Performance of Ankole and crossbred cattle in Rwanda

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Abstract

The **general aim** of this thesis was to evaluate how effective crossbreeding could be for increasing productivity in meat and milk production in Rwanda. This was done by assessing performance of Ankole (A) and its crossbreds with exotic breeds: Brown Swiss (B), Holstein Friesian (F), Jersey (J) and Sahiwal (S). Paper I-III were generated from records collected on growth, reproduction and milk yield of cattle genotypes from research stations and paper IV was based on survey data from farms in three agroecological zones.

Birth weight for Ankole-Jersey calves were significantly lower (25.8 kg) than for the other crossbreds, which did not differ from each other (27.5-28.4 kg). Ankole-Friesian calves (AF) were heavier than all other crossbreds at weaning (182 kg vs 152-168 kg) (Paper I).

In Paper II, the breed group had a significant effect on intervals from calving to first or last inseminations (CFI, CLI), calving interval (CI), and conception rate (CR). The cross AF had higher CR than the purebred Ankole and AS (78% vs 71% and 67%), and AS had lower CR than AJxS and AJ (67% vs 75% and 73%). Purebred Ankole (AA) had longer CFI and CLI than all crossbreds except AF and hade 54 days longer CI than all crossbreds (498 vs 445 days).

In the study on milk yield (Papers III-IV), AA had the lowest average daily milk yield (2.0 L); AA also tended to have longer lactation length. Among the crossbreds, there was no significant difference in milk yield between AF, AJxS, and ASxJ (4.4-4.7 L), nor between AS and ASxS (3.3 L). Paper IV revealed significant breed effects on the average milk yield, with AF producing less milk per day (8.6 L) compared with purebred Holstein Friesian (14 L). Among zones, Eastern agroecological zone recorded the highest daily milk yield, which was estimated at 14.9 L compared to 9.4, 9.2, and 8.5 L in Birunga, Central and Western agroecological zones, respectively. Generally, a crossbred of Ankole and Holstein Friesian (AF) had good growth, good conception rate, and high production, but still as long calving to first insemination and calving to last insemination intervals as Ankole.

Keywords: Breeds, Crossbreeding, Live weight, Milk yield, Reproduction, Rwanda

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Abstract

Det huvudsakliga syftet med denna avhandling var att utvärdera hur väl inkorsning med importerade raser kan fungera som ett sätt att öka produktiviteten i mjölk- och köttproduktionen i Rwanda. Renrasig lokal Ankole (A) och dess korsningar med Brown Swiss (B), Holstein Friesian (F), Jersey (J) och Sahiwal (S) jämfördes under samma förhållanden. I de tre första artiklarna analyserades information om vikter och tillväxt, fruktsamhet och mjölkavkastning från försöksstationer och i den sista artikeln användes information inhämtad från besättningar i tre olika klimatzoner i Rwanda.

Födelsevikten för Ankole-Jersey (AJ) korsningskalvar var signifikant lägre (25,8 kg) än för övriga korsningar, vilka inte skilde sig från varandra i födelsevikt (27,5-28,4 kg). Ankole-Friesian kalvar (AF) var tyngre än alla andra korsningar vid avvänjning (182 kg mot 152-168 kg).

Fruktsamhetsegenskaperna påverkades också av kons genotyp: AF hade bättre dräktighetsprocent än både renrasig Ankole (AA) och Ankole-Sahiwal korsningar (AS) (78 % vs 71 % och 67 %) och AS hade sämre dräktighetsprocent än AJxS och AJ (67 % vs 75 % och 73 %). Renrasig Ankole hade längre intervall från kalvning till första eller sista insemination än alla korsningar (utom AF) och 54 dagar längre kalvningsintervall än alla korsningar (498 vs 445 dagar).

Ankole hade lägst daglig mjölkavkastning (2,0 l.) men AA tenderade också till att ha längre laktationer. Bland korsningarna fanns ingen skillnad mellan AF, AJxS och ASxJ (4,4-4,7 l.), och inte heller mellan AS och ASxS (3,3 l.). När mjölkavkastningen jämfördes ute i kommersiella besättningar, hade AF lägre mjölkproduktion än ren Holstein Friesian (8,6 vs 14 l.). Högst mjölkavkastning uppmättes i den östra klimatzonen, 14,9 l. jämfört med 9,4, 9,2 och 8,5 l. i Birunga, centrala respektive västra zonen.

Generellt hade AF korsningar bra tillväxt, bra dräktighetsprocent och relativt hög mjölkavkastning men lika långa intervall från kalvning till första eller sista insemination som renrasig Ankole.

Keywords: Breeds, Crossbreeding, Live weight, Milk yield, Reproduction, Rwanda

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Dedication

To my beloved family and friends

This is the short and long of it.
William Shakespeare

Contents

List of publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Manzi, M*., L. Rydhmer, M. Ntawubizi, C. Karege, and E. Strandberg (2018). Growth traits of crossbreds of Ankole with Brown Swiss, Holstein Friesian, Jersey, and Sahiwal cattle in Rwanda. Trop Anim Health Prod, 50(4), pp. 825-830.

II Manzi, M*., L. Rydhmer, M. Ntawubizi, C. Karege, and E. Strandberg (2018). Reproductive performance of Ankole cattle and its crossbreds in Rwanda. Trop Anim Health Prod, DOI: 10.1007/s11250-018-1658-8

III Manzi, M*., L. Rydhmer, M. Ntawubizi, C. Hirwa, C. Karege, and E. Strandberg (2018). Milk production and lactation length of Ankole cattle and its crossbreds in Rwanda (submitted)

IV Manzi, M*., L. Rydhmer, M. Ntawubizi, C. Karege, and E. Strandberg (2018). Milk production of Ankole crossbreds and Holstein Friesian cattle in different production environments of Rwanda (2018) (manuscript)

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Abbreviations

ADGW	average daily gain from birth to weaning
ADG8	average daily gain from birth to 8 months
ADG18	average daily gain from weaning to 18 months
AGEW	age at weaning
AI	artificial insemination
AnGR	animal genetic resources
BW	birth weight
CAADP	comprehensive African agriculture development programme
CAZ	central plateau and granitic ridge agroecological zone
CBPP	contagious bovine pleuropneumonia
CC	calving to conception interval
CFI	calving to first insemination interval
CI	calving interval
CLI	calving to last insemination interval
CR	conception rate
DIM	days in milk
DMY	daily milk yield
ESAZ	eastern savannah agroecological zone
EPAZ	eastern plateau agroecological zone
FAO	Food and Agricultural Organization of the United Nations
FMD	foot and mouth disease
GDP	gross domestic product
ILRI	International Livestock Research Institute
LDS	long dry season (June - Augut)
LL	lactation length
LRS	long rainy season (March - May)
LSM	least square means
MINAGRI	Ministry of agriculture and animal resources
MY100	milk yield for 100 days
MY305	milk yield for 305 days
NINS	number of inseminations

PGF2α	prostaglandin F2 alpha
RAB	Rwanda Agricultural Board
SAS	Statistical Analysis System
SDS	short dry season (January - February)
SRS	short rainy season (September - December)
WAZ	western agroecological zone (Congo-Nile western divide)
WW_{Adj}	weaning weight adjusted to 10 months of age
WW	weaning weight
W8	weight at 8 month of age
W18	weight at 18 month of age

1 Introduction

Rwanda is a land-locked country in the Great Lakes region of Eastern and Central Africa. The country lies within latitudes 1^o and 3^oS and longitudes 29^o and 31^oE. The topography is dominated by a mountainous plateau that falls from the west to east, ranging from 4,500 metres above sea level at the highest point in the west to around 1,000 metres in the east (ISAR, 1987). The total surface area is 26,338 km^2, including areas under water. Rwanda's population is about 12 million people with annual growth rate of 2.4%. Population density has increased from 321 persons per km^2 in 2002 to 445 persons per km^2 in 2015, the highest in Africa (NISR, 2016).

The country is divided into four major agroecological zones: (1) Eastern Savannah (ESAZ); (2) Eastern Plateau (EPAZ); (3) Central Plateau and granitic ridge (CPAZ) and (4) Congo-Nile western divide (WAZ). Each agroecological niche (Fig. 1) requires unique technological interventions and innovations to address constraints and opportunities in the commodity value chains.

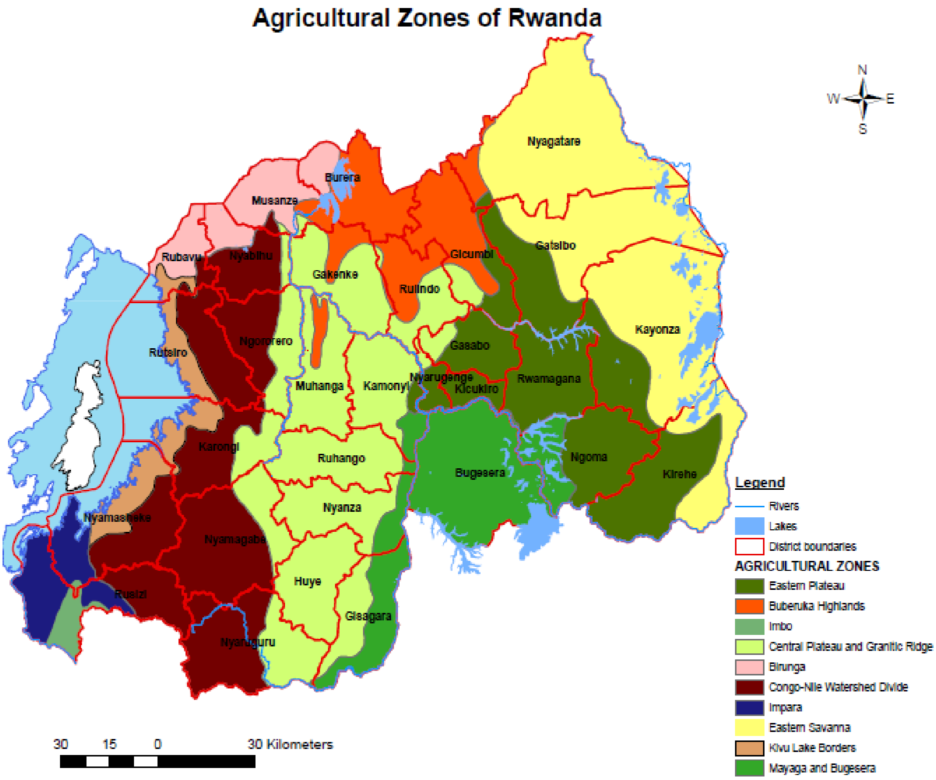

Fig.1. Agricultural zones of Rwanda (Delepierre, G. 1975)

Agriculture is affected by a bimodal type of rainfall, which generally varies from 1300 mm to over 2000 mm in the north and north-west (relatively wet throughout the year), while the east is characterized as semi-arid, with annual rainfall between 750 mm and 1000 mm and with distinct dry periods. There are four seasons. Short rains (season SRS) falling between September and December and long rains (season LRS) extending from March through May. The dry seasons extend between June and August (LDS) and January to February (SDS). The rain is heavy in March and April, and decreases gradually in May. The average temperatures range between 15 and 32 degrees Celsius.

Agriculture (mainly crop and livestock production) remains the backbone of Rwanda's economy. It contributes about 31% of the GDP, generates 60% of the foreign currency earnings and employs approximately 65% of the total population. Livestock contributes 3% of the

GDP and about 10% of the agricultural GDP (NISR, 2016). In addition to contributing to the country's agricultural GDP, also like in other sub-Saharan African countries, livestock plays several roles in the social economic wellbeing of the population (Delgado *et al.*, 1999). These include:

- Provision of milk and meat to the population all year round, thus ensuring food and nutrition security.
- An investment opportunity that buffer farmers to inflation and increases resilience to climate shocks.
- Provision of opportunity for nutrient use efficiently through integrated soil fertility management, particularly in smallholder farming system. Livestock produce manure for crops. Fodder planted on terraces provide feed to livestock while protecting slopes from erosion and conserving water for crops.
- Provisions of other products including hides and skins for export, environmentally responsive household fuel for cooking, especially in form of biogas; and traditional social security.
- Farm animal draft power that is important in agricultural production; although utilization in Rwanda is low.

The average size of landholding is 0.33 hectare, therefore land access for livestock production has been the most severe constraint in Rwanda (MINAGRI, 2006). By accepting the reality that land is a finite resource, the government of Rwanda has adopted the policy of land use intensification in arable crop and livestock agriculture as the only environmentally sustainable option to keep continued growth of the agricultural sector (FAO, 2009a).

The world's population is projected to be 9.1 billion by 2050. Virtually all the population increase is expected to take place in developing countries. In 2010, the share of the African urban population was approximately 36% and is projected to increase to 50% and 60% by 2030 and 2050, respectively (United Nation, 2011). Population growth and urbanization affect consumption and food consumption habits. Urbanization goes hand in hand with a shift in diet towards more meat and dairy products (FAO, 2009b). As a result, the total demand for livestock products as source of proteins will almost double in sub-Saharan Africa (Fig. 2), because of increased population density, urbanization and increased incomes (Seré *et al.*, 2008). Presently, sub-Saharan Africa has a deficit in livestock products and the situation is projected to worsen owing to ever-increasing gap between supply and demand (World Bank, 2008). In order to satisfy this growing demand, this gap should be narrowed by changing the way animals are raised and improving productivity and efficiency of resource use in the production of animal source foods and products.

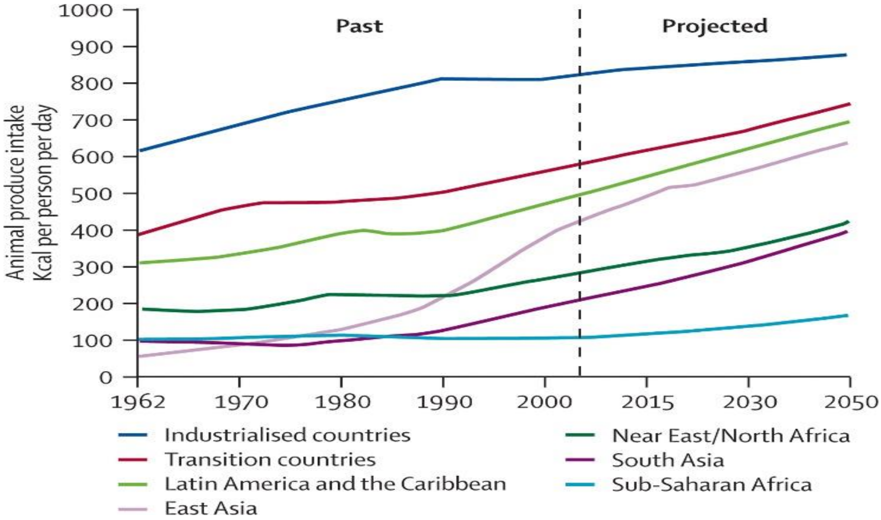

Fig. 2. Trends in consumption of livestock products per person (milk, eggs, and dairy products, excluding butter) (FAO, 2009)

Actions for addressing the increased demand vary from one country to another. In Rwanda, massive investments have been made in intensification and crop-livestock integration through the adoption of the Comprehensive Africa Agriculture Development (CAADP) and Vision 2020. In the livestock subsector, a one cow per poor household program popularly known as "Girinka program" that was initiated in 2006 has enabled the country to register a modest improvement in productivity, with a corresponding increase in the consumption of livestock products. For instance, available data indicate that milk production has increased fifteen-fold from 50,000 metric tons in 2000 to 750,000 metric tons in 2016 (NISR, 2017). Per capita consumption of milk increased from approximately 40 litres per year in 2012 to 59 litres by 2016. However, projected estimates from the Ministry of Agriculture and Animal Resources (MINAGRI) indicates that if the cattle population grows at the current pace with unchanged production per animal, the country will end up in a unsustainable situation where the gap between supply and demand will continue to widen with time (Fig. 3). The gap between supply and demand suggests the need to raise the productivity in the subsector. Reasons advanced for the low productivity are low access to improved animal genetic resources and low standards of husbandry, including both breeding and feeding.

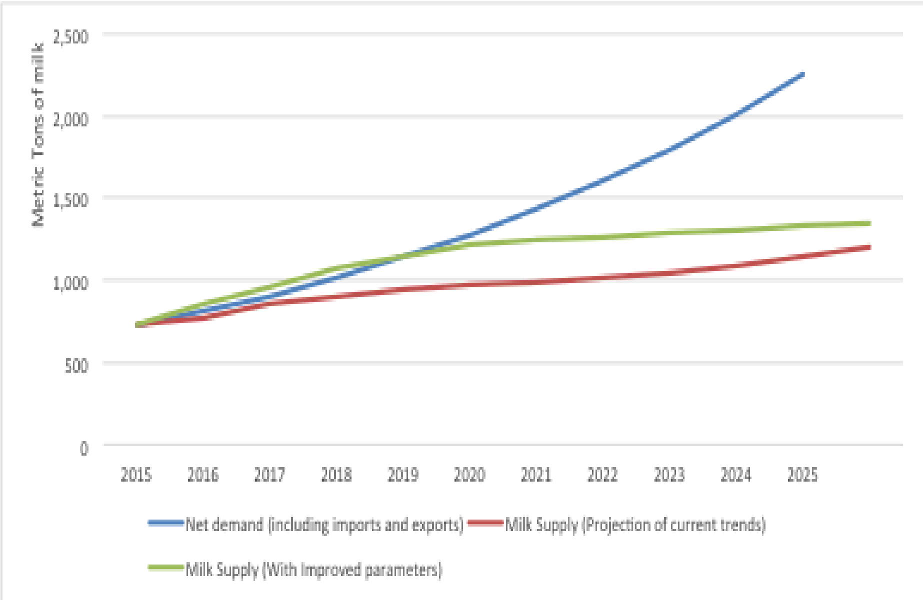

Fig. 3. Projected milk supply and demand from year 2015 to 2025 (Rwanda Dairy Development Project) Source: MINAGRI livestock, 2016

2 Background

2.1 Livestock production in Rwanda

2.1.1 Farming systems

There are four main dairy production systems in Rwanda.

i. *Extensive grazing system*. This system is common in the northern and western highlands and part of eastern province where land per household ranges from 5 to 25 hectare.

ii. *Semi-intensive system*. This system is prevalent in the eastern milk shed, which has the largest cattle population (40%) and relatively large land sizes per farmer that can be up to 25 ha and therefore adequate for forage production, compared to the national average of 0.33 ha/household. This system evolved from the traditional extensive communal grazing system following the introduction of land tenure laws with confinement regulations, which led to a major shift in husbandry and feeding practices.

iii. *Intensive system.* This system is ubiquitous in the country. Average herd size and cultivated land per household range between 2 to 5 animals. The most common feeding system is stall/zero grazing/cut-and-carry where animals are fed with forages, mostly *Pennisetum purpureum*. This system has received significant outreach among the poor through the Girinka programme and the communal kraal system.

iv. C*ommercial dairy farming system.* Also referred to as “modern” stockbreeding. They are concentrated mainly in the suburbs of Kigali and along the Kigali-Rwamagana highway. In this system, farmers raise large number of mostly purebreds or crossbreeds and most of these farms are managed by veterinary workers, and have large stocks of animal health products.

2.1.2 Cattle population and products

Rwanda has made tremendous strides in rebuilding its livestock sector in the last two decades since the 1994 socio-political crisis. Fig. 4 shows the trends in number of different species in the past ten years. The cattle population is estimated at about 1.3 million head of which 45% are indigenous breeds, 33% crossbreds and 22% exotic breeds. Total cattle population has increased more than twice from the pre-1994 level of below 600,000 heads. The country counts about 700,000 sheep, 2.6 million goats, 1.7 million pigs and about 5 million layers, broilers and indigenous chicken (MINAGRI, 2017).

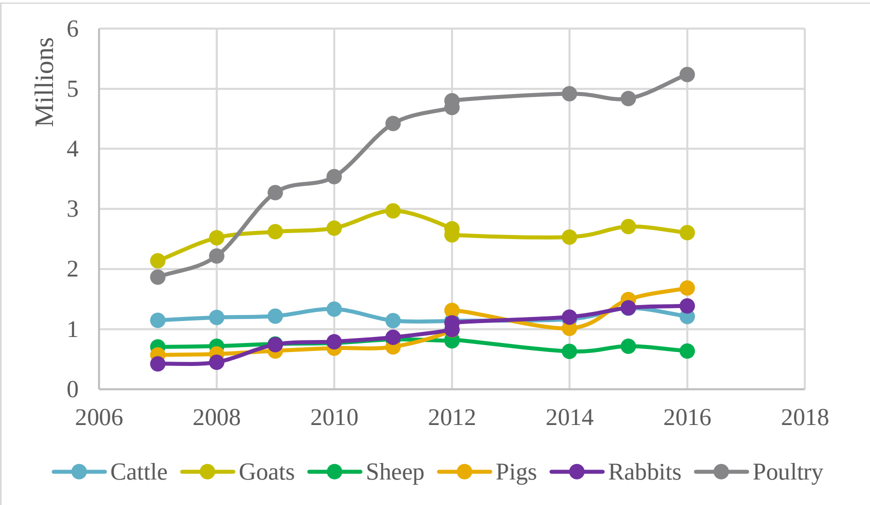

Fig. 4. Trends of number of animal populations across years (MINAGRI, 2017)

Similarly, in past decade a corresponding increase in trends of livestock products has occurred (Fig. 5). Despite the larger (45%) representation of local breeds to the national cattle herd, contribution to the total milk production (731,000 t) is only 13% and crossbreeds contribute 33% while the large balance 53% comes from pure exotic breeds (MINAGR, 2015). Most of the meat consumed in the country comes from cattle (46%, out of which 65% comes from crossbreed cattle), followed by swine (21%) while chicken, goat and sheep make up 17, 13 and 3%, respectively (MINAGR, 2017).

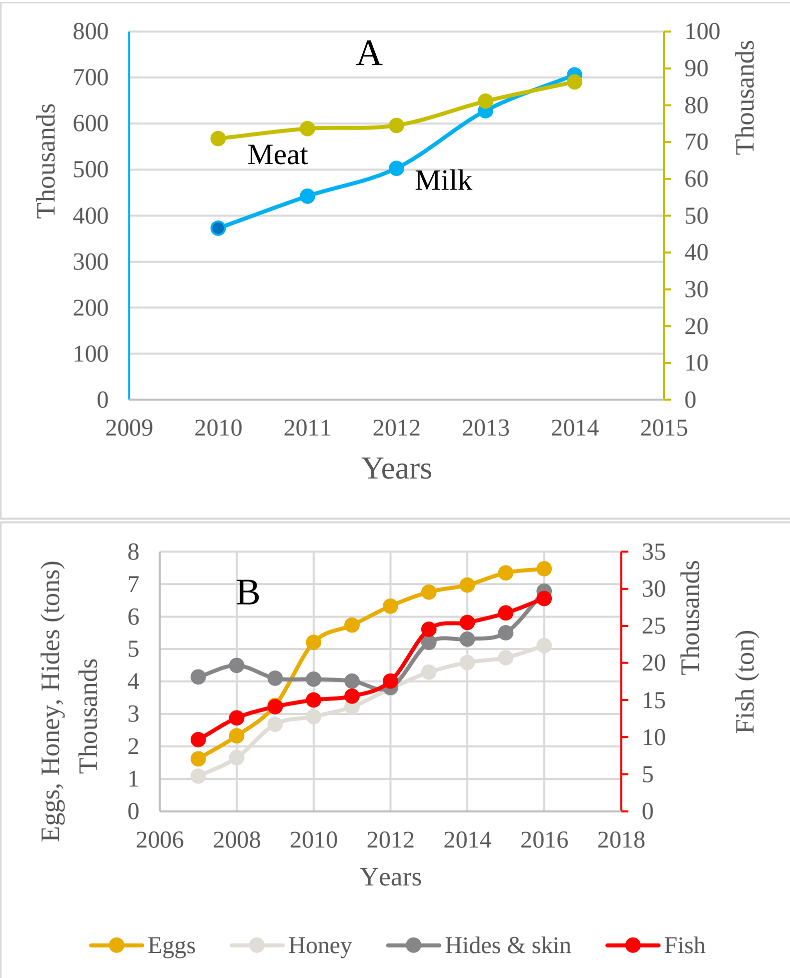

Fig. 5. Trends of milk and meat (A) eggs, honey, hides and skins, and fish (B) in Rwanda (tons) (NISR, 2017)

2.1.3 Cattle breeds and crossbreeding in Rwanda

Ankole cattle (commonly used as dam line)

The Ankole is an ancient breed belonging to the Sanga group of cattle in Africa and sometimes referred to as *Bos Africanus* (Fig. 6). It is an intermediate type of cattle believed to be the result of interbreeding between *Bos indicus* (lateral horned Zebu) and *Bos taurus* (Hamitic longhorn) breed type with a small cervico-thoracic hump and small unfolded dewlap (Sacker and Trail, 1966, Grigson, 1991). The breed with its ecotypes are indigenous to regions of Uganda, Rwanda, Tanzania, Democratic Republic of Congo and Burundi in the central and eastern Africa (Mwai *et al*. 2015, Rege and Tawah 1999). These ecotypes mainly go by the same tribal names as their owners, for instance the Watusi and Inkuku cattle from Rwanda and Bahima in Uganda (Ndumu *et al.*, 2008). The breed forms the majority of the indigenous breeds in the country, however, there exists other breed locally known as Inyambo, Bashi, Inkungu and Inkoromoijo (Hirwa *et al.,* 2017). Ankole have relatively large body frame and characteristically long, large horns that curve outwards and upwards. The common colours are brown, brown with white patches, black and red (Wurzinger *et al.*, 2006). It is highly adapted to adverse environmental conditions, including tolerance to heat (Hansen, 2004; Shabtay, 2015; Dossa and Vanvanhossou, 2016) and resistance to endemic diseases (Murray *et al.*, 1984; Mattioli *et al.*, 2000). The cattle breed can withstand periodic feed shortage better than the exotic breeds, based on the adaptive capacity to walk long distances in search of pasture and has got an added advantage of producing high quality beef (Taye *et al.*, 2017). Unfortunately, this desirable trait is not matched with the productivity traits of growth and lactation (Trail *et al.*, 1971). Like many other countries in the tropics there are no appropriate livestock policies and no due consideration is given to development of indigenous livestock breeds. Thus, there has not been any functioning breeding program to improve the Ankole cattle.

Exotic sire breeds and crossbreeding

To satisfy the demand for milk and meat the government of Rwanda has been implementing policies aimed at increasing livestock production through restocking with high yielding exotic breeds, producing crossbreds and improving animal husbandry practices. These policies have led to the transformation of the genetic structure of its national cattle herd from one dominated by local breeds, which in 2003 consisted of 86% local breeds, 13% crossbreds and 1% exotic breeds (MINAGRI, 2003) to the current structure where local breeds account for less than half (45%) of the cattle population and the rest are crossbreds (33%) or exotic dairy breeds (22%) (MINAGRI, 2016). The major driver of crossbreeding has been use of artificial insemination (AI). Despite the gains made in milk production under the current strategy, the decrease in number of indigenous breeds if continued unchecked would lead to eventual loss of genetic diversity that is important in mitigating any unpredictable change in socio- economic needs, environment conditions and production objectives (Hoffmann 2010).

The AI program is highly dependent on temperate breeds, notably the Holstein Friesian, Jersey and Brown Swiss for sire lines. These are known for high productivity under good conditions, but being susceptible to harsh environment. Also Sahiwal has been used but not on the same scale as temperate breeds (Fig. 6).

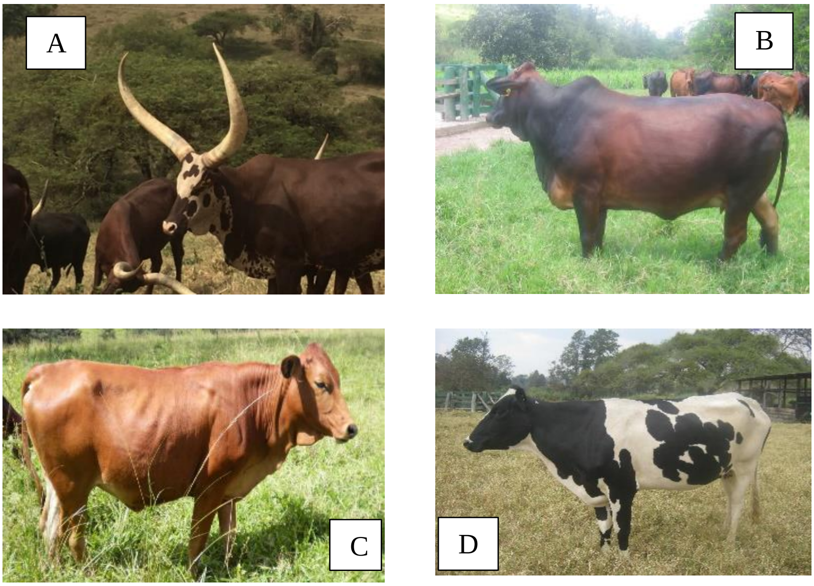

Fig. 6. Example of Ankole and crossbreds **A**. Ankole **B**. Ankole x Sahiwal **C**. Ankole x Jersey **D**. Ankole x Friesian (photos: Songa)

2.1.4 Gaps in knowledge

A crossbred is expected to have a better reproduction and productive performance than the average of the parent breeds, mainly due to heterosis effect. The additive effect of the temperate breed is expected to make the crossbred better than the local breed, especially for production traits. However, farmers rarely realize these benefits due to a number of challenges associated with feeding, veterinary care and other challenges in the production environment (Madalena *et al.*, 2002). There are also fears that indiscriminate crossbreeding and breed substitution creates a progressive disappearance of the indigenous animal genetic resources (AnGR), especially in the absence of efficient herd recording scheme to inform the national conservation program. Therefore, there is a need to ensure that the productivity gains associated with crossbreeding does not compromise conservation of AnGR, ecological integrity of the environment and social equity in the distribution of resources in the quest for improved economy and livelihoods. To date no systematic study of the outcomes of the current crossbreeding program has been carried out.

3 Aims of the thesis

The **general aim** of this thesis was to evaluate how effective crossbreeding could be for increasing productivity in meat and milk production, by assessing the performance of Ankole and its crossbreds with exotic breeds using records from research stations and farms in Rwanda.

Specific objectives include:

1. To compare body weight and growth rate from birth to 18 months of age of crossbreds of Ankole with Brown Swiss, Holstein Friesian, Jersey and Sahiwal.

2. To assess the reproductive performance of Ankole cattle and its crossbreds with Holstein Friesian, Jersey and Sahiwal.

3. To assess the daily milk yield, 100-day and 305-day milk yields, and lactation length of purebred Ankole cattle and its crossbreds with Holstein Friesian, Jersey and Sahiwal, and the influence of environmental factors on these traits.

4. To assess the productive performance of Ankole and its crossbreds and Holstein Friesian in different production environments of Rwanda.

4 Summary of the studies

This thesis consists of four papers. The first paper (I) was based on growth traits records collected at Songa research station. In two papers (II and III) records collected on reproduction and milk yield of different cattle genotypes at Songa, Rubona and Kinigi research stations were used. Data for Paper IV were from on-farm performance survey records collected from different agroecological zones.

4.1 Material and Methods

4.1.1 Study sites

The studies in paper I-III were conducted in Rwanda Agricultural Board (RAB) research stations. These stations are marked on the map in Fig. 7. RAB has the general mission of championing the agriculture sector development into a knowledge-based, technology-driven and market-oriented industry, using modern methods in crop, animal, fisheries, forestry and soil and water management in food, fibre and fuel wood production and processing. The fourth study (Paper IV) was carried out using survey data collected from four agroecological zones of Rwanda (Fig. 1).

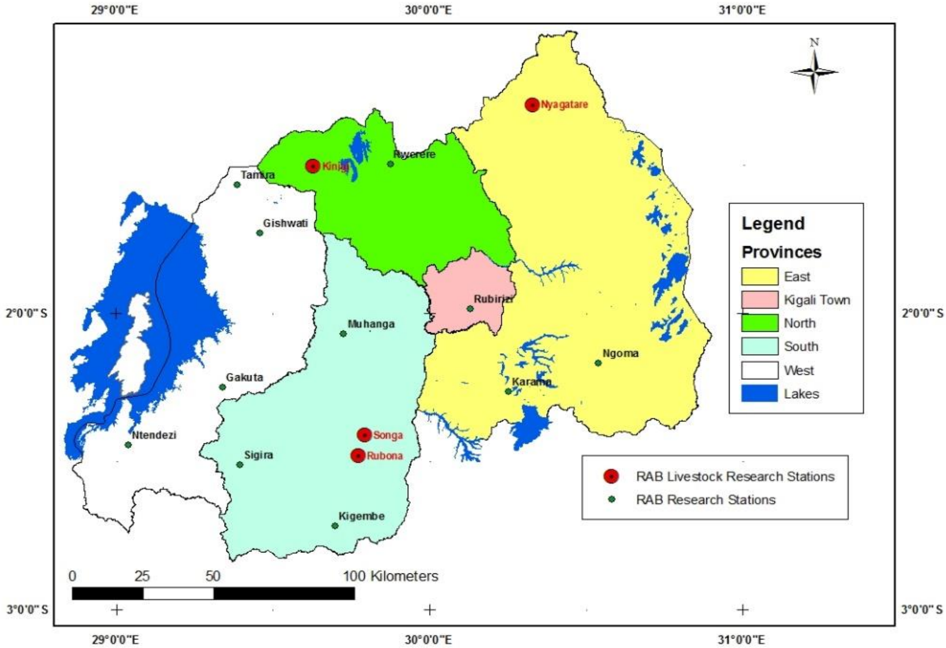

Fig. 7. Map of Rwanda showing the location of RAB livestock research station (Source: RAB)

The climate at all stations is characterized by wide fluctuations in quantity and distribution of rainfall within and across seasons. The rainfall pattern is bimodal with short rains (season SRS) falling between September and December and long rains (season LRS) extending from March through May. The dry seasons extend between June and August (LDS) and January to February (SDS).

4.1.2 Animal and herd management

For studies I-III animals had similar management and were from a crossbreeding program that was initiated in 1999 based on a foundation stock of dam lines of indigenous Ankole cattle and their female progenies that were inseminated with Brown Swiss, Holstein Friesian, Jersey and Sahiwal semen. Heifers were served by artificial insemination (AI) at between 18–24 months of age depending on age at first oestrus. Heat detection was based on observations and reports from trained herdsmen and technicians. Pregnancies were confirmed by rectal palpation and repeat breeders were inseminated accordingly. Records of individual animals born in the herd were established at birth. The records included identification of dam and sire, date of birth, birth weight, and monthly weights until the animal was sold or died. The calves were dehorned by cauterization. Most female calves were retained for replacement and others sold to private farmers for breeding. Most male calves were castrated using a burdizzo at the age of 2–3 months and sold for slaughter after six months at the earliest, based on the demand. Some male calves were sold to farmers as yearlings as breeding bulls. Weaning was done in groups when calves were about 8–13 months of age based on subjective judgment of vigour and ability of the calves to survive without milk. Partial milking was practiced, whereby calves suckled briefly to stimulate milk let-down and after milking were allowed to suckle residual milk. Culling of cows was based on subjective opinion of old age (e.g., loss of teeth) and infertility. Animals were kept on pasture and only calves were kraaled.

Animal grazed on paddocked natural pasture without any form of supplementary feed. Routine veterinary attention was provided to each animal. The animals (except young calves) were sprayed twice per week to control ectoparasites using recommended formulations of acaricides on the market. Antihelminths (mainly Albendazole) were used against endoparasites especially in the wet season (after the rains). Vaccinations against notifiable diseases (FMD, Anthrax, CBPP and Blackleg) were implemented upon notification of impending threats by competent authority of RAB.

Management of animals in paper IV varied depending on feed availability under both intensive and semi-intensive management systems. The feed included natural pasture (cut-and-carry), hay, milling by-products, concentrate mix and non-conventional feeds. Cows were hand-milked twice per day. Animals were watered from piped water and mineral licks were provided ad libitum. Both natural mating and artificial insemination were used for breeding cows.

4.1.3 Data collection

Growth traits (paper I)

Data used in this study were obtained from crossbred calves born from 1999 to 2007 of Ankole (A) or crossbred dams (AJ and AS) with Brown Swiss (B), Holstein Friesian (F), Jersey (J), and Sahiwal (S) sires (semen). For each calf, records included breed group, sex, dates, and weights from birth to 18 months of age. Weight records were taken monthly using weight balance, but for this study, the following weight traits were analysed: (a) birth weight (BW) recorded within 24 h of birth, (b) weight at approximately 8 months (W8), (c) weaning weight (WWadj) adjusted to 10 months, (d) weaning weight unadjusted (WW), and (e) weight around puberty recorded at 18 months (W18). Furthermore, we analysed the following growth rate traits: (a) average daily gain to 8 months (ADG8), computed as (W8-BW)/AGE8, (b) pre-weaning average daily gain (ADGW, from birth to weaning) computed as (WW-BW)/ AGEW, (c) post-weaning average daily gain (ADG18, from weaning to 18 months) computed as (W18-WW)/(AGE18- AGEW), where AGE8 (AGE18) is the age of the animal at the monthly weighing closest to 8 (18) months of age and AGEW is the recorded age at weaning. Furthermore, we investigated the trait age at weaning (AGEW).

Reproductive traits (paper II)

Reproductive performance records were from purebred Ankole (AA) and crossbreds with Friesian (F), Jersey (J), and Sahiwal (S). The data recorded for each animal included: breed group, date and time an animal was observed in heat, estrus type (induced estrus by PGF2α or natural estrus), date and time the cow was inseminated, service sire, and AI technician. Conception rate (CR) was based on the success or failure of individual first inseminations. Calving interval (CI) was estimated as difference in days between two successive calvings. Calving to first service interval (CFI) and calving to last insemination (CLI) were calculated as days elapsed between calving and first insemination or last insemination, respectively. Number of inseminations (NINS) per series was calculated by defining a series when inseminations were within 56 days of each other. Factors studied affecting these traits were the effect of breed group, season of AI (for CR) or calving (for CFI, CC, and CI), four season classes (SDS, LRS, LDS, SRS), and year of insemination.

Milk production traits (paper III)

Daily milk yields were recorded from 1999 to 2017 in Songa station and from 2013 to 2017 in Rubona and Kinigi stations. In total there were records from 865 cows and 1234 lactations. Average daily milk yield (DMY) was the total accumulated milk yield divided by the number of days milked. Early lactation yield (100-day, MY100) and standardized lactation yield (305-day, MY305) were calculated only for those cows that had their first day in milk (DIM) before day 28 after calving and had at least 100-day or 305-day lactations, respectively. Lactation length (LL) was also calculated and to evaluate if LL had an effect on DMY the correlation between these traits was estimated in this data set.

Milk production in different agroecological zones (paper IV)

The survey was conducted by University of Rwanda students as interviews in year 2013. The respondents were either owners or manager of the dairy farm. The survey technique was a single-visit multi-subject approach (ILRI, 1990). The structured questionnaire was used to collect information based on owners' recall. Daily milk yield was reported.

4.1.4 Statistical analysis

The difference between variables was considered statistically significant at $P < 0.05$ (all papers). All statistical analyses were carried out using the SAS software (2012).

Effects of breed group, sex, year and season of birth (paper I) were analysed using General Linear Models procedure (Proc GLM). Least Square Means (LSM) were computed to estimate differences among means of traits for different factors.

For paper II, the effects that were found to be significant were included in the final model for each trait. Conception rate (CR) was analysed using a logistic regression in Proc GLMMIX with a logit link function, whereas for CFI, CLI, NINS, and CI, a fixed linear model using Proc GLM was used.

In Paper III, analysis was performed for the effects of breed group, season and year of calving, and parity for all traits using a fixed linear model in PROC GLM.

The statistical analysis of data from the survey (Paper IV) was carried-out using Proc GLM. The model included fixed effects of breed group and the location (Province) and their interaction.

4.2 Main findings

Results from the analysis of the growth traits (paper I) showed AJ calves to be significantly lighter at birth (25.8 kg) than the other breed groups, which did not differ from each other (27.5–28.4 kg) (Table 1).

For WWadj, AB and AF were heavier than the other four groups (AJ, AS, AJxS, and ASxJ); however, without adjustment for weaning age, AF was significantly heavier than all other breed groups. Furthermore, AB, ASxJ, and AJxS did not differ significantly from each other but were all heavier than AJ and AS. For W8, the same tendency could be seen but only AB was significantly different from the last four breed groups (Table 1).

At 18 months, AF was heavier than AJ, AS, and also AB. Although AJxS and ASxJ were approximately 14 and 11 kg lighter than AF, respectively, the difference was not significant (Table 1).

Table 1. Least square means by breed group, sex and season for pre- and post-weaning traits of Ankole crossbreds. N=424-811 animals

	Trait[2]								
Factor[1]	BW	W8	WW_{adj}	WW	W18	ADG8	ADGW	ADG18	AGEW
Breed group									
AB	27.9[a]	132.2[a]	172.7[a]	167.7[b]	203.4[c]	0.435[a]	0.458[a]	0.315[b]	307.3[c]
AF	28.4[a]	126.4[ab]	173.5[a]	182.0[a]	237.7[a]	0.413[ab]	0.433[ab]	0.395[a]	353.8[a]
AJ	25.8[b]	118.4[dc]	152.8[b]	153.1[c]	218.4[bc]	0.387[bc]	0.396[c]	0.341[b]	325.7[bc]
AS	27.5[a]	122.7[bc]	156.1[b]	151.8[c]	219.2[bc]	0.398[b]	0.400[bc]	0.351[b]	310.0[c]
AJxS	27.7[a]	115.7[d]	159.3[b]	165.1[b]	226.9[ab]	0.368[c]	0.399[bc]	0.357[ab]	343.3[ab]
ASxJ	27.5[a]	123.1[bc]	159.2[b]	164.5[b]	223.5[ab]	0.398[b]	0.398[c]	0.359[ab]	345.7[a]
Sex									
F	27.0[a]	119.5[a]	161.3[a]	164.9[a]	229.5[a]	0.386[b]	0.412[a]	0.393[a]	339.3[a]
M	27.9[b]	125.9[b]	165.2[a]	164.6[a]	216.9[b]	0.410[a]	0.429[a]	0.333[b]	323.2[b]
U	27.5[a]	123.9[b]	160.3[a]	162.6[a]	218.2[b]	0.402[ab]	0.400[a]	0.332[b]	330.4[ab]
Season									
SDS	26.5[a]	121.2[b]	162.2[ab]	166.8[a]	228.2[a]	0.395[a]	0.411[a]	0.384[a]	340.8[a]
LRS	28.1[b]	126.7[a]	166.1[a]	169.9[a]	210.3[b]	0.411[a]	0.421[a]	0.314[c]	336.6[ab]
LDS	28.2[b]	123.3[ab]	163.1[ab]	162.5[ab]	220.9[a]	0.398[a]	0.418[a]	0.342[b]	325.1[ab]
SRS	27.0[a]	121.3[b]	157.7[b]	156.9[b]	226.6[a]	0.394[a]	0.406[a]	0.372[a]	321.4[b]

[1]AB=Ankole x Brown Swiss, AF=Ankole x Holstein Friesian, AJ=Ankole x Jersey, AS=Ankole x Sahiwal, AJxS=AJ x Sahiwal, ASxJ=AS x Jersey; F=Female, M=Male U=Calves with unknown sex;
SDS= Short Dry Season (Jan-Feb), LRS= Long Rainy Season (Mar-May), LDS= Long Dry Season (Jun-Aug), SRS=Short Rainy Season (Sep-Dec).
[2]BW= Birth weight (kg), W8=weight (kg) at 8 months of age, WWadj= weaning weight adjusted to 10 months, WW=weaning weight (kg), W18= Weight (kg) at 18 months, ADG8=average daily gain (g) to 8 months, ADGW=pre-weaning daily gain (g), ADG18= post-weaning daily gain (g) up to 18 months, AGEW = age at weaning (days). Mean values with different letters are significantly different ($P<0.05$)

The study on reproductive performance (Paper II) revealed the average CFI to be 192 days (n = 797, SD = 87) and the average CLI was only slightly longer 198 days (n = 797, SD = 88). Breed group (AA, AF, AJ, AS, and FF) and season had significant effect on both traits, whereas time period and station did not. Purebred Ankole had longer CFI and CLI than all other breed groups, except for AF; the latter had longer intervals than FF (Table 2). The estimate for AF was based on very few animals and might therefore not be representative for that cross.

The overall mean CR was 0.67 (n = 4354, SD = 0.47). The factors breed group (AA, AF, AJ, AJxS, AS, ASxJ), year of insemination, and technician were significant in the logistic model. There were too few FF to be included in the analysis. The genotype AF had higher CR than the purebred Ankole and AS, and AS had lower CR than AJxS and AJ (Table 2). Significant variation was observed in results among technicians. The difference between the lowest and highest technician was more than 20 percentage units.

The overall mean calving interval observed was 479 days (n = 259, SD = 103). Ankole had about 54 days longer CI than the crossbreds (LSM 498 (SE 7.7) vs 445 (SE 10.8). The season of calving had significant effect on CI. Significantly lower CI were observed in LDS (442 days) compared to SDS (486 days) and SRS (495 days); however, SDS and SRS did not differ among each other (Table 2).

Table 2. Number of observations and least square (marginal) means for breed groups and seasons from the linear models or logistic regression (for CR) for intervals from calving to first or last insemination (CFI, CLI, both having the same number of observations), calving interval (CI), and conception rate (CR).

	Trait[2]						
Factor [1]	N	CFI	CLI	N	CI	N	CR [3]
Breed group							
AA	636	202[a]	208[a]			2480	0.71[bc]
AF	14	204[ab]	207[ab]			282	0.78[a]
AJ	60	170[b]	176[b]			585	0.73[ab]
AJxS		-	-			221	0.75[ab]
AS	60	156[bc]	163[bc]			567	0.67[c]
ASxJ		-	-			219	0.71[bc]
FF	19	120[c]	131[c]				
Season							
SDS	127	189[b]	197[a]	48	486 [a]		
LRS	237	172 [ab]	179[ab]	84	462 [ab]		
LDS	200	190 [a]	170[bc]	62	442 [b]		
SRS	225	157 [a]	163[c]	65	495 [a]		

[1]AA=Pure Ankole, AF=Ankole x Holstein Friesian, AJ=Ankole x Jersey, AS=Ankole x Sahiwal, AJxS=AJ x Sahiwal, ASxJ=AS x Jersey, FF= Pure Holstein Friesian;
SDS= Short Dry Season (Jan-Feb), LRS= Long Rainy Season (Mar-May), LDS= Long Dry Season (Jun-Aug), SRS=Short Rainy Season (Sep-Dec).
[2]N= Number of observations, CFI= Calving to first insemination, CLI= Calving to last insemination, CI= Calving interval, CR= Conception Rate
[3] Values transformed back to the original scale.
[abc]=Mean values within breed group or season with different letters are significantly different ($P<0.05$)

The estimated effects of breed group, season, year of calving, and parity on milk yield from Paper III are shown in Table 3. Breed group effect was significant for all four traits. Breed group AA had the lowest average milk yield; AA also tended to have longer lactation length. Among the crossbreds, there was no significant difference in milk yield between AF, AJxS and ASxJ, nor between AS and ASxS.

Calving season had significant effect on DMY, MY100 and LL. The pattern was similar for the three milk yield traits, with cows calving in SDS having the highest yield, albeit not always significantly different from all other seasons.

The year of calving-effect was significant for all four traits. The general pattern was the same for all yield traits, however, for DMY and MY100 the highest year group was 2001-2003, whereas for MY305 the highest was 2014-2016. The lowest year group tended to be 2007-2009.

Parity of cows significantly influenced all yield traits and LL. In general, there was an increase in yield from first to fourth parity, followed by a decline in the fifth.

The survey study (Paper IV) revealed a significant difference in the overall average milk yield between AF (8.6 L) and FF (14 L). Among zones, Eastern plateau agroecological zone recorded highest milk yield which was estimated at 14.9 L/cow/day compared to 9.4, 9.2 and 8.5 L/cow/day in BAZ, CPAZ and WAZ respectively. This is contrary to our expectation, because BAZ and WAZ receives more annual rainfall, hence good pasture level compared to EPAZ. This could have been due to differences in input management levels between zones.

Table 3. Least square means for daily milk yield (DMY), milk yields at 100 and 305 days of lactation period (MY100, MY305) in litres, and lactation length (LL, days) for breed group, season, year of calving, and parity.

	Trait			
Factor[1]	DMY	MY100	MY305	LL
Breed Group				
AA	2.0[a]	174[d]	553[a]	302[a]
AF	4.7[b]	468[a]	1383[b]	281[a]
AJ	3.9[c]	411[b]	1182[c]	278[a]
AJxS	4.7[b]	463[a]	1486[b]	230[b]
AS	3.3[d]	319[c]	954[d]	283[a]
ASxJ	4.4[b]	435[ab]	1383[b]	270[ab]
ASxS	3.3[d]	328[c]	815[d]	274[ab]
Season				
SDS	3.9[a]	392[b]	1128[a]	294[a]
LRS	3.6[b]	366[b]	1102[a]	277[ab]
LDS	3.7[b]	361[a]	1093[a]	260[b]
SRS	3.8[ab]	364[b]	1108[a]	264[b]
Year				
1998-2000	3.7[ab]	360[bc]	1092[b]	275[a]
2001-2003	4.0[a]	402[a]	1150[ab]	297[a]
2004-2006	3.7[ab]	367[b]	1053[b]	291[a]
2007-2009	3.5[b]	338[c]	1025[b]	220[b]
2014-2016	3.9[a]	387[ab]	1218[a]	286[a]
Parity				
1	3.2[d]	324[d]	989[c]	267[b]
2	3.5[c]	340[cd]	1083[ab]	284[ab]
3	3.7[cb]	380[b]	1061[b]	301[a]
4	4.0[b]	385[b]	1240[a]	255[b]
5+	3.5[c]	355[cb]	1074[b]	263[b]
Unknown	4.6[a]	442[a]	-	-

[1]AA=Pure Ankole, AF=Ankole (50%) x Holstein Friesian (50%), AJ=Ankole (50%) x Jersey (50%), AS=Ankole (50%) x Sahiwal (50%), AJxS=Ankole (25%), Jersey (25%) x Sahiwal (50%), ASxJ=Ankole (25%), Sahiwal (25%) x Jersey (50%), ASS= Ankole (25%) x Sahiwal (75%); SDS= Short Dry Season (Jan-Feb), LRS= Long Rainy Season (Mar-May), LDS= Long Dry Season (Jun-Aug), SRS=Short Rainy Season (Sep-Dec).
[abcd]=Mean values in a column with different superscripts differ significantly ($P<0.05$)

5 General discussion

This thesis describes the productive and reproductive performance of Ankole cattle and its crossbreds using data collected from RAB research stations and survey data collected from different agroecological zones.

The potential of the country's livestock subsector is very high given Rwanda's comparative advantage in the region in terms of agroecological conditions and strategic location. Since 1999, milk production has been increasing rapidly (NISR, 2017). Therefore, dairy has been identified as one of the best and most profitable investment areas; it generates income from sales of milk, improves nutrition through consumption of dairy products, and improves crop production using manure.

The livestock sector's production potential is not, however, fully realized owing to constraints related to breeding, feeding, health and management. The information on cattle breeding is scant due to lack of a performance recording scheme. This makes regular monitoring of the performance at herd and national level impossible. This ultimately leads to lack of information to support decision making on breeding policies and insufficient management practices at farm level.

However, at RAB research stations, a crossbreeding project was initiated in 1999 involving three exotic breeds, Holstein Friesian, Jersey, and Brown Swiss in addition to local Ankole cattle, to develop a dual-purpose breed for milk and meat production, for the smallholder farmer. Although no synthetic breed was formed, the substantial amount of data generated has been analysed to determine the outcome of this program on growth, reproduction and milk yield of Ankole and its crossbreds at different stations.

5.1 Data collection and quality

Altogether, data were available from 1999 to 2017, however, there were gaps in the time sequence (Fig. 8). Growth records were only available from 1999 through 2007. Insemination records were the most complete, but there were two years, 2011-2012, missing. Calving records had an even larger gap, from 2005 to 2013. Milk yield records used in Paper III had a complete gap between 2010 and 2014 but also a period with only partial records during 2001-2002 (Fig. 9).

This had consequences for the construction of traits, most severely for milk yield and lactation length traits, but also for several of the reproductive traits. In order to create, say, MY305, it was necessary to restrict the data to lactations that started at least 305 days before any gap. The gaps also have consequences if one wants to analyse several traits together, e.g., milk yield and growth of calves or fertility. This is a serious quality issue to address for consistent data capture, archiving, retrieval and processing for generating information and knowledge needed for desired genetic progress.

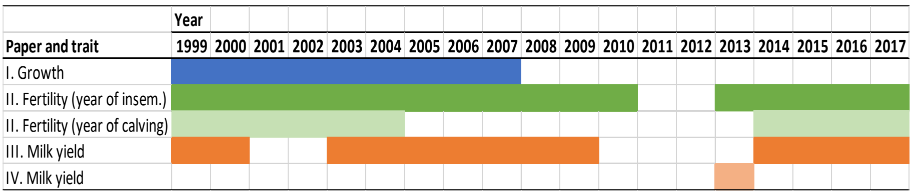

Fig. 8. Graphic description of availability of data for analysis in Papers I-IV.

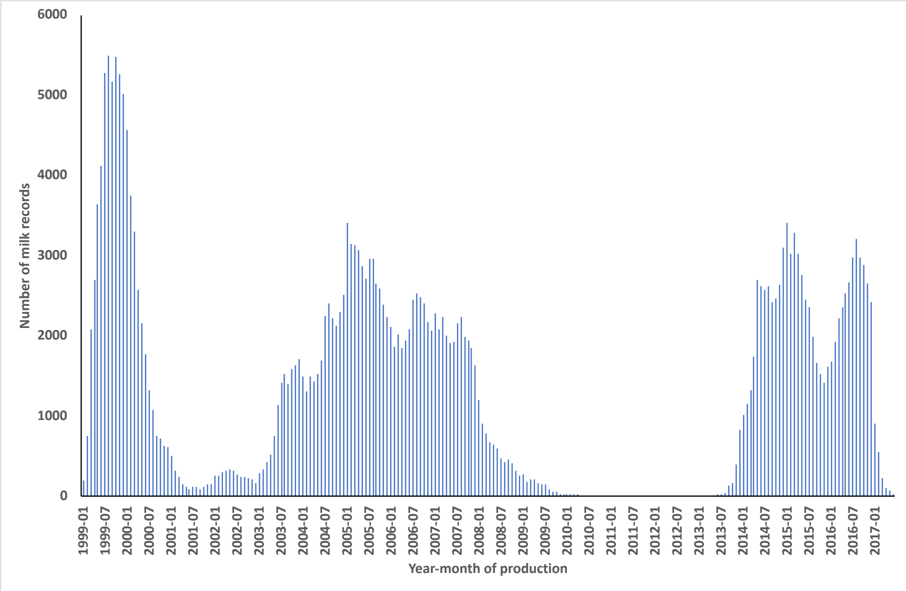

Fig. 9. Frequency of daily milk yield records for various year-months.

5.2 Growth traits (Paper I)

Growth rate is of major economic importance for the beef industry and the first trait to receive selection emphasis in beef cattle breeding due to its expression, ease of measurement and positive association with a profit per unit change in the growth rate (Parnell *et al.* 1994; Proyaga, 2003). In Rwanda, there is no specialized breed kept for beef and 46% the total meat consumed in the country comes from cattle, out which 65% comes from crossbreeds (MINAGRI, 2017), hence studying growth traits of these animals is important in order to know their growth performance.

In the analysis of the growth traits, generally, the trends for the average daily gain traits followed those for the weights; AB and AF had higher average daily weight gain, but these differences were not always significantly different from the other four breed groups. A general trend was that the daily weight gain reached maximum at or before weaning and decreased thereafter up to 18 months. AF and AB calves performed similarly in daily weight gain up to weaning, however, at 18 months of age, AF outperformed AB significantly (Table 1).

In general, AB seems to do very well during the first 8 or 10 months, as well as or better than the AF cross. However, after weaning, growth decreased and the W18 was the lowest among all breed groups. By that time, AF was heaviest. Since the weaning age for AF was higher than for AB, the actual weight at weaning for AF was higher than all other breed groups. Because the time for weaning is decided subjectively, based on the perceived ability of the calf to survive without milk, it is difficult to know if this higher weaning age for AF is truly warranted and based on previous experience. If AF calves really need to be older (and thus heavier) when weaned, it would be interesting to find out why this would be true. Do they have more problems in grazing than the other breed groups, and if so, why? This would require a more dedicated study with predetermined weaning ages and possibly also studies of grazing behaviour.

It should be noted that the mothers of AB and AF (and of AJ and AS, of course) were pure Ankole, whereas the mothers of AJxS and ASxJ were crossbred. From Paper III, it was shown that the milk offtake from AJ and AS cows was about 630 and 400 kg higher than that of AA females over 305 days, respectively. The higher milking potential of their mothers disregarding, the AJxS and ASxJ calves were lighter at weaning than AB and AF, indicating that the "genes of the calf" are more important than the "genes for milk" of the mother. However, ASxJ were heavier at weaning than AJ, and AJxS were heavier than AS. In both cases the calves are 50% J (or S) so possibly the difference in weaning weight could be due to the higher milk production of the (crossbred) mother.

It was possible to match some of the F_1 calves (AB, AF, AJ, and AS, Paper I) to their mothers' average daily milk yield (Paper III) during the calves' year of birth. However, there was no statistically significant different DMY for these groups of mothers (all being AA). Therefore, the higher growth of, say, AF calves does not seem to be an effect of higher consumption of milk from their mothers (which should show up as a lower milk offtake).

Even though the AF cross was the heaviest at 18 months, the superiority compared with, say, AJ was only about 20 kg. The difference in body weight for purebred Holstein Friesian and Jersey at that age would be expected to be in the range of 130 - 139 kg under good conditions (e.g., Heinrichs and Hargrove, 1987), which would lead to an expected difference between AF and AJ of 65-70 kg, disregarding any heterosis. The rather small differences between breed groups in this study is probably due to that the environmental conditions (e.g., feed, but also temperature and humidity stress) do not allow for the full expression of the genetic potential for growth in the exotic crosses.

5.3 Reproductive traits (Paper II)

The CFI values (120-204 days) recorded in this study (Table 2) were longer than the recommended 45-60 days considered optimum to achieve an annual calf crop target. The reasons for the delay could be postpartum anestrus as result of poor nutrition and suckling management (Diskin *et al.*, 2003, Robinson *et al.*, 2006). In Paper I (the Songa herd) it was seen that calves were weaned subjectively between the ages of eight and thirteen months. Prolonged suckling stimulus could delay resumption of ovarian cycle by interfering with hormones responsible for follicular development (Thatcher *et al.*, 2006). Therefore, better management practices including earlier weaning and restricted suckling could overcome this deficiency by shortening number of days open, leading to reduced calving intervals. However, care must be taken so that this does not shorten the lactation length and thereby decreases milk yield.

Compared to CLI values (131-208 days) obtained in our study, in a review by Nuraddis and Ahmed (2017) reported lower, comparable and higher calving to conception intervals that ranged from 120 to 316 days for crossbreeds of Holstein Friesian x Zebu, Holstein Friesian x Horro and Holstein Friesian x Arsi in Ethiopia and in the same review a CFI of 165 days for Friesian x Zebu was also reported.

There were very few AF cows (N=14) with information on calving dates, such that CFI and CLI could be calculated, so the result that their

CFI and CLI were similar to those of AA may not be representative of a larger sample. Also, the small difference between CFI and CLI indicates that a large proportion became pregnant at first insemination, as shown by the high CR. Actually, if CFI is 202 days (as for AA) then the expected CLI with a CR of 0.71 (and a cycle of 21 days) is 210 days, so the actual CLI of 208 days is not unrealistic.

The CR in study II ranged from 67 to 78 % for different breed groups (Table 2). Tahmina *et al.* (2016) reported comparable CR (76%) for the crosses of Holstein Friesian and local breeds in Bangladesh, while in the same country, Khan *et al.* (2015), reported conception rates of 64% in native cattle, 57% in Friesian cross and 53% in Sahiwal cross. In Ethiopia, Debir *et al.* (2016) in a study of AI efficiency, reported conception rates in indigenous (54%, N= 98) and crossbred cows (70% N=69).

Some authors, as in our study, have reported inter-technician variability in CR. For example, Siddiqui *et al.* (2013) reported significant effect of technician on the conception rate in smallholder farms in Bangladesh with the difference between the highest (58.6%, N=512) and the lowest (43.4%, N=281) being 15.2% units. Also, Miah *et al.* (2004) in the same country, reported significant effect of AI technician on conception rate that varied based on experience, with average conception rates of 56, 67, and 68% in cows inseminated by technicians with 1-2, 2-3, and 3-5 years of experience, respectively. Even though no recent publications on the reasons for differences between AI technicians exist, in New Zealand, Visser *et al.* (1988) reported 19% of the explained variation in conception rate to be attributed to the individual AI technician. Barth (1993) in a study on factors affecting fertility with AI in North America cited personal qualities or personal problems as possible reasons for differences in performance between individual technicians.

The length of post-partum anestrus and service periods are part of the calving interval that can be shortened by improved herd management. To achieve a calving interval of 365 days, days open should not exceed 80-85 days (Nuraddis and Ahmed, 2017). The mean CI (480 days) obtained in the present study is not within the range (365-420) considered optimal for tropical cattle breeds (Aboagye, 2002). The extended CI seems mainly to be the result of prolonged interval from calving to first service. A longer calving interval affects overall life time production and reproduction performance through fewer calves being born. In Mexican tropical environment Segura-Correa *et al.* (2017) reported long CI of 446 and 481 days for Brahman and Guzerat, respectively, and attributed this poor performance to tropical conditions, such as heat stress and poor quality pasture, that limit the reproductive functions of cows. Vinothraj *et al.* (2017) reported CI of 489 days for crossbred Jersey and Red Sindhi in India, while in Ethiopia Nuraddis and Ahmed (2016) reported even longer CI (630 days) for crosses of Friesian and Zebu. In Ghana, Samuel and Julius (2014) recorded shorter CI (413 days) for Sanga and crossbreds of Sanga with Friesian.

5.4 Milk yield traits (Papers III-IV)

The performance of a dairy cow is judged from the milk it produces during a specified period of lactation. The lactation performance is usually measured by determining total milk yield per lactation or per year, average daily milk yield over a certain time, and lactation length (Wondifraw *et al.*, 2013).

The daily average milk offtake (2.0 L) for AA obtained in this study was in the range of averages reported by other authors. For instance, studies conducted in Uganda reported average DMY for AA under the same management of extensive grazing on natural pasture with no supplementation to range from 1 to 2.5 L/cow (Galukande., 2010; Kugonza *et al.*, 2011). The average milk (4.7 L) obtained in Paper III for AF (50% Friesian) is lower than the 5.6 L reported for the same genotype investigated in selected farms in Uganda (Galukande, 2010). In Ghana, Darfour-Oduro *et al.* (2010) found a significant but small difference between Sanga (1.1 L) and Sanga x Friesian (1.4 L) animals raised under agropastoral system. In a study of the performance of Ankole x Friesian cross with different Friesian blood levels in the Democratic Republic of Congo, Kibwana *et al.* (2015) reported DMY of 4.8, 5.5, and 5.4 L in groups with 25, 38 and 44% Friesian blood levels, respectively, in control group vs 5.8, 7.0 and 7.8 L, respectively, in groups with supplementary feeding. Compared to the 3.9-4.7 L DMY observed in Paper III for AJ, AJxS and ASxJ, respectively, Hatungumukama *et al.* (2009) in Burundi reported DMY of 5.1 and

4.8 L for breed groups of SJA (50-75% Sahiwal, 12.5% Ankole, 12.5-37.5% Jersey) and JSA (62.5% Jersey, 25% Sahiwal and 12.5% Ankole), respectively.

Paper IV and Kibwana *et al.* (2015) in Democratic Republic of Congo demonstrate that cows fed with supplements record higher milk yield. In paper IV, farms where improved nutrition was practiced had overall average daily milk yield for AF (8.6 L) compared to 4.7 L from non-supplemented cows of the same genotype (Paper III**).** The large variation in performance of Holstein Friesian and its crossbreds in in different agroecological zones (Paper IV) indicates that considerable improvement could be achieved by improving the production environment.

The MY305 obtained in Paper III was significantly different between Ankole and its crossbreeds (Table 3). In Ghana, Darfour-Oduro *et al.* (2010) reported MY305 for Friesian-Sanga cross and Sanga cows raised under agropastoral system to be 339 and 244 kg, respectively, which is lower than the average obtained in our study. In a review by Poonam *et al.* (2016) several authors reported MY305 of crosses of Holstein Friesian with Indian breeds, with dams supplemented, hand milked and calves bucket fed, ranging from 1707 to 3027 kg. In Sahiwal and its crosses, MY305 ranged from 1633 to 1894 kg. The lower yields in our study are probably due to poor nutrition coupled with suckling calves and lack of supplementation.

Lactation length influences the total milk yield per year and per lactation. In most modern dairy farms, a lactation length of 305 days is commonly accepted as a standard. However, in our study some cows were not milked for a full 305 days because they went dry or the lactation terminated for some other reason, and others were milked longer than 305 days. The average LL obtained varied among breed groups (Table 3) and these were in the range of what has been reported by other authors for tropical breeds and crossbreds. For instance, in a study conducted in Ghana, Sanga and Friesian-Sanga crossbred cows were reported to have a LL of 164 and 201 days, respectively (Darfour-Oduro *et al.*, 2010). Metekia and Nezif (2017) reviewed the status of dairy cattle production in Ethiopia and reported mean LL for Holstein Friesian x Zebu crossbred animals to be in the range of 276 - 325 days. Kugonza *et al.* (2011) reported lactation length of 255 days for Ankole cattle in Uganda. An extended lactation period has been reported to have practical significance for the smallholder dairy farmer as it provides compensation for the usually extended calving interval (Tanner *et al.*, 1998).

The profitability of short or extended lactation length depends on various factors, including the lactation length persistency. Numerous studies have documented that additional days in which cows are not pregnant beyond the optimal time post calving are costly (Groenendaal *et al.*, 2004; Meadows *et al.*, 2005). However, Borman *et al.* (2004) demonstrated that extended lactations are suitable for some dairy enterprises and that the suitability depends particularly on cow milk potential, the ability to grow pasture or feed supplements economically, management expertise, environmental constraints, herd size and labour availability. Thus, it is of interest to properly evaluate the economic benefits and subsequently optimize both the lactation length and calving interval under the given production level and prevailing management conditions in Rwanda.

Owing to the gaps in data availability (Fig. 8), we could not estimate LL from all calvings. We determined that there were two gaps, one (partial) gap starting around 2001 and another more complete gap starting 2009. We therefore required an opportunity time of 500 days before the beginning of these two gaps, and also before the end of our data recording in 2017. This would allow for a LL of at least 500 days. The weak correlation (-0.08) between DMY and LL in our study suggests that the performance of breed groups in terms of milk yield arguably was not associated with lactation length. We attempted to estimate parametric lactation curves for individual cows, with the intention to extend lactation shorter than 305 days. This was, however, unsuccessful, mainly owing to the large variation in lactation curve shapes, which made commonly used functions unsuitable. However, when average daily yields were calculated for different breed groups (Fig. 10), it could be seen that AF and AJ showed a decrease from a higher value early in lactation to a plateau of around 5 or 3.5 kg, respectively. The yield dropped further for AF after around 300 days and for both breeds almost all cows stopped milking after 350-400 days. AS also had a small decline in the first 50-100 days but then kept an steady yield of about 3 kg. Pure Ankole kept almost the same yield of about 1.5-1.8 kg over the whole lactation and cows milked for longer than 500 days. It should be noted that these graphs show raw yield averages, which means that cows that stopped milking per definition are not included in the average (results not shown in paper III).

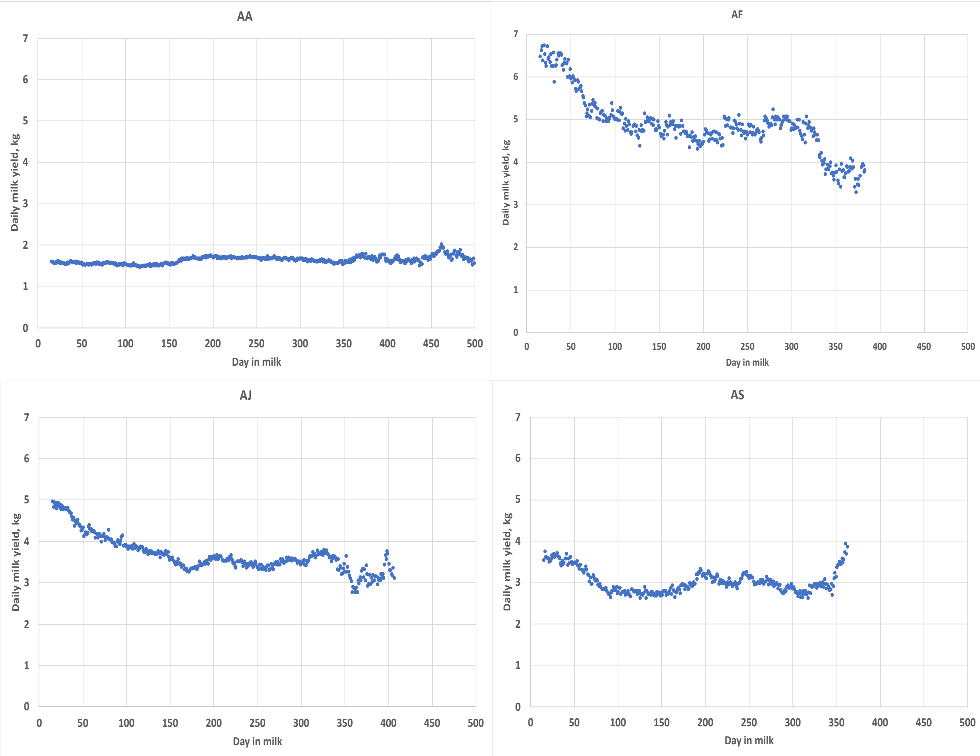

Fig 10. Lactation curves for pure Ankole (AA), Ankole x Holstein Friesian (AF), Ankole x Jersey (AJ) and Ankole x Sahiwal (AS). A minimum of 10 cows was required for an average to be plotted.

The yield recorded was only the milk offtake. Suckled milk can be roughly estimated based on weight gain of calves. In Paper I the average daily weight gain was 0.4 kg/day. From Dove and Axelsen (1979) it was estimated that 10.8 kg milk was needed per kg of daily gain. To achieve 0.4 kg/day the calf thus need to consume 4.3 L milk. At 305 days and at weaning (330 days) the calf had consumed 1311 or 1419 L. This is equal to or much higher than milk offtake (Table 3).

5.5 Overall performance of crossbreds and creating a synthetic breed

The results showed that especially AF had good growth, good conception rate, and high production but still as long CFI and CLI as AA. Some of these advantages could be due to heterosis and these would be partially lost if a synthetic AF breed were created. However, the difference in additive genetic level between the two breeds is likely to be much larger than the heterosis effect, which is normally 5-10% for production traits (Jönsson, 2015).

The best strategic option to sustainably utilize AF in this crossbreeding program is selection and formation of synthetic breed. Even though the system gives 100% of possible heterozygosity in the F_1 generation, this declines to 50% in the F_2 and subsequent generations. The percent of genes from the exotic strain is exactly 50% in the first generation, and should also be 50% in subsequent generations. The proportion of maximum heterozygosity, and hence of heterosis, retained in synthetic populations is (Dickerson, 1973) $1 - \sum p_i^2$, where p_i is the proportion of genes contributed to the synthetic by the i^{th} source breed. It can then be shown that the proportion of heterosis retained in synthetics formed with various proportions of Exotic and Local breeds is as shown in table 4.

Table 4. Expected heterosis in a synthetic breed build from two breeds

Proportion of genes from		Proportion of heterosis retained in synthetic
Exotic	Local	
0.125	0.875	0.22
0.25	0.75	0.375
0.375	0.625	0.47
0.5	0.5	0.5
0.625	0.375	0.47
0.75	0.25	0.375
0.875	0.125	0.22

The crossbred individuals are used as reproducers and inter se mated over generations. The program would include two-breed combinations Exotic and Local sired with F_1 bull. The reason for proposing two breed combination is to avoid complexity which increases substantially with more breeds.

5.5.1 Selection of bulls from abroad

The interaction of genotype and environment complicates selection because it reduces accuracy of the predictions made from phenotypic performance of a given set of genotypes in one environment from that made in other different environments (Dickerson 1962). Therefore, in Rwanda, genotype by environment interaction needs to be taken into consideration in dairy breeding decisions. For instance the bulls used for AI have been sourced from outside Rwanda, e.g., from Belgium and the Netherlands. Such sires have been ranked according to European environmental conditions for performance and these rankings would not be expected to be the same for their daughters' performance in different management conditions. Thus, proven bulls for this proposed program should probably be sourced from countries with similar tropical environment, like South Africa or Australia. In this program, proven bulls would mate with selected superior Ankole mothers to produce young AF bulls to be used for AI. That means the superiority of proven bulls reaches the population through their sons. Female AF calves born from purebred Ankole mothers could also be dispersed from the nucleus farms to the commercial farms (or to the commercial part of the same farm).

5.5.2 Development of pure Ankole breeding program

In case that all farmers were to adopt the new synthetic breed, such a program may constitute an important threat to Ankole breed (although the most important alleles from the Ankole populations will presumably be conserved). Therefore, in addition to breeding for a proposed synthetic AF breed formation, to avoid inbreeding and weakened competitiveness it is equally important to develop a sustainable breeding program for Ankole cattle. This program could be achieved through organizing farmers into Ankole cattle breeding associations. These would form committees together with livestock research and extension teams to help in setting breed standards and formulating breeding guidelines and breeding objectives for this dual purpose breed.

5.5.3 Genomic evaluation

Having accurate knowledge of breed composition is essential in evaluating the adaptability of crossbreds to a given production environment (Kuehn et al., 2011). Pedigree information is conventionally used to determine breed composition in crossbred cattle. However, the reliability of pedigree-based estimation of breed composition can be compromised by missing, inaccurate, or incomplete records (VanRaden and Cooper, 2015). In Rwanda, inadequate pedigree record keeping makes it impossible to have knowledge of the breed composition of the current cattle population structure, which consists of 46% crossbreds. Therefore, under the current situation, one way genomic evaluation of the crossbred cattle population could help would be by matching the existing cattle breed composition to their environment or ensuring that the appropriate environment is available for a certain breed composition.

It is unclear if genomic selection would be beneficial under Rwandan conditions. First, a reference population large enough for estimating accurate genomic breeding values would have to be created for the Ankole breed. This requires not only genotyping but also good phenotypic information on all important traits. As an example, using an equation from Daetwyler (2009), for a trait with heritability 0.3, one would need about 500 cows in the reference population to achieve an accuracy of about 0.5, and 1000 cows to achieve an accuracy of 0.6. For a trait with lower heritability (0.1) 500 cows would only result in an accuracy of around 0.3. It is also important that the phenotypes are expressed under the correct environmental conditions, the same conditions that the offspring later will produce under. Given enough money to test, say, all or most born bull calves, one could imagine a quite high selection intensity for bringing bull calves into the Ankole purebreeding program.

6 Conclusions

- In this study AF and AB were heavier at weaning (WW_{adj}) than other breed groups (AJ, AS, AJxS, and ASxJ), however, the difference was smaller than expected, probably due to environmental conditions that did not allow full expression of genetic potential for growth.

- The breed group AF had better CR than the purebred Ankole and AS, and AS had lower CR than AJxS and AJ.

- The AA (and AF, but based on few animals) had longer CFI and CLI than AJ, AS and purebred FF (which tended to have the shortest intervals). However, the intervals for these traits were longer than desirable for all breed groups, which is unfavorable for a profitable cattle production.

- The better milk yield of AF, AJ, AJxS and ASxJ is most likely due the higher milk production potential of Friesian and Jersey, thus the crossbreds with Ankole excelled both due to heterotic effect and additive effect. From this study it can be concluded that AF, AJ, AJxS and ASxJ crosses can be beneficial even under a management system of limited nutrition in Rwanda.

7 Future research

- A dedicated study of the comparison between growth performance of AF and AB with predetermined weaning ages and possibly also studies of grazing behavior should be carried out.
- Proper evaluation of the economic benefits and subsequently optimize both the lactation length, milk yield and calving interval under the given production conditions.
- The prolonged intervals CFI, CLI and CI observed in this study calls for proper postpartum anestrus management both in terms of nutrition and calf suckling management. Finding out the causes of extended intervals which may be indicators of missed oestrus signs and/or poor record keeping.
- Further research to improve the skill of AI technicians and animal health professionals (involved in the dairy sector) at early pregnancy diagnosis and fertility evaluation.
- Unlike in our studies, further studies should be carried out focusing on the performance of these crossbreeds under conditions of improved nutrition.

References

Aboagye, G.S. 2002. Phenotypic and genetic parameters in cattle populations in Ghana. A review paper presented to International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia. Accessed 7th September, 2013.

Ahunu B.K., Aboagye G.S. and Arthur P.F. 1994. Cattle crossbreeding research in southern Ghana. In: Smith C., Gibson, J.S., Benkel, B., Chesnais, J., Fairfull, W., Gibson, J.P., Kennedy, B.W. and Burnside E.B. (eds), Proceedings of the 5th World Congress on Genetics Applied to Livestock Production held at the University of Guelph, Ontario, Canada, 7–12 August 1994. Organizing Committee, 5th World Congress on Genetics Applied to Livestock Production, Guelph, Ontaraio, Canada. pp. 464–467.

Barth AD.1993. Factors affecting fertility with artificial insemination. Veterinary Clinics of North America: Food Animal Practice 9:275-289

Borman, J.M., Macmillan, K.L. & Fahey, J., 2004. The potential for extended lactations in Victorian dairying: a review. Australian Journal of Experimental Agriculture 44, 507- 519.

Cardoso, L.A. 2012. Environmental and economic impacts of livestock productivity increase in sub-Saharan Africa. Tropical Animal Health and Production 44(8), 1879-1884.

Daetwyler, H.D. 2009. Genome-Wide Evaluation of Populations. PhD thesis, Wageningen ISBN: 978-90-8585-528-6

Darfour-Oduro KA, Sottie ET, Hagan BA, Okantah SA. 2010. Milk yield and lactation length of Ghana Sanga and its crosses with the Friesian raised under agropastoral system. Trop Anim Health Prod. 2010 Mar; 42(3):349-56.

Debir L. B., Asrat T., Azage T. 2016. Evaluating the Efficiency of Artificial Insemination Following Estrus Synchronization of Dairy Cattle in Southern Region, Ethiopia: The Case of Dale District. Journal of Natural Sciences Research Vol.6, No.5

Delepierre, G. 1975. Les Région Agricoles due Rwanda. Bulletin Agricole du Rwanda 8(4):216-225

Delgado, C., Rosegrant, M.; Elui, S. Courbiois, C. 1999. Livestock to2020.The next Food Revolution 2020 Vision for Food, Agriculture and Environment. Discussion Paper 28. Food and Agriculture Organisation, Rome.

Dickerson, G.E. 1962. Implications of genetic environmental interaction in animal breeding. Anim. Prod., 4 (1962), pp. 47-64

Diskin, M.G., Mackey D.R., Roche J.F., Sreenan J.M. 2003. Effects of nutrition and metabolic status on circulating hormones and ovarian follicle development in cattle. Animal Reproduction Science 78 (2003) 345-370.

Dossa LH and Vanvanhossou FU. 2016. The indigenous Somba cattle of the hilly Atacora region in North-West Benin: threats and opportunities for its sustainable use. Trop. Anim. Health Prod. 48 (2): 349-359.

Dove, H., and A. Axelsen. 1979. Estimation of milk consumption in beef calves using a tritiated water dilution technique. Aust. J. Exp. Agric. Anim. Husb. 19:666–672.

FAO. 2009a World food program country director report, Rwanda making progress in food security.

FAO. 2009b. FAOSTAT statistical database. Rome (available at faostat.fao.org).

Galukande, E. 2010. Comparison of production systems with purebred Ankole vs crossbred Ankole - Friesian animals on farm using a combined cross-sectional and longitudinal approach (Kiruhura district of Uganda). Doctoral Thesis, University of Natural Resources and Applied Life Sciences, Vienna, Austria.

Grigson C. 1991. An African origin for African cattle?—some archaeological evidence. Afr Archaeol Rev. 9 (1):119–4

Groenendaal, H., Galligan, D.T. & Mulder, H.A. 2004. An economic spreadsheet model to determine optimal breeding and replacement decisions for dairy cattle. Journal of Dairy Science 87, 2146–2157.

Hansen P.J. 2004. Physiological and cellular adaptations of Zebu cattle to thermal stress. Anim. Reprod. Sci. 82-83:349-360.

Hatungumukama, G., Hornick,J.L. and J. Detilleux. 2009. Effects of on Genetic and Crossbreeding Factors on Daily Milk Yield of Jersey x Sahiwal x Ankole Cows in Burundi. Journal of Animal and Veterinary Advances, 8: 794-798.Heinrichs, A.J and Hargrove G.L. (1987) Standards of Weight and Height for Holstein Heifers: Journal of Dairy Science, Volume 70, Issue 3, 653 – 660.

Heinrichs, A.J and Hargrove G.L. (1987) Standards of Weight and Height for Holstein Heifers: Journal of Dairy Science , Volume 70 , Issue 3 , 653 – 660.

Hirwa, C.D., Kugonza, D.R., Murekezi, T., Rwemalika, J.D., Kayitesi, A., Musemakweli, A., Shabayiro, J.P., Shumbusho, F., Manzi, M., & Safari, T. 2017. Management and phenotypic features of indigenous cattle in Rwanda. International Journal of Livestock Production, 8(7), 95-112.

ISAR. 1987. (Institut des Sciences Agronomiques du Rwanda) Raport Annuel

Jones, P.G., Thornton, P.K. 2009. Croppers to livestock keepers: transition livelihood transition to 2050 in Africa due to climate change.

Jönsson, R. 2015. Estimation of heterosis and performance of crossbred Swedish dairy cows. MSc thesis, SLU. https://stud.epsilon.slu.se/7812/

Kibwana, D.K; Makunyavira, A.M., Hornomic, J.L. 2015. Effect of improved feeding and housing, Friesian blood level and parity on milk production of Ankole x Friesian cows. Pakistan Veterinary Journal (2015), 35(1), 76–80.

Khan, M.R.K., J. Uddin and M.R. Gofur. 2015. Effect of age, parity and breed on conception rate and number of service per conception in artificially inseminated cows. Bangladesh Livestock J., 1: 1-4.

Kuehn L. A., Keele J. W., Bennett G. L., McDaneld T. G., Smith T. P. L., Snelling W. M. 2011. Predicting breed composition using breed frequencies of 50,000 markers from the US Meat Animal Research Center 2,000 bull project. J. Anim. Sci. 89 1742–1750. 10.2527/jas.2010-3530

Kugonza, D.R., Nabasirye, M., Mpairwe, D., Hanotte, O. & Okeyo,A.M. 2011. Productivity and morphology of Ankole cattle in three livestock production systems in Uganda. Animal Genetic Resources, Food and Agriculture Organisation of the United Nations 48(13-22).

Madalena. F, E., Agyemang, K., Cardellino, R.C. and Jain, G.L. 2002. Genetic improvement in medium- to low-input systems of animal production, experience to date. Proceed ings of the 7th World Congress on Genetics Applied to Livestock Production, Montpellier, France, August 19–23, 25 (08).

Mattioli RC, Pandey VS, Murray M, Fitzpatrick JL. 2000. Review: immunogenetic influences on tick resistance in African cattle with particular reference to trypano-tolerant N'Dama (Bos taurus), trypano-susceptible Gobra zebu (Bos indicus) cattle. Acta Tropica, 75:263-277.

Meadows, C., Rajala-Schultz, P.J. & Frazer, G.S. 2005. A spreadsheet-based model demonstrating the nonuniform economic effects of varying reproductive performance in Ohio dairy herds. Journal of Dairy Science 88, 1244–1254.

Metekia Tamiru and Nezif Amza. 2017. Review on the status of dairy cattle production in Ethiopia. Journal of Genetic and Environmental Resources Conservation, 2017, 5(2):84-95.

Miah, A.G., Salma U. and Hossain M.M. 2004. Factors Influencing conception rate of local and crossbred cows in Bangladesh. International Journal of Agriculture and Biology, 6(5), 797-801.

MINAGRI. 2003. Situation Actuelle de l'Elevage, MINAGRI, Kigali Document Inédit, 2003.

MINAGRI. 2006. (Ministry of Agriculture and Animal Resources of Rwanda) Annual Report.

MINAGRI. 2016. (Ministry of Agriculture and Animal Resources of Rwanda) Rwanda Dairy Development Project report.

MINAGRI. 2017. (Ministry of Agriculture and Animal Resources of Rwanda) Annual Report FY 2016-2017

Murray M, Trail JCM, Grootenhuis JG. 1984. Trypanotolerant lives tock: Potential and future exploitation. Outlook Agric.13:43-51.

Mwai O, Hanotte O, Kwon Y-J, Cho S. 2015. African indigenous cattle: unique genetic resources in a rapidly changing world. Asian-Aust J Anim Sci. 28(7):911–21.

Ndumu, D.B., R. Baumung, O.Hanotte, M. Wurzinger, M.A. Okeyo, H. Jianlin, H.Kibogo, and J. Solkner. 2008. Genetic and morphological characterization of the Ankole longhorn cattle in the African Great Lakes region. Genet.Sel.Evol.40:467-490.

NISR. 2016. (National Institute of Statistics of Rwanda) Agricultural statistics, Survey report, Kigali, Rwanda.

Nuraddis, I., and Ahmed S. 2017. Review on Reproductive Performance of Crossbred Dairy Cattle in Ethiopia: Journal of Reproduction and Infertility 8 (3): 88-94, 2017

Parnell, P.F., Herd, R.M., Perry, D., and Bootle, B. 1994. The Trangie experiment-response in growth rate, size, maternal ability, reproductive performance, carcase composition, feed requirement and herd profitability. Proc. Aust. Soc. Anim. Prod. 20:17-26

Poonam Ratwan, Manoj Kumar, Ajoy Mandal. 2016. Influence of Genetic and Non-Genetic Factors on Lactation Traits in Dairy Cattle: A Review. Research & Reviews: Journal of Dairy Science and Technology 5(3): 7–22p

Proyaga, K.C. 2003. Evaluation of beef cattle genotypes and estimation of direct and martenal genetic effects in a tropical environment. 1. Growth traits. Crop and Past. Sci 54:1013-1025

Rege J, and Tawah C. 1999. The state of African cattle genetic resources II. Geographical distribution, characteristics and uses of present-day breeds andstrains. Anim Genet Res Inf 26:1–25

Robinson, J.J., Ashworth C.J., Rooke J.A., Mitchell L.M. Mcevoy,G. 2006. Nutrition and fertility in ruminant livestock. Animal feed Science and Technology 126 259-276.

Sacker, G.D. and Trail, J.C.M. 1966. A note on milk production of Ankole cattle in Uganda. Tropical Agriculture (Trinidad), 247-250.

Samuel, O.A, and Julius, K.H. 2014. The effect of non-genetic factors on the reproductive performance of Sanga and Friesian×Sanga crossbred dairy cattle breeds kept under hot and humid environment. Trop Anim Health Prod (2014) 46:1045–1050.

SAS, 2012. Statistical Analysis System. Version 9.4 for Windows. SAS Institute Inc., Cary NC, USA

Segura-Correa, José C.; Magaña-Monforte, Juan G.; Aké-López, Jesús R.; Victor M.; Hinojosa-Cuellar, José A.; Osorio-Arce, Mario M. 2017. Breed and Environmental effects on birth weight, weaning weight and Calving Interval of zebu cattle in South Eastern Mexico. Tropical and Subtropical Agroecosystems, vol. 20, núm.2, pp. 297–305.

Seré, C., van der Zijpp, A., Persley, G. & Rege, E. 2008. Dynamics of livestock production systems, drivers of change and prospects for animal genetic resources. Anim. Genet. Resour. Inf. Bull., 42: 1–27.

Shabtay A. 2015. Adaptive traits of indigenous cattle breeds: The Mediterranean Baladi as case study. Meat Sci. 109:27-39.

Siddiqui, M. A. R., Das, Z.C., Bhattacharjee, J., Rahman, M.M., Islam. M.M., Haque, M.A., Parrish, J.J and Shamsuddin, M. 2013. Factors Affecting the First Service Conception Rate of Cows in Smallholder Dairy Farms in Bangladesh. Reprod Dom Anim 48, 500–505

Tahmina Bilkis, Md. Kabirul Islam Khan, Ashutosh Das, Omar Faruk Miazi, Md. Moksedul Momin, Md. Enamul Haq Hazary. 2016. Artificial Insemination practices and factors affecting conception rate of dairy cows in the commercial dairy farms. International Journal of Science, Environment and Technology, Vol. 5, No 5, 2689 – 2700.

Tanner, J.C., McCarthy, N.A. & Omore, A. 1998. Why shorter calving intervals on smallholder farms in East Africa? BSAS/KARA. Proceedings of an International Conference on Food, Lands and Livelihoods: Setting Research Agendas for Animal Science, (BSAS, Edinburgh), 190–191.

Taye, M., Jaemin, K., Sook, H.Y, Wonseok, L., Olivier, H., Tadelle, D., Stephen, Okeyo A. M., Kelsey. C., Seoae, C., Sung, J.O., Hak-Kyo, L. and Heebal, K. 2017. Whole genome scan reveals the genetic signature of African Ankole cattle breed and potential for higher quality beef. BMC Genetics 18:11

Thatcher, W.W., Bilby, T.R., Bartolome, J.A., Silvestre, F., Staples, C.R. and Santos, J.E.P. 2006. Strategies for improving fertility in the modern dairy cow. Theriogenology, 65, 30-44.

Trail JCM, Sacker GO, Fisher IL. 1971. Crossbreeding of beef cattle in Western Uganda. I. Performance of Ankole, Boran and zebu cows. Anim. Prod. 13:127-141.

United Nations. 2011. (Department of Economic and Social Affairs) World population prospects, New York, NY 10017 USA

VanRaden, P. M., and Cooper, T. A. (2015). Genomic evaluations and breed composition for crossbred U.S. dairy cattle. Interbull Bull. 49, 1–21. Visser, A. Shannon, P and Wickham BW. 1988. Factors affecting AB conception rates in cattle. Proceedings of the New Zealand Society of Animal Production 48: 61–63.

Vinothraj S, Subramaniyan A, Venkataramanan R, Joseph C, Sivaselvam SN. 2016. Genetic evaluation of reproduction performance of Jersey × Red Sindhi crossbred cows, Veterinary World, 9(9): 1012-1017.

Wondifraw Z, Thombre B M and Bainwad D V. 2013. Effect of non- genetic factors on milk production of Holstein Friesian × Deoni crossbred cows. International Journal of Livestock Production 47:106-112.

World Bank. 2008. The livestock sector in the world development report: re-assessing the policy priorities, by G. Pica, U. Pica- Ciamarra and J. Otte FAP. PPLPI Working Paper RR Nr 08-07, August 2008.

World Bank. 2013. Africa development indicators 2012/2013. Washington, DC: World Bank. doi: 10.1596/978-0-8213-9616-2. License: Creative Commons Attribution CC BY 3.0.

Wurzinger, M., Ndumu, D.B., Baumung, R., Drucker, A., Okeyo, A.M., Semambo, D.K., Byamungu, N., Sölkner, J. 2006. Comparison of production systems and selection criteria of Ankole cattle by breeders in Burundi, Rwanda, Tanzania and Uganda Tropical Animal Health and Production, 38: 571–581.

Popular science summary

Livestock is important in low income countries, not only as a component of food security, but also for socio-economic and cultural reasons. Sub-Saharan Africa has one of the highest population growth rates in the world, at 2.5% per year (World Bank, 2013). However, the production of livestock products is not keeping pace with the population growth and hence sub-Saharan Africa has the lowest per capita consumption of livestock products in the world (Cardoso, 2012). To meet the increasing demand for meat and milk by the growing population, Rwanda's agricultural policy advocates the adoption of intensive livestock production, including restocking and improving the genetic quality of animals.

Technically, productivity of milk and meat production can be increased in the following ways:

1. Selection within the local indigenous cattle. This is an extremely slow process owing to the poor infrastructure and lack of organization among local smallholder dairy farmers.

2. Importation of pure exotic breeds. However, such breeds from industrialized countries have been developed through concurrent intensive breeding and improvement of feeding and management. Thus, the high-yielding cow would only perform well under high-input production systems, which are rarely available in Rwanda.

3. Crossbreeding and grading-up of local populations through artificial insemination and replacement of local stock. This approach is more

practical as it will allow development of animals under tropical conditions, which combines the qualities of exotic and local breeds. Effective use of a crossbreeding system allows producers to take advantage of complementarity and breed differences as well as heterosis to match cattle to available feed resources and to predominant market preferences. The first effect is additive genetic while the second is non-additive.

The Holstein Friesian and Jersey are among the exotic dairy breeds used extensively in crossbreeding in the tropics (Ahunu *et al.*, 1994). The crosses between the Ankole and Friesian, Ankole and Jersey and Ankole and Sahiwal, like similar crosses between Bos taurus and Bos indicus breeds, impacts several traits, such as body weight, growth rates, fertility and milk production through additive gene action and heterosis.

In Rwanda, a crossbreeding project was initiated at Rwanda Agricultural Board (RAB) research stations in 1999 involving the exotic breeds Holstein Friesian, Jersey and Brown Swiss and local Ankole cattle to develop a dual-purpose breed for milk and meat production for the smallholder farmer. This thesis is based on analysing data from these stations to shed some light on comparative values of different cattle genotypes with respect to growth, reproduction and milk production. Furthermore, survey data were collected from farms in four agroecological zones with different production conditions.

Growth rate and body weight traits are of major economic importance to the beef industry and normally the first traits to receive selection emphasis in beef cattle breeding. These traits are relatively easy to measure in a standardized way and repeated measures over time is possible. The relation between the traits and income from slaughter is usually very clear, often farmers are paid per kg of body weight at slaughter.

The aim of the first study was to compare body weight and growth rate traits from birth to 18 months of age of various groups of crossbred cattle born from 1999 to 2007. The calves were crossbreds of Ankole

(A) with Brown Swiss (B), Holstein Friesian (F), Jersey (J) and Sahiwal (S). It was shown that apart from breed group (cross), sex, season and year of birth also affected most traits studied.

Ankole-Jersey (AJ) crossbreds had the lowest birth weight, but were comparable with AS, AJxS, and ASxJ for weight at 8 and 18 months (W8, W18), and for age-adjusted weaning weight. AB and AF calves were of comparable weight and only significantly differed at 18 months of age. Generally, AF was heavier than other crossbreds, however, the difference was smaller than expected, probably because environmental conditions did not allow full expression of genetic potential for growth.

The aim of the second study was to assess the reproductive performance of Ankole cattle and its crossbreds with Holstein Friesian (F), Jersey (J), and Sahiwal (S). The traits studied were: intervals from calving to first or last insemination, calving interval, conception rate, and number of inseminations. The overall means of these traits were 192 days, 198 days, 480 days, 67%, and 1.23, respectively. The cross AF had better conception rate than the purebred Ankole and AS, and AS had lower conception rate than AJxS and AJ. On the other hand, Ankole (and to some extent AF) had longer intervals to first or last insemination than AJ, AS and FF. Ankole had 54 days longer calving interval than the average crossbred. The prolonged intervals observed in this study calls for proper postpartum anoestrus management both in terms of nutrition and calf suckling management.

The aim of third study was to assess the average daily milk yield, 100-day and 305-day milk yields, and lactation length (LL) for purebred Ankole and their crossbreds, and the influence of environmental factors on these traits. Milk yields (after allowing the calf to suckle) were obtained from 865 cows. Overall average daily milk yield was 2.7 L, 262 L over 100 days and 759 L over 305 days. The average lactation length was 291 days. First parity cows had lowest milk production, and highest production occurred in 4th parity. The breed group AA had the lowest average daily milk yield (2.0 L) but longest lactation length compared with crossbreds. Among the crossbreds there was no significant difference between AF, AJxS and ASxJ (4.4-4.7 L), nor between

AS and ASxS (3.3 L). AJ had a yield in-between these two groups (3.9 L).

In Paper IV we purposely targeted progressive farmers from four agroecological zones. The average milk yield was higher for Holstein Friesian compared to AF crossbreds, 14 L vs 8.6 L. Due to better management and feeding, the overall production was substantially higher than in Paper III, where there was no supplemental feeding, only pasture.

Populärvetenskaplig sammanfattning

I utvecklingsländer är husdjuren viktiga, inte bara som en del av livsmedelsförsörjningen utan också av socio-ekonomiska och kulturella skäl. Länderna söder om Sahara har en av världens högsta populationstillväxt på 2,5 % per år enligt Världsbanken. Ökningen av produktionen av animaliska livsmedel är dock betydligt mindre och dessa länder har också den lägsta konsumtionen av animalieprodukter i världen (Cardoso, 2012). För att möta den ökande efterfrågan på kött och mjölk från en ökande befolkning har Rwandas jordbrukspolitik inriktats mot högre produktivitet i husdjursproduktionen, vilket inkluderar att ersätta nuvarande djurmaterial och att genetiskt förbättra det egna djurmaterialet.

Något förenklat kan produktiviteten i mjölk- och köttproduktionen ökas på tre olika sätt.

1. Man kan bedriva selektion inom de egna lokala raserna. Detta är dock en långsam process och den blir inte snabbare av den brist på infrastruktur som finns och att det saknas samordning bland de småskaliga mjölk- och köttproducenterna på lokal nivå.
2. Man kan importera raser från industrialiserade länder. Dessa raser har utvecklats till en hög produktionsnivå tack vare en samtidig förbättring av den genetiska nivån, skötsel och utfodring. Därför kräver dessa kor en näringsförsörjning på hög nivå för att deras genetiska potential ska utnyttjas, och detta saknas ofta möjligheter till i Rwanda.
3. Korsningsavel eller uppgradering av de lokala raserna med importerad sperma. Detta är ofta en mer tillämpbar strategi eftersom de födda korsningsdjuren utvärderas under tropiska

förhållanden och man kan kombinera fördelar från såväl importerade som lokala raser. Dessutom kan man få nytta av s k heteros, eller korsningsvitalitet, som uppkommer när man korsar två skilda raser och man bryter också upp eventuell inavel. Detta kan göra att man få fram djur som bättre utnyttjar tillgängliga resurser och som ger högre inkomster av kött och mjölk.

Holstein Friesian och Jersey är de importerade raser som oftast används för korsningsavel i tropiska länder (Ahunu *et al.*, 1994). Korsningar mellan Ankole å ena sidan och Holstein Friesian, Jersey och Sahiwal å den andra, precis som liknande korsningar mellan Bos taurus- och Bos indicus-raser, påverkar olika egenskaper som kroppsvikt, tillväxt, fruktsamhet och mjölkproduktion både genom den additiva genetiska effekten och genom heteros.

Ett korsningsavelsprojekt startades 1999 av Rwandas jordbruksstyrelse (RAB) där kor av den lokala rasen Ankole på deras försöksstationer korsades med Holstein Friesian, Jersey och Brown Swiss för att undersöka möjligheten att skapa en ny mjölk- och köttras anpassad för småskaliga bönder. Denna avhandling är baserad på att analysera information från dessa försök för att jämföra hur värdefulla olika korsningar är med avseende på tillväxt, fruktsamhet och mjölkavkastning. Dessutom samlades information in från olika besättningar i tre olika klimatzoner med olika produktionsförutsättningar.

Tillväxt och levandevikt är ekonomiskt viktiga egenskaper för köttproduktionen och de är ofta de egenskaper som man först börjar selektera för i ett avelsprogram. Egenskaperna är relativt lätta att mäta på ett standardiserat sätt och man kan mäta tillväxten upprepade gånger. Kopplingen mellan dessa egenskaper och bondens ekonomi är också väldigt tydlig, ofta får man betalt vid slakt per kg levandevikt.

Syftet med den första artikeln var att jämföra levandevikt och tillväxt från födsel till 18 månaders ålder för olika korsningskalvar födda från 1999 till 2007. Kalvarna var korsningar mellan raserna Ankole (A), Brown Swiss (B), Holstein Friesian (F), Jersey (J) och Sahiwal (S). Förutom korsningstyp hade även kön, årstid och födelseår inverkan på de flesta egenskaper.

Ankole-Jersey (AJ) korsningar hade lägst födelsevikt men var jämförbara med AS, AJxS och ASxJ vad gällde vikt vid 8 och 18 månaders ålder och för avvänjningsvikt (korrigerad till 10 månaders ålder). AB- och AF-kalvar vägde ungefär lika mycket, utom vid 18 månader då AF var tyngre. Generellt var AF tyngre än övriga korsningar, men skillnaden var mindre än förväntat, antagligen för att miljö- och utfodringsförhållandena inte fullt ut tillät kalvarna att visa sin genetiska potential.

Syftet med den andra artikeln var att jämföra fruktsamheten för Ankole och dess korsningar med Holstein Friesian, Jersey, and Sahiwal. De egenskaper som studerades var intervall från kalvning till första eller sista insemination, kalvningsintervall, dräktighetsprocent och antal inseminationer. Medelvärden för dessa egenskaper var 192 dagar, 198 dagar, 480 dagar, 67%, respektive 1,23. Korsningen AF hade bättre dräktighetsprocent än renrasig Ankole och AS, och AS hade lägre dräktighetsprocent än AJxS och AJ. Å andra sidan hade Ankole (och delvis AF) längre intervall till första och sista insemination än AJ, AS och FF. Ankole hade 54 dagar längre kalvningsintervall än medeltalet för alla korsningar. Dessa långa intervall pekar på behovet av bättre hantering av icke-dräktiga kor både vad gäller energiförsörjning och rutiner för diande kalvar.

Den tredje artikeln jämförde mjölkavkastningen per dag eller totalt över 100 eller 305 dagar samt laktationsperiodens längd mellan renrasig Ankole och dess korsningar samt inverkan av miljöfaktorer på dessa egenskaper. Kalven fick börja att dia kon för att underlätta mjölknedsläpp och fick även dia efter att man mjölkat klart så i den uppmätta mjölkmängden ingår inte den mängd som kalven druckit. Mjölkmängden utan hänsyn till korsningstyp av 2.7 l., 262 l. under 100 dagar och 759 l. under 305 dagar. Laktationslängden var i medeltal 291 dagar. Förstakalvare hade lägst avkastning och fjärdekalvare högst. Renrasig Ankole hade lägst daglig mjölkavkastning (2,0 l.) men också längst laktationsperiod jämfört med korsningarna. Det fanns ingen signifikant skillnad mellan AF, AJxS och ASxJ (4,4-4,7 l.), och inte heller mellan AS och ASxS (3.3 l.). AJ hade en avkastning mellan dessa två grupper (3,9 l.).

I artikel fyra valdes ett antal progressiva bönder från tre klimatzoner ut. Medelavkastningen per dag var högre för renrasig Holstein Friesian än för AF, 14 l. mot 8,6 l. På grund av bättre skötsel och utfodring var den allmänna produktionsnivån betydligt högre än i artikel 3, där det inte fanns någon tillskottsutfodring utan bara bete.

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