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Effects of dietary supplementation with Urea Molasses Multi-nutrient Block in local Ethiopian and crossbred dairy cows in North-western Ethiopia

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Doctoral Thesis

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Effects of dietary supplementation with Urea Molasses Multi-nutrient Block in local Ethiopian and crossbred dairy cows in North-western Ethiopia

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Dedication

To my wife, W/ro Genet Assefa and my daughters, Meron and Wongelawit for their strength, kindness and motivation

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Abbreviations and Acronyms

ADF	Acid detergent fibre
ALRC	Andassa Livestock Research Center
BCS	Body condition score
BDZ	Bahir Dar Zuria
CN	Crossbred cows not supplemented
CP	Crude protein
CPI	Crude protein intake
CS	Crossbred cows supplemented
CSA	Central statistical authority
DOMD	Digestible organic matter in dry matter
DM	Dry matter
ECM	Energy corrected milk
ECR	Energy conversion ratio
F	Fogera
FN	Fogera cows not supplemented
FS	Fogera cows supplemented
GDP	Gross domestic product
GTP	Growth and transformation plan
HF	Holstein Friesian
HIDM	Hay intake in dry matter basis
l	Litre
masl	Meter above sea level
ME	Metabolisable energy
MEI	Metabolisable energy intake
MEO	Milk energy offtake
MJ	Mega joule
NAIC	National Artificial Insemination Center
NDF	Neutral detergent fibre
PCR	Protein conversion ratio
PU	Peri-urban

RS	Rural subsistence
SAS	Statistical analysis system
s_e	Residual standard deviation
TDMI	Total dry matter intake
UMMB	Urea molasses multi-nutrient block
UMMBI	Urea molasses multi-nutrient block intake
USD	United States Dollar

Summary

On-station and on-farm studies were conducted between December, 2010 and May, 2011 to evaluate the effects of dry season dietary supplementation with urea molasses multi-nutrient block (UMMB) of roughage based diets on the performance of local Fogera and their Holstein Friesian crossbred dairy cows (F_1) in North-western Ethiopia. The response variables included were saleable milk offtake, milk composition, feed and nutrient intake, body condition score, estimated body weight gain, reproductive performance and economics of feed supplementation. The on-station experiments were carried out by involving local Fogera and their Holstein Friesian crossbred dairy cows (F_1) in mid- and late lactation. The on-farm study has been conducted in a crop-livestock production system using local Fogera cows, and in a peri-urban, market-oriented livestock production system using Fogera * Holstein Friesian crossbred dairy cows (F_1). The experimental diets were the traditional feeding practices both on-station and on-farm as control and UMMB as a supplement in all the trial sites.

Regardless of dairy breeds and production systems, supplementation of dairy cows with UMMB resulted in a significant improvement of traits such as saleable milk offtake, energy corrected milk offtake, fat content of milk, milk fat yield, milk protein yield, milk energy offtake and net return per day. Under on-station condition, in addition to the improvements in productive and reproductive performance, supplementation with UMMB improved feed and nutrient intake and protein and energy conversion ratio. However, the productive, reproductive and economic performance of supplemented cows of both breeds at all experimental sites was not uniform. For example, crossbred dairy cows were superior to the local Fogera cows at all experimental sites for the majority of the traits such as daily milk offtake, milk energy offtake, reproductive performance and benefit-cost ratio. On the other hand, Fogera cows were superior in their milk constituent traits over the crossbred cows regardless of supplementation and production system.

Due to the different stage of lactation of cows, the benefit-cost ratio of UMMB supplementation was much higher under field conditions (early lactation) than on-station (mid- and late lactation). In addition to the biological and the economic parameters

measured, the farmers who participated in the field study confirmed that UMMB supplementation had a positive effect on milk yield, body condition, health status and reproductive performance of their cows regardless of breed and production system. However, the level of awareness varies between production systems: a greater number of farmers in the peri-urban livestock production system strongly emphasized the effect of UMMB on these traits than of the farmers in mixed crop-livestock production system. For a sustainable use of the UMMB technology, the farmers also suggested that the technology should be linked to dairy cooperatives and organized producer youth groups, so that the members and other farmers in the villages can also benefit from the technology.

In general, it was shown that UMMB can be a viable tool for securing sufficient energy and nutrient intake under conditions of different management and production systems in both breeds. However, if supplements such as urea molasses multi-nutrient blocks are in short supply, they should be used with a greater priority for the breeds which are likely to be more productive, such as crossbred cows with a high genetic potential for milk production.

Zusammenfassung

Fütterungsversuche auf Station und im Feld wurden durchgeführt, um die Effekte einer Supplementierung grundfutterbasierter Rationen mit sogenannten Multi-Nährstoffblöcken (UMMB), die unter anderem Melasse und Harnstoff enthielten, in der Trockenzeit im Nordwesten Äthiopiens (Dezember 2010 bis Mai 2011) auf Milchkühe der Lokalrasse Fogera und ihrer F_1-Kreuzung mit Holstein Friesian zu untersuchen. Neben anderen wurden die Merkmale Milchmenge und –zusammensetzung, Futter- und Nährstoffaufnahme, Körperkondition und Lebendmasse-Veränderung, Reproduktionsleistung sowie ökonomische Indikatoren erhoben. Der Stationsversuch wurde mit Kühen der genannten Herkünfte durchgeführt, die sich in mittleren und späten Laktationsphasen befanden. Die Feldstudie umfasste früh laktierende Fogera-Kühe in

einem integrierten (Ackerbau-Tierhaltung) Produktionssystem, das auf Subsistenz ausgerichtet war, sowie früh laktierende Kreuzungskühe in einem peri-urbanen, marktorientierten Produktionssystem. Als Kontrollration wurden jeweils ortsübliche Rationen verwendet, die in der Versuchsgruppe mit UMMB ergänzt wurden.

Unabhängig von der genetischen Herkunft und dem Produktionssystem führte die Supplementierung der Rationen zu einer signifikanten Verbesserung u.a. von Milchmenge, Fettgehalt, Fett- und Proteinmenge und dem Milcherlös abzüglich Futterkosten. Das Leistungsniveau der supplementierten Kühe war allerdings je nach Rasse verschieden: Kreuzungskühe wiesen höhere Milchmenge und bessere Reproduktionsleistung auf, waren den Fogera-Kühen allerdings im Gehalt an Milchinhaltsstoffen unterlegen.

Das Kosten-Nutzen-Verhältnis der UMMB-Ergänzung war im Feldversuch höher als im Stationsversuch, was v.a. in den unterschiedlichen Laktationsstadien und dem damit verbundenen, unterschiedlichen Leistungsniveau der Kühe begründet ist. Im Feldversuch bestätigte die Wahrnehmung der Bäuerinnen und Bauern die erhobenen Leistungsdaten: Insbesondere im peri-urbanen Produktionssystem wurden die verbesserte Milchleistung, die bessere Körperkondition, ein besserer Gesundheitszustand und eine verbesserte Reproduktion hervorgehoben. Die Bäuerinnen und Bauern betonten jedoch auch, dass die Bereitstellung von UMMB an vorhandene Strukturen wie Milcherzeugungsgenossenschaften und Erzeuger/innen-Gruppen angebunden werden sollte, um diese Technologie allgemein zugänglich zu machen.

Zusammenfassend konnte in der vorliegenden Arbeit gezeigt werden, dass der Einsatz von UMMB eine effektive Maßnahme ist, um in unterschiedlichen Produktionssystemen eine ausreichende Energie- und Nährstoffaufnahme zu sichern. Wenn Ergänzungsfuttermittel wie UMMB nur begrenzt zur Verfügung stehen, sollten sie bevorzugt an Tiere mit höherem genetischen Potenzial für Milchleistung, wie den Kreuzungskühen in der vorliegenden Arbeit, verfüttert werden.

Thesis outline

This PhD Thesis is presented in seven sections: the first section, the introduction, gives general information about dairy production systems, their contribution to the economy of the country, constraints of dairy operations in Ethiopia and intervention options, the research question and objectives of the studies. The second section is the literature review which deals with cattle production systems and resources, feed resource bases and supply, different dietary supplementation options, including urea molasses multi-nutrient block and supplementation response of dairy cows in different tropical countries. It also tries to address the dairy cattle crossbreeding efforts and its interaction with feed supply in Ethiopia and other developing countries. The information gathered in this review was utilized in planning the on-station and on-farm experiments in this study and served in comparing the results of these with the scientific literature. The third section covers the materials used and methods applied during the on-station and on-farm experiments.

The results of both the on-station and field studies are presented in the fourth section. The first part of this section covers the on-station experiments. Two manuscripts are currently prepared for submission to Tropical Animal Health and Production and to a second scientific journal not yet defined. The field study has already been published in Livestock Research for Rural Development Journal, August 2012 issue (http://www.lrrd.org/lrrd24/8/teke24130.htm). The fifth section includes the conclusions and recommendations derived from own experiments and the literature. The list of references and the appendix (which consists of the feed ingredients used during the experiments and their nutrient composition and some pictures taken during the on-station and field experiments) form the last part of the thesis.

1. Introduction and research question

Livestock production constitutes to be an important sub-sector of the agricultural production in Ethiopia, contributing 45 % of the total Agricultural Gross Domestic Product (IGAD, 2010). Livestock are also extremely important because of the dependency of a large proportion of the society on livestock products and income from their sale (ELDMPS, 2007).

According to (ELDMPS, 2007), from the economic point of view, cattle are the most important of all livestock and produce 83 % of the total milk in the country followed by goats and camel. Based on market orientation, scale and production intensity, the dairy sector is categorized into 3 major livestock production systems in Ethiopia (Gebrewold et al., 2000): the traditional smallholder, privatized state farms and urban and peri-urban production systems. From all these, the traditional smallholder system contributes 97 % of the total national milk production and 75 % of the commercial milk output (Ahmed et al., 2004), while the urban and peri-urban dairy production system produces only 2 % of the total milk output (Ketema, 2000). According to Staal et al. (2008), the smallholder sector is largely dependent on indigenous breeds which are low in their milk production (208 litres of milk/cow/lactation).

In general, despite the large livestock resource base and an ecological setting suitable for dairy production, the country is not yet self sufficient in milk production. As most research work in Ethiopia indicated, a quantitatively and qualitatively poor feed supply is the main contributor for low productivity of dairy cows in Ethiopia, among several other factors (Tilahun et al., 2005; Azage et al., 2006; Sisay, 2006; Tesfaye, 2007; Asaminew and Eyassu, 2009; Belete et al., 2009; Dejene et al., 2009; Teshome, 2009).

According to ELDMPS (2007), even during normal years there is always a deficit of 35 % in feed supply and this figure rises to 70 % during drought years and it is likely to increase as a growing human population demands more land for crop production. The main reason for shortage of feed in Ethiopia is related to reduction in grazing lands as a result of expansion of arable cropping (CSA, 2008; Asaminew and Eyassu, 2009; Belete et al., 2009; Teshome, 2009). In addition to this CSA (2010) generated further elaborated evidence about the sub-sector performance. The report shows that the contribution of improved forages to the nutritional bases of livestock is only 0.25 % and improved dairy cows account for less than 1 % of the total cattle population. In addition to these, Gebrewold et al. (2000) reported that the average chemical composition and rather low nutritive value of Ethiopian dry forages and roughages is described by a CP content of 6.2 %, NDF 69.1 %, IVOMD 50.4 % and ME 7.5 MJ/kg DM.

On the other hand, dairy crossbreeding has been undertaken in Ethiopia since 1950 (Ahmed et al., 2004), mainly by ministry of Agriculture through establishing National Artificial Insemination Center (NAIC) and distribution of crossbred in-calf heifers using multiplication centers. But the genetic improvement of the indigenous cattle via cross breeding which has been practiced for the last 5 decades, had relatively little success in Ethiopia (Azage et al., 2006; Aynalem et al., 2008).

Among the indigenous cattle breeds used in the crossbreeding programmes, Fogera cattle is one of the local breeds used extensively for crossbreeding programmes in the north-western part of Ethiopia. After reviewing a number of previous studies, Hegde (2002) reported that the mean lactation milk yield of the best 50 % and 25 % of Fogera cows were 1156 and 1462 kg, respectively. The Abay River Basin Study (1998) and a study conducted by Zewdu (2004) indicated that the average milk yield of Fogera cows ranges between 1.39 minimum and 4.63 litres maximum. On the other hand, RHHSEBS (1998) and ELDMPS (2007) indicated that, under the traditional management system, a milk yield of 1 and 3.9 litres is collected from local and crossbred dairy cows in Ethiopia, respectively.

In the Amhara Region of Ethiopia, cross breeding of Fogera with Holstein Friesian cattle has been undertaken mainly at Andassa Livestock Research Center (ALRC) and Metekel Cattle Breeding and Improvement Center (ALRC, 2006). Currently, the Bureau of Agriculture in the Amhara Region plans large scale AI services in the region as part of its development plan. On the other hand, feed shortage becomes the major constraint for livestock in the region, including Bahir Dar Zuria and Fogera districts (Asaminew and Eyassu, 2009; Teshome, 2009; Firew and Getnet, 2010).

Research question

As indicated previously, the natural pasture and crop residues in the country are low in their nutrient and energy content, which may not even be sufficient to meet the maintenance requirement of dairy cows. On the other hand, grains which frequently form the bulk of concentrate feeds could not be used as a livestock feed in Ethiopia where it is very limited and in fierce competition with human consumption. The use of agro-industrial by-products is limited because of their higher price and poor accessibility for smallholder farmers. The contribution of improved forages to the overall livestock feed is also very low. Therefore, with these facts in mind, the use of roughages as a livestock feed will continue but will need supplementation with easily available nutrients, mainly carbohydrates and Nitrogen sources. On the other hand, in Ethiopia, about 80,866 metric tons of molasses are produced per year from the existing sugar factories (Alemayehu, 1985; Tesema, 2001; Adugna, 2007). Its supply is expected to substantially increase in the near future due to the expansion of the existing factories and a number of new plants currently under construction and in their planning phases (Adugna, 2007; GTP, 2010). Molasses in the form of Urea Molasses Multi-nutrient Blocks (UMMB) has been used as a livestock feed supplement in a number of countries and a wide range of studies showed positive effects on productive and reproductive performance plus an attractive benefit-cost ratio in both local and crossbred dairy cows in different livestock production systems (Sudhaker et al., 2002; Misra et al., 2006; Sahoo et al., 2009).

However, if UMMB are to be used as a dietary supplement, it should be kept in mind that the response of dairy cows to an increased nutrient supply depends on several factors, such as the cows' genetic potential, stage of lactation, related feeding level, feed quality and climate (Wiktorsson, 1979). Getachew (2003) also indicated that an improvement in daily milk yield and overall milk production can be achieved with improvement in persistency through nutritional interventions. However, according to this author, minimum efforts have been made in Ethiopia to evaluate the performance of indigenous as well as crossbred dairy cows for their productive and reproductive performance and benefit-cost ratio on the basis of these interventions. It is also hypothesized that upon UMMB supplementation, the performance of crossbred dairy cows in terms of their milk offtake and benefit-cost ratio would be greater than the local Fogera cows and on the other hand the Fogera cows would be greater than the crossbred dairy cows in their milk constituent traits. In line with these, data is hardly found on the on-station as well as on-farm performance of local Fogera and their 50 % Holstein Friesian crossbred dairy cows using UMMB as a supplement in Amhara Region, Ethiopia. Therefore, the objectives of the studies reported herein were:

- to evaluate the effects of dry season UMMB supplementation on productive and reproductive performance and economic indicators for local Fogera and their 50 % Holstein Friesian crossbred dairy cows under on-station conditions

- to study the consequences of UMMB supplementation on milk production and economic indicators for local Fogera and their 50 % Holstein Friesian crossbred dairy cows in two different dairy production systems

2. Literature review

2.1. Livestock production systems and milk supply in Ethiopia

According to Kelay (2002) and IBC (2004), the livestock production system in Ethiopia is classified into four major production systems: mixed crop-livestock, agro-pastoral, pastoral, peri-urban and urban system. For most of these production systems, land is the limiting production factor due to fast population growth and expansion of arable cropping.

According to a report published by ELDMPS (2007), Ethiopia's livestock are integrated into the dominant smallholder or peasant farming systems of the highlands (> 1500 m) to a greater extent than in any other area in Africa. Ethiopia has 9 % of sub-Saharan Africa's annual and perennial croplands and only about 6 % of the subcontinent's permanent pasture, but the country supports 15 % of the ruminant animals and a very large proportion of perhaps 55 % of equines in the region. In the highland areas, the predominant agricultural production system is smallholder mixed farming, with crop and livestock husbandry typically practiced within the same management unit.

With an estimated 53.4 million heads, Ethiopia holds the largest cattle population in Africa (CSA, 2010). The traditional production systems which mainly rely on indigenous cattle (> 99 %) are the major source of milk supply in Ethiopia (Ahmed et al., 2004; Azage et al., 2006; Aynalem et al., 2007). However, the productivity of these huge resources is constrained by a number of interlinked factors. As a result, market supply limits the availability of milk for consumers, leading to a very low per capita milk consumption of the Ethiopian people (FAOSTAT, 2010). It is substantially lower than the African average and far below that of the neighbouring Kenya and Sudan (Fig. 1). The growth in milk production has been slow. Although the total amount of milk produced has increased due to increases in cattle and human population, the per capita milk consumption appears to have declined from 26 litres per annum in 1980 to 16 litres per annum in 2008 (calculated from FAOSTAT, 2010). As a result, the per capita milk consumption is 63 % behind the African average which ranked Ethiopia one of the least in the world (Zegeye, 2003; Azage et al., 2006; ELDMPS, 2007; Staal et al., 2008; FOASTAT, 2010).

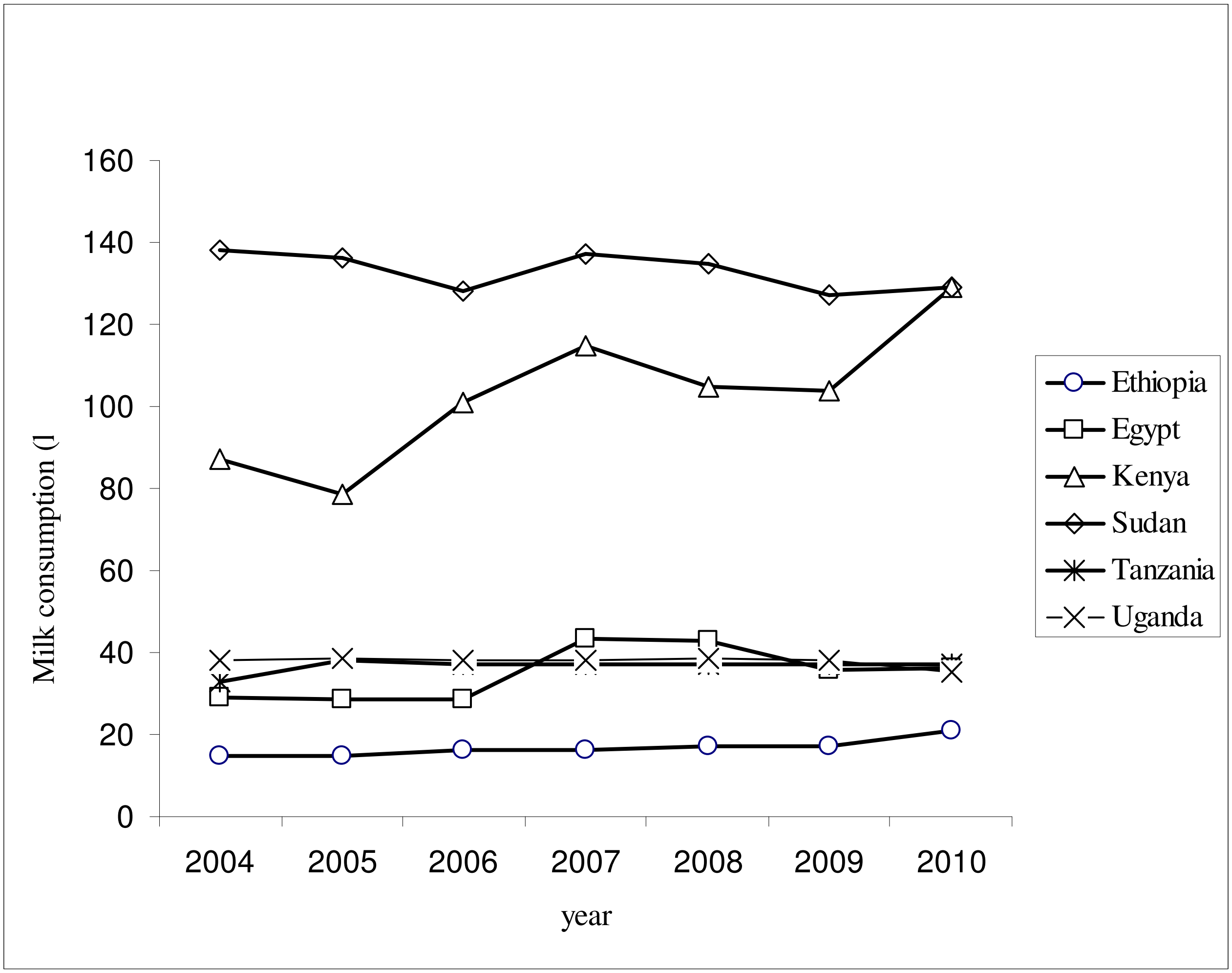

Figure 1. Per capita milk consumption of some selected African countries

The major factors responsible for the low productivity of Ethiopian livestock in general and the dairy sector in particular are inadequate nutrition, the occurrence of animal diseases and the utilization of mainly unimproved genotypes. Among these factors, feed shortage in terms of its quality and quantity is considered as the dominant problem, reported extensively by a number of authors (Zegeye, 2003; Makkar, 2006; Nega, 2006;

Sisay, 2006; Tesfaye, 2007; Asaminew and Eyassu, 2009; Belete et al., 2009; Dejene et al., 2009; Teshome, 2009).

On the other hand, in response to the low productivity and the limited milk supply, the government of Ethiopia started cattle crossbreeding in the 1950s when Ethiopia received the first batch of 300 Friesian and Brown Swiss dairy cattle from the United Nations Relief and Rehabilitation Administration (Ketema, 2000; Ahmed et al., 2004; IBC, 2004; Aynalem et al., 2007). While genetic improvement of the indigenous cattle through crossbreeding may be a measure which quickly shows effects, most research work indicated that results were highly variable, not sustainable and had little overall success on the production level in Ethiopia due to poor cattle nutrition and other management deficiencies (Tadesse et al., 2003; Azage et al., 2006; Aynalem et al., 2007). Despite cattle crossbreeding attempts which were made in the past years in improving milk production and supply, the gap between estimated milk demand (calculated from the African average of 26 litres per capita) and supply (calculated from FAOSTAT, 2010) remained nearly constant across the years (Figure 2).

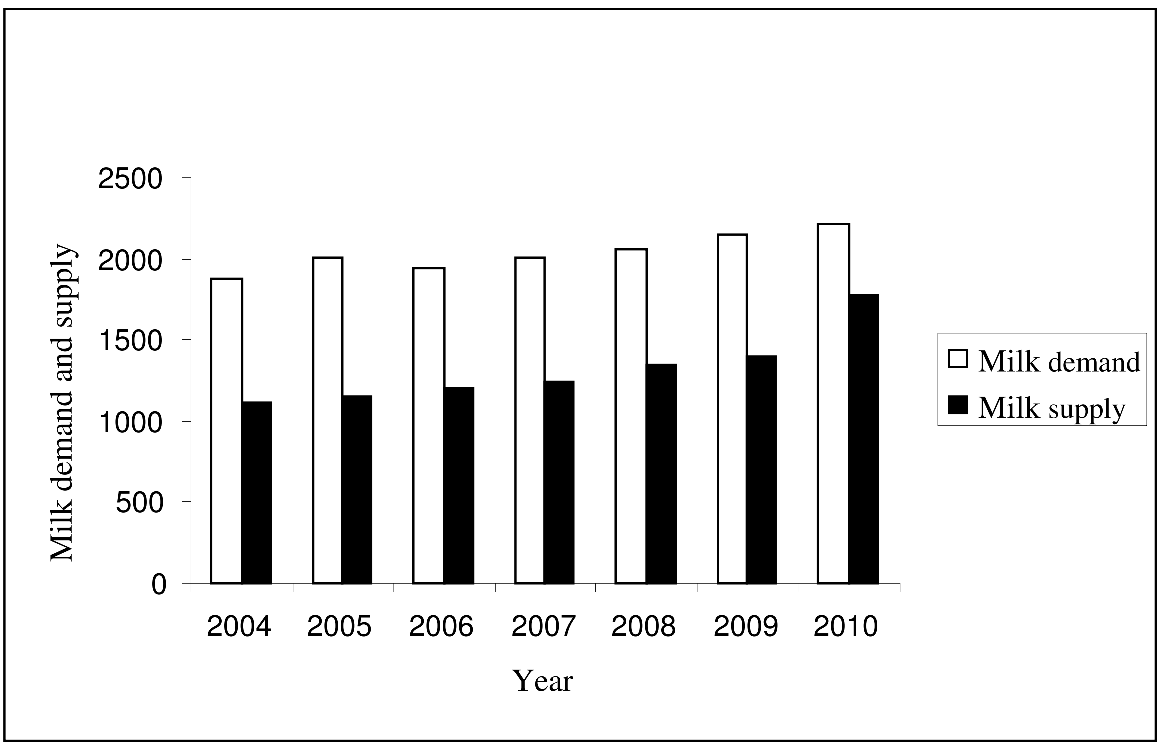

Figure 2. Trends in estimated milk demand and supply of Ethiopia

Therefore, in the light of the nutritional constraints hampering the practical success of efforts for a genetic improvement through crossbreeding, this literature review was made to assess the availability of feed resources on the production level together with the nutritional limitations which genetically improved cattle may be exposed to and to derive suggestions for an improvement of this situation based on evidence from the literature. Therefore, this review work tried to include the feed resource bases in Ethiopia, the feed supplementation efforts made so far in the country and other developing countries, crossbreeding and the performance of crossbred and local dairy cows and the interaction effect of dairy genotypes and feed supply. The results of this review also served as bases for the development of own on-station and on-farm studies.

2.2. Feed resources

For the majority of the livestock production systems in Ethiopia, the dominant feed resources for livestock include natural pasture which is fluctuating throughout the year in terms of quality and quantity, crop residues mainly from cereal and pulse crops, agro-industrial by-products like wheat bran, oil seed cakes, molasses and concentrates (Kassa et al., 2003; Seyoum and Fekede, 2006; Adugna, 2007; Birhanu et al., 2009; Dereje, 2009; CSA, 2010; Negesse, 2010). These different groups of feedstuffs contribute to a different extent to the nutritional basis of livestock in different livestock production systems in Ethiopia. Aspects which are related to the utilization of these feed resources are presented in the following sections in more detail.

2.2.1. Natural pasture and crop residues

In arid and semi-arid pastoral areas of Ethiopia, the natural pasture is estimated to supply about 80-90 % of the nutrients and energy to livestock in these regions (Birhanu et al., 2009; Negesse et al., 2009). In the last two decades, the use of communal grazing lands, private pastures and forest areas declined while the use of crop residues and purchased feed generally increased (Alemayehu, 2004; Ayantude et al., 2005; Adugna, 2007). The reduction and seasonal fluctuation of natural pasture has led to over utilization of the palatable species and domination by undesirable plant species. These degrading pastures are partially made up for by an increased use of crop residues (Beyene, 2009; Dereje, 2009; Negesse et al., 2010). Currently, the decline in available pasture land cannot be compensated for by the utilization of improved forages such as alfalfa, clover, Napier grass etc. because the contribution of these feed components to the nutritional basis of livestock is only 0.25 % in Ethiopia (CSA, 2010); for the Amhara Region the estimate is even 0.18 % (Firew and Getnet, 2010).

Like in other African countries, the use of crop residues as feed for livestock increased through time in Ethiopia, as the productivity and quality of natural pasture declined (Daka, 2000; Suttie, 2000; Seyoum and Fekede, 2006). For example, in mixed crop-livestock production systems, the contribution of crop residues to the nutritional basis of livestock may be as high as 50 % (Birhanu et al., 2009; Negesse et al., 2009).

Although there are no reliable estimates for the quantity of crop residues annually produced in Ethiopia, some sources indicated that there could be about 14 million tons of crop residues produced annually (EARO, 2003). The major crop residues in Ethiopia include straw from tef (*Eragrotis tef*), barley, wheat, sorghum, maize, finger millet and rice (Adugna, 2007; Birhanu et al., 2009). However, the crude protein content and IVOMD of straw is generally low, thereby affecting potential intake. Therefore, straw generally requires a certain degree of treatment and/or supplementation of limiting nutrients or energy (Seyoum and Fekede, 2006; Adugna, 2007; Bogale et al., 2008). Related to these, some research has been conducted in Ethiopia which yielded promising results. For example, Seyoum and Fekede (2006) reported that urea treatment of wheat and tef (*Eragrostis tef*) straw improved the milk production of Zebu and crossbred dairy cows from 1.3 to 2.3 and from 3.4 to 6.9 l/day/cow, respectively, without considering milk consumed by the calf. Similarly, Dejene et al. (2009) indicated that, when urea treated tef straw was used as a basal diet and was supplemented with an escape protein source, the CP content of straw improved from 4.3 to 8.9 %, IVOMD was increased by 7.9 % and the NDF and hemi-cellulose contents were reduced by 6.0 % and 26.7 %, respectively. Despite promising results, smallholder farmers are, however, very reluctant to adopt urea treatment in most developing countries including Ethiopia (Owen and Jayasuriya, 1989; Mekonnen et al., 2009; Walli, 2010). This is mainly related to the high costs of urea and packaging materials, excessive labour demand, the complex process during treatment and preservation and large amounts of water required for wetting the straw during periods when it is scarce.

2.2.2. Concentrate supplementation

The supplementation with energy and protein-rich concentrates of forages which are likely to be of low nutritional value, can be expected to improve dry matter intake, milk yield, milk solids content, body condition, nutrient utilization efficiency of dairy cows and most probably will result in a favourable benefit-cost ratio (Rehrahie et al., 2003; Tadesse et al., 2003; Meeske et al., 2006; Karikari et al., 2008; Kumaresan et al., 2008). However, grains which frequently form the bulk of concentrate feeds for livestock in many industrialized countries are both in short supply and expensive due to direct competition with human food in developing countries such as Ethiopia. On the other hand, the prices of milk and milk products are not sufficient to allow the use of grains as energy supplement for livestock by smallholder farmers in Ethiopia (Tadesse et al., 2003; Adugna**,** 2007; Negesse et al., 2009).

On the other hand, from small and medium scale industries, about 500,000 tons of agro-industrial by-products are produced annually in Ethiopia (EARO, 2003). These by-products include by-products from flour mills, oil seed cakes, brewery by-products and by-products from the sugar processing industries such as molasses (Adugna, 2007; Birhanu et al., 2009). The by-products from oil processing industries are of high nutritive value and can be used as components in the diets of dairy cattle and other livestock. However, the price of these oil seed by-products is limiting their utilization as feedstuffs, as they are frequently beyond the reach of the smallholder farmers (Yosef et al., 2002; Negesse et al., 2010).

The four large sugar processing plants currently existing in Ethiopia, annually process some 2.5 million tons of sugar cane, thereby supplying the market with about 81,000 metric tons of molasses per year (Alemayehu, 1985; Tesema, 2001; Adugna, 2007). Its supply is expected to substantially increase in the near future due to the expansion of the existing factories and a number of new plants currently under construction and in their planning phases (Adugna, 2007; GTP, 2010). After promotion by the government, a part of the molasses is likely to be used for ethanol production. However, so far this applies mainly to molasses produced in one of the four large sugar processing plants, Fincha Sugar Industry (Ethiopian Sugar Development Agency, personal communication). On the other hand, molasses as livestock feed supplement is frequently advocated to be used in the form of UMMB in Ethiopia (Aklilu, 2004; Teshome, 2009; Lemma, 2009).

2.2.3. Urea Molasses Multi-nutrient Block supplementation

Urea Molasses Multi-nutrient Block (UMMB) is usually made up of Molasses, urea, cement or lime, bran, eventually protein rich by-products, salt and water which are mixed and processed into the form of a solid and compact block. The block should be well accepted by livestock and shall provide essential nutrients such as protein and minerals, together with energy which most forages and crop residues are usually deficient in (PCARRD, 2001). The technology is particularly applicable in areas where ruminants basically feed on fibrous crop residues or poor quality forage diets. Several formulations are available for the production of UMMB, which allows responding to different prices and variable availability of potential ingredients.

Experiences from a number of countries indicate that UMMB supplementation resulted in a substantial improvement of productive, reproductive and economic performance of both local and crossbred dairy cows in different livestock production systems (Table 1; Bheekhee et al., 2000; Elmansoury et al., 2002; Nkya et al., 2002; Rasambainarivo et al., 2002; Waruiru, 2004; Alam et al., 2006; Seyoum and Fekede, 2006; Jian-Xin Liu et al., 2007; Khan et al., 2007; Lemma, 2009; Sahoo et al., 2009). Similar to these reports, on-farm UMMB supplementation to indigenous dairy cows in Tanzania showed an increase in milk production of 1.5 l/d during the dry season (Plaizier et al., 1999). On top of this, it was observed that dry matter intake increased from 10.1 kg/d to 12 kg/d without significant improvement in milk composition and live weight.

In Sri Lanka, buffalo cows maintained on straw-based diet supplemented with 800 g UMMB/day gave a milk yield similar to cows which were supplemented with 5 kg of concentrate (Abeygunawardane et al., 2007). Other research work (Nkya et al., 2002; Rasambainarivo et al., 2002; Misra et al., 2006) conducted in Madagascar, Tanzania and India, respectively, indicated that crossbred cows which were supplemented with UMMB together with concentrate were superior in their milk yield, milk composition, benefit-cost ratio and body condition over groups which were supplemented with a concentrate mixture alone. The release of ammonia over a longer period of time and its utilization by micro-organisms in the rumen which is supported by the simultaneous energy supply, together with a generally improved dietary energy and protein balance in UMMB supplemented groups were the reasons suggested for these. Ghulan (2010) and Khanum et al. (2010) in Pakistan and Wadhwa et al. (2010) in India also reported that UMMB supplementation improved feed intake, dry matter digestibility, weight gain, milk production, resumption of post-partum oestrus and health condition of milking cows.

Uthayathas and Perera (1998) reported that Sahiwal cows given UMMB in the intermediate zone of Sri Lanka produced 475 kg of milk more than cows fed traditional concentrates during lactation. In addition, milk quality also improved due to a higher butter fat content (4.59 %). The improved livestock performance reflected the beneficial role of UMMB on rumen fermentation, digestion and efficient feed utilization. UMMB supplementation to lactating buffaloes in India also showed increased milk yield and higher milk fat content in all stages of reproduction (Brar, 2007). The increase in butter fat content may be a result of the effect of UMMB on the proliferation of micro organisms. The increase in the number of rumen microbes in turn improve the digestion of structure carbohydrates and improve the acetic acid content in the rumen which serves as a precursor for milk fat.

In Bangladesh UMMB supplementation of indigenous cows fed a straw based diet improved the body condition score from 2.31 to 2.51 (Khan et al., 2007). On the other hand, crossbred dairy cows which were under zero grazing (straw plus green fodder together with 2.75 kg concentrate) achieved a body weight gain of 6.1 and 42.9 g/day for control and UMMB supplemented cows, respectively. The total roughage intake of these cows was also improved from 6.9 to 9.2 kg/day. The positive effects of UMMB on the performance of different dairy genotypes in different livestock production systems is summarized in Table 1.

Table 1. UMMB supplementation and performance of dairy cows in different production systems

Production system	Basal diet + UMMB	Cows	AMY of control (l)		AMY of supplemented (l)		Source
			Per day	305 days	Per day	305 days	
Mixed farming	Straw based diet	Indigenous	1.47	448*	1.84	561*	Khan et al. (2007)
Intensive	Cut and carry + Con	Crossbred	5.6	1708*	6.9	2105*	
Intensive	Grass hay + 6 kg MB	Crossbred	6.7	2044*	11.2	3416*	Plaizier et al. (1999)
Agro-pastoral	Grazing + CR	Indigenous	1.98	604*	3.14	958*	Seyoum et al. (2006)
Mixed farming	traditional feeding practice	HPC	10.25	3126*	12.28	3745*	Elmansoury et al. (2002)
Mixed farming	traditional feeding practice	MPC	5.79	1766*	7.13	2175*	
Mixed farming	traditional feeding practice	LPC	4.13	1260*	5.45	1662*	
Intensive	Cut and carry + Con	Crossbred	8.98	2739*	9.48	2892*	Bheekhee et al. (2000)
Mixed farming	traditional feeding practice	Crossbred	3.3	1007*	4.8	1464*	Alam et al. (2006)
Pastoral	Grazing	Yak	1.3	397*	1.5	458*	Jian-Xin Liu et al. (2007)

Where: CR = crop residues; Con = concentrate; MB = maize bran; HPC = high producing crossbred cows; MPC = medium producing crossbred cows; LPC = low producing crossbred cows; * Calculated by the author; AMY = average milk yield

2.3. Breeds of dairy cattle and crossbreeding in Ethiopia

In Ethiopia there are 25 indigenous cattle breeds which may be categorized into four broad groups, including humpless (Hametic, Longhorn and Shorthorn), Zebu, Sanga and the intermediate Sanga/Zebu called Zenga, to which the Fogera cattle belongs (Alberro and Haile-Mariam, 1982; IBC, 2004). According to MOA (1998), the different cattle breeds under these categories are found distributed in different agro-ecological zones of the country. This report further indicated that the majority of 46 % of the cattle lives in the highlands, 14 % are found in the arid, 16 % in semi-arid, another 16 % in sub-humid and the remaining 8 % in humid parts of the country. Among the 25 indigenous cattle breeds found in Ethiopia, the Boran, Fogera and Arsi are widely used in the crossbreeding programmes in the country (IBC, 2004). The Fogera cattle is found in the North-western part of Ethiopia, particularly around Lake Tana (Zewdu, 2004). Withstanding the periodic flood and prevalent parasitic infestations in the area, the Fogera cattle is the main source of draught power, meat and milk (Alberro and Haile-Mariam, 1982; Teshome, 2009).

Crossbreeding of cattle with the goal to increase milk production has been implemented in the country since the 1950s by government institutes and international agencies, using indigenous cows as dam lines and temperate breeds as sire lines (Ketema, 2000; Ahmed et al., 2004; Aynalem et al., 2007). According to EARO (2001) and IBC (2004), governmental institutions like the Ministry of Agriculture and the former Ministry of State Farms were involved in the establishment of cattle ranches as sources of breeding stock and production of pregnant heifers. A National Artificial Insemination Center has been responsible for production and distribution of semen and liquid Nitrogen. Research, former Relief and Rehabilitation Commission and some NGOs have also been promoting crossbreeding and distribution of crossbred pregnant heifers to smallholder farmers.

In addition to these crossbreeding programmes, due to institutional collaborations with international agencies, genetic improvement programs have been conducted by a number of development projects in Ethiopia. Among these, CADU (Chilalo Agricultural

Development Unit), WADU (Wolita Agricultural Development Unit), NLDP (National Livestock Development Projects), SDDPP (Selale Dairy Development Pilot Project) were some of the projects involved in the genetic improvement program (Fekadu, 1990; Haile-Mariam, 1994; Ketema, 2000; EARO, 2001). As an integral part of these dairy development efforts, an on-station dairy crossbreeding programme has been officially started after the establishment of the Institute of Agricultural Research (IAR) in 1966. The aim of the crossbreeding program was to test the productivity of different crossbred dairy cows, like F_1, F_2 and ¾ crosses of exotic Friesian, Jersey and Simmental sires with local dam lines (Gebrewold et al., 2000; EARO, 2001). However, most of the projects mentioned above and others failed to address the need to improve the genetic constituents and the feed basis simultaneously (Ketema, 2000; Dejene et al., 2009). According to Ketema (2000), these dairy development projects were following a high-tech approach which demanded high financial input of foreign exchange and commonly disregarded the option of improving the performance of local stock. On the other hand, research work done on crossbred dairy cows in some developing countries including Ethiopia indicated that dietary supplementation could substantially improve the milk yield and benefit-cost ratio of crossbred cows as compared to local cows (Table 1 and 2).

Table 2. Feed supplementation and performance of crossbred dairy cows in different production systems

Production system	Basal diet + supplement	Cows	AMY control (l)		AMY supplemented cows (l)		Benefit-cost ratio	Source
			Per day	305 days	Per day	305 days		
Peri-urban	Grz + CR + Con	Crossbred	-	-	9.65	2943*	2.20	Rasambainarivo et al. (2002)
Peri-urban	Grz+ CR + Con + UMMB	Crossbred	-	-	10.82	3300*	4.40	
Intensive	Cut and carry + Con	Crossbred	6.7	2044*	8.0	2440*	1.34*	Nkya et al. (2002)
Intensive	Cut and carry + UMMB	Crossbred	5.5	1678*	7.0	2135*	2.27*	
Mixed farming	CR + Hay + UMMB	Crossbred	4.61	1406*	5.98	1824*	6.44	Misra et al. (2006)
Mixed farming	Grz+ treated CR + Con	Crossbred	3.66	1116*	7.14	2178*	1.78*	Dejene et al. (2009)
Mixed farming	Grz + CR + UMMB	Crossbred	3.09	942*	7.47	2278*	-	Seyoum et al. (2006)
Urban/peri-urban	Cut and carry + UMMB	Crossbred	10.2*	3111*	10.62*	3239*	-	

Where: CR = crop residues; * calculated by the author; - data not available; AMY = average milk yield; Con = concentrate, Grz = grazing

On the other hand, as stated by several authors (FAO, 1990; Ketema, 2000; FAO, 2001; Azage et al., 2006), the milk yield from local breeds could also be substantially and sustainably improved if sound breeding schemes and improved management are properly implemented. According to these authors, indigenous livestock, through their adaptation to the tropical environment and to temporarily deficient diets produce a reasonable amount of milk and need relatively less environmental modification to achieve an increased productivity. Related to this, some studies have been conducted in Ethiopia under on-station and field conditions to evaluate the milk production potential of local breeds; the result indicated that, although it is highly variable, there is an immense potential (Table 3).

Table 3. Milk production performance of some local cattle breeds in Ethiopia

<table>
<tr><td>Local breeds</td><td>DMY (kg)</td><td>Management system</td><td>Source</td></tr>
<tr><td>Horro</td><td>1.96*</td><td>On-station</td><td>Galal and Beyene (1982)</td></tr>
<tr><td>Arsi</td><td>2.97*</td><td>On-station</td><td>Kiwuwa et al. (1983)</td></tr>
<tr><td>Barka</td><td>4.31*</td><td>On-station</td><td>Goshu (1981)</td></tr>
<tr><td>Boran</td><td>2.84*</td><td rowspan="4">On-station</td><td rowspan="4">Gebrewold et al. (2000)</td></tr>
<tr><td>Horro</td><td>2.67*</td></tr>
<tr><td>Barka</td><td>3.88*</td></tr>
<tr><td rowspan="2">Fogera</td><td>4.49*</td></tr>
<tr><td>2.56</td><td>On-farm</td><td>Zewdu (2004)</td></tr>
<tr><td>Highland zebu</td><td>1.91</td><td>On-farm</td><td>Solomon (2006)</td></tr>
</table>

Where: DMY = daily milk yield * Calculated by the author

2.4. Dairy genotype by nutrition interaction

Farmers in tropical and developing countries often rely on the use of exotic genotypes to crossbreed with their indigenous breeds so as to improve their milk yield. But because of the difference in production systems, including climatic factors and feed supply, the performance of animals resulting from such a breeding program may be substantially behind expectations, eventually indicating a genotype by environmental interaction (G x E ; Phung, 2009): performance differences between different genotypes may depend on the environment they are exposed to (Hedi et al., 2009).

According to Indetie (2009), an insufficient intake of energy, protein and minerals is associated with suboptimal reproductive performance, resulting in delayed ovulation and conception rates regardless of the genotype. According to Chilliard (1989), bovine milk yield is related to both intrinsic genetic and extrinsic nutritional and environmental factors. According to this author, on short term basis, the efficiency of nutrient use for milk production is primarily dependent on the milk production level. As milk yield increases, a lower portion of total feed intake is used for maintenance of the cow. A cow producing 12 kg/day of milk is using about 50 % of available nutrients for milk synthesis, whereas the corresponding value is 66 % when milk yield increases to 22 kg/day. It is also stated that about 80 % of the variance in fertility of dairy cows is due to environmental factors of which more than 50 % is explained by nutrition (Lotthammer, 1989). In addition to this, Devendra (1988) further elaborated the efficiency of feed conversion as influenced by several factors and include inherent genetic capacity, diet quality and level of feeding, processing of feed ingredients, potential response and prices of the products.

According to other sources (Luingi, 2005; Azage et al., 2006; Phung, 2009), under harsh environmental conditions and despite their low genetic potential for primary performance traits, indigenous livestock may still do relatively well due to their adaptation to the tropical environment and to poor quality feed. On the other hand, temperate livestock breeds, despite their high genetic potential, may show a substantially reduced productivity, viability and increased incidences of reproductive disorders and deficiency diseases (Wondwosen, 2000; Kelay, 2002; Hunderra et al., 2005; Shiferaw et al., 2005; Fikre et al., 2007; Mureda and Mekuriaw, 2007).

However, a feeding trial in the Gambia using N'Dama, N'Dama x Holstein-Friesian and N'Dama x Jersey under two feeding regimes (groundnut hay ad lib as control and ground nut hay plus 2 kg concentrate as a treatment diet) indicated that, in absolute terms, crossbreds are superior in milk offtake, DM intake and feed conversion efficiency over the pure N' Dama cows (Nouala et al., 2003). Due to supplementation, the milk offtake increased from 1-1.4, 4-5 and 3.2-4.1 liters for N'Dama, N' Dama x Holstein Friesian and N' Dama x Jersey, respectively.

A 2 (genotype) x 2 (plane of nutrition) feeding trial using Holstein-Friesian and Norwegian first lactation dairy cows offered grass silage-based diets which were supplemented either with high amounts of concentrate (600, 500, and 400 g/kg DM) or low amounts of concentrate (300, 200 and 100 g/kg DM) had been conducted in Northern Ireland (Yan et al., 2006). The result indicated that Holstein Friesian cows had a consistently lower accumulated live weight and body condition score and a higher ME intake and milk energy output than Norwegian cows irrespective of the plane of nutrition. For example, Holstein-Friesian cows produced on average 13.3 and 5.3 MJ/d more milk energy than Norwegian cows during the whole lactation when offered high and low concentrate diets, respectively. Holstein Friesian cows also produced a significantly higher proportion of milk energy output over ME intake in early and mid lactation but Norwegian cows were superior in partitioning ME intake into body tissue.

Body condition score (BCS) and lactation response were assessed starting from late pregnancy using 2 indigenous, Tuli (T) and Nkone (N), and two crossbreeds, Jersey x Nkone (JN) and Jersey x Tuli (JT) dairy cows at smallholder farms in a semi arid area of Zimbabwe (Nyoni et al., 2001). Cows were grazed on a natural range land and were supplemented with 0; 3; 6 and 12 kg sorghum-lablab silage on dry matter basis/cow/day. The results demonstrated that the supplemented groups had a higher BCS than the control group and that the indigenous breeds had higher BCS than the crossbreds throughout the monitoring period. Milk yield was greater for the crossbreds than the indigenous cows.

3. Animals, materials and methods

These studies were conducted under on-station and on-farm conditions using UMMB as a supplement to Fogera (F) and their 50 % Holstein Friesian (HF) crossbred dairy cows during the dry period (December-May). The on-station studies were conducted at ALRC in two phases using mid and late lactation cows, respectively. The on-farm study was conducted at peri-urban livestock production system, Bahir Dar Zuria (BDZ) district using crossbred dairy cows and at a rural subsistence crop-livestock production system, Fogera district using local Fogera cows. These two districts in the region were selected based on relatively more number of crossbred cows in BDZ district than the adjacent districts and Fogera district being home for Fogera cattle. The differences between the on-station and on-farm studies were on the type of data collected, on the degree of control of external factors and stage of lactations of dairy cows. For all sites, UMMBs were manufactured at ALRC using feed ingredients like molasses, urea, cement, wheat bran, nug (*Guizotia abyssinica*) seed cake and common salt.

3.1. UMMB supplementation in mid- and late lactation cows on-station

3.1.1. Design of the experiments, experimental site

Within this study, two experiments were consecutively conducted on station using a nested design. Sixteen dairy cows of each breed (local Fogera and F_1 Fogera * Holstein Friesian crossbred) were divided into two groups of 8 cows each and were fed either a control diet consisting of forage and concentrate or the control diet plus UMMB as a supplement. Cows were in their second and third lactation. The studies were carried out at the ALRC, Amhara Region, Ethiopia. ALRC is located at 11°29´N latitude, 37°29´ E longitude, at an altitude of 1730 meter above sea level (masl)). The annual average rainfall at the center is 1150 mm and the mean minimum and maximum temperatures during the experiments were 9 and 34^{0}C, respectively (December-May). These experiments were conducted consecutively during the dry period, but with an altered dietary nutrient supply in reaction to different stages of lactation. The four treatments used for both the experiments were Fogera cows fed with the control diet (FN), Fogera cows fed with control diet plus UMMB supplementation as experimental group (FS), crossbred cows fed with the control diet (CN) and crossbred cows fed with control diet plus UMMB supplementation (CS).

3.1.2. Experiment one: high nutrient supply in mid-lactation dairy cows

This feeding trial was carried out between December 2010 and February 2011, including a 4 week adaptation period. The experimental cows of both breeds were in their mid stage of lactation. Cows of each breed were selected based on their days in milk, number of lactation, initial milk yield, body condition score (≥ 1.5) and health status. From each breed 16 relatively uniform cows were equally divided into two groups and assigned to the control and UMMB supplemented treatment. During this phase of the experiment, the daily dietary energy and protein supply for both breeds were planned to be 57 and 64 MJ ME with 615 and 879 g crude protein for the control and UMMB supplemented groups, respectively. The nutrient requirements for non pregnant lactating dairy cows of 300 kg live weight which produce 4 l of milk with 4 % fat were the basis for defining the control diet (Moran, 2005). This performance level is similar to the average dry season daily milk production performance of crossbred cows in Ethiopia (RHHSEBS, 1998; ELDMPS, 2007). UMMB supplementation of the control diet was planned to result in 12 and 43 % higher energy and protein supply, respectively.

3.1.3. Experiment two: moderate nutrient supply in late lactation dairy cows

Apart from the nutrient supply and stage of lactation, the experimental design and management were similar to the first experiment. Cows remained in the same treatment as in the first experiment. The dietary energy and protein levels were adjusted based on the milk yield and change in body condition of the two breeds during the first experiment. Accordingly, 35 and 40 MJ ME with 380 and 517 g CP were planned to be supplied to Fogera cows in the control and the supplemented group, respectively. The corresponding values for crossbred cows were 47 and 54 MJ ME with 546 and 738 g CP for the control and supplemented group, respectively. This adjustment in nutrient and energy supply was reached by total withdrawal of the concentrate from the Fogera and by offering 1 kg concentrate to the crossbred cows. The experiment lasted from March to May 2011, including a two week adaptation period. Cows were already in their declining stage of lactation.

3.1.4. Cow management and feeding

Cows were housed individually in a well-ventilated, open barn in tie-stall pens with concrete floor. Prior to the experiment, cows were treated for internal and external parasites and were vaccinated for Anthrax and Bovine Pasteurellosis. Postpartum oestrus activity was monitored daily by a researcher, veterinarian, herd attendants and with the help of a teaser bull. Before milking, calves were allowed to suckle for about 1 minute to initiate milk letdown and again after milking. Cows were milked twice daily by hand and milk offtake was recorded at each milking period.

The daily basal diets during the first phase of the experiment consisted of baled hay (ad libitum), freshly harvested Napier grass (4 kg/cow), and 1.5 kg of home made concentrate/cow (74 % wheat bran, 25 % nug (*Guizotia abyssinica*) seed cake, 1 % common salt). During the second phase of the experiment, similar amounts of the basal diets were fed to both breeds, but concentrate was ceased from the Fogera cows and reduced to 1 kg for crossbred cows. One bale of hay, weighing between 18 and 25 kg, was offered to an individual cow and was consumed over a period of 3 to 4 days. The daily hay offer depended on the consumption level of individual cows. As soon as about 20 % of the previously offered hay was left, additional hay was given from the same bale. Hay was offered throughout day time (6 am to 7 pm). The remaining were collected every morning as refusals before additional feed was offered. Samples from the refusals were taken every morning and were bulked for analysis.

The hay consisted of grasses such as *Andropogon abyssinicus, Cynodon dactylon, Digitaria abyssinicus* and of legumes such as *Trifolium quartinianum*, *Trifolium polystachyu* and *Indigofera atriceps*. Four kg of Napier grass were offered to individual cows at around 10 am. Home made concentrate was offered after milking (8 am). The supplemented groups were offered UMMB in addition to the basal diets. Cows were allowed to lick the block between 10 am and 5 pm, after which the blocks were collected. During this time, a cow was assumed to consume about 500-700 g UMMB.

UMMB were formulated from 37 % molasses, 10 % urea, 10 % cement, 25 % wheat bran, 15 % nug seed cake and 3 % common salt (Bediye et al., 2009). Using this formula, a 5 kg UMMB was produced by thoroughly mixing the exact quantities of the components. Cement and salt were dissolved in 200 ml of water prior to being added to the other components. The mixture finally had a dough texture and was put into a plastic sheet lined, rectangular wooden frame of 30*20*20 cm depth, length and width, respectively, for molding. Compaction was applied using a wooden bar; afterwards the block was left for 15 minutes until it maintained a proper shape. Finally, it was removed from the frame and left to dry in a well ventilated room for about 72 hours, after which it was ready for feeding. Cows had access to fresh water from the nearby river two times per day.

3.1.5. Data recording

After the adaptation period, data were collected for daily milk offtake, intake of all feedstuffs pooled for a one week period, estimated body weight and body condition every two weeks. Representative individual milk samples of 25 ml were taken in triplicates every two weeks for a rapid analysis of milk composition using a Lactoscan milk analyzer (Milkotronic Ltd, Nova Zagora Bulgaria[1]).

Body weight was estimated from heart girth measurement on the cows every two weeks by using the regression formula developed at ALRC (Addisu, 2010):

Body weight = 2.126 * heart girth (cm) – 87.39

At the same time, Body Condition Scores (BCS) were estimated by two independent observers and the mean was recorded as the body condition of the cows. Body condition estimation was done according to the procedure designed by Rodenburg (2000), using a scale from 1 (very thin) to 5 points (over conditioned) which combined both visual and tactile appraisals.

Cows coming into heat were recorded for both breeds during the second experiment only (no heat was observed in the course of the first experiment), as was the case for any unforeseen events. Protein and energy conversion ratios were calculated using protein and energy intake over milk protein and energy offtake. Offtake of Energy Corrected Milk (ECM) was calculated using the formula by Tyrrell and Reid (1965, equ.2):

ECM = Milk yield (40.72 (% fat) + 22.65 (% protein) + 102.77)/314

Milk energy offtake was calculated based on an equation published by Tyrrell and Reid (1965, equ. 1):

MEO = ((0.0384 fat + 0.0223 protein + 0.0199 lactose – 0.108) * milk offtake)

Where, MEO = Milk energy offtake (MJ/d) and units for fat, protein and lactose in milk are g/kg and milk offtake is in kg/d.

Nutrient analysis of all feed components and refusals was made by taking representative samples from each feedstuff and employing the standard method of Near-Infrared Spectroscopy (NIRS) as used in the feed laboratory at Holetta Agricultural Research Center (Fekadu et al., 2010). The nutrient composition of the basal diets and UMMB is summarized and presented as appendix Table 1. The Metabolisable Energy (ME) content of each feedstuff was estimated by using a formula published by MAFF (1984):

ME (MJ kg^{-1} DM) = DOMD * 0.015

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[1] Lactoscan milk analyzer, Narodni Buditeli Str. 8900. Nova Zagora, Bulgaria. www.milkotronic.com

Where, DOMD = Digestible Organic Matter in Dry Matter (g kg^{-1}DM)

Results from feed analysis (appendix Table 1) were used to calculate the Organic Matter, Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF) intake which are presented in Tables 4 and 6. The Protein conversion ratio was calculated using the daily crude protein intake in the feed over the daily milk protein offtake. Similarly, the energy conversion ratio was calculated using the daily energy intake from the feed over the daily milk energy offtake. Data on variable costs and price of milk were collected for partial budgeting. Prevailing market prices for feed ingredients and milk during the experimental period were used to calculate net return/cow/day, net return/l of milk, feed costs/l of milk and benefit-cost ratios. Net return/cow/day was calculated as the difference of daily milk sold per cow minus daily feed costs per cow. Feed costs/l of milk was calculated using feed costs per day divided by milk offtake/day. The benefit-cost ratio was calculated from change in net return between the control and supplemented diet during the experiment divided by change in feed costs.

3.1.6. Statistical analysis

Data for milk offtake, milk composition, feed and nutrient intake, milk energy offtake, energy and protein conversion ratio, net return/cow/day, net return/l of milk, feed costs/l of milk, estimated body weight gain, BCS, intake of OM, NDF and ADF were analyzed using the Mixed Linear Model procedure of SAS (2009). The occurrence of heat was analysed using Chi-square test and benefit-cost ratios were analysed using descriptive statistics. Treatment was included in the model as the main independent variable. All collected data were subjected to analysis of variance, including days in milk and estimated initial body weight as co-variables. Tukey-Kramer test was used to separate least square means. Significance was defined as $P < 0.05$ unless stated otherwise. The statistical model used for data analysis was:

$Y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + X + \varepsilon_{ijk}$

Where

Y_{ijk} = milk offtake, milk constituents, feed and nutrient intake and conversion, daily gain, BCS, cost and return

μ = overall mean

α_i = fixed effect of i^{th} treatment (i = Fogera cows unsupplemented, Fogera cows supplemented, crossbred cows unsupplemented, crossbred cows supplemented)

$\beta_{j(i)}$ = random effect of j^{th} cow within i^{th} treatment

X = days in milk and estimated initial body weight as co-variables

ε_{ijk} = residuals

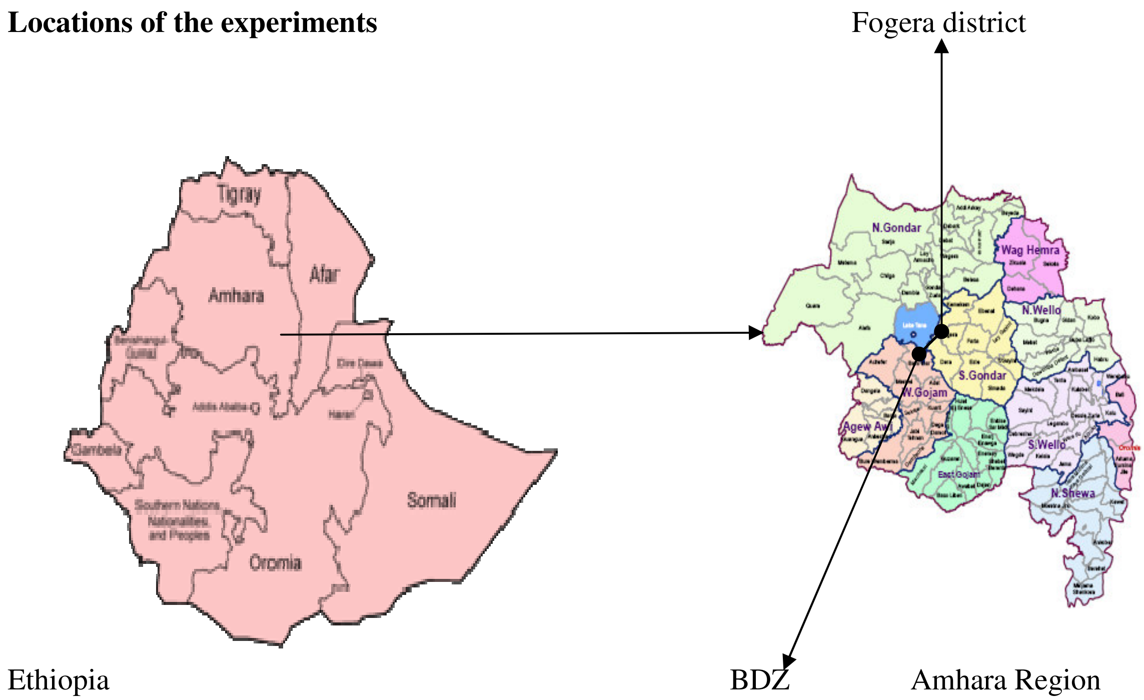
3.2. UMMB supplementation of cows in two different dairy production systems

3.2.1. Study sites

This study was conducted at two sites in Fogera and Bahir Dar Zuria (BDZ) districts during the dry period (December–April), when feed shortage is very critical. Fogera district is situated at $11^{0}58'$ latitude, $37^{0}41'$ longitude and at an altitude of 1774 to 2410 masl. The mean annual rainfall is 1216 mm (1103 to 1336 mm) (Fogera Woreda Pilot Learning Site Diagnosis and Program Design, 2005). The minimum and maximum daily temperatures of the area are 10 and 28^{0}C, respectively (Dejene et al., 2008). The major feed types in the study area include natural pasture, hay, crop residues from tef (*Eragrostis tef*), maize, rice and finger millet with hardly any concentrate and improved forage supplementation. The Fogera cattle is the dominant breed in the area which thrives well in marshy areas and which is kept for draught, milk and meat purposes (Alberro and Haile-Mariam, 1982). This production system is characterized as crop-livestock production, where more than 66 % of milk produced is processed into butter due to absence of a milk market and transportation (Belete et al., 2009; personal observations).

The BDZ district is located at an altitude of 1700-2300 masl. The area receives an average annual rainfall of about 820 to 1250 mm. The minimum and maximum daily temperatures of the area are 10 and 32^{0}C, respectively. The major feed resources for cattle are natural pasture, crop residues, hay and non-conventional feedstuffs like local brewery by-products, but the supplies of improved forage is not common and concentrate supplementation is generally low (Yitaye et al., 2008; Asaminew and Eyassu, 2009). However, those farmers who own crossbred cows usually supplement the diets with oil seed by-products like nug (*Guizotia abyssinica*) seed cake, wheat bran and local brewery by-products. According to Asaminew and Eyassu (2009), due to better extension and AI services in the area, the number of crossbred dairy cows in this district is higher as compared to adjacent districts. The average milk production of local cows in the district is 1.2 litres and the corresponding value for crossbred cows is 5.2 litres.

Locations of the experiments



3.2.2. Experimental design

Prior to the actual feeding trial, discussions with district officials and early technology adopters ("model farmers") were held and secondary data were reviewed about dry season feed supply, constraints, farmers' feeding strategy and livestock product marketing. Based on this information, localities and farmers were selected purposively from the regional rural subsistence and peri-urban, market oriented dairy production systems of these two districts.

Experimental cows from Fogera and BDZ district were selected based on their lactation number, stage of lactation, current milk yield, body condition and health status. The selected cows were distributed evenly to a control and an intervention diet. Due to the very small number of cows per farm, either one or – in rare cases – two cows per farm were selected to participate in the experiment. This means that the treatment effect is inevitably confounded with the farm effect, as a particular farm was either within the control or within the experimental treatment. The control diets used were the traditional feeding practices of the farmers in their respective production system and the intervention diet included UMMB as a supplement to the usual feeding regime. The selected farmers were trained on the production and use of UMMB and on data recording.

3.2.3. Cows management and feeding

A total of 18 multi-parous lactating local Fogera cows of parity two and three in the Fogera district and 16 multi-parous Fogera * Holstein Friesian (F_1) crossbred dairy cows in BDZ district with a similar distribution of parities as for the Fogera cows were used over a period of 5 months (December 2010 to April 2011). In both livestock production systems, cows were in their early stages of lactation (8-49 days of lactation) at the start of the experiment. Before the start of the trial, cows were de-wormed using Albendazol 2500 mg (one bolus/250 kg live weight), were vaccinated against anthrax, bovine pasteurellosis and lump skin disease. All animals had a close supervision by a veterinarian in charge of each district. All cows were hand milked twice a day after having been suckled by their calves for about 1 minute. Body weight estimation using hearth girth measurement and body condition scoring were done every two weeks, following a procedure similar to the on-station experiments of this study. All animals were managed as commonly practiced by the farmers; breeding was not controlled and done at any time when the cows were observed as being in heat. Cows were inseminated either by a local bull or artificially by skilled AI technicians.

UMMBs were manufactured at Andassa Livestock Research Center and transported to the respective district every 10 days. UMMBs were formulated with similar formula of the on-station experiments of this study (see 3.1.4). In the two livestock production systems, feed supplementation including UMMB and management were different:

- Fogera cows in the rural subsistence area were grazing between 9 am and 6 pm on communal and/or private grazing lands. Crop residues were fed during the morning and evening hours. UMMB was supplied early in the morning between 6-8 am before milking and between 6-7 pm in the evening after milking.
- Crossbred cows in the market oriented peri-urban production system were usually offered hay, a mixture of local brewery by-products, wheat bran and nug seed cake after milking and before they went out for grazing. UMMB supplementation continued for an hour after the morning supplementation and the cows remained on pasture between 9-12 am afterwards. Between 12 am and 3 pm, crossbred cows were usually kept around the homestead and allowed to lick the block for about 3 hours. During the afternoon, they went out again for grazing from 3-5 pm. Similar to the morning feeding, supplements were given during the evening before milking and then UMMB was offered after milking for about an hour.

3.2.4. Data recording

After the adaptation period, daily milk offtake was measured using graduated plastic jug by the farmers, and paid enumerators assisted recording. Representative milk samples were taken in triplicates every two weeks and were analyzed for their composition using a Lactoscan milk analyzer[2]. The weight of the individual block offered to each cow was recorded every time before a new block was offered to individual cow to calculate the UMMB intake. Estimated body weight changes, BCS, medicaments given and feed costs were collected during the whole period at the two sites. Cows inseminated and date of insemination was also recorded. Milk Energy Offtake (MEO) and Energy Corrected Milk (ECM) were calculated based on the equations as published by Tyrrell and Reid (1965, 1 and 2) and as described for the on-station experiments of this study (see 3.1.5).

Using check lists, farmers' perception about the technology was collected during routine visits and workshops. Data on feed costs and price of milk were collected for partial budgeting. Using this information, net return/cow/day, net return/l of milk, feed cost/l of milk and benefit-cost ratio were calculated. Net return/cow/day was calculated as the difference of daily milk sold per cow minus daily feed costs per cow. Feed costs/l of milk were calculated using feed costs per day divided by daily milk offtake, whereas net return/l of milk was calculated as net return/cow/day divided by milk offtake/cow/day. The benefit-cost ratio was calculated from change in net return between the control and supplemented group divided by change in feed costs.

3.2.5. Statistical analysis

Data regarding milk offtake, milk composition, milk energy offtake, estimated body weight gain, BCS, feed cost/l of milk, net return/cow/day and net return/l of milk were analyzed using the Mixed Linear Model procedure of SAS 2009. The postpartum oestrus was analysed using Chi-square test and benefit-cost ratios were analysed using descriptive statistics. All collected data were subjected to analysis of variance, including the initial milk offtake, estimated initial body weight and initial BCS as co-variables for analysis of the respective response trait. For BCS, differences between treatments were analysed using the Kruskal-Wallis test (non-parametric one way procedure; SAS 2009). The results are presented as Least

[2] Lactoscan milk analyzer, Narodni Buditeli Str. 8900 Nova Zagora, Bulgaria. www.milkotronic.com

Square Means and residual standard deviation (s_e) and significance is defined at ($P < 0.05$), unless stated otherwise. The statistical model used for data analysis was:

$y_{ijklm} = \mu + \delta_i + \alpha_j(_i) + \lambda_k + \beta_l + X + \varepsilon_{ijklm}$

Where:

y_{ijklm} = the dependent variables, milk offtake, milk composition, MEO, estimated body weight gain and BCS

μ = the overall (constant) mean

δ_i = fixed effect of i^{th} diet (i = control, UMMB)

$\alpha_j(_i)$ = random effect of j^{th} cow within i^{th} diet

λ_k = fixed effect of k^{th} lactation number (k = 2, 3)

β_l = fixed effect of l^{th} week (l = 1…12)

X = initial milk offtake; initial estimated body weight; initial BCS

ε_{ijklm} = residuals

Economic traits were analysed using similar model, but without co-variables.

4. Results and discussion

4.1. Experiment one: high nutrient supply in mid-lactation cows

4.1.1. Effects of UMMB supplementation on productive performance and feed intake

Data for daily milk offtake and selected parameters of milk quality are presented in Table 4. The saleable milk offtake of cows receiving the UMMB supplementation was significantly increased by 24 % and 34 % for Fogera and crossbred dairy cows, respectively. In agreement to this, a substantial increment in daily saleable milk offtake as a result of UMMB supplementation was also reported for Buffalo and crossbred cows (Uddin et al., 2002 and Alam et al., 2006, respectively). In addition, UMMB supplementation also significantly increased the milk fat content by 12 % and 7 % in Fogera and crossbred dairy cows, respectively. The lower increase in milk offtake for local Fogera cows may be due to the fact that this breed has not been predominantly selected for milk yield for decades. This result is in agreement with a study conducted on indigenous and crossbred dairy cows (Nyoni et al., 2001).

As suggested from previous studies (Preston and Leng, 1987; Leng et al., 1991; Sudhaker et al., 2002; Upreti et al., 2010), the rather well balanced fermentable nitrogen and energy content of UMMB supports the microbial activity and thereby contributes to an increased fiber digestibility, which is in turn associated with high ruminal acetic acid fermentation and increased milk fat formation. However, supplementation did not seem to have an effect ($P > 0.05$) on the protein content of milk and only breed-related differences were observed for this trait (Table 4). This is in agreement with results from other authors (Bui Xuan An et al., 1993; Plaizier et al., 1999; Akter et al., 2004; Misra et al., 2006; Khan et al., 2007) who reported that UMMB or concentrate supplementation had no effect on milk protein content of dairy cows. In contrast to these findings, the milk protein content was significantly improved when local cows were supplemented with UMMB under on-farm conditions in India (Sahoo et al., 2009). Even though supplemented Fogera cows were superior to supplemented crossbred cows in milk constituents, because of the higher milk offtake in supplemented crossbred cows, the milk energy offtake (MJ/day) was much higher for the crossbred than the Fogera cows (Table 4).

Similar to milk offtake and milk fat traits, UMMB supplementation had a significant (P = 0.03) effect on estimated body weight gain irrespective of breed (Table 4). As a result, a 121 % and 97 % improvement in estimated body weight gain was observed for Fogera and crossbred cows, respectively. In agreement with the present findings, there is evidence to indicate that UMMB supplementation has a significant effect on daily body weight gain, both in crossbred cows (Alam et al., 2006) and local cows (Ghosh et al., 1993; Alam et al., 2009); similar effects were observed in other ruminant species, such as Lohi ewes (Rafiq et al., 2007) and Buffalo cows (Nimal et al., 2007). This is also in line with the significant (P = 0.01) positive impact of UMMB supplementation on BCS: supplemented Fogera and crossbred cows had a 17 % and 9 % greater BCS, respectively, as compared to the control cows.

Even though body weight gains were estimates from changes in heart girth, values seem to indicate that Fogera cows may partition the nutrients supplemented via UMMB with a greater priority into body substance and milk constituent traits, while in the crossbred cows milk output seemed to be prioritized. When studying the response of Holstein Friesian (HF) and Norwegian dairy cows to high and low levels of dietary concentrates, Yan et al. (2006) also reported that HF cows had a consistently lower body weight gain and body condition score, but a higher milk energy output than Norwegian cows when supplemented with similar concentrate levels. The authors mainly attribute this to the ability of HF cows to partition more energy into milk and less into body tissue. The productive performance, feed and nutrient intake of both breeds during mid stage of lactations is summarized in Table 4.

Table 4. Production performance and feed intake of mid-lactation cows of different breeds fed different diets

Traits	FN	FS	CN	CS	s_e
	Treatments				
Milk offtake (l/day)	1.90^{a}	2.35^{b}	3.69^{c}	4.95^{d}	0.641
ECM offtake (l/day)	2.12^{a}	2.78^{b}	3.90^{c}	5.42^{d}	0.690
Milk fat (g/l of milk)	42.4^{b}	47.5^{c}	39.4^{a}	42.1^{b}	1.98
Milk protein (g/l of milk)	33.0^{b}	33.2^{b}	30.7^{a}	30.8^{a}	0.97
Milk total solids (g/l of milk)	133.4^{b}	137.6^{c}	123.4^{a}	125.8^{a}	3.62
Milk fat yield (g/day)	80.6^{a}	111.6^{b}	145.4^{c}	208.4^{d}	30.00
Milk protein yield (g/day)	62.7^{a}	78.0^{b}	113.3^{c}	152.5^{d}	19.21
MEO (MJ/day)	6.09^{a}	8.13^{a}	11.16^{b}	15.54^{c}	1.939
Estimated body weight gain (g/day)	107^{a}	237^{b}	120^{a}	236^{b}	105.0
BCS	2.3^{a}	2.7^{b}	2.2^{a}	2.4^{ab}	0.23
TDMI (kg/day)	7.30^{a}	8.17^{b}	8.05^{b}	8.98^{c}	0.870
HIDM (kg/day)	5.25^{a}	5.66^{ab}	6.00^{bc}	6.35^{c}	0.873
UMMBI (g/day)		456^{a}		583^{b}	0.1
OMI (kg/day)	6.64^{a}	7.43^{b}	7.32^{b}	8.18^{c}	0.794
CPI (g/day)	669^{a}	819^{c}	713^{b}	894^{d}	53.0
MEI (MJ/day)	55.13^{a}	62.08^{b}	59.77^{b}	67.56^{c}	5.393
NDFI (kg/day)	4.44^{a}	4.85^{ab}	4.94^{bc}	5.35^{c}	0.581
ADFI (kg/day)	1.84^{a}	2.94^{b}	2.07^{a}	3.25^{c}	0.324
PCR	11.23^{b}	10.82^{b}	6.62^{a}	5.89^{a}	1.979
ECR	9.44^{b}	7.92^{b}	5.69^{a}	4.43^{a}	1.660

Note: ^{abcd} Different superscripts indicate significant ($P \leq 0.05$) differences between means in the same row; FN = Fogera cows non-supplemented; FS = Fogera cows supplemented; CN = Crossbred cows non-supplemented; CS = Crossbred cows supplemented; s_e = residual standard deviation; ECM = energy corrected milk; MEO = milk energy offtake; TDMI = total dry matter intake; HIDM = hay intake on dry matter basis; UMMBI = UMMB intake; OMI= organic matter intake; CPI = crude protein intake; MEI = metabolisable energy intake; NDFI = neutral detergent fibre intake; ADFI = acid detergent fibre intake; PCR = protein conversion ratio; ECR = energy conversion ratio.

In addition to improvements in productive traits, UMMB supplementation also significantly improved the total dry matter intake of cows of both breeds (Table 4). This may be due to the positive effects of UMMB as a source of soluble nitrogen and easily fermentable carbohydrates which probably increased the activity of cellulolytic rumen microflora, hence the fermentation of roughages and concomitantly their intake (Leng et al., 1991; Sudhaker et al., 2002). It is known that increasing the concentrate level in ruminant diets will increase dry matter intake as a result of proliferation in microflora population (Santra and Karim, 2009). Consumption of low quality forage may be particularly improved by UMMB supplementation causing an increase in the activity of cellulolytic rumen microflora (Van Soest, 1994), as has been shown for the intake of maize stover in goats (Faftine and Zanetti, 2010). UMMB supplementation to Fogera cows in mid-lactation contributed 6.5 % and 14 % to the overall ME and CP intake over the control diet, respectively. The corresponding values for crossbred dairy cows were 7.6 % and 16.4 %, respectively (Table 4).

Crossbred cows ingested about 0.8 kg significantly more dry matter than Fogera cows, regardless of their dietary treatment. This is probably due to their higher genetic potential for milk production, which increases their nutrient and energy requirements beyond that of the lower yielding Fogera cows. It was also observed that the organic matter intake of supplemented Fogera cows was greater than that of the control cows: 7.43 vs. 6.64 kg/day, respectively. The corresponding values for crossbred dairy cows were 8.18 vs. 7.32 kg/day, respectively. On the other hand, as opposed to the higher total dry matter intake of UMMB supplemented Fogera and crossbred dairy cows, the intake of NDF was not significantly ($P = 0.068$) different between control and supplemented Fogera and crossbred dairy cows, respectively. UMMB supplementation probably increased the proliferation and fermentation activity of rumen microflora, thereby improving feed intake as a consequence.

As a result of supplementation, cows of both breeds consumed significantly ($P \leq 0.05$) more protein and energy as compared to the unsupplemented groups. A 22 % and 25 % increase in protein intake was observed in supplemented Fogera and crossbred cows, respectively. The increase in energy intake was similar for supplemented Fogera and crossbred cows (13 %). In converting feed energy and protein into milk energy and protein available for human consumption, the crossbreds were more effective than the Fogera cows, but no significant supplementation effect were observed for these traits. On a short-term basis, the efficiency of nutrient use for milk production is primarily dependent on the milk production level of the cows (Chilliard, 1989). The results presented herein follow this pattern: ECM offtake was on average 95 % greater in crossbred cows, which only consumed 9 % more energy as compared to Fogera.

4.1.2. Benefit-cost analysis of UMMB supplementation in mid-lactation

The UMMB supplementation practiced herein proved to be economically beneficial. Taking into account milk production and feed costs alone, the relative average improvement in net return per day as a result of supplementation with UMMB was very similar for Fogera and crossbred dairy cows (43 % and 44 %, respectively; Table 5). However, the supplementation effect was not statistically significant for the Fogera cows (Table 5). In absolute numbers, financial gains resulting from supplementation were greater for crossbred dairy cows than for their Fogera counterparts, resulting in a three times greater benefit-cost ratio for the F * HF cows. Uddin et al. (2002) also reported that, when buffalo cows were supplemented with urea-molasses or urea-molasses-concentrate mix, buffalo cows which were supplemented with urea-molasses had a greater net return per day than those of the urea-molasses-concentrate supplemented group. This was attributed to the lower cost of urea-molasses compared to concentrate.

Table 5. Economics of UMMB supplementation to mid-lactating cows of different breeds fed different diets

	Treatments				
Traits	FN	FS	CN	CS	s_e
Net return (USD/day)	0.24[a]	0.34[a]	1.00[b]	1.43[c]	0.284
Net return (USD/l of milk)	0.12[a]	0.14[a]	0.26[b]	0.28[b]	0.062
Feed costs (USD/l of milk)	0.32[b]	0.30[b]	0.18[a]	0.15[a]	0.062
Benefit : cost ratio		1.21		3.66	

Note: [abc] Different superscripts indicate significant ($P \leq 0.05$) differences between means in the same row; FN = Fogera cows non-supplemented; FS = Fogera cows supplemented; CN = Crossbred cows non-supplemented; CS = Crossbred cows supplemented; s_e = residual standard deviation; USD = United States Dollar (1 USD = 16 Ethiopian Birr).

4.2. Experiment two: moderate nutrient supply in late lactation cows

4.2.1. Effects of UMMB supplementation on productive and reproductive performance

Similar to the first experiment, the milk production performance of dairy cows was significantly ($P < 0.05$) improved by UMMB supplementation by 0.6 (43 %) and 1.65 (52 %) liters per cow and day for Fogera and crossbred dairy cows, respectively (Table 6). Despite the differences between experiments in dietary concentrate proportion and hence in the nutrient supply, both the Fogera and crossbred dairy cows responded positively to UMMB supplementation by a 50 % and 54 % increase in energy corrected milk offtake, respectively. However, from mid to late stage of lactation, a 14 % and 2 % drop in energy corrected milk offtake was observed in supplemented Fogera and crossbred cows, respectively. In addition to the more pronounced reduction in protein and energy intake from mid to late stage of lactation for the Fogera cows, the greater persistency in daily milk offtake of crossbred dairy cows as compared to Fogera may have contributed to this. Kabir and Islam (2009) also reported that the lactation length of local cows is much shorter than that of crossbred cows. In line with this, Addisu et al. (2010) reported a lactation length of 292 days for Fogera cows, whereas Demeke et al. (2000) reported 374 days of lactation for crossbred cows in Ethiopia.

Besides an increase in daily milk offtake, all the UMMB supplemented cows had a significantly ($P < 0.05$) improved butter fat content as compared to their control. Nevertheless the rate of increase in milk fat content of supplemented Fogera cows in this experiment was greater than that of crossbred cows (Table 6). Similar to the results presented here, local Boran (*Bos indicus*) were found to have higher contents of milk fat, protein and total solids as compared to their crosses with Holstein Friesian (Mesfin and Getachew, 2007; Aynalem et al., 2008).

Similar to the results of the previous (see 4.1.1) and this experiment, Khan et al. (2007) and Misra et al. (2006) also reported that UMMB supplementation did not affect milk protein content. Despite the different stage of lactation and the related changes in dietary nutrient supply, there was again no significant effect of UMMB supplementation on milk protein content. Effects of dietary protein content on milk fat and protein percentage were also analysed by Sinclair et al. (2009). In their report, multi-parous Holstein dairy cows fed low protein diets had significantly higher milk fat content, while milk protein percentage was not affected by level of dietary protein. The overall production performance, feed and nutrient intake of late stage of lactation Fogera and crossbred dairy cows is summarized in Table 6.

Table 6. Production performance and feed intake of late lactation cows of different breeds fed different diets

	Treatments				
Traits	FN	FS	CN	CS	s_e
Milk offtake (l/day)	1.40^a	2.00^b	3.19^c	4.84^d	0.543
ECM offtake (l/day)	1.60^a	2.40^b	3.45^c	5.31^d	0.609
Milk fat (g/l of milk)	45.4^c	49.6^d	41.5^a	42.7^b	1.68
Milk protein (g/l of milk)	32.5^b	32.5^b	30.4^a	30.5^a	1.30
Milk total solids (g/l of milk)	134.2^b	139.9^c	125.0^a	126.1^a	3.27
Milk fat yield (g/day)	63.6^a	99.2^b	132.4^c	206.7^d	24.08
Milk protein yield (g/day)	45.6^a	64.6^b	96.9^c	147.4^d	16.71
MEO (MJ/day)	4.70^a	7.21^b	9.83^c	14.85^d	1.736
Estimated body weight gain (g/day)	12	69	23	88	47.0
BCS	2.3^a	2.7^b	2.3^a	2.6^{ab}	0.21
TDMI (kg/day)	4.90^a	6.62^b	7.32^c	8.52^d	0.898
HIDM (kg/day)	4.16^a	5.35^b	5.68^{bc}	6.18^c	0.894
UMMBI (g/day)		528^a		704^b	0.1
OMI (kg/day)	4.47^a	6.03^b	6.66^c	7.76^d	0.819
CPI (g/day)	306^a	520^b	598^c	820^d	53.0
MEI (MJ/day)	32.95^a	45.38^b	52.93^c	62.78^d	5.587
NDFI (kg/day)	3.36^a	4.31^b	4.63^b	5.17^c	0.602
ADFI (kg/day)	2.08^a	2.67^b	2.84^b	3.16^c	0.377
PCR	6.91^{ab}	8.32^b	6.62^{ab}	5.66^a	1.641
ECR	7.25^b	6.68^b	5.81^{ab}	4.20^a	1.500

Note: ^{abcd} Different superscripts indicate significant (P≤0.05) differences between means in the same row; FN = Fogera cows non-supplemented; FS = Fogera cows supplemented with UMMB; CN = Crossbred cows non-supplemented; CS = Crossbred cows supplemented with UMMB; s_e =residual standard deviation; ECM = energy corrected milk; MEO = milk energy offtake; TDMI = total dry matter intake; HIDM = hay intake on dry matter basis; UMMBI = UMMB intake; OMI = organic matter intake; CPI = crude protein intake; MEI = metabolisable energy intake; NDFI = neutral detergent fibre intake; ADFI = acid detergent fibre intake; PCR = protein conversion ratio; ECR = energy conversion ratio.

In agreement with the preceding trial, supplementation had a significant ($P \leq 0.05$) effect on milk energy offtake during this experiment. However, despite a decline in daily milk offtake during late as compared to mid stage of lactation, the differences in milk energy offtake between control and UMMB-supplemented cows was very similar for both breeds: 53 % vs. 51 % for Fogera and crossbred cows, respectively. The greater persistency in milk offtake of crossbred cows was highlighted by 12 % and 2 % reduction in energy corrected milk offtake in late as compared to mid-lactation control and supplemented cows. The corresponding values for Fogera cows were 25 % and 14 % for control and supplemented cows, respectively. In addition to a greater persistency of the crossbred cows (Kabir and Islam, 2009; Demeke et al. 2000; Addisu et al., 2010), the more pronounced reduction in daily protein and energy intake for the Fogera cows in late as compared to mid-lactation may have contributed to a lower energy corrected milk offtake (Table 4 and 6).

Besides the observed changes in milk production traits, most of the supplemented cows showed symptoms of heat earlier than cows in the control groups. Behavioral oestrus was observed in 38 % and 75 % of the supplemented Fogera and crossbred cows, respectively. Conversely, only 25 % of the Fogera and 13 % of the crossbred cows without UMMB supplementation came into heat. UMMB supplementation apparently had a greater effect in crossbred as compared to Fogera cows. Due to the low number of observations, no statistical analysis was performed on this trait. However, it seems logical that the genotype with the greater genetic potential for milk production shows a greater depression in reproductive performance unless it is supplied with sufficient amounts of nutrients and energy (Kelay, 2002; Indetie, 2009).

As opposed to the first experiment, no significant breed effect was found on estimated body weight gain between treatments. However, due to supplementation with UMMB a slightly higher estimated body weight gain was observed for both breeds as compared to their respective control groups (Table 6). This is also partially reflected in a 17 % significant ($P \leq 0.05$) improvement in BCS of supplemented as compared to non supplemented Fogera cows. The 13 % difference in BCS observed between control and supplemented crossbred cows did not reach the level of significance ($P = 0.14$). Upreti et al. (2010) reported that supplementation of crossbred dairy cows with UMMB during the dry season improved the body condition of the cows from score 3.5 to 4 in Nepal.

Similar to the productive traits, supplementation with UMMB had a significant ($P \leq 0.05$) effect on total dry matter and hay intake. However, in relative terms, the Fogera cows had a greater response for hay intake as compared to crossbred cows (29 % vs. 9 %; Table 6). During the first phase of the experiment the increment was only 8 % and 6 % for Fogera and crossbred cows, respectively. A reason for this could be that UMMB supplementation specifically enabled the Fogera cows to ingest substantially greater amounts of hay, thereby following their motivation for increased forage consumption which was fostered by not receiving any concentrates, while the crossbreds were still supplemented with some concentrates because of their higher milk yield. Consistent with the present results, Leng et al. (1991) reported that feeding UMMB, with its soluble nitrogen and other microbial growth factors optimizes the ruminal fermentation capacity which leads to an increased rate of fiber digestion and outflow of bacterial protein, thereby eventually stimulating feed intake.

The daily UMMB intake per cow was also higher during the second as compared to the first phase of the experiment (Table 4 and 6). Reasons for this could be that the cows became more accustomed to the blocks and that the reduced (crossbreds) or even ceased concentrate supply (Fogera) pushed the cows to ingest more of the UMMB. UMMB supplementation to late lactation Fogera cows contributed 10.8 % and 25.6 % to the overall ME and CP intake, respectively. The corresponding values for the crossbred dairy cows were 10 % and 21.6 %, respectively. Due to lower consumption of hay and concentrate and at the same time higher intake of UMMB in late as compared to mid lactation, the contribution of UMMB to total ME and CP intake increased from the first to the second experiment: 6.5 % vs. 10.8 % in ME and 14 % vs. 25.6 % in CP intake in Fogera cows, respectively. The corresponding values for crossbred dairy cows were 7.6 % vs. 10 % and 16.4 % vs. 21.6 %, respectively. The supplementation of forage based diets with UMMB may improve roughage intake more than the supplementation with commonly used concentrates, as it was reported for buffalo calves (Mirza et al., 2004).

Similar to dry matter intake, a significant ($P \leq 0.05$) increment in crude protein and energy intake of cows was observed as a result of UMMB supplementation for both breeds. However, the relative increase in crude protein intake was greater for Fogera as compared to the crossbred cows (70 % vs. 37 %, Table 6). This may be related to the relatively greater total dry matter and hay intake as a result of UMMB supplementation and on the other hand the control Fogera cows were solely dependent on roughage based diets. Irrespective of supplementation, the daily NDF intake was reduced from mid to late stage of lactation. However, during late lactation, a significant difference in NDF intake was observed between control and UMMB supplemented groups (Table 6). For the Fogera cows, the protein and energy conversion ratio improved from the first to the second experiment, probably because of the substantially lowered intake of protein and energy in late lactation (Table 4 and 6). Protein and energy conversion ratio was rather similar between the two experiments for crossbred cows. In contrast to Fogera, crossbred cows consumed 37 % more CP and had a 52 % higher milk protein offtake when supplemented with UMMB (Table 6), while the Fogera cows consumed 70 % more protein to produce 42 % more milk protein.

4.2.2. Benefit- cost analysis of UMMB supplementation during late lactation

In late lactation, UMMB supplementation seems to be economically meaningful for crossbred cows only: a greater increase was observed for income from milk sales as compared to feed costs in crossbred cows, whereas a benefit-cost ratio smaller than one was found for late lactating Fogera cows (Table 7). These results are different to those from the first experiment, where supplementation of dairy cows with UMMB was found to be economically beneficial for both breeds despite the higher nutrient and energy supply in mid- as compared to late lactation. As a result of greater persistency in daily milk offtake between mid and late stage of lactations, the crossbred cows were more consistent in their benefit–cost ratio than their Fogera counter parts. Between mid and late stage of lactation, a 55 % and 5 % reduction in benefit–cost ratio was observed for Fogera and crossbred dairy cows, respectively.

Table 7. Economics of UMMB supplementation to late lactating cows of different breeds fed different diets

	Treatments				
Traits	FN	FS	CN	CS	s_e
Net return (USD/day)	0.33[a]	0.44[a]	0.84[b]	1.39[c]	0.240
Net return (USD/l of milk)	0.23[a]	0.20[a]	0.25[ab]	0.29[b]	0.053
Feed costs (USD/l of milk)	0.21[b]	0.24[b]	0.19[ab]	0.15[a]	0.053
Benefit :Cost ratio		0.54		3.46	

Note: [abc] Different superscripts indicate significant ($P \leq 0.05$) differences between means in the same row; FN = Fogera cows non-supplemented; FS = Fogera cows supplemented; CN = Crossbred cows non-supplemented; CS = Crossbred cows supplemented; s_e = residual standard deviation; USD = United States Dollar (1 USD = 16 Ethiopian Birr).

4.3. Effect of UMMB on dairy cows in two different livestock production systems

4.3.1. Effects of UMMB on productive and reproductive performance

Data related to average saleable milk and milk energy offtake and selected parameters of milk quality traits are presented in Table 8. A highly significant ($P < 0.01$) difference was observed in daily milk offtake as a result of UMMB supplementation for both production systems. It should be noted that the differences between production systems are most probably to a great extent caused by the breed effect, but due to the design chosen for this study, the production system is completely confounded with breed. While this simply reflects the reality in the field, no differentiation can be made between genetic and environmental effects for any of the response traits.

The relative improvement in average daily energy corrected milk (ECM) offtake due to supplementation was similar in the rural subsistence (RS) and the peri-urban (PU; 28 %; Table 8) production systems. Due to breed-related differences in milk offtake, milk fat and protein content, the improvement in milk energy offtake that resulted from UMMB supplementation were 28 and 30 % for RS and PU production systems, respectively. A greater positive response of 55 % in milk offtake was observed in local cows in Bangladesh due to UMMB supplementation (Akter et al., 2004). The lower milk offtake response of cows in this study as compared to the Bangladesh case may be related to the difference in nutrient and energy intake and management systems. Leng (1997) found an increase in milk yield of 30 % due to UMMB-supplementation for lactating dairy cows in India, which is closer to the values reported herein. In a Vietnamese study, supplementation of crossbred dairy cows with UMMB resulted in an 11 % increase in milk yield (Doan Duc Vu et al., 1999).

Table 8. UMMB-supplementation and performance of dairy cows in two different livestock production systems

Trait	RS				PU			
	Control	UMMB	s_e	P	Control	UMMB	s_e	P
Milk offtake (l/day)	1.12	1.38	0.187	<0.001	4.86	6.07	0.944	0.007
ECM offtake (l/day)	1.27	1.63	0.218	<0.001	5.25	6.74	1.043	0.004
Milk fat content (g/l of milk)	45.4	48.4	2.30	<0.001	41.4	43.7	1.69	<0.001
Milk protein content (g/l of milk)	31.2	31.3	0.93	0.590	30.3	30.6	0.88	0.080
Milk fat offtake (g/day)	51	67	9.0	<0.001	199	264	41.4	0.002
Milk protein offtake (g/day)	35	43	5.9	0.001	147	186	27.5	0.004
MEO (MJ/day)	3.65	4.69	0.626	<0.001	14.8	19.2	2.959	0.002
UMMB intake (g/day)		334				514		
Estimated body weight change (g/day)	-25	93	50.3	<0.001	-16	174	76.0	<0.001
Body Condition Score (BCS)	1.9	2.3	0.20	<0.001	2.2	2.7	0.27	0.002
Cows inseminated (n (%))	1 (11)	4 (44)			3 (38)	5 (63)		

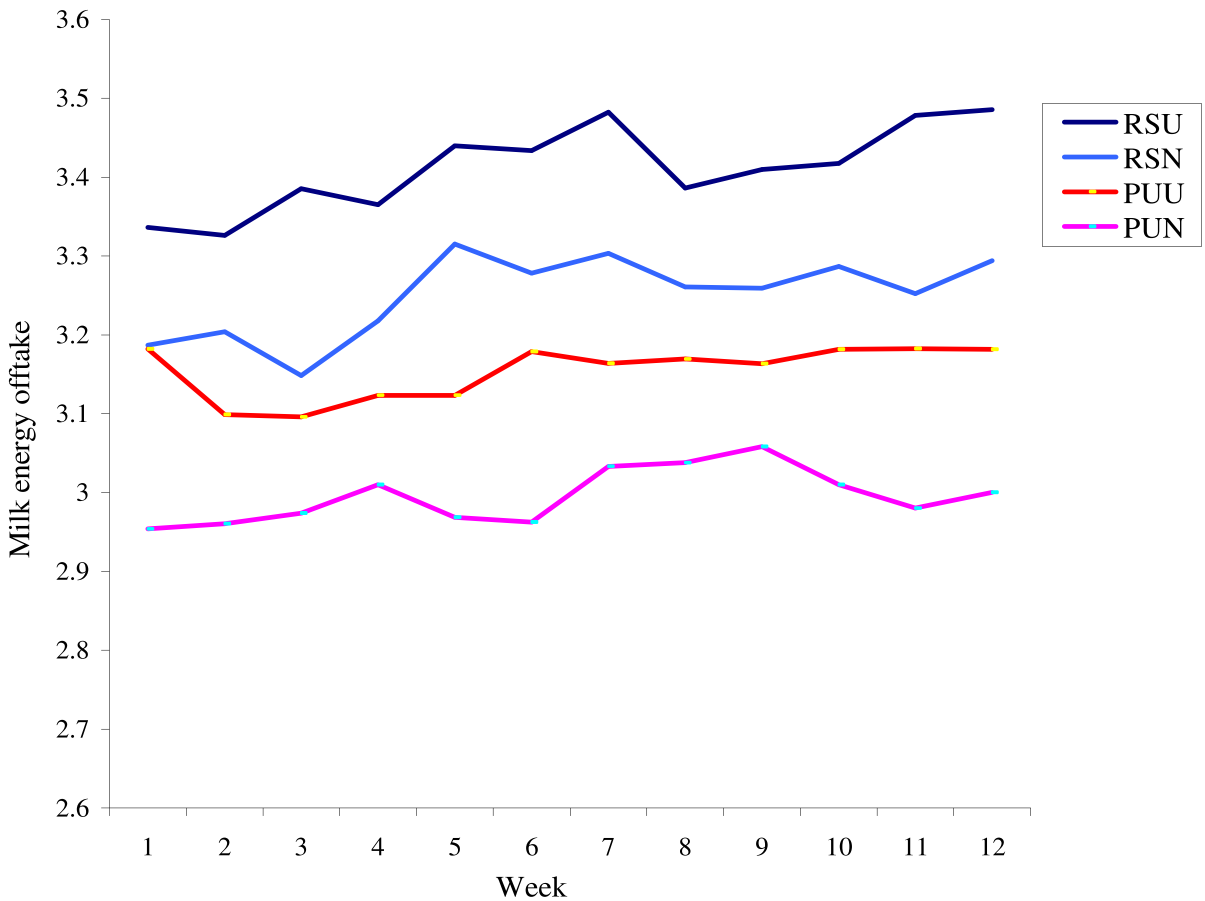
Note: RS = Rural subsistence (Fogera); PU = Peri-urban (Crossbred); ECM = energy corrected milk; MEO = milk energy offtake; s_e = residual standard deviation; (n (%)) = number of cows coming into heat and inseminated and their percentage.

In addition to milk offtake, supplementation of UMMB significantly ($P < 0.05$) improved the butter fat content of milk in RS (7 %) and PU (6 %; Table 8). UMMB supplementation to crossbred dairy cows in Vietnam resulted in a much higher (15 %) increase in milk fat content than in the present study (Bui Xuan An et al., 1993). This may be partially due to the 95 % greater UMMB and nutrient intake for the Vietnamese group (514 vs. 1000 g). A similar study using crossbred dairy cows in Nepal indicated that UMMB supplementation resulted in an increase in milk fat content that was very similar (6%) to the present findings (Upreti et al., 2010). Other related research also indicated that UMMB, through its balanced fermentable nitrogen and energy content, improved milk fat content in dairy cows (Leng et al., 1991; Doan Duc Vu et al., 1999; Sudhaker et al., 2002; Alam et al., 2006). Even though a slight improvement was observed in milk protein content following UMMB supplementation in the PU production system, its effect was not significant. The milk protein content of Fogera cows in the RS system did not react at all to UMMB supplementation. A number of previous studies (Bui Xuan An et al., 1993; Misra et al., 2006; Reyes Sánchez et al., 2006) also indicated that UMMB and/or concentrate supplementation had no effect on the protein content of milk. On the contrary, Sahoo et al. (2009) reported a significant improvement in the protein content of local cows' milk when they were supplemented with UMMB. The greater supply of crude proteins by UMMB and grass hay as compared to the present study coupled with the balanced nutrients within the UMMB, may be the reason for the significant improvement in the protein content of milk as compared to the present study.

Similar to the daily milk offtake, a significant ($P < 0.05$) improvement in daily fat and protein offtake was observed due to UMMB supplementation in both production systems. This increase is mainly a result of the changes in milk offtake and hence the absolute differences are greater for the peri-urban production system in which higher yielding crossbred cows are utilized than for the rural subsistence production system, in which farmers keep local Fogera cows.

The average daily UMMB intake of Fogera cows in RS in this study was 334 g whereas the corresponding figure for crossbred cows in PU was 514 g. The greater UMMB intake by crossbred PU-dairy cows may have been related to the greater quantities of nutrients and energy required for their higher milk offtake; this was accompanied by longer time periods during which they were allowed consuming the blocks and by a greater requirement for body maintenance of crossbred cows. A study conducted in Thailand using crossbred cows also indicated that cows consumed on average 520 g UMMB per head and day (Narong, 2007) .

The increase in milk offtake and milk constituents for the UMMB supplemented dairy cows consequently led to a significant ($P < 0.05$) improvement in milk energy offtake for both production systems (Table 8). However, the Fogera cows at RS were superior to crossbred cows at PU in their milk energy offtake per litre of milk: for example, supplemented cows at RS had an 8.3 % higher milk energy offtake than supplemented cows at PU (Figure 3). The on-station studies in which the same breeds were used (Table 4 and 6) also indicated that the higher protein and energy intake from UMMB supplementation resulted in a better milk energy offtake than in the control groups.



Note: RSU = Rural subsistence with UMMB supplementation; RSN = Rural subsistence without UMMB supplementation; PUU = Peri-urban with UMMB supplementation; PUN = Peri-urban without UMMB supplementation.

Figure 3. Milk energy offtake of dairy cows in two different livestock production systems

Irrespective of the production system, UMMB supplementation also substantially improved the estimated body weight gain of dairy cows as compared to non-supplemented cows (Table 8): While the unsupplemented cows slightly lost body weight, the UMMB supplementation led to a positive change in estimated body weight, which is remarkable, given that the cows were in their early stages of lactation. Similar to this finding, UMMB supplementation exerted a positive effect on body weight gain irrespective of the breed in the previous on-station experiments (Table 4 and 6). A similar response to consumption of urea-molasses blocks was also reported for growing buffalos (Jian-Xin Liu et al., 2007). The positive influence of the UMMB supplementation on estimated body weight gain is paralleled by a significant ($P < 0.05$) 0.4 to 0.5 score points improvement of BCS of dairy cows in RS and PU production systems, respectively. Contrary to these findings, UMMB supplementation failed to show positive effects on body weight and body condition of crossbred dairy cows under smallholder conditions in Vietnam (Doan Duc Vu et al., 1999). As suggested by the authors, one reason for this may have been a continuous selection for increased milk yield rather than body weight and a concomitant priority in nutrient partitioning.

In addition to the improvement in body weight and body condition, UMMB supplementation also seemed to have positively influenced reproductive performance. The result given in Table 8 show that more of the supplemented than of the control cows were inseminated, although the numbers of observations were too small to result in significant differences. Overall, cows in the peri-urban livestock production system seemed to have a slightly better reproductive performance than the Fogera cows in the rural subsistence-oriented production system. In addition to the higher intake of UMMB by crossbred cows, farmers in the peri-urban production system usually supply their cows with home made concentrates to improve the milk yield of their cows which may in turn have improved the reproductive performance of dairy cows in this production system as compared to the rural subsistence system. Similar to this finding, it was concluded from a previous on-station study (Table 6), which involved Fogera and crossbred dairy cows, that the effect of UMMB on postpartum oestrus was more prominent in crossbred than in local Fogera cows. These results are in agreement with the work of Khanum et al. (2010) who found that UMMB supplementation improved post-partum ovarian activity in addition to an increase in milk yield, feed intake and weight gain of dairy cows.

4.3.2. Effects of UMMB on selected economic traits in two different livestock production systems

Taking into account the returns from saleable milk offtake and costs of feed only, the benefit-cost ratio for Fogera and crossbred dairy cows in their respective production system were 2.64 and 5.53, respectively (Table 9). Upreti et al. (2010) concluded from their study with crossbred dairy cows in Nepal that due to UMMB supplementation an additional net profit was obtained of 10.77 NRs [1 USD = 75.1880] per day. The improvements in net return per day due to UMMB supplementation were 24 and 45 % for the rural subsistence-oriented production system (Fogera) and the peri-urban farms (crossbred), respectively. The economic gain obtained under farm conditions was better than that observed in the previous on-station experiments (Table 5 and 7). The differences to this field study may be related to the differences in stage of lactation between the two studies: cows were in their mid and late stage in the on-station, but in early lactation in the on-farm trial. For the net return per day a significant ($P < 0.05$) difference was observed between supplemented and control groups of cows in both production systems (Table 9). Due to their higher milk yield, cows in the peri-urban livestock production system which were supplemented with UMMB showed a higher net return per day than their control group and PU cows were clearly superior to cows in the rural subsistence-oriented production system.

Table 9. Economics of UMMB supplementation in two different livestock production systems

Traits	RS				PU			
	Control	UMMB	s_e	P	Control	UMMB	s_e	P
Net return (USD/day)	0.25	0.31	0.072	0.081	1.02	1.48	0.42	0.050
Net return (USD/l of milk)	0.22	0.22	0.008	0.539	0.23	0.23	0.009	0.363
Feed costs (USD/l of milk)	0.06	0.07	0.008	0.539	0.05	0.05	0.009	0.363
Benefit: Cost		2.64				5.53		

Note: USD = RS = Rural subsistence (Fogera); PU = Peri-urban (Crossbred); United States Dollar, 1 USD = 16 Ethiopian Birr; s_e = residual standard deviation.

4.3.3. Farmers' perception on the use of UMMB

During routine visits, at the time of distribution of the blocks and a workshop conducted at the end of the feeding trial, the following observations made by farmers, development agents and researchers were collected and summarized. Notable improvements in milk offtake, body condition, reproductive performance, health status of the cows and an increased straw intake were the major observations compiled from the 34 respondents (Table 10), using open-ended questions.

Table 10. Feedback on the use of UMMB

Feedback	Respondents (%)
Improved milk offtake	98
Improved body condition	88
Improved postpartum oestrus	69
Improved health status	72
Observed urea poisoning	0
Observed initial UMMB licking problem	31
Ready to produce UMMB by their own	40
Preferred to buy UMMB from the market	60
Preferred establishment of production unit at village level	74

Contrary to its positive effect, some farmers also raised the following concerns in relation to a potential upscaling of the technology:

- Future uncertainties about the supply of molasses/blocks in the local market.
- The currently insufficient knowledge of the farmers on the production and use of the technology coupled with the poor linkage between extension and research offices.
- A market access problem exists for milk and milk products which results in the loss of interest to invest in the technology by some of the smallholder farmers in RS production system.

For future action, the following points were suggested by the farmers, extension agents and researchers:

- Training of farmers and demonstration of the technology through farmers training centres.
- Training of extension agents, researchers and organized producer youth groups on the technology.
- Local government, extension department, research, cooperatives, sugar industries and relevant NGOs need to be involved in the transfer of the technology and create a link among themselves.
- Establishment of more dairy cooperatives and specialised UMMB producer youth groups.
- The use of revolving fund approach for mass production of the block by dairy cooperatives and/or specialised UMMB producer youth groups and creating of market linkage.
- Assigning facilitators for transfer and upscaling of the technology at districts level.
- Establishment of monitoring and evaluation systems on the use and dissemination of UMMB technology.

5. Conclusions and recommendations

From the two studies reported herein and from literature sources it is concluded that a strategic nutrient and energy supplementation with urea molasses multi-nutrient block can substantially improve the productive, reproductive and economic performance of dairy cows regardless of their genotype and the respective production system. However, it was also observed that supplementation of urea molasses multi-nutrient block does not guarantee a similar performance in different dairy genotypes and production systems. Due to a likely interaction effect between dairy genotype and nutrient supply, the quantitative difference in performance between genetically improved (e.g. crossbred) and local dairy cows will depend on the nutrient and energy supply of cows. Crossbred cows will nevertheless be better than local (e.g. Fogera) cows in their productive performance, the nutrient and energy conversion and eventually in important economic indicators under most practical feeding regimes. On the other hand, local cows may be superior to crossbred cows in milk constituents.

The effect of urea molasses multi-nutrient block will most likely also improve the roughage intake of dairy cows. This is particularly important for countries like Ethiopia, where concentrate supplementation is limited and where the basal diets of the animals generally consist of low quality roughage. In converting energy and protein to milk energy and protein for human consumption, crossbred dairy cows are more efficient than the local Fogera cows. The improvement in feed and nutrient intake and the concomitant increase in the daily milk offtake and fat content of milk have different economic implications for the farmers in different livestock production systems. For instance, the greater improvement in daily milk offtake of crossbred dairy cows in market oriented, peri-urban livestock production systems, where milk marketing is very attractive, will result in a significant economic advantage as compared to rural productions systems, where milk has to be frequently converted into butter because of lacking market access. On the other hand, the higher milk fat content of local Fogera cows may offer a certain advantage for farmers who depend on butter sale. Therefore, depending on the demand of the products in a particular region, urea molasses multi-nutrient block may offer particular advantages if it is strategically used.

The response of the farmers on the effect of urea molasses multi-nutrient block supplementation on milk yield, body condition of cows and on reproductive performance go hand in hand with the observations from both the on-station and field experiments. For a sustainable use and promotion of the utilization of urea molasses multi-nutrient blocks, dairy cooperatives and organized and specialised producer youth groups should be involved in the production and distribution of the blocks to cooperative members and others farmers in the respective villages. Based on the conclusions of this study, recommendations are made for different levels of the Ethiopian institutional structure.

Regional Government

- Coordinating and networking of different stakeholders such as local government, extension department, research, cooperatives, sugar industries, credit institutions, relevant NGOs in promotion and use of the UMMB technology and strengthening the existing Research – Extension – Farmers – Advisory Council.
- Currently there are not enough credit services for the rural farmers engaged in dairy business. Therefore, facilitation of the regional government through Bureau of Economy and Finance is required to link the farmers and producer groups to credit institutions.
- Attracting investors on establishments of small scale milk processing units at strategic market points in the region so that milk market will be open for the farmers.
- Organizing specialized UMMB producer youth groups and assist in infrastructure development and closer supervision.

Agriculture Bureau

- The extension department should promote UMMB technology mainly through dairy cooperatives and organized and specialized producer youth groups in disseminating the technology.
- Organizing UMMB field days in different agro-ecological zones to explain to the farmers the importance of UMMB and to foster experience sharing among farmers.
- Training of farmers and development agents and demonstration of the production and use of the UMMB technology at farmers' training centres.
- Extension service shall assist individual farmers, dairy cooperatives and specialized producer youth groups in getting revolving funds and credits for mass production and distribution of the blocks. This should be done together with Bureau of Economy and Finance.

- Nomination of qualified personnel as facilitators for transfer and scaling up of the technology at district level should be done by each respective district extension offices.
- To gather with the districts facilitators, the livestock extension officers at Bureau and districts level, shall monitor and evaluate the production and use of UMMB by the rural farmers.

Research Institutions

- Because of the limited availability of concentrates, future studies should address the substitution of concentrates by UMMB which should be specifically formulated for this purpose.
- Different UMMB formulas which are to be tailored specifically for certain scenarios should be tested across different livestock management and production systems. The economical consequences of their use should be studied in more detail than was done within this study.
- Besides its supplementation characteristic, UMMB may also act as a vehicle for other interventions such as administering anthelimentic drugs to small and large ruminants.
- UMMB should also be tested on other ruminant species and different age groups. The season and productive stage in which UMMB exerts the greatest effect should be identified for each livestock category.

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Appendix

Appendix 1. Chemical composition of feedstuffs used in the experiments

Feed stuff	DM %	Ash %	OM %	NDF %	ADF %	Lignin %	CP %	DOMD %	ME MJ/kg
Concentrate	90.3	9.98	90.0	28.5	13.4	03.78	22.5	78.1	11.7
UMMB	91.8	8.43	91.6	29.7	16.9	06.40	27.4	64.1	09.6
Nug cake	92.3	8.72	91.3	35.8	29.6	11.30	34.9	64.5	09.7
Hay	91.5	8.78	91.2	66.8	41.9	04.45	05.8	41.3	06.2
Napier	18	9.45	90.6	78.6	45.5	08.37	08.7	64.5	09.7

Where: DM = Dry matter; OM = Organic matter; NDF = Neutral detergent fibre; ADF = Acid detergent fibre; CP = Crude protein; DOMD = Digestible organic matter in dry matter; ME = Metabolisable energy

Appendix 2. Pictures taken during the on-station experiments

Baled hay used on-station (1)

Napier grass used on-station (2)

Home made concentrate on-station (3)

Raw materials for UMMB production (4)

UMMB production demonstration (5)

Women producing UMMB (6)

UMMB during drying (7)

UMMB in store (8)

UMMB demonstration to university students (9)

On-station housing (10)


Enumerators during data recording (11)


Milk analysis (12)

Appendix 3. Pictures taken during on-farm experiment


Grazing situation during wet season (13)


Communal grazing during dry season (14)


Focus group discussion (15)


On-farm selection of Fogera cows (16)

First day exposure to UMMB (17)

Woman measuring milk on-farm (18)

Crossbred cow licking UMMB (19)

Fogera cow licking UMMB (20)

On-farm heart-girth measurement (21)

Milking a Fogera cow on-farm (22)

Workshop at the end of on-farm research (23))