise the shortage of grazing forage, than was observed in the Barka cattle area. The shortage of grazing forage for the Arado cattle area is consistent with the results reported in Table 4.2 in section 4.3. The second principal component (PC2.2) explains 24% of the total variance in the seven productivity measurements. PC2.2 has positive loadings for milk yield (MY), live weight (LW) and calf weight at birth (wtbirth). Milk yield plus calf birth weight is interpreted as a 'breed productivity index'. The mean value of PC2.2 for the Arado breed area is -0.69339 and PC2.2 for the Barka breed area is 0.69339. The mean values shows that compared to the Arado cattle area, subsistence farmers in the Barka cattle area, on average, achieve

Table 4.13 Principal components describing the variability in cattle productivity of a sample of 80 subsistence farmers in Eritrea, 2002

Principal components (PCs)*	PC2.1	PC2.2	PC2.3
Percentage of variance explained	35	24	14
Eigenvalue	2.5	1.7	1.0
Variables:			
Income from sale of live animal (ISA_avg)	0.951		
Off-take rate (OT_avg)	0.952		
Milk yield /cow (MY)		0.743	
Body mass or Live weight (BM/LW)		0.653	
Calf birth weight (wtbirth)		0.889	
Calving rate (CR)			0.664
Mortality rate (MR)			-0.816
The mean values of PCs for:			
Barka breed area	-0.13329	0.69339	0.28783
Arado breed area	0.13329	-0.69339	-0.28783

* = is a general method for making a factor solution easier to interpret.

higher milk productivity and farm relatively larger cattle (higher body live weight as well as a higher calf weight at birth). This result therefore reflects differences in traits of the Arado and Barka breeds of cattle, but may also reflect that there is a greater availability of forage in the Barka region compared to the Arado region.

PC2.3 accounts 14% of the total variance in the seven productivity measurements. It is positively related to calving rate and negatively related to mortality rate and is interpreted as an index of “calving rate productivity”. The mean value of PC2.3 for the Arado breed area is -0.28783 and for the Barka breed area is 0.28783. Farmers with high values for PC2.3 have high calving rate productivity and farmers with low values for PC2.3 have low calving rate productivity because the index of PC2.3 is positively related to calving rate and negatively related to mortality.

The principal components elicited in this analysis closely match the results of the ordination analysis presented in the previous section. For example, “isa_avg” and “ot_avg” are closely grouped in the ordination diagram and are also grouped together in PC2.1. Likewise, “milkyield”, “liveweight” and “wtbirth” are closely grouped in the ordination diagram and in PC2.2.

4.4.7 A regression analysis of factors affecting cattle productivity of smallholder farmers in the Arado and Barka regions of Eritrea.

Regression analysis was used to identify factors that account for observed variation in cattle productivity of the 80 smallholder farmers surveyed in this study. PC2.1, PC2.2 and PC2.3 were used as dependent variables in the regression analyses as these principal components were interpreted as indices of cattle productivity in the previous section. The explanatory variables were chosen to capture characteristics of farmers’ cattle production systems, including information on their access to grazing resources. These explanatory variables are presented in Table 4.14.

Table 4.14 Explanatory variables included in regression analyses for PC2.1, PC2.2 and PC2.3 using data for a sample of 80 subsistence farmers

Variables	Description	Measures
AREA	Grazing area in Arado & Barka cattle breeds	(Barka=1, Arado=0)
Size	Herd size	number
Quality of herding	An index positively related to the costs of hiring labour to assist with herding and milking cattle	Index
Grazing	Grazing commons	Exclusive use rights to grazing land = 1; otherwise zero.
Prop of cows	Proportion of cows	Number
Prop of oxen	Proportion of oxen	Number
Lc_avg	Average number of lactating cows	Number
Con_avg	Average supply of concentrate	Kg
Rou_avg	Agricultural by-product	Kg
Lact days	Length of lactation days	Day/month
ToTLABlu	Total family and hired labour	Number
Education	People who can write, read and further formal school level	Dichotomous
Family size	Number of people in one household	No
Experience	length of time farmers dealing with cattle farming activities	Year
Age	Cattle owner's age	Year

Note: Since there is no collinearity problem for the Barka and Arado cattle farming analysis, principal components (PC2.1, PC2.2 and PC2.3) are not included in the list of explanatory variables in this Table, instead, variables such as herd size and proportion of cows are used.

4.4.7.1 Definition of the explanatory variables presented in Table 4.14

Area : is a dummy variable equal to one if the farmer is based in the Barka region and zero if the farmer is based in the Arado region. In general, subsistence farmers in the Barka region tend to farm with Barka cattle and farmers in the Arado region tend to farm with Arado cattle. Consequently, it is expected that **Area** will account for the general traits of the two breeds of cattle as well as the relative availability of forage in the two regions.

Grazing commons is a variable that is equal to one if the farmer has exclusive use rights to grazing resources, and zero if the cattle are grazed on communally farmed land. As noted previously, three farmers in the Arado region indicated that they have exclusive use to grazing land, although it is unlikely that these farmers have strong tenure security over their grazing areas relative to commercial cattle farmers. It is expected that farmers are more likely to invest in improving their grazing resources and will control stocking rates to sustainable levels if they have exclusive use rights over land. Therefore, having exclusive use rights over grazing land (as opposed to common access to grazing resources) is expected to have a positive impact on cattle productivity.

Herd size is a measure of the size of each farmers' herd in livestock units. Herd size is included to capture the effects on cattle productivity associated with economies and diseconomies of size. Other variables describing the herd composition and structure included in this analysis are **Proportion of cows**, (the number of cows in the herd as a proportion of the total herd), **Lactating cows**, (the proportion of cows in the herd that were producing milk at the time of the survey), and **Proportion of oxen** (the number of oxen as a proportion of the total herd). Herd structure and composition is likely to be related to the purpose of the herd (e.g. dairy vs. dual purpose), which will have an impact on herd productivity. Although several of these variables were found to be collinear in the analysis using the pooled data set (80 subsistence farmers and 12 commercial farmers), collinearity did not prove to be problematic using the data set for only the 80 subsistence farmers.

Management practices such as control over the average period of lactation per cow and feeding of supplementary feeds to cattle are expected to be important determinants of cattle productivity. In this analysis the variable **Lactating days** was also included as an indicator of herd purpose: for example, dairy farmers are likely to aim for longer lactation periods than farmers who use cows for draft power. **Quality of herding** is an index that was derived from information about farmers' expenditure on hiring labour for herding and milking cattle. Higher values of this index reflect greater expenditure on improving the quantity and quality of forage obtained by cattle from grazing. **ToTLABlu** is a related variable that includes use of both hired and household labour in cattle production per livestock unit. Use of supplementary feeding is captured through the variables **Con_avg** and **Rou_avg**, which respectively measure the average amount of concentrates and

roughage feeds fed to cattle during the 12 month period preceding the survey. It is expected that provision of supplementary feeds will have a positive effect on productivity, however, it is also noted that if farmers tend to only provide supplementary feeds to sustain their cattle during periods of inadequate grazing, then provision of supplementary feeding may be associated with low productivity.

Finally, household characteristics are expected to be determinants of cattle productivity. For example, use of household labour in cattle production is captured in the variable. **Education** and **Experience** are both expected to improve farmers abilities to use available information and therefore to make better decisions, which will impact positively on achieved productivity. **Family size** is also an important variable as household labour is a substitute for hired labour in cattle farming.

The three regression equations were estimated using ordinary least squares regression. Variables were only retained in the models if their estimated regression coefficients were significantly different from zero. The following three sub-sections report the three estimated regression equations.

4.4.7.2 Factors affecting off-take productivity (PC2.1)

The estimated regression model for PC2.1 is presented in Table 4.15. The model is statistically significant at the 99% level of confidence (shown by the F-statistics of 23.5) and the model accounts for more than 55% of the variation in PC2.1. The estimated Beta coefficients and t-statistics identify herd size and composition as the most factors influencing the off-take rates of subsistence farmers in Eritrea. Herd size, in particular, is important. The estimated regression coefficient indicates that as herd size increases the proportion of the herd that is sold each year declines. In other words, off-take rates tend to be highest amongst subsistence farmers with relatively few cattle. Likewise, results indicate that off-take rates are higher in herds that contain a relatively high proportion of cows. Herding quality was found to be positively related to off-take productivity at the 90% level of statistical confidence. Finally, results show that subsistence farmers with exclusive use-rights to grazing land do not achieve off-take rates that are significantly different from those of other farmers. One reason for this finding is that the three

subsistence farmers in the sample who had exclusive use rights to grazing land were all dairy farmers rather than beef farmers.

Table 4.15 Estimated regression coefficients for the regression on Off-take rate (PC2.1) using data for a sample of 80 subsistence farmers

Variables	B	Beta	t-value	Sig
(Constant)	1.942		2.854	.006
Size (converted to log base)	-1.130	-0.703	-9.040	.000
Herding and milking cost	0.001	0.138	1.785	.078
Proportion of cows	1.216	0.136	1.763	.082
Grazing commons	-0.248	-0.039	-0.505	.615
R square (R²) =.557				
F-value = 23.5, significance (Sig) =.000				

Dependent variable: Off-take rate.

4.4.7.3 Factors affecting milk productivity (PC2.2)

The estimated regression model for PC2.2 is presented in Table 4.16. The model is statistically significant at the 99% level of confidence (shown by the F-statistics of 26) and the model accounts for more than 58% of the variation in PC2.2. The estimated Beta coefficients and t-statistics identify region (cattle breed) as the most factors influencing milk yield productivity amongst subsistence farmers in Eritrea. The estimated regression coefficients show that, on average, subsistence farmers in the Barka region achieve significantly higher milk yields than farmers in the Arado region. This is consistent with expectations as the Barka breed of cattle is generally considered to be better suited to dairy production than the Arado breed.

Cattle management practices are also shown to influence milk yield productivity. In particular, cattle farmers that use relatively longer lactation periods tend to have higher milk yield productivity. Likewise, farmers that use more labour intensive cattle production (more labour per livestock unit) tend to have higher milk yield productivity. Finally, results indicate that farmers with exclusive use rights to grazing resources (grazing

commons) tend to achieve higher milk yields. It is not clear whether this is due to investments in the grazing resource, investments in the herd quality or from having reduced stocking rates.

Table 4.16 Estimated regression coefficients for the regression on Milk yield (PC2.2) using data for a sample of 80 subsistence farmers

Variable	B	Beta	t-value	Sig
(Constant)	-3.879		-4.195	.000
Area	1.450	0.730	9.206	.000
Total labour/LU	2.103	0.173	2.292	.025
Lactating days	0.011	0.230	2.941	.004
Grazing commons	0.761	0.119	1.576	.119
R square (R²) =.582				
F-value =26, Significance (Sig)=.000				

Dependent variable: Milk yield.

4.4.7.4 Factors affecting calving rate productivity (PC2.3)

The estimated regression model for PC2.3 is presented in Table 4.17. The model is statistically significant at the 99% level of confidence (shown by the F-statistics of 4.2), although the model accounts for only 29% of the variation in PC2.3. The estimated Beta coefficients and t-statistics identify herd size and composition, provision of supplementary feeding as the most factors influencing the calving rate productivity of subsistence farmers in Eritrea. The estimated regression coefficients for the variables size and size² indicate that calving rate productivity increases at a decreasing rate with herd size. As may be expected, calving rate productivity tends to be higher in cattle herds with a relatively high proportion of cows, and lower in cattle herds that are characterised by a relatively high proportion of oxen.

Provision of supplementary feeds was found to have a positive effect on calving rate productivity if the supplementary feed is a concentrate, but a negative effect if the supplementary feed is primarily roughage. The former result is consistent with expectations, but the latter result is surprising. It seems likely that subsistence farmers

Table 4.17 Estimated regression coefficients for the regression on Calving rate (PC3) using data for a sample of 80 subsistence farmers

Variable	B	Beta	t-value	Sig
(Constant)	-0.418		-0.506	.614
Lactating cows	0.983	0.538	3.610	.001
Size_Sq (converted to square)	-0.002	-0.735	-2.324	.023
Herd size	0.090	0.768	2.327	.023
Concentrate (average)	0.161	0.346	2.837	.006
Roughage (average)	-0.072	-0.355	-2.336	.022
Proportion of oxen	-1.928	-0.210	-1.985	.051
Grazing commons	-0.586	-0.092	-0.894	.374
R square (R²) = 0.291				
F-value = 4.2, Significance (Sig) = .001				

Dependent variable: Calving rate.

consider concentrates to be productivity enhancing, however, roughage feed supplements are used to sustain cattle. Finally, the regression model was unable to find a statistically significant relationship between exclusive use rights to grazing (grazing commons) and calving productivity.

4.5 Results of group discussions with farmers

To have improved rangelands, the application of proper grazing systems (controlled stocking rates) that can result in productive rangelands is not only important but also necessary. However, this study found that communities of the Barka and Arado cattle subsistence farmers do not adopt such grazing systems. Focusing on this issue, group discussions were carried out with the subsistence and commercial farmers to explore this issue. Information was collected by asking questions and jotting down the responses. The aim of the group discussion was to get additional information to dig out the real constraints why the farmers did not use or apply controlled stocking rates to promote forage production. This section presents the main findings of the group discussions.

Farmers were unable to reach consensus about the need to include rules for stocking rates in farmers' bylaws on village level. Because they didn't come to agreement, it was suggested that subsistence farmers do have sufficient information about the benefits of controlled stocking rates and do have access to information on how to promote forage production. However, their response was that investing individually on commons grazing lands is not guaranteed because free riders can use the benefits. Investing on group level demands high costs of organizing the groups. For applying controlled stocking rates, their reply was that reducing animal numbers on individual levels didn't make sense unless the whole village farmers agree and follow similar principles. As observed from the group discussion, this was evidenced through the individual farmers' trial that some of them tried to reduce their animal numbers and invested their fixed inputs on the rangelands, but they did not get any followers. The majority did not follow the individuals' examples. Rather people who made individual investments were unable to protect their investments from destruction by other livestock farmers.

On the other hand, some farmers noted that because rangelands are under the control of villages, it is the responsibility of the farmers within each village community to set rules guiding how to apply their grazing resources. In other words, the rules for applying controlled grazing must be originated from the farmers themselves. An important observation that arose from the group discussions is that a large proportion of farmers seemed reluctant to agree to set rules such as controlled stocking rates in their bylaws. It was apparent that they did not trust one another and their neighbouring villages' communities to secure their rangelands forage.

It was concluded from the group discussions that cooperation amongst communities to implement controlled stocking rates and investments in improved grazing resources is unlikely. Consequently, in order to promote improved rangeland management it is important to provide farmers with exclusive use rights to grazing resources. This may be achieved through the expansion of the lease holding systems and facilitating access to credit by farmers.

Though government intervention is inevitable, communities of subsistence farmers should not wait for external donations to address the low productivity of their rangelands. They should rather seek ways to create cooperation amongst themselves to use better rangeland

management by applying controlled stocking rates. However, among the ultimate solutions that can help to apply proper grazing management is to facilitate the lease land holding systems, which is already in process. This can ensure the property rights resulting in motivating the farmers' perception to minimise their herd size and maximising their rangeland productivity.

4.6 General discussion

The core discussion in this chapter focuses on the issues of rangeland productivity in Eritrea and its impact of rangeland cattle productivity in subsistence and commercial farming systems. Four stages of analysis were conducted to study these issues. First, the assessment of common access grazing systems in comparison with the private access grazing systems and the related grazing topics productivity indicators were undertaken. In this first issue, the availability and types of croplands winter forage and the dry season supplementary feeds between the Barka and Arado cattle areas are discussed all with the help of descriptive and t-Test statistics analysis. This analysis bench-marks current rangeland practices and levels of rangeland and cattle productivity in Eritrea for commercial farming and subsistence farming in the Barka and Arado regions. Future studies can use these bench-marks to assess trends on rangeland management and cattle productivity over time, and in particular, to assess the impact of various programmes and policies that may be implemented with the expectation of improving rangeland and cattle farming productivity.

An important finding of this first stage of analysis is that, in general, rangeland management practiced by surveyed commercial cattle farmers are markedly distinct from those practiced on the communal rangelands used by the surveyed subsistence farmers. Commercial farmers are more likely than subsistence farmers to invest in their rangeland resources and control stocking rates. Findings also suggest that commercial farmers are inclined to use supplementary feeding to promote productivity, whereas subsistence farmers tend to use supplementary feeds to sustain their livestock during periods of feed shortages. Differences in livestock management practices are clearly reflected in the relative productivity of the two categories of farms: on average the surveyed commercial farms achieved higher levels of productivity (especially milk productivity) and lower cattle mortality rates than did the surveyed subsistence farmers.

Regarding crop residues and supplementary feeds, both the Barka and Arado cattle farming areas had a shortage of quantity as well as quality forage during 2002 winter and dry seasons. Among the reasons, farmers were dependent only on rain fed crop production. Irrigation was not applied for grain crop production. Due to the lack of credit either in kind such as chemical fertilizers or liquid money, subsistence farmers couldn't afford to promote soil fertility. The traditional farming practices of crop rotation and fallow were also low in both cattle areas. Out of the total crop residues produced, the legumes residue was reported to be 22% and 14% for the Barka and Arado cattle, respectively. This indicates that the contribution of crop rotation to improve the nutritive value of crop residues was low during 2002. The shortage of agricultural and agro-industrial by-products supplementary feeds was rather more serious than the crop residues forage. Priority of agro-industrial by-products was given to commercial farming due to the total shortage of these by-products in the country.

The second, third and fourth stages of analysis (i.e. the ordination diagrams, the principal components analyses of cattle productivity and the regression analyses) were intended to statistically analyse factors affecting the productivity of cattle farming in commercial and subsistence cattle farming systems in Eritrea. Factors that explain variation in measured productivity of the surveyed farmers include: (a) whether or not farmers have exclusive or common access rights to grazing, (b) the breed of cattle farmed, (c) the composition of the herd, and (d) the quality of animal husbandry. Findings show that exclusive use rights to land are positively associated with cattle productivity. An important finding is that the strength of these property rights is important. For example, three subsistence farmers with weak exclusive use rights over grazing land did not invest in improving their grazing land and achieved low levels of productivity relative to the surveyed commercial farmers. Consequently, in order for exclusive use rights to grazing land to promote productivity, these rights must be perceived to be durable. The exclusive use rights must also permit farmers to enforce these rights, e.g. by allowing farmers to fence grazing land.

Results show that the Barka cattle achieve higher levels of milk productivity, however, many subsistence farmers in the Arado region continue to farm with Arado cattle, suggesting that the Arado breed is better suited to the region or that it is better suited to use in agro-pastoral farming systems. The herd composition is also indicative of the purpose of

the herd. For example, dairy herds tend to have a relatively low proportion of oxen in the herd and a high proportion of cows tend to be lactating. Finally, results show that farmers who spend relatively more on herding cattle tend to achieve better results. It is likely that other factors not considered in the statistical analysis of this study may also be important for explaining why some farmers achieve higher productivity levels than others. For example, as Eritrea is a newly independent country, the financial and other agricultural potential to supply the rural farmers is low. Government financial credit and lease land provision in Eritrea primarily benefit commercial farmers. Consequently, liquidity constraints of subsistence farmers may be an important factor explaining why their performance levels are, on average, relatively low.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This study has investigated rangeland productivity and the productivity of commercial and subsistence cattle farming in Eritrea. The study has produced descriptive statistics that bench-mark rangeland management practices and cattle productivity in Eritrea during 2002/2003. These bench-marks will be useful for future studies to assess trends in rangeland management practices and cattle productivity over time in Eritrea, or to compare the productivity of cattle farming in Eritrea with cattle farming in its neighbouring countries.

It is concluded that cattle farmed in commercial farming systems tend to be more productive than cattle farmed in subsistence cattle farming systems. This finding shows that the policy of establishing a commercial cattle farming sector in Eritrea has been successful in applying reduced stocking rates that help to improve rangeland management and cattle farming productivity. These policies have included programmes of credit, improved infrastructure and access to markets in addition to land lease programmes that provide farmers with exclusive use rights to grazing land. Currently only five percent of cattle are farmed in commercial cattle farming systems, suggesting that the government should consider expanding its programme to commercialize cattle farming in Eritrea.

From a theoretical perspective, common access grazing systems are expected to be managed better and be more productive than open access grazing systems. The success of common access grazing systems, however, depends upon how successful the community is at establishing and enforcing rules for the collective use of the resource and collective investment in the resource. The lack of effective collective action of communities of farmers to enforce controlled stocking rates in this respect will result in free-rider problems within the group inhibiting effective range land management. An important conclusion of this study is that many subsistence farming communities in Eritrea are unable to implement sound rangeland management practices. As a consequence, cattle productivity in these regions is relatively low. It is important that the MOA uses its extension services to assist communities to establish and enforce sound rules for rangeland management. These rules need to be comprehensive (i.e. they need to consider all uses of rangelands, not only cattle farming), and they need to provide for collective investments in the rangeland resource.

MOA extension services can therefore participate in establishing these rules as well as over-seeing dispute resolution. However, it is critical that all stakeholders participate in establishing these rules or it is unlikely that they will be adhered to or enforced by farmers.

Cattle migration is a management practice used by Eritrean subsistence farmers to ensure that their cattle have adequate access to forage throughout the year. The practice enables subsistence farmers to keep more livestock that would otherwise be possible because if forage in their communal area is in short supply, cattle can be herded to regions where better forage is available. Because this practice is costly (e.g. hiring cattle herders), farmers may delay cattle migration until after the range land resource has suffered the effects of overstocking. Consequently, it is particularly important that rules surrounding cattle migration are adequately dealt within each community's rules for management of their communal rangeland area to prevent situations of over-stocking in the Highlands and the populated area of the Western Lowlands where rangelands are seriously overgrazed.

This study has demonstrated the multi-dimensional nature of cattle productivity. The multi-dimensional nature of productivity is important when comparing the relative productivity of two breeds of cattle. The findings indicate that the Barka cattle breed is better in milk yield and live weight gain and other outputs like calf weight at birth compared to the Arado cattle breed, both in their respective areas. To improve the breed quality of the low breed herds, crossbreeding of the Arado cattle with the Barka breed, and more recently, crossing Barka cattle with Friesian dairy cattle has been carried out by Eritrean commercial and subsistence farmers. However, due to the limitation of sustaining grazing forage supply, the general breeding system was not successful because the hybrid cattle proved less hardy (heat and stress resistant) than the original breeds. The cross breeding programme stands to be more successful if subsistence farmers, especially, introduce improved forage management practices. It is therefore recommended that cattle farmers in the Arado should introduce Barka cattle genetics into their herds through crossbreeding to improve milk productivity in conjunction with the introduction of improved rangeland management practices.

Crop encroachment is another constraint to rangeland productivity in Eritrea. Crop farming encroachment causes shortage of grazing resources by encroaching on rangelands and by creating rangeland fragmentation. When fertile land of rangelands is encroached, the

marginal lands used for cattle grazing become fragmented. This is inconvenient for cattle grazing and discourages investment in improving fragmented areas of rangeland. Situations of severe rangeland fragmentation mostly occur in the areas where there are high human and animal population densities, particularly in the Highlands (Arado cattle regions) and populated areas of the Western Lowlands (Barka cattle region).

In addition, this study has evaluated management practices on rangelands (grazing resources) applied by the smallholder cattle farmers in the Barka and Arado cattle regions with respect to improving herd productivity. In order to accelerate the adoption of management practices on communally farmed rangeland, farmers need to engage in appropriate collective action. This will require communities of farmers jointly agreeing to a particular goal, agreeing to a strategy for achieving that goal, and then implementing that strategy. However, property rights and collective action issues are important constraints in this case to the adoption of management practices and improved technologies that can help smallholder farmers and reduce rangeland overgrazing. Such improved grazing resources management practices require long-term investments and farmers will only make these investments if they have sufficiently secure and long-term rights to their rangelands so that they know they will harvest the benefits of their investment. Because, in Eritrea, grazing resources management practices have to be undertaken by group of farmers working together or require effective community management of common property resources. Ineffective collective action at village level becomes a constraint on the adoption of these grazing resource management practices. Therefore, to help farmers carry out improved rangeland management practices, government intervention may be required to introduce rules and regulations that guide communities in the management of their rangeland. The intervention can have great role to encourage the community farmers to facilitate the rules and regulations for its practicality.

Creating favourable conditions such as workshops, seminars and other practical activities are essential to interpret the rules and regulations and to provide the farmers with expertise of cattle farming modern technologies. Moreover, access to extension services such as financial and in-kind credits, better infrastructure, input/output market supply and organized crossbreeding system and veterinary services can motivate the smallholder cattle owners to promote rangeland management practices and improve cattle productivity.

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APPENDIX A Correlation matrix for ordination diagrams of commercial and subsistence as well as the Barka and Arado cattle farming production systems

Table A.1 Correlation matrix of commercial and subsistence cattle farming

Correlation	my_lc	vac_far	lc	cr	nc	lu	mr	ot	grc_lu
Variables									
my_lc	1.								
vac_far	.431	1.							
lc	.355	-.013	1.						
cr	.156	-.099	.316	1.					
nc	.291	.146	.595	-.023	1.				
lu	.214	.232	.340	-.241	.260	1.			
mr	-.440	-.322	-.357	-.231	-.258	-.242	1.		
ot	.192	.242	.083	-.321	.093	.692	-.089	1.	
grc_lu	.275	.476	-.102	-.095	-.015	-.031	-.081	.103	1.

Significance:

Variables:

vac_far	.000								
lc	.000	.451							
cr	.068	.174	.001						
nc	.002	.082	.000	.415					
lu	.020	.013	.000	.010	.006				
mr	.000	.001	.000	.013	.007	.010			
ot	.033	.010	.215	.001	.189	.000	.199		
grc_lu	.004	.000	.167	.183	.442	.383	.223	.165	

(Source: SPSS 1990)

Note: my_lc = milk yield per lactation; vac_far = variable cost/farmer; lc = lactating cows; cr = calving rate; grac_lu = grazing costs/livestock unit; nc = number of cows; lu = herd size in livestock unit; mr = mortality rate and ot = off-take rate

Table A2 Ordination Correlation Matrix of the Barka and Arado cattle farming

variables	my	cr	blw	wab	mr	ot_av	isa_a	graz_co	fd_c	im_lc
my	1									
cr	.209	1								
blw	.456*	.215	1							
wab	.499*	.141	.359	1						
mr	-.408*	-.241	-.263	-.010	1					
ot_av	-.08	-.213	.010	-.018	.114	1				
isa_a	-.116	-.209	-.039	-.151	.016	.848*	1			
graz_co	-.078	-.065	-.194	-.123	.065	.140	.295	1		
fd_c	.476*	.002	.138	.186	-.316	.060	.128	.101	1	
im_lc	.400*	.037	.213	.021	-.255	.131	.124	.199	.247	1

Significance:

variables

my	1.									
cr	0.033	1.								
blw	0.000	0.029	1.							
wab	0.000	0.108	0.001	1.						
mr	0.000	0.016	0.010	0.464	1.					
ot_av	0.241	0.030	0.472	0.437	0.158	1.				
isa_a	0.154	0.032	0.366	0.092	0.446	0.000	1.			
graz_co	0.246	0.286	0.044	0.141	0.283	0.109	0.004	1.		
fd_c	0.000	0.495	0.112	0.050	0.002	0.301	0.130	0.188	1.	
im_lc	0.000	0.372	0.030	0.429	0.012	0.125	0.138	0.040	0.014	1.

(Sources: SPSS 1990)

Note: variable names-

my = milk yield; cr = calving rate; blw = body live weight, wab = calf weight at birth; mr = mortality rate; ot_av = off-take rate average; isa_a = income from sale of live animals; graz_co = grazing cost; fd_c = feed cost; im_lc = milk yield per lactation

APPENDIX B Correlation matrix checking whether the milk yield and calving rate variables used are unrelated, according to Bertlett's (1950 and 1951) test, chi-square test

Table B1 correlation matrix of milk yield, milk income and calving rate variables for commercial and subsistence farmers

Correlation coefficient	Variables	my_lc	im_lc	cr
	my_lc	1.000	.205	.158
	mi_lc	.205	1.000	.014
	cr	.158	.014	1.000
Significance.	my_lc	1	.025	.068
	im_lc	.025	1	.448
	cr	.068	.448	1

(Sources: SPSS 1990)

Note: -Milk yield per lactation = my_lc; calving rate = cr and milk income per lactation = im_lc

RLevel of statistical significance: If the correlation coefficient is above 0.200 and the level of probability is $P < 0.05$. Hence, my and cr variables are statistically significantly uncorrelated, thus fit to be used as dependent variables for regression analysis (according to Bartlett's (1950 and 1951) test)