THESIS APPROVAL

GRADUATE SCHOOL, KASETSART UNIVERSITY

Doctor of Philosophy (Tropical Agriculture)

DEGREE

Tropical Agriculture — **FIELD**

Interdisciplinary Graduate Program — **PROGRAM**

TITLE: Studies on the Utilization of Crop Residues and the Potential of Urea Treated Maize Stover for Cattle Performances in East Shoa Zone, Ethiopia

NAME: Mr. Tesfaye Alemu Aredo

THIS THESIS HAS BEEN ACCEPTED BY

______________________ **THESIS ADVISOR**

(Associate Professor Pornsri Chairatanayuth, Ph.D.)

______________________ **COMMITTEE MEMBER**

(Associate Professor Pravee Vijchulata, Ph.D.)

______________________ **COMMITTEE MEMBER**

(Professor Sayan Tudsri, Ph.D.)

______________________ **PROGRAM CHAIRMAN**

(Associate Professor Somnuk Wongtong, Ph.D.)

APPROVED BY THE GRADUATE SCHOOL ON 23 May, 2006

______________________ **DEAN**

(Associate Professor Vinai Artkongharn, M.A.)

THESIS

STUDIES ON THE UTILIZATION OF CROP RESIDUES AND THE POTENTIAL OF UREA TREATED MAIZE STOVER FOR CATTLE PERFORMANCES IN EAST SHOA ZONE, ETHIOPIA

TESFAYE ALEMU AREDO

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Doctor of Philosophy (Tropical Agriculture)
Graduate School, Kasetsart University
2006

ISBN 974-16-1881-6

Tesfaye Alemu Aredo 2006: Studies on the Utilization of Crop Residues and the Potential of Urea Treated Maize Stover for Cattle Performances in East Shoa Zone, Ethiopia. Doctor of Philosophy (Tropical Agriculture), Major Field: Tropical Agriculture, Interdisciplinary Graduate Program.
Thesis Advisor: Associate Professor Pornsri Chairatanayuth, PhD. 146 pages.
ISBN 974-16-1881-6

A survey in which 300 households were interviewed using semi-structured questionnaire was conducted to study the production, management and utilization of crop residues in three AEZs of the East Shoa Zone, Oromiya Regional State, Ethiopia. Simultaneously, the potential of urea treatment in improving the feeding value of maize stover and the performance of weaned crossbred calves and Borana bulls fed on such stover was investigated. The survey results revealed that total annual production of the major crop residues (tef, barley and wheat straws, and maize and sorghum stovers, and haricot bean haulms) did not vary ($p>0.05$) among households in the three AEZs. With regard to utilization, respondents in all the AEZs tended to use their crop residues primarily for animal feeding, and in most cases, without any attempt to improve their feeding values through some types of processing and/or treatment. Although 30 to 40% of the respondents indicated that some of their crop residues were wasted mainly because of improper storage and inability to collect, it was estimated that, with an annual average production of about 0.67 to 1.01 ton DM per TLU of a household, crop residues could contribute 26 to 40% to the total annual maintenance feed requirement of ruminants in the study areas. To further increase their contribution, a coordinated effort of government and expertise is essential in availing to farmers improved technologies and inputs that boost both grain and residue yields, and in advising them as to how best and economical they can manage their crop residues.

Results of the study on the effects of urea levels and treatment durations on chemical composition and IVDMD of maize stover revealed that treatment with 5% urea for a period of 2 weeks was more ideal than treatment with either 4 or 6% urea in terms of improving nutritive value of the stover. Besides improving IVDMD of maize stover by 9%, urea treatment markedly increased CP content of the treated stover compared with that of the untreated maize stover (UNMS) and the natural pasture hay (NPH). By feeding *ad libitum* amounts of either UNMS or urea treated maize stover (UTMS) or NPH plus 1.0 kg concentrate mixture per head per day to weaned crossbred calves, an improvement of 22% in DM intake of the stover was achieved due to urea treatment. In feeding Borana bulls with similar types and levels of these roughage feeds plus 1.5 kg concentrate mixture per head per day, urea treatment brought an improvement of 37% in DM intake of the stover. Animals those fed the diet containing UTMS out-gained ($p<0.05$) the animals fed the diet containing UNMS. However, there was no difference ($p>0.05$) in daily weight gain between animals fed the UTMS diet and those fed the NPH diet. With regard to carcass characteristics, no appreciable differences were noted among the Borana bulls fed the three experimental diets. Generally, with the added advantage of being more cost effective than feeding hay, feeding urea treated maize stover may be considered as one of the strategies that bring about the efficient utilization of crop residues for livestock feeding especially in arid and semi-arid areas where crop residues constitute the bulk of ruminant feeds and the grass hay is not easily available. However, its economic advantage over other alternatives must carefully be examined under the prevailing price conditions before it is implemented.

Student's signature — Thesis Advisor's signature

Pornsri Chairatanayuth 16/5/2006

ACKNOWLEDGMENTS

First and foremost, I would like to thank my thesis advisor, Associate professor Pornsri Chairatanayuth for her wise guidance and supervision. Her kindly advice in other aspects of my personal life had made my stay in Thailand pleasant and successful. I am also grateful to my other advisors, Associate Professor Pravee Vijchulata and Professor Sayan Tudsri for their valuable comments and suggestions that enriched this work. Assistant Prof. Dr. Panwadee Soparnnarath and Assistant Prof. Dr. Skorn Koonawootrittriron are highly acknowledged for their wholeheartedly advice on statistical analysis.

The Oromiya Agricultural Research Institute (OARI) is highly acknowledged for giving me the chance to pursue this study which was financed by the Ethiopian Agricultural Research Organization through the Agricultural Research and Training Project. The Adami Tulu Agricultural Research Center (ATARC) and the Abernosa Cattle Improvement Ranch are also acknowledged for facilitating my research work and for providing me experimental animals, respectively. I thank the Agriculture and Rural Development Bureaus of the Boset, Adama, Lume, Dogdabora and Adamitulu Jidokombolcha districts for their cooperation in selecting representative peasant associations and households for my survey study. I am also thankful to the ELFORA agro-industry for the interest they had in this research as a result of which they allowed me to use their slaughter house at Debre zeit for carcass evaluation study.

My sincere thanks are extended to the OARI Director General, Mr. Aliyi Hussen, without the effort of whom my enrollment in this study would have been impossible. I am also grateful to the center manager of ATARC, Mr. Hailu Dadi and the Administrator, Mr. Yosef Eba for their cooperation and understanding while I was conducting my research at the center. Other staff of the center who encouraged and supported me, in one way or the other, are highly appreciated. Special thanks are due to Miss Kassaye Tolessa who kept me in touch with my family by passing information to and fro through e-mail communication during my last year of stay in Thailand. All my Ethiopian friends who were with me in Thailand for similar study are thanked for their companion and encouragement. I am also thankful to all my relatives and friends who have been visiting, encouraging and supporting my families so that they do not fell lonely while I was abroad. My final words of thanks go to my wife, Mrs. Bezawork Asrat, for her understanding and encouragement and, above all, for her boldly shouldering all our livelihood responsibilities, regardless of being lonely, during my two years of stay in Thailand. I also appreciate all my children who patiently endured the pain of missing me while I was abroad.

Tesfaye Alemu

March 2006

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Cont'd)

Page

LIST OF TABLES

LIST OF TABLES (Cont'd)

LIST OF FIGURES

STUDIES ON THE UTILIZATION OF CROP RESIDUES AND THE POTENTIAL OF UREA TREATED MAIZE STOVER FOR CATTLE PERFORMANCES IN EAST SHOA ZONE, ETHIOPIA

INTRODUCTION

Ethiopia is located in the eastern part of Africa at 8^0 N latitude and 38^0 E longitudes. The country covers a total area of 1,127,127 km^2 and has a population of 71 million (CSA, 2004b), 80% of which is engaged in agriculture. Currently the country is subdivided in to 11 regional states the largest of which is the Oromiya Regional State occupying nearly two thirds of the total area of the country and comprising more than 40% of the country's population (FAO, 2005).

Agriculture is the most important sector of Ethiopia's economy accounting for over 40% of Gross Domestic Product (GDP), 80% of exports and 80% of the labour force. According to estimates of 1987, livestock production contributed one-third of agriculture's share of GDP, or nearly 15% of the total GDP. Hides and skins constituted the second largest export earner, averaging about 15% of the total export value during the period 1984/85 to 1988/89. With an estimated livestock population of about 78.4 million in 1988, Ethiopia is believed to be the first in Africa (FAO, 2005). According to CSA (2004b), the country possesses 40.9 million cattle, 23.5 million goats, 25.5 million sheep, 5.8 million equines and 2.3 million camels. Though livestock production is an important sector of the country's economy, its contribution is not proportional to the huge livestock population. This, among many factors, is attributed to poor nutrition both in quantity and quality.

In tropical conditions, to which Ethiopia is a part, natural pasture provides the main diet of ruminant animals. However, the total area under natural pasture and hence the quantity of feed to be derived from it is decreasing from year to year because of the allocation of more and more range and forest areas to crop production to feed the increasing human population. Moreover, the quality of natural pasture varies with seasons being deteriorated during dry seasons. Under such circumstances, arable farm by products (crop residues) play an important role in reducing the dry season feed stress. Crop residues (straws or stovers) are remnants of food crops after the parts edible by human beings have been harvested. They include leaves, leaf sheath and stems.

With regard to production within tropical system, Africa is second to Asia in crop residue production with a total production of 2.2 tons of dry matter (DM) per livestock unit of herbivores (Kossila, 1985). The same source indicated that in Ethiopia, about 0.6 ton DM of crop residues per livestock unit was produced annually. Based on the 1979/86 national crop production, it was estimated that about 13 million tons of crop residues were annually produced in Ethiopia 95% of which were contributed by cereal straws and the remaining percentage by pulses (Seyoum and Zinash, 1998). With regard to crop type, tef straw alone, contributed more than 25% of the total straw production with an annual production of about 3.5 million tons. In a study carried out by De Leeuw (1997), of the 13.7 million tons of crop residues annually produced as DM in Ethiopia, wheat, barley and tef, the typical highland crops, accounted for 6, 10 and 17% of the total, respectively.

Crop residues are the major source of animal feeds in mixed crop livestock farming systems. In such systems, the grazing area is limited, native grass is seasonally available and ruminants graze on marginal land and/or on roadsides to obtain green forage during the rainy season. During the dry period, when green forages are scarce, crop residues and farm wastes represent the important source of feeds for ruminants upon which animal production is based. According to Guo and Yang (2002), the importance of developing animal production based on crop residues goes beyond the animal industry it self. It has got significant economic, social, agronomic and environmental benefits. These authors further elaborated that the use of crop residues for animal feeding saves grain feeding; it favors agriculture by promoting the return of the residues to farmlands as manure rather than direct application which has negative consequences in terms of costs of its application, its harmful effects to germination of the following crop and perpetuation of crop diseases and pests. Application as manure, on the other hand, spares chemical fertilizers thus leading to a reduction in grain production costs. Use of crop residues for livestock feeding avoids their burning as a means of disposal and hence resolves the problems of air pollution, uncontrolled conflagrations and the risks for people's health and industrial production. Feeding crop residues to animals increases beef and mutton out puts and availability, and it releases farmers from poverty by allowing them to raise animals- a reliable alternative to earn money.

The proportion of total crop residues allocated to animal feeding depends on such factors as livestock density and rules of access, which are in turn influenced by land tenure, the relative importance of livestock in the farming system and access to markets for livestock products. De Leeuw (1997) stated that the potential availability of crop residues for livestock feed increases with an increase in the area of land put under food crop production. In areas where the proportion of cropped land is relatively low, the contribution of crop residues to the total feed will be minimal. In this regard, Varvikko (1991) reported that in Selale district of Northern Shoa, Ethiopia, where only 40% of the land is cultivated, 40% of the fed consisted of stored hay and only 12% was contributed by crop straws. On the other hand, Gryseels (1988) reported that in the highlands of Ethiopia where grazing lands are being converted to crop land, residues from cereal crops and pulses combined with post-harvest stubble grazing accounted for over 90% of all feeds.

According to De Leeuw (1997), the three major sources of crop residues, namely, the cereals, legumes and roots/tubers, differ with regard to their use by livestock. Most cereal stovers are gazed *in situ* while leguminous residues are often collected as hay or for sale or stall feeding. Similarly the foliage of roots and tubers is harvested and only becomes available, together with other by-products, when the crops are processed as human food.

The nutritional value of crop residues is variable depending on a number of factors including cereal species, variety, stage of harvest, length of storage, proportion of stem to leaf, fertilizer application and soil fertility, irrigation use and plant disease

(Preston and Leng, 1986). Nutritionally these feed resources are generally low in essential nutrients, especially crude protein, and are high in fiber content. Hence they are grouped under low intake and digestibility feeds. In countries with specialized livestock production systems, crop residues are considered of such low feed value that they are burned, but in developing countries where livestock are integrated with cropping, they are valuable feed resources. Therefore, it is of great importance to explore the potential for improving their feeding value through practical and low cost systems of treatment. Towards this end, much efforts have been directed to up-grading them through physical and chemical treatments and through strategic supplementation to complement their deficiencies.

Of all the chemical treatment methods, ammoniation with urea has been considered to be a method of choice for improving the feeding value of straws (FAO, 1986). Ammoniation with urea is preferred because of being less hazardous to use, cheap and easily obtainable compared with sodium hydroxide and other sources of ammonia such as aqueous and anhydrous ammonia. The use of a cheap source of nitrogen such as urea also improves nitrogen content of the straws. Nevertheless, due to other prevailing factors such as cost and availability, the significance of using urea and the degree of its applicability vary from one country to another. In countries where urea is produced locally and the margin between the cost of urea-treated straw and alternative roughages is sufficiently attractive, the likelihood of using urea treatment is very high.

In the animal feeds and nutrition research strategy of the Ethiopian Agricultural Research Organization, it is clearly stated that there is a need to generate information on the availability and nutritional quality of feed resources, and on the appropriate technologies for efficient utilization of crop residues. Like in other parts of Ethiopia, in East Shoa Zone of Oromiya Regional State, crop residues are observed to be valuable livestock feed resources with additional uses as building, roofing and fencing materials, as fuel and as fertilizer for surface mulch in croplands. However, the total annual crop residue production, the management practices undertaken by farmers in handling, processing and feeding of the residues, and the priority of uses to which farmers put their residues are not well known and documented. It is believed that the availability of such information is of vital importance as these are among the essential prerequisites needed in an endeavor to match the livestock population of an area to the existing feed resources.

Though it is generally known that urea treatment has a considerable advantage in terms of improving the nutritional value of straws and hence the performances of animals fed on the treated straws, research on this subject is scanty in Ethiopia. The potential of urea treatment of tef and barley straws for crossbred dairy cows has been investigated by Rehrahie (2001). However, the potential of such treatment in upgrading the nutritive value of maize stover and in improving performances of animals fed on the treated stover was not so far assessed. Also the knowledge on the optimum level of urea and the treatment (ensiling) duration is essential for quick uptake of the technology thus leading to better utilization of the residues. In this regard, Preston (1995) cited lack of fully defined optimum conditions for straw treatment as one of the several reasons why urea treatment of straws has not been widely applied in spite of expectations of rapid implementation in many developing countries. Therefore, in line with these concepts, it was also felt important to determine the optimum urea level and treatment duration that would bring about a maximum improvement in chemical composition and *in vitro* dry matter digestibility of maize stover, one of the important and abundantly produced crop residues in the East Shoa Zone of Oromiya region, Ethiopia.

From their previous work Brand *et al*. (1991) suggested that the digestible nutrient intake of ammoniated wheat, oat and barley straw and oat hay was inadequate for production functions like growth, pregnancy and lactation. This implies that, for better performance of animals, there is a need to further strengthen the nutritional status of diets based on the treated crop residues through strategic supplementation. Therefore, this work also investigated the potential of urea treated maize stover supplemented with minimum concentrate for growth performance and carcass characteristics of cattle.

OBJECTIVES

General objective

In line with the above mentioned justifications, this research was designed with an overall objective of assessing the production, management and utilization of crop residues in three Agro Ecological Zones (AEZs) of East Shoa Zone, Ethiopia and, investigating the potential of urea treatment in improving the nutritive value of maize stover and animal performances.

Specific objectives

1. To assess the production and utilization of crop residues and estimate their potential contribution to the annual feed requirement of animals in sub-moist, sub-humid and semi-arid AEZs of East Shoa Zone.

2. To investigate the crop residue management (collection, storage, processing, etc.) and feeding systems employed in the area.

3. To identify the constraints and the opportunities for the production and better utilization of crop residues in the area.

4. To determine the optimum level of urea and treatment duration to treat maize stover under Ethiopian condition.

5. To investigate the improvement in chemical composition, intake and digestibility due to urea treatment of maize stover as compared with the untreated stover and natural pasture hay.

6. To investigate the potential of urea treated maize stover for growth and fattening performances of cattle.

7. To evaluate the economics of feeding urea treated maize stover as compared with feeding untreated maize stover and natural pasture hay to both young and mature animals.

LITERATURE REVIEW

Crop residue production

Information on the global production of crop residues is limited to the works of Kossila (1985) who described the situation on their production for the year 1981. According to this author, Asia was the leading region in production of fibrous crop residues with a production of 3.6 tons per Livestock Unit (LU, 1 LU = 500 kg live weight at maintenance level) of grass eaters in 1981. In Africa, 2.2 tons of fibrous crop residues were produced per livestock unit of grass eaters. Butterworth and Mosi (1985) reported that a large quantity of crop residues is produced annually in East Africa which amounts to about 700 to 800 kg per livestock unit. However, these authors remarked that making precise estimates of crop residues is difficult because of uncertainty both as crop production figures and extraction indices. According to Mclntire *et al.* (1988) the average cereal crop residue yields in the medium altitude areas of highlands of Ethiopia was about 2 tons DM ha^{-1} , 70% of which was edible. The major cereals were tef and wheat, covering up to 85% of the cultivated areas.

Production of crop residues per ruminant livestock varies greatly between regions and countries. While there are many countries where ruminant livestock is starving to death due to lack of feed, there are many countries where the amount of crop residues per livestock of ruminants exceeds the amount that can actually be used as feed. According to Kossila (1985), some of such discrepancies could be explained by climatic factors, level of technology in agricultural production systems, availability of grazing lands, soil conditions, land topography, animal diseases, type of ruminant production systems (intensive or extension), cultural and religious factors (prohibition of cattle slaughter) and political and economic regulation systems (price policy). In this regard, Kossila (1988) stated that most countries in sub Saharan Africa have a low ratio of crop residues to livestock unit as a result of having large areas of arid to semiarid rangelands, large livestock populations and relatively low production of cereals. On the other hand, countries in the humid zones of West Africa where cereal yields were higher but cattle populations were severely limited by trypanosomiasis had high ratio of residues to livestock unit. Kabatange and Kitalyi (1989) also stated that variation in crop residue production are likely to exist due to wide variations in plant height and density which may, in turn, be affected by differences in soil fertility, seed quality, variety and husbandry practices followed. The practice of collecting, handling and storage are also known to affect crop residue yields. In traditional farms of central Tanzania, Kabatange and Kitalyi (1989) observed high variations ranging from 0.6 to 10 tons/ha in stover yields as a result of differences in management practices. De Leeuw (1997) sated that crop selection, cropping practice (eg. double- and intercropping) and level of inputs influence crop residue yields. More importantly, changes in cropping pattern may affect access and use, while intensification of production through improved varieties, increased fertilizer use, better tillage and weeding, should increase yields of both crops and residues. Inter-annual fluctuations in rainfall also affect crop residue yields, which in turn may affect the ratio between edible and non-edible fractions within residues. Thimoty *et al*. (1997) cited from literature that, in northern Nigeria, a negative correlation between total crop residue yields and the edible fractions of sorghum was observed as high stover yields were associated with ticker and less edible stalks.

Crop residue yields are usually estimated from the crop residue to grain yield ratios. Kossila (1988) and Nordblom and Shomo (1995) used a simple ratio in which grain yield is divided by an agreed factor expressing the harvest index, a proportion of grain to the total above-ground biomass. De Leeuw (1997), on the other hand, suggested the need for a second ratio which is related to edibility as it makes little sense to include inedible plant parts in the potential feed budget. To estimate the consumable fraction of a crop residue, however, data are required on such parameters as the likely removal rates by grazing animals or the refusal rates of stall-fed animals. Crop residue to grain ratios usually decrease with increasing grain yields. Accordingly, Kossila (1988) observed higher ratios in Africa than in Asia (2.0 vs. 1.3 for wheat) or South America (3.0 vs. 2 for maize). Although crop residue to grain ratios decline with rising grain yields, crop residue yields usually do increase, albeit at much lower rate than grain. In this regard, while determining grain and stover yields in 78 samples of brown, red and white sorghum varieties in Ethiopia, Mclntire *et al*.

(1988) observed that the actual stover yield increased from 5.7 to 7.0 tons DM/ha, regardless of a decline of crop residue to grain ratios from 2.3 to 1.2.

Crop residue utilization

Large quantities of crop residues are used as animal feed in many countries, but much is still wasted for various reasons or used for other purposes. According to Timothy *et al.* (1997), in south Asia, crop residues are used as compost and mulch for crop production, bedding for livestock, as substrate for growing mushrooms, fiber for paper manufacture and as fuel. In semiarid sub-Saharan Africa, they are used to control wind erosion and in the construction of roofs, fences, granaries, beds and doormats.

With regard to the use of crop residues for animal feeding, Kossila (1985) reported that in both developed and developing countries, crop residues account for about 24% of the total feed energy suitable for ruminant livestock. The author further stated that if all crop residues were considered, the total production would on average give 3.4 tons and 6166 Mcal metabolizable energy (ME) per LU of grass eaters per year in the whole world. Sandford (1989) reported that in various parts of semiarid sub-Saharan Africa, cattle derive up to 45% of their total annual feed intake from crop residues, and up to 80% during critical period. In a village survey carried out in western Maharashtra, India, Thole *et al.* (1988) found that sorghum stover contributed between 20 and 45% of the total dry matter feed provided to dairy animals by small scale farmers. Also, in the case of communal areas of Zimbabwe, Sibanda (1986) emphasized the importance of crop residues by stating the likely hood of cropping to be jeopardized without crop residues since the condition of the draught animals at ploughing and planting would be far worse.

Although crop residues are known to have such a significant contribution to the livestock feed requirements, there are varying opportunities for their use as animal feeds. The greatest potential for the use of crop residues as animal feeds exists in the mixed crop/livestock systems. Where crop and livestock production are segregated, most crop residues are wasted or they are used for non-feed purposes. Generally, as production systems become more specialized, crop residues are likely to be included in ruminant diets in lower proportions or only at phases of production with lower nutritional requirements. This is because, the specialized systems require animals of highest genetic potential and feeds of better quality to achieve higher milk yields or animal growth rates. On the other hand, it was found that crop residues can be a suitable feed in specialized beef (Klopenstein *et al*., 1987) and dairy (Klopenstein and Owen, 1981) enterprises, particularly during phases when animal nutritional demands are lowest.

Timothy *et al.* (1997) stated that the pattern of crop residue use is often dictated by population density, herd management practices and level of transport and marketing infrastructure. In areas with low population densities and where animals are herded communally, they observed open access to residues to occur as opposed to densely populated and heavily stocked areas in which restricted access to residues is practiced. Anderson (1978) described that the extent to which crop residues are utilized also varies with geographic locations. In drier climates, the small amount of residues available makes it uneconomical to gather and remove it, whereas in areas where the topography is steep it is essential to leave residues on the soil to prevent water erosion and to allow adequate moisture penetration. Moreover, as residues must be collected and transported for efficient utilization, the financial capacity of the farmers to undertake such activities also becomes a major factor regulating their extent of utilization.

The reliance on crop residues for livestock feeding increases as farm sizes decreases. In the case of Eastern Kenya, Fernandez-Rivera *et al*. (1995) reported that farmers with only 2 ha of land barely covered two-thirds of the feed needs of their livestock and are forced to exploit their crop residues to the full, to herd their cattle along road side and on waste lands, to rent grazing lands from other farmers or as a last resort, to purchase feed. Kayouli (1996) also stated that as pasture production declined, ruminant animals in the Sahel have became more dependent on crop residues which assumed progressively greater proportion of the total diet being mainly used during the dry season.

In summary, the use of crop residues for animal feeding not only improves animal production but it also increases the overall utilization efficiency of crops such as maize whose utilization efficiency is low. In this regard, Alemu *et al.* (1991) stated that when only the grain is used for human consumption or for livestock feed, only about 39% of the energy and 20% of the protein are utilized.

Crop residue management and feeding systems

The practices used in crop residue management (harvesting, handling, collection and storage) have effects on both the quantity and quality of the residues. Regarding this, Owen and Aboud (1988) stated that as straws and stovers comprise leaf and leaf sheath (the more nutritious parts), the harvesting, handling and storing systems should minimize the loss of these parts. They further warned that delayed harvesting or relay harvesting in an intercropped field would be expected to cause greater loss of leaf and leaf sheath, with a consequent reduction in nutritive value. Emphasizing the importance of crop residue collection, Dyer *et al.* (1975) stated that the energy required to produce the world's protein needs through ruminant animals could be provided if only 5% of the waste cellulosic materials could be economically collected and processed. According to the remark made by Owen and Aboud (1988) and Hilmerson *et al.* (1984), even if the effects of residue management are acknowledged, the difficulty of handling and storing of crop residues have not been given adequate attention by researchers.

The farmers' decision as to whether or not to collect and store crop residues depends on many factors which include the farmers' capacity in terms of having means of transportation (labor, capital, draught animal, etc.), availability of other feed resources, livestock population and market availability. The availability of labour, large livestock population and easy access to markets encourage farmers to collect their residues from fields. Once collected and stored, due attention must be given also as storage problems such as pest infestation, moulding and fire may result in losses of the residues. Timothy *et al.* (1997) stated that, combined with seasonal nature of their production, storage problems can create an annual cycle of brief peaks in crop residues availability followed by long periods of scarcity.

With regard to crop residue feeding, Timothy *et al*. (1997) identified five feeding systems. These, arranged in increasing order of labour, requirements are:

1. open access to whole residues on harvested fields,
2. harvest and removal of stalks, with subsequent open access to stubble on harvested fields,
3. harvest and removal of stalks, with subsequent restricted access to stubble on harvested fields,
4. transport and storage for feed or sale and
5. harvest of thinnings from cultivated fields for feeding before the main harvest. The relative importance of these systems varies depending on the factors mentioned above those affect the farmers' decision to collect or not to collect their crop residues. From their study on constraints to crop residue utilization in Tanzania, Kabatange and Kitalyi (1989) found grazing in the crop fields after grain harvest to be the most common method of availing crop residues to livestock, though a higher proportion of farmers in the maize zone indicated that they do not allow animals to graze in the crop fields after grain harvest, alleging that the practice led to reduced grain yields in subsequent crops. On the other hand, Klopfenstein *et al.* (1987) stated that though direct grazing of crop residues from crop fields results in low utilization rates due to trampling and spoilage, it allows for the consumption of most nutritious plant parts and the return of nutrients to the soil.

Limitations to crop residue feeding

On global basis, Kossila (1985) indicated that if all the potentially available crop residues could be utilized for feeding, each herbivore would receive over 9 kg DM and about 17 Mcal ME/day, thus largely covering requirements. Unfortunately, a much lower level of utilization is possible because of problems of collection, transportation, storage and processing, alternative uses, seasonal availability, and more importantly, their poor feeding value. Smith (1993) stated that most crop residues are deficient in protein, essential minerals like sodium, phosphorous and calcium, and are rather fibrous (40 to 45% crude fiber). The consequences of such a profile for ruminants are a low intake (1.0 to 1.25 kg DM/100 kg live weight), poor digestibility of the order of 30 to 45%, and a low level of performance. Low intakes and poor digestibility result specifically from high cell wall lignin content and the chemical bonding between this fraction and the potentially nutritious cell wall constituents such as cellulose and hemicellulose. Preston and Leng (1986) also reported that when straws are fed to ruminants the primary limitations to production are: the slow rate of and low total digestibility, the rate at which straw particles break down to a size that can leave the rumen, the low propionate fermentation pattern in the rumen, and the negligible content of both fermentable nitrogen and by-pass protein. The mineral content of straws is generally low and imbalanced but deficiencies are unlikely to be manifested in animals at maintenance or working. For production of meat and milk, requirements for minerals are increased many folds and supplements should be supplied. Because of limited nutrients in fibrous feeds such as crop residues, Leng (1990), Preston and Leng (1984) suggested several methods which improve the usefulness of these feed resources by establishing optimal rumen ecology with optimal ammonia (NH_3) nitrogen, increasing the ratio between energy and protein, and providing supplemental by-pass or protected protein and fat.

Improvement of the feeding value of crop residues

Poor animal nutrition and productivity arising from inadequate supply of feed both in quantity and quality are among the major constraints facing livestock production in developing countries. According to Doyle *et al.* (1986), the quality of a feed or its feeding value is influenced by:

1. its chemical composition (representing the gross amount of nutrients available),

2. level of voluntary intake (indicating the amount of nutrients consumed),

3. digestibility (indicating the proportions of nutrients that are digested and absorbed and become available for metabolism) and

4. efficiency of metabolism at the tissue or cell level. Any improvement in one or more of these factors has a positive effect on the feeding value of the feed.

As indicated earlier, crop residues are characterized by the unbalanced nature of nutrients they supply. Regarding their chemical composition, most of them do not contain adequate soluble nitrogen and fermentable carbohydrates, or essential minerals, and these needs to be supplied to ensure a balance of nutrients. Their intake and digestibility are as well low. This problem has prompted researchers and development workers to look for various strategies that improve the nutritive value of crop residues, thus leading to the better and efficient utilization of these readily available feed resources. To this end researchers have developed various technologies in the past. These include: crop management practices (Bartle and Klopfenstein, 1988); variety selection (Orskov, 1991); Chemical (Sundstol and owen, 1984), physical (Riquelme-Villagran, 1988) and biological (Kamra and Zadrazil, 1988) treatments; supplementation (Preston and Leng, 1987; Dixon and Egan, 1988); feeding strategies such as excess feeding or selective grazing (Owen and Aboud, 1988); genetic manipulation of rumen microbes (Orskov and Flint, 1991; Wallace, 1994); and selection of animals better suited to the utilization of fibrous by-products (Coombe, 1981 and Orskov, 1991). Despite the positive results achieved on the experiment station, the adoption of these technologies, especially by farmers in developing countries, remained low. In this regard, Timothy *et al.* (1997) indicated that, in many cases, high labour and/or capital requirements to have been the main constraints that have hindered adoption. Moreover, these authors disclosed the fact that no enough efforts were made to investigate the resource requirements of these technologies at farm level as this is a major determinant of the profitability and adoption of any technology.

Smith (1993) suggested two approaches to improve the quality of crop residues: first, to eliminate deficiencies and stimulate efficient fermentative activities that extract the maximum possible amounts of nutrients from the feed in the rumen; and second to by-pass the rumen and balance nutrients absorbed in the lower gut for maintenance and production. Part of the first approach can be implemented through several ways one of which is treatment of the residues by physical, chemical or biological means.

The objective of straw treatment as a means of improving the feeding value of straws is to increase the digestibility of the straw and/or the amount of it voluntarily consumed thus increasing the digestible energy the animals can derive from the straw. Methods of straw treatment may be classified broadly into physical, chemical and biological categories. Chemical treatments disrupt the bonds between lignin and the cellulose and hemicellulose constituents, causing partial solubilisation of the lignin and hemicellulose fractions, with a resultant increase in the digestibility of the cellulose and hemicellulose fractions. Increased digestibility leads to a shorter feed residence period in the rumen, and hence increased intake. Effectiveness of chemical treatments with regard to increased digestibility is generally variable because of several modifying factors. The effect of some of these factors was studied by Flachowsky and Schneider (1989). These authors investigated the effect of ammonia level, moisture content, temperature and duration of treatment on rumen DM degradability of wheat straw, and concluded that the optimum conditions which gave an increase in digestibility of 27% units were: 3% ammonia, a straw moisture level of 30%, a treatment temperature of 40 to 60^0C and a treatment duration of 7 to 14 days.

The various treatment methods tested to date differ in terms of mechanism of action, effectiveness and suitability for target production systems. The principal methods of chemical treatment use alkalis, of which the most widely studied is sodium hydroxide. While this chemical is highly effective in increasing digestibility of the treated straws, it has been almost completely discarded, particularly in developing countries, because of its disadvantages in terms of high cost, pollution through accumulation of sodium ions and the dangers to people and animals due to its corrosive nature (Preston and Leng, 1986). Although there have been various methods of chemical treatment identified, the major problem in the developing countries is to find methods that are both acceptable and effective especially at the smallholder farmer level.

Of the chemical treatments, using the nitrogenous alkali has been found to be advantageous as compared with using sodium hydroxide mainly because the increase in the microbial requirement for nitrogen when the potential digestibility is increased is supplied by ammonia which is absorbed by the straw. According to Zhang and Yan (2002), ammoniation usually increases digestibility by 20% and crude protein content up to 1 to 2 times; it can improve palatability and consumption rate; the total nutritional value can be doubled reaching 0.4 to 0.5 feed units for each kg of ammoniated straw. Ammoniation also reduces mould development, and it destroys weed seeds, parasite eggs and bacteria.

Preston and Leng (1986) stated that there are a number of ways in which ammonia can be used to increase the digestibility of fibrous feeds. These include methods that use ammonia gas, ammonia in solution or ammonia generated from urea by ensiling the fibrous feed such as straws and stovers at high moisture content. The use of ammonia generated from urea has a distinct advantage over using ammonia gas in that urea is easily available as a fertilizer for food crops, easy to transport, store and handle, and also less costly. Moreover, it is a technique which smallholder farmers can easily apply. However, it is worth mentioning that Preston and Leng (1986) reported that urea-ensiling appears to be less effective than using ammonia gas because of the formation of ammonium carbonate, which locks up part of the ammonia.

Urea treatment and its underlying principles

Chenost and Kayouli (1997) described the process of urea treatment as a simple technique consisting of spraying a solution of urea onto the dry mass of forage and covering with materials locally available so as to form a hermetic seal. The process involves the hydrolysis of urea into gaseous ammonia and carbonic gas through reaction with an enzyme called urease which is produced by ureolytic bacteria within the forage being treated. The ammonia thus generated provokes the alkaline reaction which gradually spreads and treats the forage mass. The hydrolysis reaction is as follows:

$$\mathbf{CO\ (NH_2)_2 + H_2O \xrightarrow{heat,urease} 2NH_3 + CO_2}$$

According to a report by Kayouli (1996), urea treatment developed in Niger, was a simple technique that made use of locally available materials. Stovers and straws were treated with 5% urea (5 kg urea dissolved in 50 litters of water to treat 100 kg dry residue) and made into a stack using the traditional storage method and locally available air-tight system: silos made from *Andropogon gayanus* or briquettes made from clay and straw. Air-tightness was successfully ensured by tying with braids made from *Andropogon gayanus* and no plastic sheets were required.

The principle underlying urea treatment is that the ammonia generated from urea by bacterial and/or plant ureases in the ensiling process hydrolyses the chemical/physical bonds between lignin and the cellulose and hemicellulose in the plant cell wall. The hydrolysis of these bonds makes the cellulose and hemicellulose more accessible to microorganisms in the rumen and increases total fermentation and usually the rate of fermentation. Some chemical hydrolysis of hemicellulose also takes place resulting in an increase in the portion of soluble carbohydrates in the straw (FAO, 1986). Response to urea treatment is thus a combination of the effect of the alkali on cell wall structure and the effect of added nitrogen on rumen microbial activity (Preston and Leng, 1984).

Chenost and Kayouli (1997) stated that the success in urea treatment depends on interdependent factors such as the presence of urease, the rate of urea applied, the moisture content, the ambient temperature, length of the treatment period, the degree of the hermetic sealing achieved during treatment and the quality of forage to be treated.

From the statement made by Chenost and Kayouli (1997) regarding urea application rate, it is now well established that the optimum rates lie between 4 and 6 kg urea per 100 kg of straw matter which corresponds to treating with ammonia in a range of 2.27 to 3.4 kg (because one molecule of urea, that is 60 g, generates two molecules of ammonia, that is 34 g). The level of 4 to 5 kg urea for treatment of 100 kg dry straw has been widely used in many countries such as Thailand, China, Sri Lanka, etc. In other countries, levels as high as 6 to 7 kg per 100 kg dry straws were used. Bui and Le (2001), on the other hand, stated that, though DM, crude fiber (CF) and organic matter (OM) degradability of rice straw treated with 4 or 5% urea were slightly higher than that of the straw treated with 2.25% urea plus 0.5% lime, the latter treatment seemed to be the reasonable alternative for farmers to accept the technique due to the fact that urea was rather expensive in Vietnam. In this case, the treatment time was 7 days. Nguyen *et al*. (1998) also suggested that 3% urea plus 0.5% calcium hydroxide may be more economical than 5% urea in treating rice straw provided that it has good effects on digestibility and intake of the straw by ruminants. The premise of their suggestion is that, when urea level was increased by 2% units from 3% to 5%, only 17.4 % of the additional urea nitrogen was fixed indicating loss of nitrogen when the level of urea applied is high. In addition, the authors remarked that the partial replacement of urea with calcium hydroxide could be technically and economically justified. Based on the available knowledge for urea treatment, Said and Wanyoike (1987) recommended that smallholders in Kenya should treat their maize stover with 5% urea (batches of 10 kg chopped stover sprinkled with urea solution made of 0.5 kg urea dissolved in 10 liters of water) for two weeks.

Preston and Leng (1984) indicated that, as a rule of thumb, 30 g N per kg digestible organic matter (DOM) is required to maximize the development of rumen microbes. According to Durand (1989), the total level of nitrogen required to optimize the activity of rumen microbes is 26 g N per kg DOM. In accordance with these recommendations, Nguyen (2000) stated that straw treatment with 4 % urea is an expensive way of supplying nitrogen as the level is required for effective treatment but is much greater than what is needed by the rumen microbes.

Effects of urea treatment on chemical composition and digestibility

According to the statement by Chenost and Kayouli (1997), the effects of ammonia generated during urea treatment are:

1. dissolving the parietal carbohydrate mainly the hemicelluloses;

2. swelling the vegetal mater in an aqueous environment, so easing access by the rumen cellulolytic microorganisms;

3. easing mastication by the animals and digestion by the microorganisms by reducing the physical strength of cells;

4. enriching the forage in nitrogen content. The net effect of the treatment process is increased nutritive value through increasing forage digestibility by as much as 8 to 10 points, nitrogen content by more than double and intake by as much as 25 to 50%.

The effect of urea treatment in improving the nutritive value of crop residues varies between leguminous and none-leguminous residues. By using sheep to assess the nutritive value of urea-treated straws and legume haulms, Butterworth and Mosi (1985) observed no response to treatment when a mixture of haricot bean and horse bean haulms treated with 4% urea was fed to sheep. They attributed this to the higher level of lignin in the forages. On the other hand, the authors found that the digestibility of tef straw was significantly improved by the 4% urea treatment and that, according to them, was associated with a decrease in both ADF and NDF fractions of the forage and a relatively low level of lignin. Wongsrikeao and Wanapat (1985) investigated the effect of urea treatment of rice straw on feed intake and live weight gain of buffaloes. They reported a 92.8% dry matter and 3.8% crude protein for untreated straw as compared to 60.8% dry matter and 6.8% crude protein for a 6% urea-treated straw. Similarly, the dry matter digestibility of the treated straw was higher (55.4%) than that of the untreated straw (43.2%).

From their study on sorghum head residue, Chairatanayuth and Wannamole (1987) concluded that urea or urea in combination with water melon seeds (source of urease to reduce the storage time during treatment) can successfully be used as a treatment to improve nutritive value of the residue. They found a higher protein content for the urea treated residue than the control and the sodium hydroxide (NaOH) treated residues. The values reported for the control, the 5% urea treatment and the 5% NaOH treatment after a storage period of 21 days were 4.5, 10.4 and 4.6%, respectively. However, urea treatment, in this case, was found to be slightly less efficient than NaOH in improving *in vitro* dry matter digestibility (IVDMD) of the residue (65.4 vs. 69.6%).

A comparative study conducted to evaluate the effects of alkali treatment of barley straw on digestibility and metabolizability (Wanapat *et al.,* 1986) revealed an enhanced CP contents (21 versus 139 g per kg DM) and reduced both NDF and ADF contents due to 5% urea treatment. Moreover, digestibility of nutrients, especially of CP, ether extract (EE) and crude fiber (CF) as measured in sheep were enhanced after urea treatment. However, the increases in DM and OM digestibility were only 4 and 7 percentage units, respectively. Tran and Nguyen (2000) investigated the effects on chemical composition of four levels of urea (1.5, 2, 2.5 and 3%, w/w) used to treat maize stover for 4 different periods (1, 30, 60 and 90 days). From the results, they concluded that the CP content of the treated maize stover increased and its CF decreased with increasing levels of urea. Shen *et al.* (1998) conducted a study on untreated and urea treated rice straw to estimate the differences in straw degradation between different varieties. According to their finding, urea treatment significantly increased straw DM and OM degradability. On average, the DM and OM degradability of the straw after 96 hour incubation were improved by 18 and 24.5%, respectively. Brand *et al.* (1991) observed a marked increase in nitrogen content of ammoniated (with 55 g urea/kg straw) wheat straw. As these authors cited from literature, ammoniation generally causes a reduction in the NDF and hemicellulose contents of crop residues. However, they obtained no conclusive evidence of such reduction in their investigation. Moreover, these authors reported improvements of 7.9, 18.9, 13.7 and 36.5%, respectively in apparent digestibility coefficients of OM, cell wall constituents, ADF and hemicellulose of urea-ammoniated wheat straw compared with the untreated straw diets.

According to Orskov *et al.* (1990), in many countries, particularly in Asian cropping areas, where straw is the main feed for ruminants, a proportional increase of 0.1 in digestibility of straw can have enormous implications for resource availability and thus animal production. The implications are often greater than the changes in digestibility suggest in so far that the *ad libitum* consumption is considerably greater. This enables straws to form a large proportion of the diet of high-producing animals and of the animals receiving mainly straws to achieve a better performance.

Nowadays urea supplementation is used as an alternative to urea treatment. However, the addition of urea to stover at feeding as a supplement only corrects the deficiency in nitrogen without overcoming the limitations of cell wall lignification on intake and digestibility. On low quality roughage diets such as crop residues, the utilization of urea for microbial protein synthesis is primarily limited by the low availability of fermentable energy (Farid *et al.,* 1986). Thus it would be expected that the efficiency of utilization of the ammonia nitrogen would be greater with stover treated with urea compared with stover supplemented with urea because of the higher DM degradability and hence the more energy obtained from the urea treated stover diet. The authors stated that the nitrogen incorporated during treatment is readily available for use by rumen microbes as confirmed by the high rumen ammonia levels on urea treated stover. Fermentable energy supplements such as molasses may further increase the efficiency of incorporation of urea nitrogen to microbial protein in the rumen. However, Supplementation with readily fermentable carbohydrates in the absence of rumen degradable nitrogen can not be expected to improve the utilization of poor quality roughages by ruminants.

Performance of animals on urea treated crop residue based diets

In Niger, Kayouli (1996) observed that the consumption of urea-treated forages during dry season is often accompanied by an improvement in body condition of the animals and maintenance of live weight. The animals were also more resistant to diseases and their coat was improved (brighter hair). Thin and weak animals recuperated rapidly and milk from dairy cows increased significantly. Moreover, farmers have noted a positive effect on animal fattening in such a way that the fattening period was reduced with a consequent saving in concentrates. According to Preston and Leng (1986), the technique of using urea-treated forages also enables the use of animals with higher genetic merits as these animals can consume much of the digestible feeds to meet their requirements. Another positive effect of urea treated forages, observed by Kayouli (1996), is that feeding of such forages to draught oxen resulted in improved body condition with no loss of weight during ploughing period. Moreover, animals worked harder and longer (often ploughed 1.5 to 2 hours more per day) than those fed on untreated straws and stovers.

Urea treatment increases the acceptability and voluntary intake of the treated straw as compared with the untreated straw when it is fed *ad libitum*. The increase in intake is very important because what and how much animals eat (their feed intakes) are the most important factors that determine the productivity of ruminants. In this regard, Wongsrikeao and Wanapat (1985) found a significant difference in dry matter intake between the urea treated and untreated rice straw with values of 5.87 and 7.32 kg per day for untreated and treated straw, respectively. In terms of animal performance, those animals that fed the urea treated straw gained 0.21 kg/day while those that fed the untreated straw lost 0.13 kg per day.

From feeding of 2.5% urea treated maize stover as a sole source of roughage to growing cattle, Tran and Nguyen (2000) found that the treated straw had positive effects upon intake, digestibility and growth rates of the animals during a 60-days feeding trial. In a trial which compared the relative effectiveness of ammoniation using urea and supplementing untreated rice straw with a molasses-urea block (MUB), Bui and Le (2001) found consistently higher growth rates for crossbred cattle on ammoniated straw compared with those on the MUB supplemented untreated straw (449 vs. 363 g per head per day). The improvement in growth rate due to urea treatment was 25% ($p<0.001$). The DM intake of the straw was also higher ($p<0.001$) for the group fed ammoniated straw than those fed the straw supplemented with MUB.

Although moderate rates of live weight gain can be obtained with ruminants on diets based on treated crop residues, better animal performances require supplementation of such residues with nutrients that have beneficial effects on rumen function. Research works done in Thailand and Australia depicted that the critical supplementary nutrients on a straw based diet are bypass protein, starch and long chain fatty acids. High rates of growth were obtained when the ammoniated straw (urea ensiling in Thailand and ammonia gas in Australia) was supplemented with starch, protein and oil in the byproduct meals that are known to escape rumen fermentation (Elliot *et al*., 1978a and 1978b). Live weight gain of young Brahman bulls weighing 150 kg increased from 0.47 to 0.83 kg/day as the level of supplementation of ammoniated rice straw with a mixture of fat, protein and rice starch increased from 1 to 3 kg/day (Wanapat *et al.,* 1986). In another study on the effects of various levels of bypass protein supplementation on the body weight change of cattle given diet of ammonia treated or untreated rice straw, sole treated rice straw gave 52.1% more growth rate than the untreated one. The live weight gain further increased to as high as 639 and 365 g/day due to protein meal supplement on treated and untreated straw, respectively (Preston and Leng, 1986).

By feeding urea treated wheat straw with limited amount of concentrate composed of cottonseed cake and wheat bran to Chinese cattle, Ma *et al.* (1990) found considerable improvement in 48 hours degradability (69.4 and 47.3% for treated and untreated straw, respectively). Moreover, the ammoniation resulted in faster and more efficient growth and was also cost effective. The percentage improvement obtained in daily weight gain, DM conversion and cost of feed per kg gain due to treatment were 341% (485 vs. 110g), 76.4% (10.8 vs. 44.3) and 64% (1.82 vs. 5.0 Yuan), respectively. In another study by Gao (2000), Chinese Yellow cattle (young bulls) of 160 to 210 kg live weight and 12 to 14 months of age were fed wheat straw treated with anhydrous ammonia or urea plus 1.0, 1.5 and 2 kg/day of cotton seed cake. Though the live weight gains of animals given the anhydrous ammonia treated straw were significantly higher than that of the animals given urea treated straw, daily weight gains of 602, 687 and 733 g were attained for urea treatment plus the 1.0, 1.5 and 2 kg/day of supplement, respectively.

From their study on yearling crossbred (Friesian x Malawi Zebu) cattle, Munthali *et al.* (1992) reported the highest live weight gain for animals fed 4% urea-treated maize stover supplemented with 2 to 3 kg maize bran per day. The authors attributed the improvement in live weight gain to the increased intake of energy and an accompanying improvement in the utilization of non protein nitrogen in the urea treated straw. Preliminary works at ILCA (1983) has also indicated that mature nonworking oxen fattened readily on straw-based diets when given fermentable nitrogen such as urea and small amounts of oilseed cakes.

Promma *et al.* (1985) studied the effects of urea treated rice straw on growth and milk production of crossbred Holstein Friesian dairy cattle. From the results they concluded that urea treated rice straw supplied together with concentrates, minerals and vitamins can be used instead of other preserved feeds such as grass hay, silage or fresh grass as no differences were found in live weight gain of the heifers.

Other effects of urea treatment

In Niger where it has been shown that the improvement in ruminant feeding system based on urea treated crop residues was rapidly and enthusiastically received by resource poor farmers, such improvements of the animal feed based on better utilization of crop residues, not only led to better maintenance of live weight and other animal performances, but also extended to greater integration of crop and livestock production systems through improvements in draught animal power and increased availability of organic manure. Fields were ploughed more efficiently and rapidly, and nitrogen content in dung was sharply increased when animals were fed the urea-treated forages compared to the untreated forages (7 to 8.3% instead of 4.5 to 5.8%). This was extremely important for soil fertility as a result of which crop yields were increased and hence, food security and income of farmers were improved (Kayouli, 1996). According to this author, the urea or ammonia treatment brought about an increase in nitrogen excreted in the dung as a result of nitrogen fixed to indigestible cell walls and the microbial nitrogen coming from fermentation in the large intestine and not able to be digested. It is also expected that the microbial protein in the rumen, which contain about 20% indigestible nucleic acids, has significantly increased after intake of urea-treated forages since there was more energy and nitrogen in treated forages which stimulate rumen microbial growth.

Urea treatment minimizes wastage of residues as intake of the treated residues is much increased and refusals are decreased. In this regard, Kayouli (1996) reported that about 70% of the treated stovers were edible as opposed to the usual edible proportion which was only 30 to 40% with the untreated stovers. Moreover, he noted an increase of about 30% in water intake as a consequence of higher DM intake of the treated stovers.

MATERIALS AND METHODS

This study has got four experiments. The first experiment was a survey type designed to assess the crop residue production, management and utilization in three AEZs of East Shoa Zone. The other three were controlled experiments with the objective of investigating the potential of urea treatment in improving the nutritive value of maize stover with subsequent evaluation of the effect of feeding the treated stover on feedlot performance and carcass characteristics of cattle. The title of each experiment and, the materials and methodologies employed to execute each of the experiments are presented as follows.

Experiment 1: Production, Management and Utilization of Crop Residues in Three Agro Ecological Zones of East Shoa Zone, Ethiopia

Description of the study area

This study was conducted in East Shoa Zone of Oromiya Regional State (Figure 1), Ethiopia. The Oromiya region has a diversified climate suitable for growing variety of crops such as maize, tef, wheat, sorghum, haricot bean, barley, pulses, and fruit and vegetables. The region accounts for more than 51 percent of the total production of the country (CSA, 2004a; ESPO, 1999). Cereal crops play the major role accounting for 82% of each of the cropped area and production (CSA, 2001). Tef, maize, wheat, barley and sorghum are the major food crops, the former three crops sharing 59 percent of the crop area and 60 percent of the production (CSA, 2001). About 5.9 million tons of crop residues are annually produced in the region with cereal straws accounting for 95% and legume haulms for the remaining 5% (ESPO, 1999). Maize stover, tef straw and sorghum stover each account for nearly one-third of the total residues produced in the region.

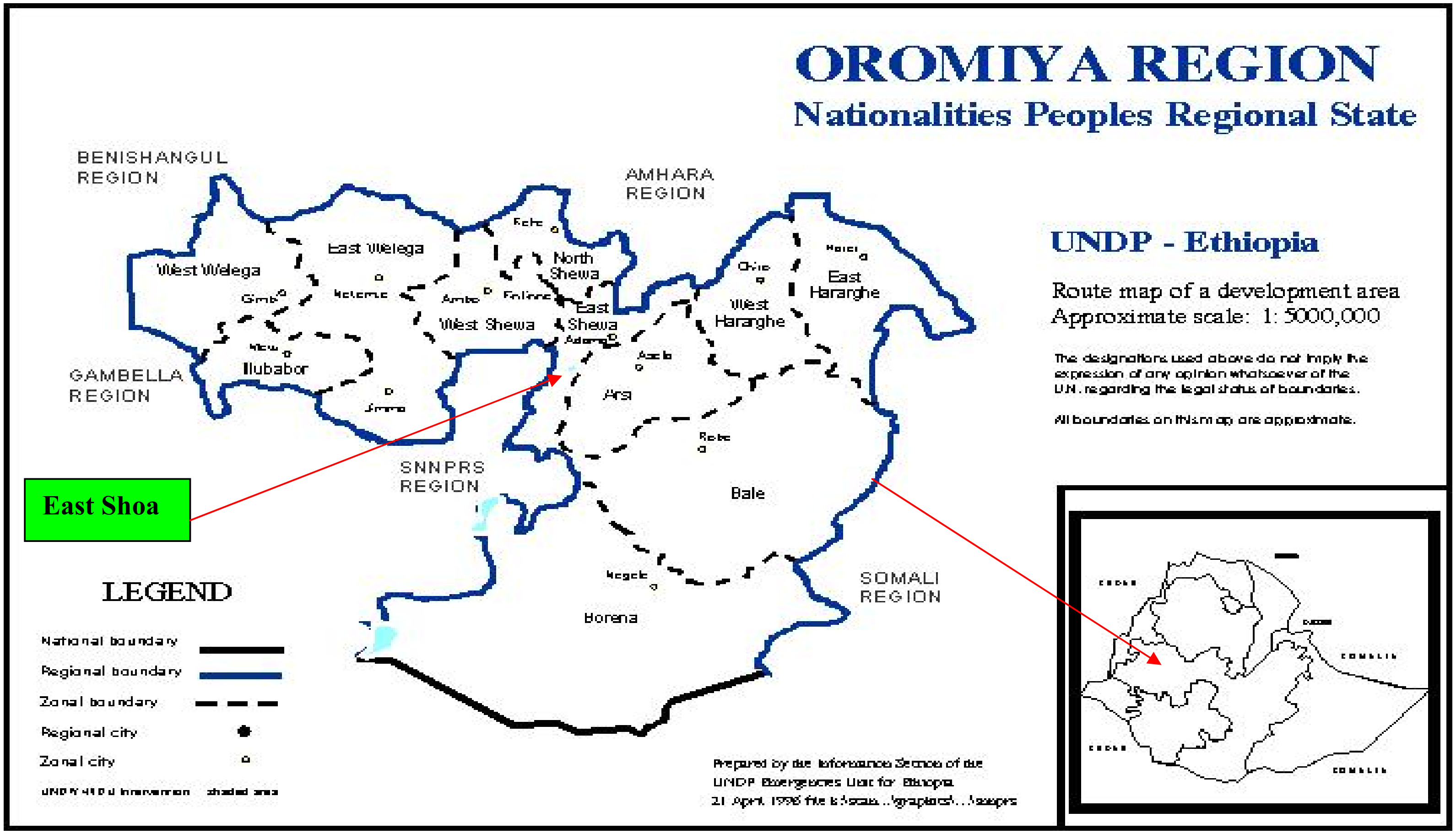

Figure 1 Map showing East Shoa Zone of Oromiya Regional State, Ethiopia.

Source: UNDP (1996)

East Shoa Zone is one of the 12 Zones of Oromiya Regional State, with an area of 1.4 million ha of which 11.2% is covered by water, 38.4% is an agricultural land, 14.3% is used for grazing, 14.5% is forest land and 3.8% is uncultivable land. The zone encompasses areas with an altitude range of 900 to 2400 m above sea level and receiving an annual rainfall of 700 to 1400 mm (SPM, 1999). The zone is subdivided in to 9 districts, covering arid to moist agro-ecological zones. There are 1.8 million people in the zone; 72% of which lives in rural areas, and the rest living in urban areas. The farming systems in the area consist mostly of mixed farming, with only one district in the lowland being dominated by semi-nomadic activities.

This survey was designed to address three AEZs of the East Shoa Zone that cover the larger proportion of the zone. An Agro-ecological Zone is a land resource mapping unit, defined in terms of climate, landform and soils, and/or land cover, and having a specific range of potentials and constraints for land use (FAO, 1996)**.** The AEZ classification of Ethiopia (MOA, 1998) was based on length of growing period and thermal regime. According to FAO (1996)**,** the growing period defines the period of the year when both moisture and temperature conditions are suitable for crop production. The estimation of growing period is based on a water balance model which compares rainfall (P) with potential evapo-transpiration (PET). The length of growing period is defined as the period (in days) during the year when rain-fed available soil moisture supply is greater than half the PET. It includes the period required for evapo-transpiration of up to 100 mm of available soil moisture stored in the soil profile. It excludes any time interval with daily mean temperatures less than 5^0 C. The thermal regime, on the other hand, refers to the amount of heat available for plant growth and development during the growing period. It is usually defined by the mean daily temperature during the growing period. In regional and national AEZ assessments, thermal zones may be defined based on temperature intervals of 5^0C or 2.5^0C.

The specific AEZs considered in this study, as shown in Figure 2, were sub-moist (SM2), sub-humid (SH2) and semi-arid (SA2) agro-ecologies. These AEZs were purposively selected as they cover more than 75% (46.3, 21.1 and 7.9% by SM2, SH2 and SA2, respectively) of the total area of the zone (EARO GIS unit, personal communication). SM2 refers to tepid to cool sub-moist mid highland areas with an altitude range of 1000 to 3000 m above sea level and an annual rainfall of 300 to 1600 mm. These areas have a mean annual temperature of 16 to 27.5^{0}C. SH2 encompasses tepid to cool sub-humid mid highlands whose altitude ranges from 1000 to 3200 m. above sea level and receiving 700 to 2200 mm rainfall annually. Their mean annual temperature varies from 11 to 21^{0}C. SA2 represents areas with tepid to cool semi-arid mid altitude (1600 to 2200 m above sea level) and that receive annual rainfall of 400 to 800 mm. Their mean annual temperature ranges from 16 to 21^{0}C.

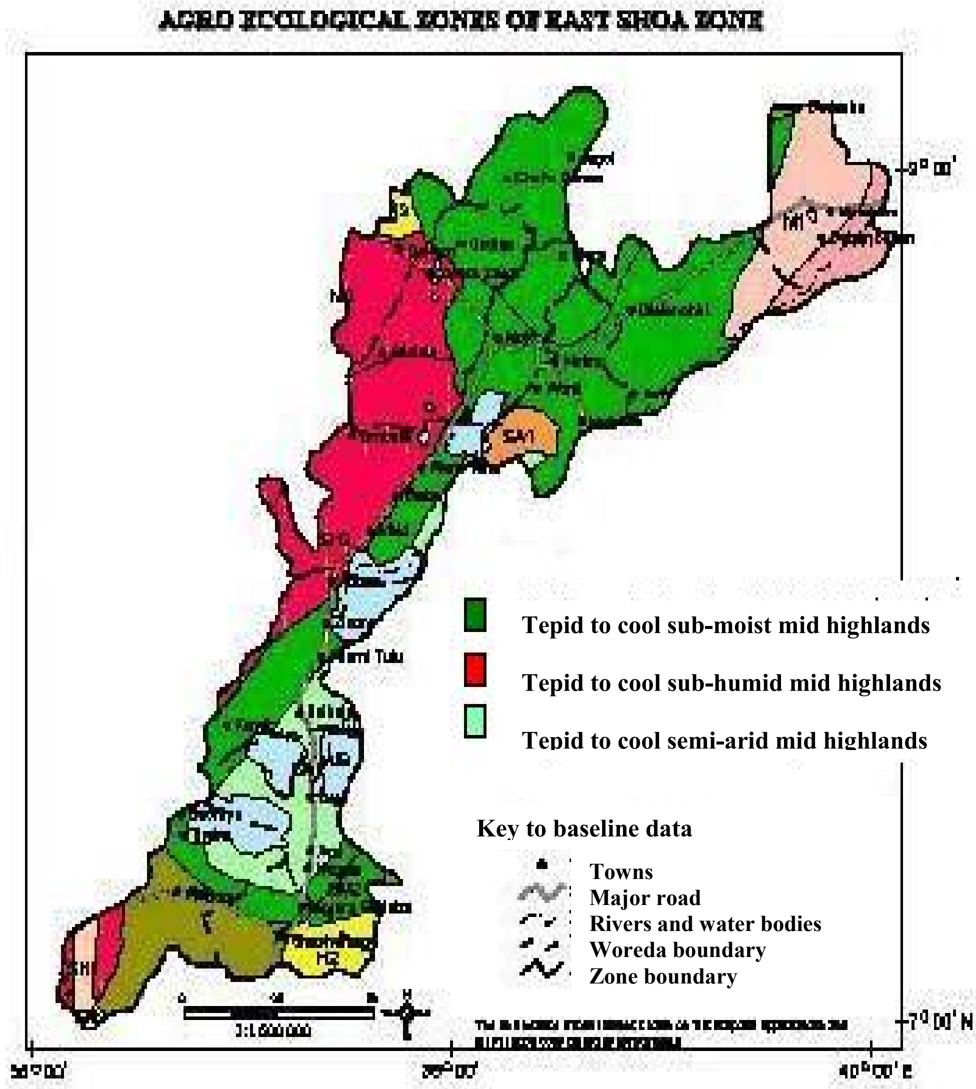

Figure 2 Map showing the Agro-ecological Zones of East Shoa Zone.

Source: EARO GIS unit, personal communication

Sampling techniques

Multistage purposive sampling technique was used in this survey. The three AEZs were selected based on the criterion that they cover more than 75% of the total area of the zone. Districts from each AEZ and peasant associations (PAs) from each district were identified based on their accessibility. Households from each PA were selected according to systematic random sampling using lists of households available with the development agents. Generally, in proportion to the area each of the three AEZs cover, three districts (Boset, Adama and Lume) from SM2, one district (Dugdabora) from SH2 and one district (Adamitulu Jidokombolcha) from SA2 agro-ecologies were considered. Then 3, 4 and 2 PAs from each of the selected districts of SM2, SH2 and SA2, respectively were selected. Finally 20 households were included per PA thus forming a total sample size of 300 respondents (180, 80 and 40 from SM2, SH2 and SA2, respectively).

Data collection

Using semi-structured questionnaire, information on farm size, livestock type and number, crops grown and their yield, management and use of crop residues, constraints to crop residue production and utilization were obtained from primary source in the year 2005. For comparison purpose, information on crop land allocation in the year 2003 and crop production during the year 2004 were also obtained from the respondents. Grain yield data were used to estimate their equivalent residue yields using the previously established residue to grain ratios which were 1.5, 2.0, 3.0 and 5.0 for barley, wheat, maize and sorghum residues, respectively (Kossila, 1988) and, 1.0 and 3.0 for haricot bean and tef residues, respectively (Tesfaye, 1999).

Animal numbers were converted to Tropical Livestock Unit (TLU, 1 TLU = 250 kg bovine on maintenance level) as 1 cattle, 1 goat or sheep, 1 horse and 1 donkey equals 1.0, 0.15, 1.0 and 0.65 TLU, respectively (Ramakrishna and Assefa, 2002) and 1 calf equals 0.25 TLU (IFPRI, 2004).

Statistical analysis

Descriptive statistics and frequencies were conducted using the statistical package for social sciences (SPSS, 1999). Some parameters were analyzed using the general linear model (GLM) procedure and differences among the AEZs were tested by Duncan Multiple Range Test (DMRT).

Experiment 2: Effects of Urea Levels and Treatment Durations on Chemical Composition and *In Vitro* Dry Matter Digestibility of Maize Stover

The study site

This and the next two experiments were conducted at Adami Tulu Agricultural Research Center which is found at 167 km south of Addis Ababa. The center is located at 7^0 9" N latitude and 38^0 7" E longitude at an elevation of 1650 m above sea level (ATARC, 1998). The area receives a mean annual rainfall of 800 mm, most of which fall during the months of June to September. Its mean maximum and minimum temperature ranges from 25 to 28^0 C and 8 to 12^0 C, respectively.

Treatment of the stover

Sun dried maize stover of improved maize varieties was used for this study. Four hundred grams of the chopped stover was weighed in plastic bucket and treated at an average room temperature of 24^0C according to a 3 X 3 factorial design involving three levels of urea (4, 5 and 6% of the dry stover weight) and three treatment durations (7, 14 and 21 days). Each combination of urea level and treatment duration was carried out in duplicates. In all cases 80 g of the urea solution containing 10 g cane molasses and the amount of urea that gives the respective percentage was added per 100 g of the dry stover. This was thoroughly mixed in a bucket and transferred into air tight, double layered plastic bag in where it was squeezed to expel excess air (to make it air tight). Then it was sealed and ensiled for the pre-determined durations mentioned above. After treatment, the stover was aerated for 2 to 4 hours and representative samples were taken and kept frozen for total nitrogen determination. The remaining straws were dried to constant weight at 65^0C and ground prior to other chemical analyses.

Chemical analyses

Dry matter, ash and Kjeldhal nitrogen were determined according to the procedures of AOAC (1990). The frozen samples were thawed, then chopped into small pieces and well blended before they are analysed for nitrogen content. Neutral detergent fiber (NDF) was analysed using the procedures described by Goering and Van Soest (1970). *In vitro* dry matter digestibility (IVDMD) was determined by the two stage methods of Tilley and Terry (1963). Crude protein (CP) percentage was calculated as % N × 6.25.

Statistical analyses

Fixed effects of the factor levels of urea concentration, treatment duration and their interaction on chemical composition and digestibility of the treated stover were analysed as a 3 x 3 factorial experiment in completely randomized design using the general linear model procedure of SAS (SAS, 2000). Duncan Multiple Range Test was used to test the difference among treatment means. The statistical model used was:

$$\mathbf{Y_{ijk} = \mu + U_i + D_j + UD_{(ij)} + \varepsilon_{ijk}}$$

Where, Y_{ijk} = Response variable (Chemical entities and IVDMD)

μ = Overall mean

U_i = Effect of i^{th} urea level (i = 1, 2, 3)

D_j = Effect of j^{th} treatment duration (j = 1, 2, 3)

$UD_{(ij)}$ = Effect of i^{th} urea level at j^{th} treatment duration

ε_{ijk} = Random error

Experiment 3: The Potential of Urea Treated Maize Stover for Growth Performance of Weaned Crossbred Calves

Animals and treatments

Twenty one weaned crossbred (50% Borana and 50% Friesian) male calves of 9 to 12 months of age and an average initial live weight of 138.9 kg were used for this study. The animals were drenched for internal parasites and sprayed against external parasites after which they were assigned to one of the following three dietary treatments designed in a completely randomized design having seven animals in each treatment. The three dietary treatments were:

Diet 1: Untreated maize stover (UNMS) *ad libitum* plus 1 kg concentrate mixture per head per day

Diet 2: Urea treated maize stover (UTMS) *ad libitum* plus 1 kg concentrate mixture per head per day

Diet 3: Natural pasture hay (NPH) *ad libitum* plus 1 kg concentrate mixture per head per day

Feed preparation and feeding

Maize stover of improved maize varieties was purchased from the surrounding farmers and machine chopped into 3 to 5 cm length. Urea treatment was conducted by dissolving 5 kg urea and 10 kg cane molasses in 65 kg water to be sprayed over 100 kg air dried maize stover. Untreated maize stover, in batches of 10 kg, was spread in a 2.0 m x 1.5 m x 1.5 m cemented pit and 8 kg of the urea solution was sprinkled uniformly over the straw using a watering can. The soaked straw was pressed by trampling to expel as much air as possible. Likewise several layers were put on until the pit was filled after which it was covered with a plastic sheet and loaded with sacks full of sand to make it air tight. The straw was kept treated in such a way for two weeks after which it was aerated for an overnight and then fed to the animals. Natural pasture hay, which was dominated by *Andropogon, Pennisetum, Cynodon* and *Trifolium* species was purchased from the neighboring zone. The concentrate mixture was formulated from 59% wheat bran, 40% linseed cake and 1% salt.

The basal diets were weighed and given to each animal individually at the rate of 20 to 25% and 25-30% in excess of the previous daily intake of hay and maize stover, respectively. These were offered in two meals at 09:00 and 15:00 hours. Every morning, feed refusals were collected and weighed before feeding. Animals were given the concentrate mixture every day prior to offering the basal diet and they were watered to appetite once per day to simulate the common watering frequency practiced in the area. The animals were weighed fortnightly through out the experimental period. The experiment lasted for 21 days adaptation and 99 days experimental periods.

Feed intake, digestibility and growth rate measurement

Daily feed intake of each animal was calculated as a difference between the amount of feed offered and refused during the experimental period. Daily live weight gains were estimated from the fortnightly weight records of each animal by regression analyses. After completion of the experimental period, 12 randomly selected animals (4 animals per treatment) were transferred into metabolic crates to determine apparent digestibility of the feeds. Here faeces and urine were collected separately for 7 days. Records were kept on the amount of feed offered and refused, the faeces and urine excreted. Each day, 5% of the samples of feeds offered and refused and faeces voided by each animal were taken, bulked and stored at -20^0C. After the 7 days collection period, the samples were mixed thoroughly and sub samples were taken. Then the sub samples were dried to constant weight and ground pending for chemical analyses. The total daily urine from each animal was collected into a plastic bucket containing enough amount of 10% sulphuric acid to maintain the urinary pH below 3. This was weighed and 5% sample was taken and stored at -20^0C until analysed for nitrogen content.

Chemical analyses

Samples of feed, orts and faeces were analysed for DM, Ash and total nitrogen according to AOAC (1990). To avoid nitrogen loss due to oven drying, N content of the urea treated maize stover and the faeces samples were determined from wet samples after the necessary preparation of the samples was made. The NDF was determined following the procedure of Goering and Van Soest (1970). *In vitro* digestibility of the feeds offered was determined using the two stage methods of Tilley and Terry (1963). Urinary nitrogen content was also determined according to the Kjeldhal nitrogen procedure of AOAC (1990). Percent nitrogen contents were converted to CP percent by multiplying by 6.25. Standard procedures were followed for calculations of apparent digestibility coefficients and the nitrogen balance.

Cost analyses

Cost analysis was based on comparison of only feed costs for each animal on the three dietary treatments. The current feed costs calculated on per kg DM basis were 0.72 Birr (Birr = Ethiopian currency, 8.60 Birr = 1 USD) for natural pasture hay, 0.30 Birr for untreated maize stover, 0.50 Birr for urea treated maize stover and 0.88 Birr for the concentrate mixture. Labour costs for feeding the experimental animals, cost of chopping maize stover and cost of water for preparing the urea solution were not considered.

Statistical analyses

The effects of dietary treatments on different parameters were analyzed using the generalized linear model procedure of SAS (SAS, 2000) for a completely randomized design with three treatments. While analyzing live weight change and feed intake data, initial live weight was used as a covariate. Differences among treatment means were evaluated using DMRT. The statistical model used was:

$$Y_{ij} = \mu + T_i + b(x_{ij} - \bar{x}) + \varepsilon_{ij}$$

Where, Y_{ij} = Response variables (feed intake, growth rate, apparent digestibility, nitrogen utilization, feed cost, etc.)

μ = Overall mean

T_i = Effects of i^{th} dietary treatment (i = 1, 2, 3)

$b(x_{ij} - \bar{x})$ = Covariate effect, b is the regression coefficient for initial weight x

ε_{ij} = Random error

Experiment 4: The Potential of Urea Treated Maize Stover for Feedlot Performance and Carcass Characteristics of Borana Bulls

Animals and treatments

Twenty one Borana bulls of 284.7 kg average initial live weight were purchased from Guji Zone of Oromiya Regional State and brought to Adami Tulu Agricultural Research Center, where the research was conducted. The animals were drenched for internal parasites and sprayed against external parasites before starting the experiment. Then they were assigned to three dietary treatments designed in a completely randomized design having seven animals in each treatment. The dietary treatments were:

Diet 1: Untreated maize stover (UNMS) *ad libitum* plus 1.5 kg concentrate mixture per head per day

Diet 2: Urea treated maize stover (UTMS) *ad libitum* plus 1.5 kg concentrate mixture per head per day

Diet 3: Natural pasture hay (NPH) *ad libitum* plus 1.5 kg concentrate mixture per head per day

Types and chemical composition of the diets used in this experiment were similar to that of the diets used in experiment three. Also with regard to feed preparation and feeding, measurement of feed intake, digestibility and growth rate, laboratory analyses, cost analysis and statistical procedures, the same methodologies described in experiment three were employed

Measurement of carcass characteristics

At the end of the feeding period, 3 representative animals from each treatment were randomly selected and slaughtered following 24 hours fasting. After skinning and evisceration, weights of different external (hide, legs, head) and internal (heart, kidney, liver, lung and trachea, etc.) parts were taken and the whole carcass was split into two halves which were then weighed and put in chilling room at 2^0C for 18 hours**.** Thereafter, the right half of each animal was manually deboned and the whole of the boneless meat was separated into lean meat and fat. After the weights of each part were taken, both the lean and the fat were mixed and minced from which samples were taken for chemical analyses.

The left half of each animal was used to take measurements of some important carcass characteristics such as fat thickness, total tissue depth, rib eye area and muscle pH. Back fat thickness and total tissue depth were measured over the rib eye muscle. Rib eye area was measured between the 12^{th} and 13^{th} ribs by tracing a transparent paper which was later converted to area units using planimeter. Muscle pH was measured on the rib eye muscle. Dressing percentage was determined as carcass weight as percent of the slaughter weight of each animal.

Moisture content of the fresh meat was determined according to AOAC (1990) procedure. Meat samples were freeze dried and DM, Ash, nitrogen and ether extract were determined using the same procedure.

RESULTS AND DISCUSSIONS

Experiment 1: Production, Management and Utilization of Crop Residues in Three Agro Ecological Zones of East Shoa Zone, Ethiopia

Herd and farm size distribution

Herd size distribution across households in the three AEZs in the year 2005 is given in Table 1. Number of animals each household possesses was converted to Tropical Livestock Unit according to the factors indicated in the materials and method section. As can be seen from the standard deviation figures, there was a great variation in livestock ownership across the households in all the AEZs. About 50, 33 and 39% of the interviewed households in SM2, SH2 and SA2, respectively had less than 6 TLU, whereas another 34% in each of the SM2 and SH2 agro-ecological zones and 41% in SA2 had 6 to 10.9 TLU. Compared with the number of respondents in SM2 and SA2, there were more numbers of respondents (16%) in SH2 those had 16 or more TLU. This was likely to be due to the existence of some communal grazing areas in this AEZ, as mentioned by the respondents, and hence the lesser feed problem which then encouraged the farmers to keep more number of animals. Moreover, as shown in Table 2, about 70% of the respondents in this AEZ possessed few hectares of private grazing land. From analysis of the whole study area, it can be observed that about 44% of the interviewed farmers in the area owned less than 6 TLU. This is an indication that there was a critical shortage of grazing land in the area and, as the crop residues alone could not support more than a limited number of animals, the farmers were not able to keep many heads of animals.

Table 1 Herd size distribution across households in the three AEZs in the year 2005.

Herd size (TLU)	Percentage of households in:			
	SM2	SH2	SA2	Over all
> 0 and < 6	49.7	32.5	38.5	43.7
6 – 10.9	33.9	33.8	41.0	35.0
11 – 15.9	9.6	17.5	12.8	12.0
16 – 20.9	2.8	10.0	7.7	5.3
21 – 25.9	2.9	1.2	-	2.0
≥ 26	1.1	5.0	-	2.0
Median	6.0	7.4	6.6	6.5
SD	5.2	6.9	5.0	5.7

Farm size distribution across households is shown in Table 2. The distribution ranged from 0.25 ha to 18 ha per household. About 75% of the interviewed households in SM2 and almost half of the households in each of the SH2 and SA2 agro-ecologies owned only less than 3 ha of crop land. Generally, more than 90% of the respondents in SH2 and almost all of those in SM2 and SA2 had less than 6 ha of cropping land. With regard to grazing land, private grazing lands are literary absent with 90 and 75% of the households in SM2 and SA2, respectively having none. Of the respondents in SH2 and SA2, 65 and 25%, respectively had less than 2 ha of grazing land. If the whole study area is considered, about 72% of the interviewed households had no grazing land and only about 27% had some less than 2 ha. These holdings generally indicate the presence of critical shortage of grazing land in all the AEZs as farmers allocated more and more of their land to crop production. In this survey, almost all respondents stated that the major constraint to livestock production was the scarcity of feed as a result of shortage/absence of grazing land. Therefore, they heavily depended on crop residues especially during the dry season. In some areas there were few hectares of communal grazing areas that supply a meager feed during the wet season.

Table 2 Distribution of crop and grazing lands across households in the three AEZs in the year 2005.

Farm size (ha)	Percentage of households in:			
	SM2	SH2	SA2	Over all
Crop land				
> 0 and < 3	75.6	47.5	55.0	65.3
3 – 5.9	22.7	45.0	45.0	31.7
6 – 8.9	0.6	7.5	-	2.3
15 - 18	1.1	-	-	0.7
SD	1.9	1.6	1.2	1.8
Grazing land				
none	90.0	28.8	75.0	71.7
> 0 and < 1	10.0	32.5	22.5	17.6
1 – 1.9	-	32.5	2.5	9.0
2 - 3	-	6.2	-	1.7
SD	0.1	0.7	0.3	0.5

The allocation of cultivable land to the major crops during the year 2003 and 2004 is indicated in Table 3. The allocation varied ($p<0.05$) among households in the three AEZs. In both years households in SM2 allocated more land to tef than those households in SH2 and SA2 did. During the same years, respondents in the latter two AEZs allocated more land to maize and haricot bean than those respondents in SM2 did. Households in SM2 allocated more of their land to tef followed by maize in both years, whereas the households in SH2 and SA2 allocated more of their land to maize followed by tef in 2003. Generally as SA2 encompasses more moisture stress areas than the other two AEZs, the respondents in this AEZs seem to prefer allocating more land to maize and haricot beans as these crops demand relatively less moisture than other crops.

Table 3 Allocation of cultivable land to the major crops by households in the three AEZs in 2003 and 2004.

Years and AEZ	Percentage area allocated to:					
	Tef	Wheat	Barley	Maize	Sorghum	Haricot bean
2003						
SM_2	55.7[a]	8.6[b]	4.0[ab]	16.3[c]	4.6[a]	10.8[c]
SH_2	28.5[b]	15.0[a]	3.0[b]	30.8[b]	5.7[a]	17.0[b]
SA_2	27.1[b]	2.2[c]	5.9[a]	40.0[a]	0.3[b]	24.5[a]
2004						
SM_2	55.0[a]	10.2[b]	4.4	16.1[c]	2.5	11.8[c]
SH_2	28.2[b]	18.2[a]	4.1	25.7[b]	5.0	18.9[b]
SA_2	26.1[b]	3.1[c]	4.9	33.4[a]	2.3	30.2[a]
Two years' average						
SM_2	54.8[a]	9.5[b]	4.3	16.2[c]	3.8[ab]	11.5[c]
SH_2	28.5[b]	16.7[a]	3.6	27.8[b]	5.4[a]	18.2[b]
SA_2	26.6[b]	2.6[c]	5.7	37.0[a]	1.2[b]	26.9[a]

[abc] Within each year, means in the same column with different letters are different ($p<0.05$).

Taking the study area as a whole, tef, maize, haricot bean and wheat, in that order, occupied the largest of the cultivated land both in 2003 and 2004. This is shown in Figure 3.

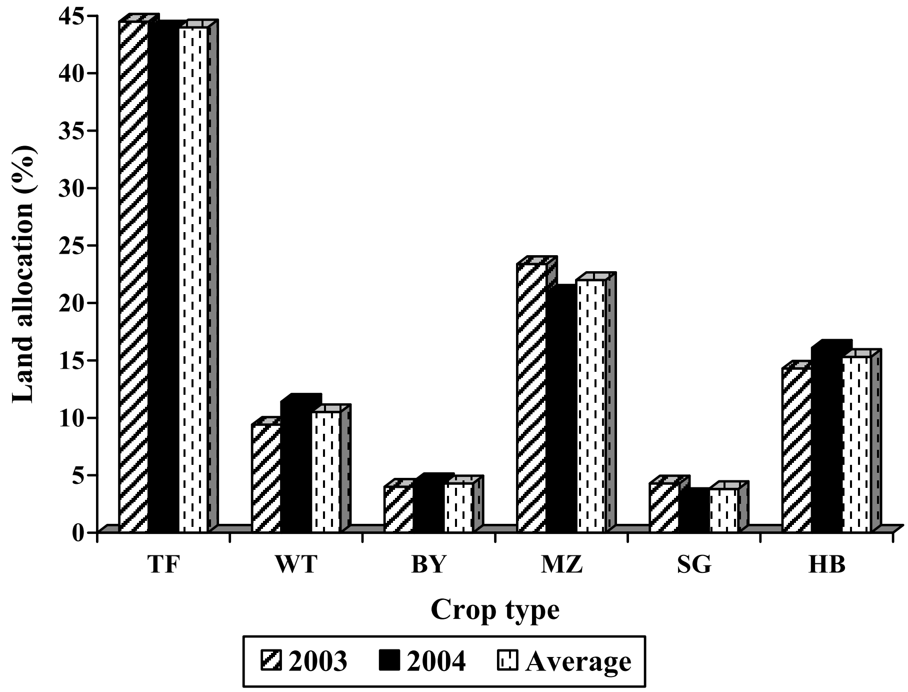

Figure 3 Allocation of cultivable land to the major crops (TF=tef, WT=wheat, BY=barley, MZ=maize, SG=sorghum, HB=haricot bean) by households in the entire study area in 2003 and 2004 cropping season.

Production and contribution of crop residues

Crop residue production by households in the three AEZs during the years 2004 and 2005 is indicated in Table 4. These production figures were based on grain yield data obtained directly from the selected households through interview. From the table, it can be seen that there was no statistically sound variation among households in the AEZs in the total crop residue production during the two years. However, the households in SM2 produced relatively more crop residues than those in the other two AEZs. This could be attributed to the difference among households in the three AEZs in allocation of cultivable land to all crops in general and to individual crops in particular and, to the difference in climatic conditions of the AEZs. Households in all the three AEZs produced relatively more crop residues in year 2004 than in 2005. This is likely to be due to the inter-year variability in crop production, which could have in turn been influenced by differences in climate (especially rainfall) and soil conditions, utilization of various agricultural inputs, planting and crop management practices, and the size of land allocated to different crops. Moreover, as Butterworth and Mosi (1985) described, there could be variation in accuracy of estimation of production. These authors stated that it is difficult to make precise estimation of residue production because of uncertainty both as crop production figures and extraction indices. The authors elaborated that the relationship between grain yield and crop residue yield depends on many factors particularly rainfall and time of planting.

Table 4 Crop residue production[1] per household in the three AEZs during the year 2004 and 2005 (in tons).

AEZ	2004	2005	Annual average
SM_2	8.04	6.72	7.38
SH_2	7.46	5.56	6.51
SA_2	6.35	4.70	5.52
Overall	7.28	5.66	6.47

[1] On air dried basis.

Contribution of each crop residue to the annual total crop residue production of the interviewed households in the three AEZs in 2004 and 2005 is indicated in Table 5. During both years, households in SM2 obtained half of their crop residues from tef straw. Respondents in SH2 and SA2 did not differ ($p>0.05$) in the amount of tef straw they obtained in both years. In these two AEZs, maize stover, followed by tef straw constituted the largest share of the total annual crop residue production of the households. This followed the trend of the proportion of land annually allocated to the corresponding crops of these residues. The larger the area allocated to the crop the higher was the contribution of its residue. The higher contribution of maize stover in SH2 and SA2 was in agreement with the findings of De Leeuw (1997) who stated that in the mid- to low-altitude zones, residues from maize and from sorghum/pearl millet appeared more important with maize stover contributing 39% of the total.

Table 5 Contribution of different crop residues to the total annual crop residue production of each household in the three AEZs in 2004 and 2005.

Years and AEZs	Percentage contribution of:					
	Tef straw	Wheat straw	Barley straw	Maize stover	Sorghum stover	Haricot bean haulms
2004						
SM_2	51.9[a]	9.7[b]	3.3[a]	23.3[c]	7.4[a]	4.4[c]
SH_2	22.7[b]	13.9[a]	2.5[b]	44.1[b]	10.4[a]	6.5[b]
SA_2	21.9[b]	2.0[c]	6.3[a]	58.9[a]	0.4[b]	10.4[a]
2005						
SM_2	52.3[a]	10.8[b]	3.5[b]	23.3[c]	4.9	5.3[b]
SH_2	25.7[b]	21.4[a]	4.6[ab]	31.9[b]	8.8	7.5[b]
SA_2	30.4[b]	3.2[c]	6.9[a]	42.2[a]	3.9	13.4[a]
Two years' average						
SM_2	50.6[a]	10.0[b]	3.2[b]	23.5[c]	8.2[a]	4.5[c]
SH_2	23.8[b]	16.4[a]	3.2[b]	39.0[b]	10.9[a]	6.7[b]
SA_2	24.6[b]	2.6[c]	6.6[a]	53.3[a]	1.8[b]	11.2[a]

[abc] Within a year, means in the same column with different letters are different ($p<0.05$).

The overall picture (figure 4) showed that tef straw, followed by maize stover and wheat straw contributed significantly to the total annual crop residue production by households in the entire study area.

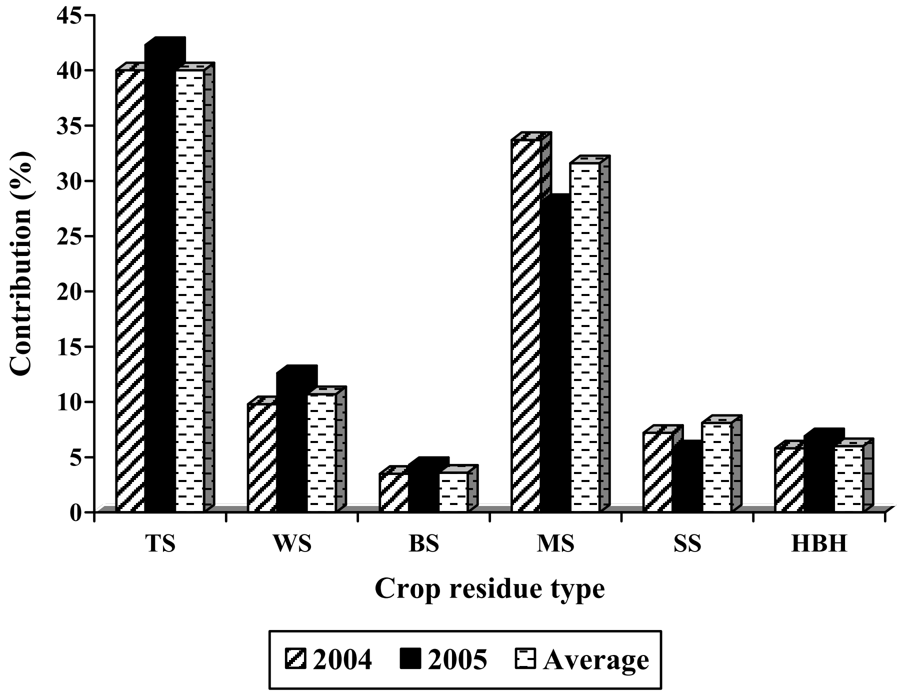

Figure 4 Contribution of different crop residues (TS=tef straw, WS=wheat straw, BS=barley straw, MS=maize stover, SS=sorghum stover, HBH=haricot bean haulms) to the total annual crop residue production per household in the whole study area in 2004 and 2005.

Livestock ownership in TLU and annual crop residue production per TLU of the interviewed households are summarized in Table 6. Households in SH2 owned more ($p<0.05$) number of animals than those in the other two AEZs which did not differ in their livestock ownership. However, households in all the AEZs did not statistically differ ($p>0.05$) in their annual crop residue production per TLU even if there were slight differences both between the years and among the AEZs. Assuming that the number of animals each respondent had in the years 2004 and 2005 was similar, relatively more tons of crop residues per TLU were produced in 2004 than in 2005. This was likely to be as the crop residue production per household was higher during the year 2004 than during the year 2005. Households in SM2 produced more tons of crop residues (Table 4) than those households in either SH2 or SA2. Accordingly, the crop residue production per TLU was highest for households in the

SM2 AEZ compared with that of the households in the other two AEZs. As indicated in the foregoing discussion, households in SA2 produced fewer tons of crop residues than those households in SH2. However, because of the relatively lesser number of animals owned by households in SA2 than by those in SH2, higher tons of crop residues per TLU were produced by households in the former AEZ than in the latter. Kossila (1985) stated that the production of fibrous crop residues per livestock unit of grass eaters varies greatly between regions and countries depending on factors such as availability of other feed resources, climatic variation, water resources, soil conditions, land topography, animal disease, type of ruminant production systems, and levels of modern technology in agricultural production systems. In the current study, it seems that climate and other factors that brought about an increased crop production in SM2 contributed to the highest production of crop residues per TLU in this AEZ compared to production in the other two AEZs.

Table 6 Herd size and average crop residue production per TLU of households in the three AEZs during the years 2004 and 2005.

AEZ	Herd size per household in 2005 (TLU)	Residue production[1]/TLU (tons)		
		2004	2005	Average
SM2	7.15[b]	1.10	0.92	1.01
SH2	9.42[a]	0.77	0.58	0.67
SA2	7.21[b]	0.84	0.62	0.73
Overall	7.93	0.90	0.71	0.80

[ab] Means in the same column with different letters are different ($p<0.05$).
[1] On air dried basis.

Assuming the edible proportion of crop residues to be 70% (Kayouli, 1996), if the average annual crop residue production per TLU is converted to the daily production, it can be noted that the least amount of crop residue produced per TLU in SH2 would mean a supply of 1.16 kg crop residue DM (assuming 90% DM content) per TLU per day. This is equivalent to 26% of the daily DM requirement of a 250 kg cattle which, according to Kearl (1982), is 4.4 kg DM for maintenance level.

Similarly, the highest average annual crop residue production per TLU attained in SM2 would supply 1.74 kg crop residue DM per day which is equivalent to 40% of the daily requirement of the same type of animal. Therefore, from these, it can be generalized that crop residues, on average, could annually contribute 26 to 40% of the total maintenance feed requirements of animals in the entire study area.

Crop residue collection and storage

Distribution of households according to the crop residue collection and storage practices they undertake is shown in Table 7. In SM2 and SH2, almost all the interviewed households stated that they collect and then store all their tef, wheat and barley straws in open air (without shelter) to use it later in the year. More than 77% of the households in each of the three AEZs also indicated that they collect and store their haricot bean haulms in similar way. In Figure 5 is shown stacks of mixed straws and haricot bean haulms stacked in open air.

In case of sorghum stover, the largest proportion of households in SH2 and SA2 AEZs stated that they leave their stovers on the crop fields. In SM2 most of the households either collect and store it or leave it on crop fields. Unlike the case for sorghum stover, about 60% of the households in each of the SM2 and SA2 AEZs collect and store their maize stover for later use. It was only in SH2 where there was relatively some gazing areas that maize stover was left on crop fields by more than half of the interviewed households.

Table 7 Crop residue[1] collection and storage practices in the three AEZs.

Collection & storage practices	% of households undertaking the practice for:					
	TS	WS	BS	MS	SS	HBH
SM2						
Collect & store all in open	99.4	99.3	99.2	60.8	44.0	90.9
Collect & store all in shelter	0.6	0.7	0.8	-	-	0.6
Collect & store only some	-	-	-	16.4	16.0	1.3
Leave all on field or threshing place	-	-	-	22.9	40.0	7.1
SH2						
Collect & store all in open	100	100	100	31.3	12.9	77.2
Collect & store only some	-	-	-	15.0	7.1	2.5
Leave all on field or threshing place	-	-	-	53.8	80.0	20.3
SA2						
Collect & store all in open	100	48.1	84.4	64.1	9.1	86.8
Collect & store only some	-	25.9	6.3	15.4	4.5	13.2
Leave all on field or threshing place	-	25.9	9.4	20.5	86.4	-

[1] TS=tef straw, WS=wheat straw, BS=barley straw, MS=maize stover, SS=sorghum stover, HBH=haricot bean haulm.

Figure 5 Mixed straws (left) and haricot bean haulms (right) stacked in open air.

The crop residues collection and storage practices were observed to depend on the mechanism of removing grain from the crops. With tef, wheat, barley and haricot bean, removal of grains from the crops necessarily demands harvesting and transporting of the crops to homesteads where they are threshed and their grain and straws are separated. Finally the straws are stacked near homesteads and, in some cases, fenced with local materials (Figure 6). In case of maize and sorghum, the maize ears and sorghum grain heads are usually removed from the stalk right in the field leaving the rest for *in situ* grazing. This condition is further complemented with the status of farmers in having suitable conditions that enable them to collect these residues, the severity of feed problem the farmers have and the importance of none-feed purposes for which the stovers are required. In situations where farmers have no means of transportation, or where they have sufficient feeds from other sources, or where they need the stovers for other non-feed purposes, less stovers are collected and stored for animal feeding. Owen and Aboud (1988) also found the bulky nature of crop residues and lack of means of transportation to be among the factors that constrain the collection and hence the greater use of straws and stovers as feed.

Figure 6 Crop residues fenced with thorny woods.

If the practice of residue collection and storage is considered for the entire study area (Table 8), it can be observed that more than 90% of the respondents collect and store each of their tef, wheat and barley straws and 53% do the same for maize stover. In case of sorghum stover about 67% of the respondents indicated that they leave it on the crop field.

Table 8 Crop residue collection and storage practices in the whole study area.

Residue type[1]	Percentage of households who:			
	Collect & store all in open	Collect & store all in shelter	Collect & store Only some	Leave all on field /threshing place
TS	99.7	0.3	-	-
WS	94.0	0.4	2.8	2.8
BS	97.5	0.4	0.8	1.2
MS	52.6	-	15.8	31.6
SS	23.2	-	9.8	66.9
HBH	86.3	0.4	3.3	10.0

[1] TS=tef straw, WS=wheat straw, BS=barley straw, MS=maize stover, SS=sorghum stover, HBH=haricot bean haulm.

Major constraints to crop residue collection in the study area were assessed by asking the respondents to identify, in order of importance, three major reasons for not collecting crop residues. The orders were then converted to scores in such a way that score 3 was given for the most important reason and score 1 for the least important reason. Then the percentage score for each reason was calculated as its total weighted score divided by the total scores given for all the reasons. Calculated accordingly, percentage scores for the possible reasons of not collecting crop residues by the respondents are given in Table 9. Relative importance of the possible reasons varied from one AEZ to the other. In SM2, lack of means of transportation, followed by use of the residues for mulching purposes did not encourage the farmers to collect and store their residues for future use. This is similar to the finding of Mlay (1986) who observed lack of transportation to be the main constraint to collection of crop residues under Tanzanian condition. In SH2, other factors (which include lack of awareness and time and un-palatability of the residues, especially the stovers) followed by lack of means of transportation and use of the residues for mulching were found to be the major reasons for not collecting residues. For more than 60% of the respondents in SA2, the reasons were either their fields were too far from homesteads, or the crop residues were of such a small quantity that they did not deserve collection, or there were no means of transportation. With regard to means of transportation, more than 90% of the respondents in all the AEZs stated that they use donkeys either of their own or by begging or hiring from others.

Table 9 Percentage scores for reasons of not collecting crop residues by households in the three AEZs.

Reasons	Percentage scores for the reasons in:			
	SM2	SH2	SA2	Overall
Lack of transportation[1]	44.5	32.3	21.5	35.6
Small quantity	15.5	1.7	20.6	10.4
Far from homestead	11.3	9.5	22.4	12.3
Use for mulching	16.6	16.3	12.1	15.8
Have no feed problem	8.1	6.8	4.7	7.0
Others[2]	3.9	33.3	18.7	18.9

[1] Include shortage of labour and finance, lack of pack animals such as donkeys.
[2] Shortage of time, un-palatability of the residues and lack of awareness.

Regarding crop residue storage problems, 65.0, 78.8 and 66.7% of the respondents in SM2, SH2 and SA2, respectively indicated that they have no storage problems as they take maximum care at storage places. The problems mentioned by the rest of the respondents are summarized in Table 10. Percentage scores for the problems were calculated in similar way the percentage scores for reasons of not collecting crop residues were calculated. Mould formation due to rain fall followed by termite attack has been the principal storage problem in all the three AEZs. The possible effect of moulding is a reduction in quality of the stover followed by rejection by animals. In this regard, Devendra (1982) observed a decrease in nutritive value of rice straw due to exposure to weather. In the current study, it was observed that most of the respondents stack their crop residues in open air with out any top cover with materials such as plastic sheets. On the other hand, some respondents cover the top of their crop residue stacks by tef straw as they knew that this, to some extent, has the ability to protect the percolation of rainfall through the stack, provided that the stacking is well performed. Other storage problems listed by the households include rodents, birds, wind and roaming animals.

Table 10 Percentage scores for major crop residue storage problems in the AEZs.

AEZ	Percentage scores for:			
	Fire problem	Termite problem	Mould due to rain fall	Other problems
SM2	5.4	24.3	68.9	1.4
SH2	1.4	25.2	56.7	16.7
SA2	3.7	16.5	67.9	11.9
Overall	3.8	23.6	64.7	7.9

Crop residue processing and treatment

Various earlier works mentioned in the preceding sections have depicted that some sort of processing or treatment of crop residues have positive effects on improving, to a variable degree, the intake and/or digestibility of crop residues. Percentage of respondents who use some kind of processing methods is given in Table 11. Most of the respondents in all the AEZs physically process their stoves by means of chopping manually or threshing by animals. None of the households in SH2 and insignificant number of those in the other two AEZs spray their residues while feeding. More than 90% of the respondents in each of the three AEZs do not get their residues balled. Other than what are indicated in the table, there were no other crop residue processing methods practiced by respondents in all the three AEZs.

Table 11 Percentage of respondents who use some kind of crop residue processing methods in the AEZs**.**

Processing methods used	% of households using/not using processing methods			
	SM2	SH2	SA2	Overall
Physical processing	76.1	66.3	92.3	75.6
Soaking (spraying)[1]	1.7	-	2.6	1.3
Balling	8.3	1.3	5.1	6.0
Use no any processing	13.9	32.4	-	17.1

[1] With salt, molasses, urea solution and brewer's grain (locally known as *Atela*).

From summary of constraints to the use of residue processing methods given in Table 12, it can be seen that the major bottle-neck for the application these methods was the farmers' lack of knowledge about the uses and advantages of the methods. In SM2, relatively more households know the advantage of balling as some government and private organizations bale the residues, especially tef straw, themselves and pay the farmers on per bale basis. However, the farmers were constrained by lack of finance and access to machineries to undertake the practice themselves and get more benefit. Summarized for the overall study area, shortage of labor, lack of awareness and shortage of finance have, respectively been the major constraints to undertake physical processing, chemical treatment and balling of crop residues.

Table 12 Constraints (1= major, 2= moderate, 3= minor) to the use of some crop residue processing and treatment methods in the three AEZs.

AEZ	Constraints to the use of:								
	Physical processing			Chemical treatment			Balling		
	1	2	3	1	2	3	1	2	3
SM2	labor	awareness	finance	awareness	finance	access	finance	awareness	access
SH2	labor	awareness	finance	awareness	finance	access	awareness	access	finance
SA2	awareness	labor	-	awareness	finance	access	awareness	access	finance
Overall	labor	awareness	finance	awareness	finance	access	finance	awareness	access

Utilization of crop residues and their left overs

To assess the different uses to which crop residues are put, the selected households were asked to identify, in order of importance, three major uses of each crop residue. These orders were later converted to scores in such a way that score 3 was given for the most important use and score 1 for the least important use. Then the percentage score for each use of a crop residue was calculated as its total weighted score divided by the total scores given for all uses of that crop residue. Based on these percentage scores, the primary, secondary and tertiary uses to which each crop residue was put by respondents in the three AEZs are summarized in Table 13.

Respondents in all the three AEZs seem to use their crop residues for similar purposes. All the crop residues, with the exception of sorghum stover, were primarily used for livestock feeding. This, on the one hand, indicates the high dependence of farmers on crop residues as other feed resources are scarce and, on the other hand, it shows the relative betterment in feeding value of these residues due to both their physical nature and their chemical composition. With regard to chemical composition, crude protein contents of 5.5% for tef straw and 5.4% for haricot bean haulms (Tesfaye, 1999); 4.02% for maize stover (Tesfaye, 2005); 4.0% for wheat straw and 3.1% for sorghum stover (Seyoum and Zinash, 1989); and 4.7% for barley straw (Lulseged and Jamal, 1989) were previously reported. Sorghum stover was majorly used for construction and as fire wood. This was mainly because of its poor feeding value resulting primarily from its physical nature (stemmy with few leaves). From the table, it can be seen that the alternative uses of crop residues slightly varied with the type of residue. Stovers were alternatively used as firewood and for construction of fences, granaries, and shades, whereas straws of wheat and barley were used either for mattresses making or were sold to generate a limited amount of income for the family. Next to animal feeding tef straw was used, together with mud, in construction of walls of local houses. Here the role of the straw is to bind the mud making it stick to the wall and avoiding its cracking.

Table 13 Primary, secondary and tertiary uses of different crop residues in the three AEZs.

Priority of use by AEZ	Crop residue types and their uses					
	Tef straw	Wheat straw	Barley straw	Maize stover	Sorghum stover	Haricot bean haulms
Primary uses						
SM2	Animal feed	Animal feed	Animal feed	Animal feed	Fire wood	Animal feed
SH2	Animal feed	Animal feed	Animal feed	Animal feed	Construction	Animal feed
SA2	Animal feed	Sale	Animal feed	Animal feed	Construction	Animal feed
Secondary uses						
SM2	Construction	Mattress	Mattress	Fire wood	Animal feed	Mulching
SH2	Construction	Sale	Sale	Fire wood	Animal feed	Mulching
SA2	Construction	Animal feed	Sale	Fire wood	Fire wood	Sale
Tertiary uses						
SM2	Sale	Sale	Sale	Mulching	Construction	Fire wood
SH2	Sale	Mattress	Mattress	Construction	Fire wood	Sale
SA2	Sale	Mattress	Mattress	Construction	Animal feed	Mulching

The respondents stated that they use the bulk of their haricot bean haulms for livestock feeding as it was known to be of high feeding value because of being a legume. Alternatively, they majorly use it either as a mulch to improve soil fertility or they sell it to get some income. The fact that most of the respondents indicated they use almost all types of their residues primarily for animal feeding agrees with the previous work done by Zinash and Seyoum (1991). These authors found that in central zone of Ethiopia, to which East Shoa Zone is a part, about 63% of cereal straws were used for animal feeding with only 7, 20 and 10% being used for bedding, fuel and construction purposes, respectively.

To show the overall picture of uses of crop residues in the study area as a whole, the percentage scores of different uses of the major crop residues are given in Figure 7. This was more or less similar to their uses summarized in Table 13 for Each AEZ.

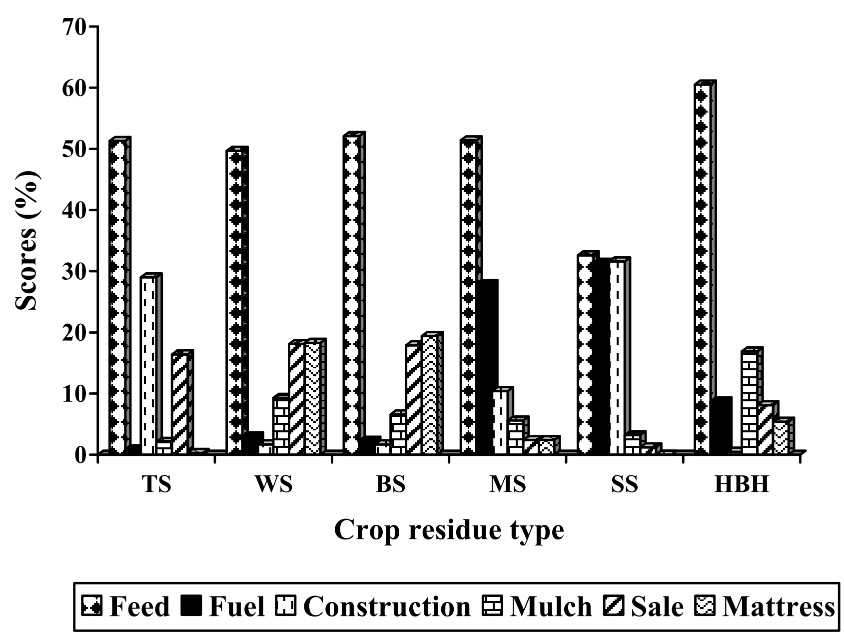

Figure 7 Percentage scores for different uses of major crop residues (TS=tef straw, WS=wheat straw, BS=barley straw, MS=maize stover, SS=sorghum stover, HBH=haricot bean haulm) in the entire study area.

By left overs is meant the orts left by animals after they are fed on crop residues. Generally more than 90% of the respondents stated that they use left overs of their crop residues for different purposes. Specific uses of left over of each crop residue were determined using the method described above for uses of crop residues. As notable differences were not observed among households in the three AEZs with respect to utilization of left overs of different crop residues, their utilization in the entire study area are indicated in Table 14. Except for the left overs of stovers, which were primarily used as fire wood, left overs of all other by-products were majorly used as surface mulch to amend the fertility of crop lands. The respondents stated that as the left overs are mixed with dung during feeding, spreading such left overs onto their fields had positive impacts on fertility of their lands. In this regard, however, the farmers need to be taught that they could get more benefit if they prepare the left overs, together with other wastes, as compost. Those farmers who stated that they use left overs for animal feeding explained that they do this by mixing the left overs with fresh residues or by spraying them with salt to make them more palatable. Some other farmers feed the left overs to less selective animals like donkeys.

Table 14 Percentage scores for uses of left-overs of the major crop residues in the entire study area.

Residue type	Percentage scores for uses as:				Not used
	Fire wood	Animal feed	Mulching	Construction	
Tef straw	2.3	28.2	59.1	3.2	7.2
Wheat straw	9.1	16.6	62.2	3.2	8.9
Barley straw	7.9	19.5	62.1	2.0	8.6
Maize stover	59.8	9.6	26.0	-	4.7
Sorghum stover	54.0	5.2	26.6	-	14.3
Haricot bean haulms	10.2	12.4	64.8	0.5	12.2

Regarding the use of crop residues, a general question was presented to the respondents as to whether or not they use their crop residues efficiently. Fifty six, 59 and 64% of the respondents in SM2, SH2 and SA2, respectively replied that they use their crop residues efficiently by collecting and storing them properly. Causes of crop residue wastage cited by the rest of the respondents who stated that they did not use their residues efficiently are summarized in Table 15. The percentage score for each cause was determined according to the procedure used for determination of percentage scores for different uses of crop residues. In SM2 and SA2, improper storage and inability to collect, in that order, were found to be the major causes of residue wastage. In SH2, inability to collect followed by the nature of the residue (being stemmy and bulky) was the major cause of wastage. Other reasons for inefficient utilization of crop residues include respondents' lack of know-how as to how to manage the residues, poor feeding system (eg. lack of feeding troughs), lack of fences around the stacks and damage by rodents. In studying constraints to cereal crop residue utilization in central Tanzania, Kabatange and Kitalyi (1989) found that efficient utilization of crop residues was limited by big herd sizes, long distances from crop fields to homesteads, lack of transport and low level of technology. In the current study, some of these factors have also contributed to the general causes of crop residue wastage mentioned in the table bellow.

Table 15 Percentage scores for the major causes of crop residue wastage in the three AEZs.

AEZ	Causes of wastage and their percentage scores			
	Inability to collect	Improper storage	Nature of the residue	Others[1]
SM2	30.3	39.7	17.9	12.0
SH2	34.4	20.4	26.8	18.5
SA2	25.0	40.3	13.9	20.8
Overall	30.7	35.8	19.1	14.4

[1] Lack of awareness, poor feeding system (eg. no trough), rodents and lack of fences.

Crop residue feeding systems

From questions posed to know when do farmers use their main livestock feed resources, namely, natural pasture, weeds and crop thinnings, road side grazing and crop residues, 76 and 99% of the respondents stated that they use their natural pasture and road side grazing, respectively only during the wet seasons, whereas all respondents indicated that they use weeds and crop thinnings during the wet seasons as these feeds are available only during such seasons. With regard to crop residues, 50% of the respondents replied that they use these feeds only during the dry seasons, and the remaining 50% stated that they use their residues both during the wet and dry seasons. Distribution of households according to how they feed straws and stovers to their animals is shown in Table 16. About two thirds of the interviewed households in SM2 and SH2 AEZs stated that they stack the tef, wheat, barley and haricot bean straws together and feed the mixture to their animals. According to what the respondents replied, mix-stacking (Figure 8) has the advantage of resisting, to some degree, the damages by rain as residues like tef straws are put on top of the stack. Moreover, providing the mixed straws to animals increases palatability of the straws more than when they are fed alone.

Table 16 Distribution of households according to the crop residue feeding systems they employ in the three AEZs.

Feeding systems	Percentage of households applying the systems			
	SM2	SH2	SA2	Overall
For straws				
Feed alone	35.0	33.8	56.4	37.5
Mix with each other & feed	65.0	66.3	43.6	62.5
For stovers				
Graze *in situ*	19.8	51.3	17.9	28.3
Collect & feed alone	34.1	41.3	79.5	42.3
Collect, mix with others & feed	46.1	7.5	2.6	29.4

Figure 8 Mixed crop residues stacked in open air and with tef straw put on top.

In case of stovers, there were great variations among households in the three AEZs in the way they feed these residues to their animals. In SA2, about 80% of the respondents collect the stovers and feed them alone to their animals, whereas half of the households in SH2 agro-ecology allow their animals to gaze the stovers *in situ.* The disparity between these two AEZs is attributed to their difference in having other feed resources. Households in SH2 AEZ had, relatively, more alternative feeds than households in SA2 AEZ as a result of which they did not bother to collect the stovers as households in SA2 AEZ did. In Zimbabwe, Sibanda (1986) noted that most stovers were fed to animals *in situ,* while only some farmers harvested and stored the residues for later use. In the current survey, about 42% of the respondents in the entire study area (Table 16) were found to exercise the practice of collecting and feeding stovers alone to their animals. Although some respondents stated that they mix their stovers with other residues while feeding, great majority of the respondents indicated that there was no much advantage in mixing them with other residues such as straws as animals tend to select the fine straws leaving the stovers behind.

Generally, the methods of residue feeding that involve collection and storing are known to be better than other methods in view of minimizing crop residue wastage and maintaining quality of the residues. However, such systems are more demanding in terms of labor, transport and storage facilities. For such systems to be appealing to farmers, research based convincing information which depict the economic benefits of such methods must be available and demonstrated to farmers.

From the point of view of using crop residues efficiently in feeding to different ruminants, it is important to know whether or not the farmers prefer one type of crop residue for one animal species than for the other. In all the three AEZs, more than 80% of the interviewed households revealed that they do prefer one type of residue for one species of animal than for the other species. Preference scores for the types of straws or stovers the respondents in the whole study area prefer for their cattle, goats, sheep and equines are shown in Figure 9. Significant observation from the figure is that, by virtue of being soft and fine, tef straw was the most preferred residue for all species of animals with the exception for small ruminants for which the respondents preferred haricot bean haulms the most. The respondents stated that the small ruminants prefer haricot bean haulms as they will get some grains left in the residue during the threshing process. For any species of ruminant, sorghum stover was the least preferred type of residue. This agrees with the fact that the respondents stated this stover was used more for construction and fuel purposes than for livestock feeding.

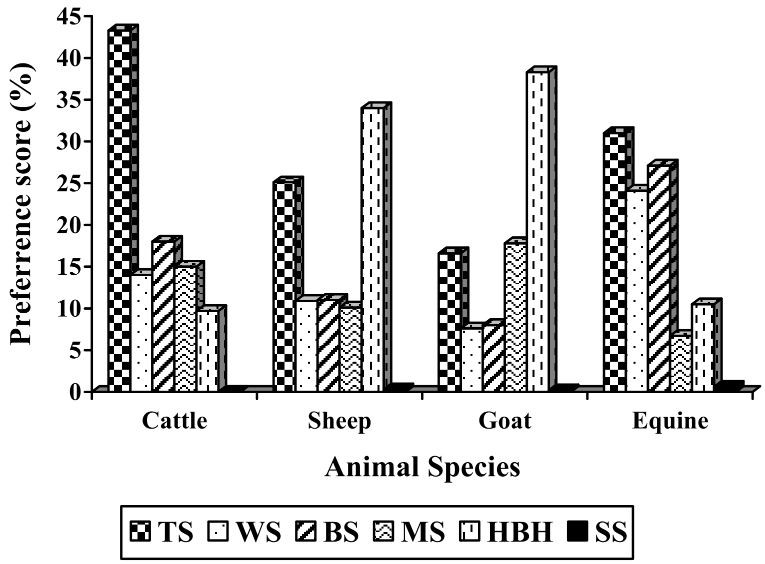

Figure 9 Household preference of crop residues (TS=tef straw, WS=wheat straw, BS=barley straw, MS=maize stover, SS=sorghum stover, HBH=haricot bean haulm) for different animal species in the whole study area.

Summary of the interview as to whether or not the respondents use any supplementary feed, in addition to grazing and crop residues indicated that more than 80% of the respondents in SM2 use one or more of some supplementary feeds, whereas the same proportion of respondents in each of the SH2 and SA2 AEZs stated that they do not use any supplementary feed for their animals. As can be observed from the percentage scores of different supplementary feeds indicated in Figure 10, in SM2 the most used supplementary feeds were oil seed cakes (linseed cake, noug seed cake and cotton seed cake). This was likely to be due to the existence of relatively more oil extraction plants within the vicinity of this AEZ. In the other two AEZs, milling by-products (wheat bran and wheat middling) followed by oil seed cakes were the most used types of supplementary feeds. These were available at relatively cheaper prices than the oil seed cakes. Utilization of forage legumes was generally insignificant and was observed only in SM2 and SA2 AEZS. This was because of the existence of research centers in these AEZs that provided the forage materials to the farmers. Other supplements used in the area include brewer's grain and mineral soils locally known as *atela* and *bole*, respectively.

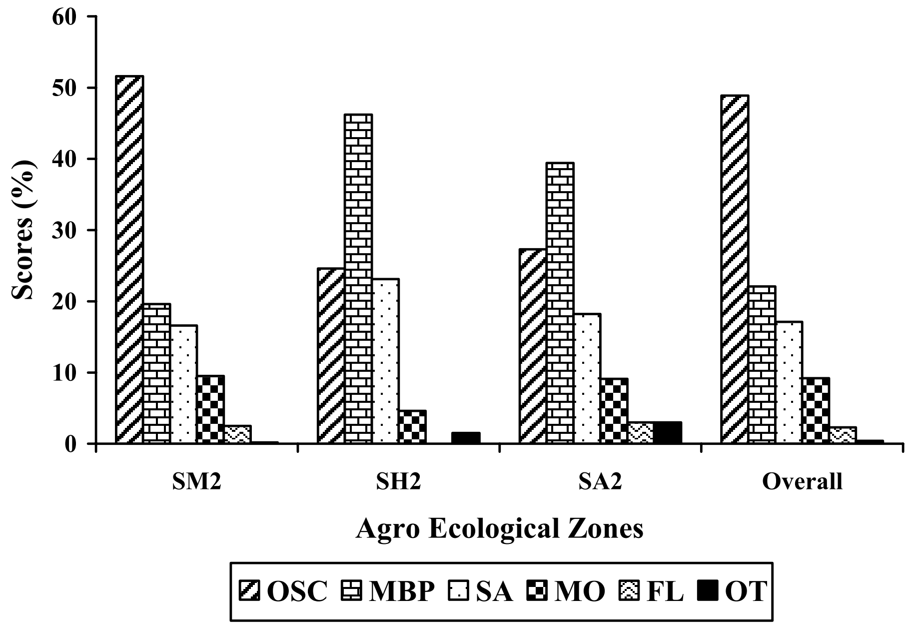

Figure 10 Percentage scores for use of different supplementary feeds (OSC=oil seed cakes, MBP=milling by-products, SA=salt, MO=molasses, FL=forage legumes, OT=others) by households in the thee AEZs.

Some constraints to the use of concentrates (oil seed cakes and milling by-products) and forage legumes by households in the study area are summarized in Table 17. In all the three AEZs, the major bottleneck for the use of concentrate supplements was found to be lack of finance. However, there were also a large number of respondents who did not know the use of such feeds because of being very far from urban centers where such feeds are available. Legume supplements in the form of either browse plants or forages were either not known to the farmers or were not easily obtainable. The latter case , as indicated by the respondents, was evident in areas where some government and non-government organizations tried to demonstrate the uses of forage legumes and browse such as leucaena and sesbania species to some farmers, but many other farmers were not provided with seeds and necessary advices so that they also use the legumes. In some cases where farmers have both the access and the know-how of using legumes, shortage of land was cited as a factor which constrain the use of these forages.

Table 17 Constraints (1= major, 2= moderate, 3= minor) to the use of concentrate and legume supplements by households in the study areas.

AEZ	Constraints to the use of:					
	Concentrate supplements			Legume supplements		
	1	2	3	1	2	3
SM2	finance	awareness	access	access	awareness	land
SH2	finance	awareness	access	awareness	access	land
SA2	awareness	finance	access	access	awareness	land
Overall	finance	awareness	access	awareness	access	land

Experiment 2: Effects of Urea Levels and Treatment Durations on Chemical Composition and *In Vitro* Dry Matter Digestibility of Urea Treated Maize Stover

Effects of urea levels

The effects of urea concentration on chemical composition and *in vitro* dry matter digestibility (IVDMD) of the urea treated maize stover are given in Table 18. Urea levels affected ($p<0.05$) CP and NDF contents and IVDMD of the treated stover. CP contents, as determined from wet samples, were 14.9, 15.92 and 16.87% for the 4, 5 and 6% urea levels, respectively. In comparison with the untreated maize stover used in this study, the 4% urea treatment brought a 3.7 times increase in CP content of the stover (4.02% vs. 14.9%). This is in close agreement with what Dias-da-Silva *et al.* (1988) reported for maize stover treated with 6% urea. In the current study, CP content of the 5% urea treated maize stover was 1.02 percentage units higher than that of the stover treated with 4% urea, but only 0.95 percentage units lower than the one treated with 6% urea**.** The 6% urea level resulted in an increase of 0.15% nitrogen over the 5% urea level at the expense of 1% urea. Taking 91.58% as the DM content of the untreated maize stover and assuming the nitrogen content of urea is 46%, this increment in nitrogen content amounts to 30% of the additional urea nitrogen. This indicates the existence of high loss of nitrogen as a result of high levels of urea application. In a study conducted by Nguyen *et al.* (1998) only 17.4% of the additional urea nitrogen was fixed when rice straw was treated with 5% urea compared with 3% urea plus 0.5% $Ca(OH)_2$. These authors attributed the low increment of nitrogen to the fact that the nitrogen detected was only the fraction of nitrogen which was chemically fixed to the cells of the straw and insoluble in water, thus being unrepresentative of the total nitrogen in the treated straw.

Chemical analysis of the untreated maize stover used in this study showed that its CP and DM contents were 4.02 and 91.58%, respectively. Based on these values, the urea nitrogen retained as percent of the added urea nitrogen through the 4, 5 and 6% urea levels were 87, 76 and 68%, respectively. These values indicate that animals can derive a good amount of nitrogen from urea treated materials if they are fed the wet stover only after aeration for some hours. The urea nitrogen retained in the current study was higher than what Saadullah *et al.* (1981) observed for 3 and 5% urea treatment. The decreasing trend in nitrogen retained with the increasing urea levels is in agreement with the works of Chenost and Kayouli (1997). These authors stated that the nitrogen fixation ratio usually falls with the increase in the urea level because, large amounts of free ammonia (not fixed yet) built up within the straw matter may stop or hinder hydrolysis of the urea.

Table 18 Effects of urea concentration on chemical composition and IVDMD of urea-treated maize stover.

Parameters	Urea concentration (%)			SE
	4	5	6	
DM, %	63.46	64.07	68.91	1.84
Chemical composition, % of DM				
CP	14.90^{c}	15.92^{b}	16.87^{a}	0.27
NDF	79.31^{a}	77.25^{b}	76.14^{c}	0.12
Ash	8.37	7.90	8.37	0.22
IVDMD, %	55.94^{c}	60.27^{b}	61.26^{a}	0.24

^{abc} Means in the same row with different letters are different (p<0.05).

Compared with the 4% urea level, the 5 and 6% urea levels have reduced the NDF fraction of the treated stover by about 2 and 3 percentage units, respectively. Though the differences were not significant (p>0.05), the increasing trend in DM content with increasing urea levels was in agreement with the findings of Saadullah *et al.* (1981). Zaman and Owen (1995) observed no difference in ash content of barley straw treated with 3% and 6% urea. As can be seen from the table, this is supported also by the current study.

IVDMD of the treated stover increased significantly (p<0.05) with the increase in urea levels. The maize stover treated with 5 and 6% urea had 7.7 and 9.5% higher IVDMD than the stover treated with 4% urea. This could partly be attributed to the lower NDF contents of the stover treated with higher urea levels than the one treated with lower urea level. Saadullah *et al.* (1981) also found poorer results in digestibility for lower urea levels of 3% as compared with the 5% urea level.

Generally, in terms of both the chemical composition and the IVDMD, this finding was in favour of the 6% urea concentration. However, at this stage it would be incorrect to conclude likewise as the interaction between urea levels and treatment durations was significant with respect to NDF content and IVDMD.

Effects of treatment durations

As indicated in Table 19, treatment durations had significant ($p<0.05$) effects on all the chemical entities. In all parameters, intermediate values were observed for the treatment duration of 14 days. DM content of the treated stover decreased from 68.11% in the case of treatment duration of 7 days to 66.94 and 61 39% in the case of treatment durations of 14 and 21 days, respectively. In studying the effects of urea levels and preservation time on chemical composition of the treated maize stover, Tran and Nguyen (2000) also found a decreasing trend in DM content with increasing time of preservation. On the other hand, the ash content of the treated stover increased with the increase in treatment durations and this was also in agreement with the works of Tran and Nguyen (2000). However, the difference between treatment duration of 7 and 14 days was not significant ($p>0.05$).

Crude protein content of the samples treated for 7, 14 and 21 days were 14.90, 16.05 and 16.73%, respectively. CP content of the samples treated for 7 days was significantly ($p<0.05$) lower than CP content of the samples treated for either 14 or 21 days. The increasing trend in CP content with increasing treatment durations agrees with the works of Nguyen *et al.* (1998) who reported increased fixed nitrogen content over treatment times of 10, 20 and 30 days. According to these authors, at the beginning of urea treatment the added nitrogen existed mainly in the form of urea with free ammonia being released later from which more and more nitrogen would be fixed together with the straw. As only this fixed nitrogen could be detected while analyzing the pre-dried samples, resulting in evaporation of the free and loosely bound ammonia, the short treatment duration is likely to give lower nitrogen content than the longer treatment duration. Hence it is likely that with short treatment times the response to urea ammoniation may be reduced.

Table 19 Effects of treatment durations on chemical composition and IVDMD of urea-treated maize stover.

Parameters	Treatment durations (days)			SE
	7	14	21	
DM, %	68.11[a]	66.94[ab]	61.39[b]	1.84
Chemical composition, % of DM				
CP	14.90[b]	16.05[a]	16.73[a]	0.27
NDF	78.29[a]	77.32[b]	77.09[b]	0.12
Ash	7.68[b]	7.76[b]	8.66[a]	0.22
IVDMD, %	57.88[b]	59.48[a]	60.11[a]	0.24

[abc] Means in the same row with different letters are different ($p<0.05$).

Compared with the treatment duration of 7 days, treatment durations of either 14 or 21 days have significantly ($p<0.05$) reduced the NDF content of the treated stover. This was at variance with findings of Nguyen *et al.* (1998) who found no appreciable differences in NDF content among the rice straws treated for 10, 20 and 30 days. Treatment durations influenced also IVDMD of the stovers with stovers treated for 14 and 21 days being more ($p<0.05$) digestible than those treated only for a week. This could be due to the sufficient time allowed for the urea to act on the cell wall structure. Dias-Da-Silva, *et al.* (1988) also reported a significant increase in *in vitro* OM digestibility of the urea treated maize stover with increasing treatment times.

Combined effects of urea levels and treatment durations

Significant ($p<0.05$) interaction between the two factors (urea level and treatment duration) were observed only for NDF content and IVDMD. Combined effects of the two factors on NDF content of the treated stover are given in Table 20. There was a decreasing trend in NDF content with increasing urea levels and treatment durations. The results were in favour of the 5% urea treatment for a period of 14 days as none of the higher levels of both the urea concentration and the treatment duration brought about an NDF percentage that differed significantly from that of the 5% urea treatment for a period of two weeks. This supports the works of Dias-Da-Silva, *et al.* (1988) who reported ensiling with urea as being effective in reducing the NDF content, with the effects being highly dependent on time. There was a decrease in NDF content with an increase in treatment times. Tran and Nguyen (2000) also reported a decreasing trend in crude fiber with increasing treatment durations. Such observations could be attributed to the sufficient time urea got to act upon the insoluble fractions of the cell wall components of the stover changing them into soluble fractions that are essential for microbial fermentation in the rumen.

Table 20 Effects of urea levels and treatment durations on NDF content (%) of the urea treated maize stover.

Treatment durations (days)	Urea levels (%)		
	4	5	6
7	80.19^{a}	78.42^{c}	76.25^{de}
14	79.23^{b}	76.56^{de}	76.17^{de}
21	78.51^{c}	76.77^{d}	76.00^{e}

^{abcde} Means with different letters are different ($p<0.05$).

The effects of urea levels and treatment durations on IVDMD are presented in Table 21. Treating the stover with 5 and 6% urea for 2 weeks had significantly ($p<0.05$) increased IVDMD over the 4% urea treatment. However, the differences among treating the stover with 5% urea for 2 weeks and treating it with 6% urea for either 2 or 3 weeks were not statistically significant ($p>0.05$). This was in agreement with the findings of Chenost and Kayouli (1997) who reported that higher urea application rates did not bring about a significant increase in nutritive value of the straw, despite increasing treatment costs to farmers thus limiting uptake of the technology. Under Sri Lanka condition these authors recommended an application rate of 4% urea.

Table 21 Effects of urea levels and treatment durations on IVDMD (%) of the urea treated maize stover.

Treatment durations (days)	Urea levels (%)		
	4	5	6
7	55.02^{f}	59.07^{d}	59.55^{dc}
14	55.37^{f}	61.23^{ab}	61.85^{ab}
21	57.44^{e}	60.52^{bc}	62.38^{a}

^{abcdef} Means with different letters are different ($p<0.05$).

Experiment 3: The Potential of Urea Treated Maize Stover for Growth Performance of Weaned Crossbred Calves

Chemical composition

Chemical composition and in vitro dry matter digestibility of the untreated and urea treated maize stover, the natural pasture hay and the concentrate mixture are shown in Table 22. Crude protein content of the urea-treated maize stover, as determined from wet samples, was close to 4 and 3 folds higher than that of the untreated stover and the natural pasture hay, respectively. In studying the effects of urea treatment of maize stover on the performance of growing steers and heifers, Munthali et al. (1992) also observed a four fold (2.8 vs.14 .4%) increase in CP content of the 4% urea treated maize stover compared with that of the water treated stover. Jackson (1978), Klopfenstein (1978) and Sundstol et al. (1978) also found similar increments in CP content of the treated straws.

In vitro dry matter digestibility (IVDMD) of the urea-treated maize stover was 8.8% higher than that of the untreated stover. This, however, is lower than the 27% increase in apparent dry matter digestibility obtained by Saadullah et al. (1982) for a 5% urea treated straw fed to 18 months old calves. If seen from the point of view of making efficient use of the low quality and yet, the abundantly available feed resources, the small increment in digestibility, such as the one found in this study, would mean a lot to livestock owners. With this regard Orskov et al. (1990) stated that in areas where straws are the main feeds for ruminants, a proportional increase of 0.1 in digestibility can have an enormous implication for resource availability and thus animal performance.

Urea treatment has reduced the NDF content of the maize stover by about 6 percentage units. Nguyen (2000) also reported urea as being effective in delignifying rice straw thus reducing its NDF content. The author stated that the changes in NDF content were mainly determined by treatment effect on hemicellulose. This is in accordance with the findings of Males (1987) who described hemicellulose as the cell wall component that is most sensitive to delignification treatment.

Table 22 Chemical composition and IVDMD of the untreated and urea treated maize stover, the hay and the concentrate mixture.

Items	UNMS	UTMS	NPH	Concentrate
DM, %	91.58	65.47	91.43	88.99
Chemical composition (% of DM)				
OM	93.41	92.10	92.21	92.18
CP	4.02	15.40	5.70	20.64
NDF	82.24	76.15	78.32	51.52
Ash	6.59	7.92	7.79	7.82
IVDMD, %	55.70	60.60	45.03	68.81

Feed intake

Table 23 shows dry matter intake (DMI) of the weaned crossbred calves fed the three experimental diets containing either untreated maize stover or urea treated maize stover or natural pasture hay. Daily roughage intake of the calves varied from 3.1 kg for the untreated maize stover to 3.8 and 4.4 kg for the urea treated stover and the natural pasture hay, respectively. Daily intake of the urea treated maize stover was 22% higher than that of the untreated stover. FAO (1986) stated that urea treatment may increase voluntary intake of the treated straw by as much as 25 to 30% over that of the untreated straw. Smith *et al.* (1989) also reported a significant increase in DMI of the urea-treated maize stover compared with that of the dry fresh maize stover. On the other hand, Saadullah *et al.* (1982) observed no trend of intake increment for urea treated rice straw fed to calves. Also according to Munthali *et al.* (1992), urea treatment of maize stover did not increase dry matter intake compared with the water treatment of maize stover.

Expressed on body weight (average of all the fortnightly weights) basis, the daily total DM intake of animals fed the diet containing urea treated maize stover was significantly ($p<0.05$) higher than that of the animals fed the diet containing the untreated stover. However, the difference between the intake of animals fed the diet containing urea treated stover and that of the animals fed the diet containing hay was not statistically significant. Generally, the daily feed intakes of calves in all the three treatments were above the levels recommended by Kearl (1982) for animals of comparable live weight to produce a daily weight gain of 250 to 500 g. With regard to CP intake, the daily intake of calves fed the diet containing urea treated maize stover was significantly ($p<0.05$) higher than the intake of animals fed the other two diets. This was likely to be in accordance with the differences in CP content and in intake of the three diets.

Table 23 Feed intake of calves fed the three experimental diets.

Parameter	Experimental diets[1]			SE
	1	2	3	
Roughage DM intake (kg/d)	3.13[c]	3.83[b]	4.35[a]	0.13
Concentrate DM intake (kg/d)	0.89	0.89	0.89	0.00
Total DM intake (kg/d)	4.02[c]	4.72[b]	5.24[a]	0.13
Total DM intake (g/kg $W^{0.75}$/d)	93[b]	108[a]	114[a]	2.80
Roughage DM intake (% BW)	2.07[b]	2.49[a]	2.65[a]	0.08
Concentrate DM intake (% BW)	0.60[a]	0.58[a]	0.54[b]	0.01
Total DM intake (% BW)	2.66[b]	3.10[a]	3.20[a]	0.08
Total CP intake (g/d)	320[c]	781[a]	442[b]	0.02

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1 kg concentrate mixture/head/day.
2 = Urea-treated maize stover *ad libitum* + 1 kg concentrate mixture /head/day.
3 = Natural pasture hay *ad libitum* + 1 kg concentrate mixture /head/day.

Digestible feed and energy intake

The digestible DM, OM and CP intakes of the calves, calculated based on the apparent digestion coefficients given in Table 25, as well as their metabolizable energy intake are shown in Table 24. Though the DMI of animals fed the hay based diet was significantly higher than that of the animals fed the urea-treated maize stover based diet, there were no differences ($p>0.05$) in digestible dry matter intake (DDMI) and digestible organic matter intake (DOMI) among animals fed these two diets. This could be attributed to the superiority in digestibility of the diet that contained urea-treated stover over the one that contained hay. With regard to protein, the animals fed the urea-treated stover diet had higher ($p<0.05$) digestible crude protein intake (DCPI) than those animals fed the diets containing either untreated stover or hay. Though the daily DMI of animals fed the diet containing untreated maize stover was within the recommended values (Kearl, 1982), the daily DCPI of the animals was slightly below the amount required to ensure a daily live weight gain of 250 g. This is attributed to the low CP content of the untreated stover. On the other hand, as a result of the lesser CP content of hay compared with the urea-treated maize stover and the lower CP digestibility of the diet that contained hay compared with the one that contained urea treated maize stover, animals on the hay based diet obtained lesser ($p<0.05$) digestible CP than animals on the urea treated maize stover diet.

Table 24 Digestible feed and metabolizable energy (ME) intakes of the calves fed the three experimental diets.

Parameter	Experimental diets[1]			SE
	1	2	3	
Dig. DM intake (kg/d)	2.51[b]	3.10[a]	2.96[a]	0.08
Dig. DM intake (g/kg $W^{0.75}$/d)	58[c]	71[a]	65[b]	1.75
Dig. OM intake (kg/d)	2.46[b]	2.95[a]	2.88[a]	0.08
Dig. CP intake (g/d)	210[c]	604[a]	267[b]	13.43
ME energy intake (MJ/d)	38.3[b]	46.0[a]	44.7[a]	1.25
ME energy intake (KJ/kg $W^{0.75}$/d)	887[b]	1053[a]	976[a]	26.19
Energy concentration (MJ/kg DM)	9.5[b]	9.7[a]	8.5[c]	0.001

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover ad libitum + 1 kg concentrate mixture/head/day.
2 = Urea-treated maize stover ad libitum + 1 kg concentrate mixture /head/day.
3 = Natural pasture hay ad libitum + 1 kg concentrate mixture /head/day.

Metabolizable energy was estimated as kg DOM x 15.56 (ARC, 1980). Metabolizable energy intake (MEI) of the calves generally followed the trends of digestible DM and OM intakes. Calves fed the diets containing hay and urea treated maize stover obtained higher ($p<0.05$) ME than those fed the diet containing untreated stover. However, even the daily ME intake of calves fed the latter diet was within the recommended range for animals of similar live weight to show some gain. This was likely to be due to the high energy concentration (9.5 MJ or 2.3 Mcal/kg DM) of the diet. On the other hand, even if the energy concentration of the diet based on hay was lower than that of the diet based on the urea treated maize stover, the daily ME intake of animals on these two diets did not vary significantly ($p>0.05$). This could be because, the lower energy concentration of the hay based diet must have been compensated by the higher feed intake of animals on this diet from which the animals maximized their metabolizable energy intake. While evaluating the effectiveness of ammonification through urea in improving the feeding value of rice straw in ruminants, Saadullah *et al.* (1981) found that urea treatment increased ME concentration in terms of MJ/kg DM of the straw from 6.93 in the untreated straw to a maximum of 9.51 in straw treated with 5% urea. In the current study it was not possible to exactly tell the effect of urea treatment on energy concentration of the treated stover as the values obtained in here represent energy concentration of the whole feed (roughage plus the concentrate). However, it was very likely that the higher ($p<0.05$) energy concentration of the diet containing urea-treated maize stover, compared with that of the other two diets could be due to the roughage feed of urea treated stover as the amount of concentrate offered with all the diets was the same. The molasses, a readily available carbohydrate, which was included as part of the urea treatment process could have played an important role in increasing the energy content of the treated stover.

Apparent digestibility and nitrogen utilization

The apparent digestibility and nitrogen utilization by the calves fed the three experimental diets are presented in Table 25. Dry matter and OM digestibilities of the diet containing maize stover, whether treated or untreated, were higher ($p<0.05$) than those of the hay based diet. In spite of the higher *in vitro* DM digestibility of the urea treated maize stover (Table 22) than that of the untreated stover, no significant difference in apparent DM digestibility was observed between the diets containing each of these stover types. This might be due to the difference in synergistic effect the concentrate had with the treated and the untreated stovers. CP digestibility of the diet that contained the urea treated maize stover was significantly ($p<0.05$) higher than that of the other two diets.

Table 25 Apparent digestibility by and nitrogen balance for calves fed the experimental diets.

Parameters	Experimental diets[1]			SE
	1	2	3	
Apparent digestibility (%)				
Dry matter	62.5[a]	65.8[a]	56.4[b]	1.65
Organic matter	65.6[a]	67.9[a]	59.4[b]	1.63
Crude protein	65.6[b]	77.4[a]	60.4[b]	1.73
NDF	68.7[a]	77.3[a]	62.8[b]	1.40
Nitrogen intake (g/d)	51.4[c]	123.1[a]	64.2[b]	1.67
Fecal nitrogen (g/d)	17.8[b]	27.9[a]	25.5[a]	1.41
Urine nitrogen (g/d)	7.9[b]	40.8[a]	8.1[b]	1.22
Nitrogen retention				
g /day	25.7[c]	54.4[a]	30.7[b]	1.48
as % of nitrogen intake	50.1	44.3	47.7	2.48
as % of nitrogen digested	76.1[a]	57.1[b]	79.0[a]	2.04

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1 kg concentrate mixture/head/day.
2 = Urea-treated maize stover *ad libitum* + 1 kg concentrate mixture /head/day.
3 = Natural pasture hay *ad libitum* + 1 kg concentrate mixture /head/day.

Regarding nitrogen utilization, animals on all the three diets were in positive nitrogen balance. All parameters in the nitrogen balance showed a significant ($p< 0.05$) linear trend with increases in the diet protein. Crude protein content of the diets containing untreated maize stover, urea treated maize stover and hay were calculated to be 79.6, 165.5 and 84 4 g per kg DM. Accordingly in all parameters in the nitrogen balance, animals on urea treated maize stover diet registered higher ($p< 0.05$) values than those on the other two diets. This was in agreement with the findings of Neville *et al.* (1977) who found significantly ($p<0.05$) lower nitrogen retention for a diet containing lower CP percentage than those diets containing higher CP percentages. Brand *et al.* (1991) also reported higher ($p<0.05$) nitrogen balance figures for sheep fed the urea-ammoniated wheat straw than those fed the untreated or the urea supplemented wheat straw receiving similar supplements. Animals on urea treated maize stover diet excreted more nitrogen in urine than animals on either untreated stover or hay based diets which excreted most of their nitrogen through feces. This may partly explain the lower efficiency in nitrogen retention of animals on the former diet compared with that of the animals on the latter two diets.

As a rule of thumb, Preston and Leng (1984) recommended 30 gm nitrogen per kg DOM to maximize rumen microbe development. Based on nitrogen content of the urea treated stover in the present study, the amount of nitrogen left in the 5% urea-treated stover would be 26.7 g per kg OM. Hence if the organic matter digestibility of the urea treated stover is estimated to be 60.99% (estimated as 1.84 + 0.976 × IVDMD%, Barber *et al*., 1984), the stover alone should have given 43.8 g nitrogen per kg DOM which, together with the nitrogen provided by the concentrate, was high compared to the above recommended amount. Hence in this study it was possible that the urea treated stover supplied excess nitrogen which the animals excreted in the form of urea in urine. This, according to Preston (1995), is causing not only nitrogen loss but also energy costs for the synthesis of urea from ammonia.

Growth rate and feed efficiency

Live weight changes of animals fed the experimental diets are given in Table 26. In accordance with their higher feed intake, animals fed the diets containing urea treated maize stover and natural pasture hay out gained ($p<0.05$) those animals fed the diet containing untreated stover. This was in agreement with the findings of Bui and Le (2001) who reported considerably higher growth rates for cattle fed ammoniated rice straw than for those fed untreated straw plus molasses-urea block. These authors attributed such improvements in growth rate, which was 25%, to a 50% increase in DMI of the ammoniated straw. From their study on the effects of urea treatment of maize stover on performance of growing steers and heifers, Munthali *et al.* (1992) also concluded that the increased intake of energy and an accompanying improvement in the utilization of non protein nitrogen in the treated straw resulted in improvement of live weight gain of the animals. On the other hand, there was no difference (p>0.05) in live weight gain between animals fed the urea treated stover diet and those fed the hay based diet. This supported the findings of Tran and Nguyen (2000) who concluded that urea treated maize stover could be used to replace grass for ruminant feeding as cattle had acceptable weight gain when fed such diet. In the current study, the slightly higher live weight gain of animals fed the urea treated stover diet than those fed the hay diet could be attributed to the higher crude protein content of the urea treated stover which in turn resulted in higher CPI of the animals. Though the daily DM intake of animals fed the diet containing untreated stover was above the recommended value (Kearl, 1982) that enables that group of animals to attain a daily weight gain of more than 400 g, the animals could not gain more than an average of 284 g per day. This could be due to the lower CP content of the diet and consequently, the lower CP intake of the animals.

Table 26 Live weight changes and feed efficiency of the calves fed the three experimental diets.

Parameter	Experimental diets[1]			SE
	1	2	3	
Initial weight (kg)	137.9	133.7	145.1	5.70
Final weight (kg)	165.7[b]	171.4[b]	181.7[a]	2.00
Total weight gain (kg)	27.9[b]	37.7[a]	36.6[a]	2.00
Daily weight gain (g)	284[b]	385[a]	377[a]	0.02
Feed conversion ratio (kg DM/kg weight gain)	14.2	12.4	14.2	0.67

[ab] Means in the same row with different letters are different (p<0.05).
[1] 1 = Untreated maize stover *ad libitum* + 1 kg concentrate mixture/head/day.
2 = Urea-treated maize stover *ad libitum* + 1 kg concentrate mixture /head/day.
3 = Natural pasture hay *ad libitum* + 1 kg concentrate mixture /head/day.

With regard to feed efficiency, though the differences among animals fed the dietary treatments were not significant (p>0.05), animals fed the urea treated stover diet were relatively more efficient than those fed the other two diets in converting feed to live weights. For every kg live weight gain, animals on urea treated stover diet consumed 1.8 kg less DM than those animals on the diets containing either hay or untreated maize stover. This difference was higher than what Li *et al.* (1993) found (0.91 kg for every kg weight gain) for crossbred cattle fed ammonia treated maize stover. On the other hand, Zou *et al*. (1995) found an improvement of 1.6 kg in feed conversion efficiency of young Holstein cows fed wheat straw ammoniated with urea compared with the efficiency of those cows fed the untreated straw. The discrepancies between findings of these studies and that of the current study could be explained by the differences in the type and species animals and the type of the straws used in the two studies.

Cost analysis

Costs of feeding the experimental feeds are summarized in Table 27. Hay was so expensive that both the total cost and the cost per kg live weight gain were higher ($p<0.05$) for the diet containing hay than the corresponding costs for the diets containing maize stover, whether treated or untreated. When cost per kg live weight gain was considered, the cost of feeding the two stover based diets did not statistically differ ($p>0.05$). In studying the effects of ammoniated wheat straw on growth of beef cattle, Gao (2000) reported 16.4% lower cost of 1 kg weight gain for steers fed 5% urea ammoniated wheat straw compared with the corresponding cost for animals fed the untreated straw. In the current study, though the cost per kg weight gain of feeding urea treated maize stover diet was about 16% higher than the corresponding cost of feeding the untreated stover diet, it was 33% lower than the cost of feeding the hay based diet. This indicates that feeding urea treated maize stover could be a possible alternative to hay feeding, enabling the realization of more weight gains with reasonably higher cost than feeding untreated stover based diet and lower cost than feeding the hay based diet.

Table 27 Costs of feeding the three experimental diets to the calves.

Parameter	Experimental diets[1]			SE
	1	2	3	
Roughage cost (Birr[2]/hd/d)	0.94[c]	1.91[b]	3.13[a]	0.07
Concentrate cost (Birr/hd/d)	0.78	0.78	0.78	0.00
Total feed cost (Birr/hd/d)	1.72[c]	2.70[b]	3.92[a]	1.07
Total feed cost/kg weight gain (Birr/hd)	6.09[b]	7.08[b]	10.61[a]	0.41

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1 kg concentrate mixture/head/day.
2 = Urea-treated maize stover *ad libitum* + 1 kg concentrate mixture /head/day.
3 = Natural pasture hay *ad libitum* + 1 kg concentrate mixture /head/day.
[2] Birr = Ethiopian currency (8.60 Birr = 1 USD at the time).

Experiment 4: The Potential of Urea Treated Maize Stover for Feedlot Performance and Carcass Characteristics of Borana Bulls

Feed intake

Feed intakes adjusted to the same initial live weight of Borana bulls fed on the experimental diets are shown in Table 28. Expressed both on daily basis or as percent of body weight (average of all the fortnightly weights), the roughage and the total feed intakes varied ($p<0.05$) among animals fed the three experimental diets. Animals on urea treated maize stover diet consumed the highest and those on the untreated stover diet consumed the least amount of DM of both the roughage and the total feed daily. The difference between the intake of animals fed the diet that contained urea treated maize stover and that of the animals fed the diet that contained natural pasture hay was not statistically significant ($p>0.05$). The total CP intake of animals increased with the increase in the CP content of the diets. The daily CP intake of animals on the untreated maize stover diet was less than the recommended amount of about 679 g (Kearl, 1982) for a 300 kg animal to gain at least 500 g per day. Similarly the intake of those animals on the hay containing diet was 50 g less than the amount of CP recommended for animal of the same live weight to gain 500 g daily.

The improvement in daily intake of the maize stover due to urea treatment was about 37%, compared with that of the untreated stover. This was within the range of intake improvement reported by Chenost and Kayouli (1997). These authors indicated that an increase of 25 to 50% in feed intake can be attained as a result of treatment with ammonia generated from urea. The daily total DM intake of 2.01 kg per 100 kg live weight of animals fed the untreated maize stover diet was equivalent to the intake level recommended (Kearl, 1982) for a 300 kg animal to attain a daily live weight gain of 250 g. However, because of the high energy concentration of the diet and hence the high metabolizable energy intake (Table 29), animals on this diet gained more weight daily than expected. On the other hand, the DM intake of those animals fed the natural pasture hay diet matched the recommended values, whereas the intake of those animals on urea treated maize stover diet was about 7% higher than the value required to bring about a daily live weight gain of about 580 registered by the group.

Table 28 Daily feed intake of Borana bulls fed the experimental diets.

Parameter	Experimental diets[1]			SE
	1	2	3	
Roughage DM intake (kg/d)	4.75[b]	6.50[a]	6.01[a]	0.21
Concentrate DM intake (kg/d)	1.34	1.34	1.34	0.00
Total DM intake (kg/d)	6.09[b]	7.83[a]	7.35[a]	0.21
Total DM intake (g/kg $W^{0.75}$/d)	83.8[b]	106 0[a]	97.7[a]	0.07
Roughage DM intake (% BW)	1.56[b]	2.10[a]	1.89[a]	0.003
Concentrate DM intake (% BW)	0.45[a]	0.43[b]	0.42[b]	0.07
Total DM intake (% BW)	2.01[b]	2.53[a]	2.32[a]	3.00
Total CP intake (g/d)	485[c]	1290[a]	64[b]	0.02

[abc] Means in the same row with different letters are different (p<0.05).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

Digestible feed and energy intake

The digestible feed and energy intakes were calculated based on the digestion coefficients given in Table 30. Accordingly, the digestible DM, OM and CP as well as the metabolizable energy intakes by animals fed the three experimental diets are shown in Table 29. The daily intakes of digestible DM, OM and CP were all varied (p<0.05) among animals on the three dietary treatments. In all cases, the highest digestible feed was consumed by animals fed the urea treated maize stover diet followed by those fed the natural pasture hay diet. Though the DM, OM and CP digestion coefficients of the diet containing untreated maize stover were higher (p<0.05) than the corresponding values for the diet containing natural pasture hay, more digestible amount of these components were consumed by animals on the latter diet than by those animals on the former diet. This was in line with the higher DM intake of animals on the diet containing hay than that of the animals on the diet containing untreated stover. The daily DCPI of animals on untreated maize stover and natural pasture hay diets were about 18 and 4%, respectively, lower than the amount recommended (Kearl, 1982) for animals in the live weight range of 300 to 350 kg to attain a daily live weight gain of 500 g. The intake of animals on the urea treated maize stover diet however, was over 100% in excess of requirement for attaining the same daily weight gain.

Table 29 Digestible feed and metabolizable energy intakes of Borana bulls fed the three diets.

Parameter	Experimental diets[1]			SE
	1	2	3	
Dig. DM intake (kg/d)	4.01[b]	5.49[a]	4.30[b]	0.14
Dig. DM intake (g/kg $W^{0.75}$/d)	55.2[b]	74.3[a]	57.2[b]	1.98
Dig. OM intake (kg/d)	3.93[b]	5.27[a]	4.23[b]	0.13
Dig. CP intake (g/d)	336[c]	1020[a]	396[b]	12.01
ME energy intake (MJ/d)	61.7[b]	82.0[a]	65.8[b]	2.07
ME energy intake (KJ/kg $W^{0.75}$/d)	842[b]	1110[a]	875[b]	29.98
Energy concentration (MJ/kg DM)	10.05[b]	10.47[a]	8.95[c]	0.001

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

As was the case with the previous experiment, metabolizable energy was estimated as kg DOM × 15.56 (ARC, 1980). Metabolizable energy intake of the animals, both on per head basis or on metabolic body weight basis followed the trend of digestible DM and OM intakes. In both cases animals on the urea treated maize stover based diet consumed higher ($p<0.05$) ME than those animals on either the hay based diet or the untreated maize stover based diet. This may be attributed partly to the higher ($p<0.05$) energy concentration of the urea treated maize stover diet and partly to the higher feed intake of animals on this diet. On the other hand, though the energy concentration of the diet based on the untreated maize stover was higher ($p<0.05$) than that of the diet based on natural pasture hay, ME intake of animals on the latter diet was only slightly higher ($p>0.05$) than that of the animals on the former diet. This could mainly be because of the higher DM intake of animals on the hay based diet than that of the animals on the untreated maize stover based diet. However, even the ME intake of animals on the diet containing untreated maize stover was higher than the requirement (Kearl, 1982) of an animal of similar live weight. This could partly be attributed to the high NDF content (82%) of the stover as NDF is known to be a good source of energy and, partly to the effect of the concentrate supplement. Regarding this, Alemu *et al*. (1991) stated that cell wall estimate as NDF accounts for as much as 80% of the dry matter in cereal crop residues and represents a large source of energy for ruminants.

<u>Apparent digestibility and nitrogen utilization</u>

Results of the apparent digestibility and nitrogen utilization by bulls fed the three diets are shown in Table 30. Significant ($p<0.05$) differences in DM, OM, CP and NDF digestibility coefficients were observed among the three dietary treatments. Coefficients of the respective parameters for urea treated maize stover diet were 6.5, 5.3, 14.1 and 4.1% higher than the corresponding values for the untreated maize stover diet. The difference between the urea treated stover diet and the hay diet regarding these corresponding coefficients was much larger. As presented in experiment three, the *in vitro* DM digestibility of the untreated maize stover was higher than that of the hay. As a reflection of this, the diet containing the untreated maize stover was more digestible than the diet containing hay. On the other hand, although the CP content of hay was higher than that of the untreated maize stover, higher ($p<0.05$) apparent CP digestibility coefficient was observed for the diet containing the untreated stover than for the diet containing the hay. This was at variance with the findings of Kay *et al.* (1968) who reported increased protein digestibility which accompanied the increased CP content of the diet. With regard to DM digestibility, however, Umunna *et al.* (1980) did not find differences between diets of varying protein contents.

All the digestibility values observed in this experiment are higher than the corresponding values reported for weaned calves in experiment three above. This could be due to the fact that the Borana bulls, being an indigenous breeds and mature animals, were more adapted than the Borana × Friesian crossbred weaned calves to using the fibrous maize stover.

Table 30 Apparent digestibility by and nitrogen balances for Borana bulls fed the experimental diets.

Parameters	Experimental diets[1]			SE
	1	2	3	
Apparent digestibility (%)				
Dry matter	65.8[b]	70.1[a]	58.5[c]	0.81
Organic matter	69.3[b]	73.0[a]	62.3[c]	0.68
Crude protein	69.3[b]	79.1[a]	61.8[c]	0.91
NDF	73.6[b]	76.6[a]	65.3[c]	0.70
Nitrogen intake (g/d)	73.5[c]	207.2[a]	92.2[b]	6.54
Fecal nitrogen (g/d)	22.8[b]	43.4[a]	35.3[a]	2.04
Urine nitrogen (g/d)	17.2[b]	77.9[a]	14.8[b]	1.86
Nitrogen retention				
g /day	33.5[c]	85.8[a]	42.1[b]	3.87
as % of nitrogen intake	45.9	41.3	45.5	2.09
as % of nitrogen digested	66.1[a]	52.3[b]	73.6[a]	2.54

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

With regard to nitrogen utilization, with the exception of urinary nitrogen, all items in the nitrogen balance showed an increasing trend with an increase in CP content of the diets. This is in agreement with the findings of Neville *et al*. (1977). Animals on the diet containing urea treated maize stover consumed more ($p<0.05$) nitrogen per day than animals on the other two diets. The nitrogen excretion, especially in urine, was also higher for animals on this diet than for those on the other two diets. This was evident from the fact that about 38% of the nitrogen consumed by animals fed the urea treated stover diet was voided in urine, whereas the corresponding values for animals fed the untreated stover diet and the hay diet were only 23 and 16%, respectively. As was the case with calves in experiment 3, this indicates inefficiency in nitrogen retention by animals on the urea treated maize stover diet compared with those animals on the other two diets. When expressed as percentage of nitrogen intake, there were no differences ($p>0.05$) in nitrogen retention among animals fed the three experimental diets.

Live weight changes and feed efficiency

Live weight changes and feed efficiency of animals fed the experimental diets are presented in Table 31. Both the total and the daily weight gains of animals fed the diet containing urea treated maize stover and natural pasture hay were significantly ($p<0.05$) higher than the corresponding weight gains of animals fed the diet containing untreated maize stover. This was in parallel with the daily DM intake of animals on each of the three dietary treatments. However, the difference between animals fed the urea treated maize stover diet and those fed the natural pasture hay diet, in terms of their digestible feed intake, did not result in proportional difference in live weight gain of the animals. This could be because of the fact that the animals that fed the urea treated maize stover diet might have used the energy available in the feed less efficiently than those animals fed the hay based diet. As Kearl (1982) stated, the utilization of ME per unit of DM intake might have been reduced as a result of increased level of intake of the urea treated maize stover diet. Moreover, as can be noted from the carcass data given in forthcoming table, the fact that the animals those fed the urea treated maize stover diet deposited more fat (which is light by nature) than the animals fed the hay based diet could justify the lack of discrepancy in weight gain of the animals on the two diets.

Regarding feed conversion efficiency, no differences were observed ($p>0.05$) among animals on the three experimental diets. However, animals on the diet containing urea treated maize stover were more efficient in converting feed to live weights than those animals on the diet containing either the untreated stover or hay.

Table 31 Live weight changes and feed conversion efficiency of Borana bulls fed the experimental diets.

Parameters	Experimental diets[1]			SE
	1	2	3	
Initial weight (kg)	279.3	283.0	291.9	9.21
Final weight (kg)	319.1[b]	338.3[a]	340.7[a]	2.65
Total weight gain (kg)	39.9[b]	55.3[a]	48.9[a]	2.65
Daily weight gain (g)	409[b]	573[a]	500[a]	0.03
Feed conversion ratio (kg DM/ kg weight gain)	14.9	13.9	14.9	0.72

[ab] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

Cost analysis

As indicated in the materials and methods section, cost analysis was solely based on the cost of feeds consumed to bring about the live weight gains attained. This is summarized in Table 32. The cost of feeding animals with the diet containing natural pasture hay was significantly ($p<0.05$) higher than the cost of feeding them with the other two diets. This was mainly because of the high purchasing and transporting costs of hay as it was not available in the area. The purchasing of hay from distant areas where it is available is being undertaken by government and some private investors dealing with livestock activities as they can not obtain the high animal performances they envisage by using only crop residues that are available in the locality. The total feed cost per kg live weight gain was the highest in the case of feeding the diet containing hay followed by feeding the diet containing the urea treated maize stover. This shows that the higher intakes of both the urea treated maize stover and the natural pasture hay diets did not result in proportionally higher live weight gains of the animals. As it was discussed in the previous section, there might have been a reduction in utilization of metabolizable energy per unit of DM of the urea treated maize stover and the natural pasture hay diets associated with their increased levels of intake. However, each kg live weight gained by animals fed the urea treated maize stover diet was achieved relatively at lesser expense than the weight gained by animals fed the hay diet. This justifies that urea treated maize stover could be used as an alternative to natural pasture hay and most probably at much lesser expense (lesser than what was found in this study) than hay as the price difference between maize stover and hay is likely to increase more than the current difference because of the increasing trend in the price of hay from time to time.

Table 32 Costs of feeding the three experimental diets to Borana bulls.

Parameter	Experimental diets[1]			SE
	1	2	3	
Roughage cost (Birr[2]/hd/d)	1.43[c]	3.25[b]	4.33[a]	0.12
Concentrate cost (Birr/hd/d)	1.18	1.18	1.18	0.00
Total feed cost (Birr/hd/d)	2.60[c]	4.42[b]	5.50[a]	0.12
Total feed cost/kg weight gain (Birr/hd)	6.39[c]	7.85[b]	11.19[a]	0.46

[abc] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.
[2] Birr = Ethiopian currency (8.60 Birr = 1 USD at the time).

It is worth mentioning that the cost advantage to be obtained from feeding urea treated straws depends on the type of animals for which we use the residues. If the treated straws are fed to high performing animals such as milking cows, the additional cost incurred due to urea treatment could be paid back easily by income obtained from the extra production. In this regard, depending on the price of milk, Rehrahie (2001) found net profit of 2.13 to 3.00 Birr from feeding urea treated tef straw to dairy cows.

Carcass yield and dressing percentage

Effects of the three experimental diets on carcass yield and dressing percentage are presented in Table 33. The diets did not have statistically significant ($p>0.05$) effects on all the carcass parameters except on fat weight. With regard to carcass fat animals those fed the urea treated maize stover diet yielded more ($p<0.05$) carcass fat than those fed the other two diets. In all the other parameters, with the exception of dressing percentage, animals those fed the diet containing urea treated maize stover followed by the ones fed the diet containing natural pasture hay registered higher values than the animals fed the diet containing untreated maize stover. The carcass weights of animals on each of the dietary treatments were generally the direct reflections of the size of animals at slaughter. Though the difference was not significant ($p>0.05$), relatively lower dressing percentage was obtained for animals fed the diet containing natural pasture hay than for those fed the diet containing untreated maize stover. This could be attributed to the heavier hide and head weights (as indicated in the forthcoming sections) of animals fed the former diet than those of the animals fed the latter diet. Moreover, the differences in weight of Gastro Intestinal Tract (GIT), both full and empty, among animals on the diets must have contributed to such difference in dressing percentage. Strydom *et al.* (2000) also reported lower dressing percentage for Afrkander breed compared with Simmentaler, Charolais and Bonsmara breeds because of higher hide and larger head weights of the former breed.

Table 33 Carcass yield and dressing percentage of Borana bulls fed the experimental diets.

parameters	Experimental diets[1]			SE
	1	2	3	
Weight before slaughter (kg)	312	340	338	10.28
Slaughter weight (kg)	306	331	329	10.45
Hot carcass weight (kg)	166.2	184.8	168.7	9.67
Cold carcass weight (kg)	162.7	181.2	165.5	9.32
Lean meat weight (kg)	111.1	119.9	112.3	9.08
Fat weight (kg)	22.0[b]	29.2[a]	21.7[b]	1.81
Bone weight (kg)	29.9	33.2	31.8	1.99
Dressing percentage (%)				
Hot carcass	54.3	55.7	51.3	1.53
Cold carcass	53.1	54.6	50.3	1.36

[ab] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

The proportion of lean meat and bone to both the total carcass and to the slaughter weights were not affected by the type of diet (Table 34). The proportion of fat to both the total carcass and to the slaughter weight was highest for animals fed the urea treated maize stover based diet. However, the differences among treatments were statistically significant ($p<0.05$) only in the case of the proportion of fat to the slaughter weight. Animals on untreated maize stover diet converted their diet to more lean meat than animals on the other two diets did.

The relatively high proportion of carcass fat observed for animals fed on urea treated maize stover diet could be partially due to the high CP content of the diet compared with that of the other two diets. Similarly, Martin *et al*. (1978) and Anderson *et al.* (1988) ascribed the thicker subcutaneous fat they observed to a higher protein level in the diet and thus a higher protein to energy ratio. However, this fact did not hold true for the diets containing untreated maize stover and hay as, regardless of their difference in CP content, the fat percentage of carcasses of animals fed each of these diets did not vary significantly.

Table 34 Proportions of fat, lean meat and bone in the total carcass of Borana bulls fed the three experimental diets.

Proportions of:	Experimental diet[1]			SE
	1	2	3	
Lean : total carcass weight	68.3	65.9	67.7	1.96
Lean : slaughter weight	36.3	36.0	34.1	1.66
Fat : total carcass weight	13.5	16.3	13.2	1.26
Fat : slaughter weight	7.2[ab]	8.8[a]	6.6[b]	0.57
Bone: total carcass weight	18.4	18.5	19.3	1.42
Bone : slaughter weight	9.8	10.1	9.7	0.76
Lean to bone ratio	3.8	3.6	3.6	0.38

[ab] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

Measurements of some carcass characteristics are indicated in Table 35. The diets had significant ($p<0.05$) effects on fat thickness, kidney fat and heart fat measurements with animals fed the urea treated maize stover diet registering the highest values. In all other parameters, with the exception of rib-eye area per 100 kg hot carcass weight, animals fed the untreated maize stover based diet registered the lowest and those fed the urea treated maize stover based diet registered the highest values. Coupled with their lower live and carcass weights, animals those fed the untreated maize stover diet had relatively smaller eye muscle area than animals fed the other two diets. However, the differences in eye muscle areas among carcasses of animals on all the three dietary treatments were not statistically significant ($p>0.05$). This was similar to the findings of Umunna *et al.* (1980). Back fat thicknesses observed in the current study were by far lower than what Umunna *et al.* (1980)

found. This could be due to differences in the breed of animals and in the quantity and quality of the diets used in the two studies. The rib-eye area per 100 kg carcass weight, recorded in the current study, was nearly similar to the finding of Umunna *et al.* (1980).

Table 35 Carcass characteristics of Borana bulls fed the experimental diets.

Carcass characteristics	Experimental diet[1]			SE
	1	2	3	
Fat depth (mm)	0.13[b]	0.27[a]	0.20[ab]	0.03
Tissue depth (mm)	4.4	5.6	5.0	0.62
Rib-eye area (cm^2)	56.3	66.3	61.9	4.08
Rib-eye area/100 kg hot carcass weight (cm^2)	34.0	35.9	36.6	1.56
Kidney fat (kg)	1.6[b]	2.7[a]	1.8[b]	0.23
Heart fat (kg)	0.8[a]	0.9[a]	0.6[b]	0.05
Muscle pH	5.8	6.1	5.9	0.25

[ab] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

Measurements of some non-carcass parts are given in Table 36. Differences among animals on the three dietary treatments were observed only in weights of head, legs, full GIT and omental fat. Fimbres *et al*. (2002) ascribed the heavier full GIT of lambs finished on ration containing various levels of forage to the higher fiber content of the forages which has the capacity to retain water. The current study, however, is at variance with this finding as the full GIT weight of animals on a diet containing natural pasture hay, which has lower NDF content than untreated maize stover, was significantly ($p<0.05$) higher than the full GIT weights of animals on the diet containing the untreated maize stover. The difference is more likely attributed to the difference in the mass of the fill than in the proportion of fiber content. In line with what Fimbres *et al*. (2002) stated, the weights of most of these organs are related to the size of the animals.

Table 36 Measurements of non-carcass parts (fifth quarter) of Borana bulls fed the experimental diets.

Parts	Experimental diets[1]			SE
	1	2	3	
Head with tongue (kg)	14.6[b]	16.4[a]	17.0[a]	0.39
Hide with tail (kg)	22.0	23.0	24.5	1.41
Hind plus fore legs (kg)	5.3[b]	5.7[a]	5.7[a]	0.07
GIT full (kg)	50.7[b]	47.7[b]	67.3[a]	4.53
GIT empty (kg)	20.6	22.5	24.8	1.22
Liver with bile (kg)	3.5	4.0	3.7	0.25
Spleen (kg)	0.9	0.9	0.8	0.10
Omental fat (kg)	3.2[b]	4.2[a]	2.9[b]	0.25
Lung and trachea (kg)	3.0	2.9	3.0	0.15

[ab] Means in the same row with different letters are different ($p<0.05$).
[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

Chemical composition of the carcass

Effects of the diets on chemical composition of the carcass are illustrated in Table 37. None of the carcass chemical entities were affected by the dietary treatments. However, when expressed on DM basis, the carcass of animals fed the diet containing urea treated maize stover had slightly higher CP and EE percentages, than the carcasses of animals fed the other two diets. The relatively higher CP content of the carcass of animals fed the urea treated stover diet may be attributed to the higher CP content of the urea treated stover compared with the untreated stover and the hay. The EE content followed the trend of fat content of the carcasses shown in the preceding tables. The higher EE percentage of carcass of the animals fed the diet containing untreated maize stover, when expressed on as is basis, was the reflection of the higher initial DM or the lower moisture content of this carcass compared with the carcasses of animals fed the other two diets..

Table 37 Chemical composition of carcass from Borana bulls fed the three diets.

Parameters	Experimental diet[1]			SE
	1	2	3	
Moisture content (%)	63.1	66.9	66.3	1.73
DM (%)	97.6	97.2	97.7	0.21
CP - (% of DM)	59.9	69.8	59.5	2.96
- (% of as is)	21.9	23.1	20.1	0.94
EE - (% of DM)	36.5	37.6	34.8	2.97
- (% of as is)	13.5	12.4	11.9	1.40
Ash (% of DM)	2.5	3.1	3.1	0.24

[1] 1 = Untreated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
2 = Urea-treated maize stover *ad libitum* + 1.5 kg concentrate/head/day.
3 = Natural pasture hay *ad libitum* + 1.5 kg concentrate/head/day.

CONCLUSSIONS AND RECOMMENDATIONS

The major crop residues available in the three AEZs were tef, wheat and barley straws, maize and sorghum stovers and haricot bean haulms. In accordance with the differences in the size of cultivable land annually allocated to the different crops, contribution of the corresponding crop residues to the total annual crop residue production by households in the three AEZs varied greatly. However, the actual total annual crop residue production per household was not statistically different among households in the three AEZs. With regard to utilization, farmers in all the AEZs seem to utilize their crop residues for similar purposes. They use their crop residues primarily for animal feeding. Alternative uses of crop residues were observed to vary more with the type of residue than with the AEZs. It can be concluded that with an annual average production of 0.67 to 1.01 ton DM per TLU of a household, crop residues can contribute at least 26 to 40% of the total annual maintenance feed requirement of ruminants in the AEZs studied. However, figures regarding the availability of crop residues on per livestock unit basis should be used with caution as great differences exist among ruminants in their feeding behaviour and nutritional physiology, and among crop residues in their edibility. To further increase the contribution of crop residues and hence the benefits farmers should get from these valuable and readily available feed resources, a coordinated effort of government and expertise is essential to avail to farmers improved technologies and inputs that boost both grain and residue yields.

As the effects of collection and storage systems on the quantity and quality of crop residues are well known, more than 90% of the respondents in this survey were found to collect and store their residues, with the exception of stovers, especially the sorghum stovers. For the rest of the respondents, lack of means of transportation has been the major constraint to collect their residues. Thirty to 40% of the respondents indicated that some of their crop residues are wasted mainly because of improper storage and inability to collect. Mould formation followed by termite attack was the major storage problem identified.

With regard to feeding systems, nearly two thirds of the respondents in each of the three AEZs stated that they feed their straws to animals by mixing them together rather than alone. Stovers were either grazed *in situ* or fed alone. While there is a great potential for improving the feeding value of crop residues through supplementation and/or simple treatment or processing methods, the residues in the study area were fed without much attention to improving their feeding values. The only processing method undertaken by appreciable number of respondents (more than 75%) was physical processing (chopping and threshing). Except in SM2, more than 80% of the respondents in each of the other two AEZs did not use any supplement to enhance the feeding value of crop residues. Shortage of labour and capital, lack of awareness and access were the major constraints the respondents had to undertake the above mentioned nutritive-value-improvement practices. For any beneficial practice to be appealing to farmers, it must be as economical as possible. Therefore, farmers need to be trained and advised as to how best and economical they can manage and feed their residues. Extension workers need to teach the farmers and demonstrate to them as to how to implement the already known simple, feeding-value-improvement techniques such as physical processing, supplementation and urea utilization. Research should also be directed towards investigating the resource requirements of different crop-residue-management and nutritive-value-improvement techniques, both on station and at farm levels, to justify feasibility of the same. Moreover, some important practices which are being undertaken by some farmers (eg. mix stacking and feeding the mixed residues) should be appreciated and extended to other farmers with sufficient explanation about the advantages of the practices.

Results of the study on the effects of urea levels and treatment durations on chemical composition and IVDMD of maize stover revealed that there was no statistically sound difference between the 5% urea treatment for 2 weeks and the 6% urea treatment for 2 or 3 weeks in NDF content and IVDMD. This, with the added advantage in cost saving, makes the 5% urea treatment for a period of two weeks to be more attractive than the 6% urea treatment. Moreover, though the nitrogen content of the 6% urea treatment was higher than that of the 5% urea treatment, the latter case was likely to be preferred as the nitrogen in the former case would by far be more than the requirement for rumen microorganisms and would be wasted. Even the 4% urea treatment having a 14.9% CP could provide sufficient nitrogen of 46 g per kg DOM (because it has 26 g nitrogen per kg OM and its OMD is 56.4) for rumen microbes. Therefore, except for its disadvantage in having relatively high NDF content and low IVDMD, the 4% urea treatment was likely to be more economical than the 5% urea treatment and can be employed especially in areas where urea is highly expensive and in cases where moderate reduction in NDF and moderate increase in IVDMD are considered to be acceptable.

Besides an improvement of 9% in IVDMD of maize stover, urea treatment markedly increased ($p<0.05$) CP content of the treated stover compared with that of the untreated stover and the natural pasture hay. Also increments of 22 and 37% in dry matter intake of maize stover by weaned crossbred caves and Borana bulls, respectively, have been achieved as a result of urea treatment. These improvements in terms of chemical composition, intake and digestibility have led to higher live weight gain of animals fed the diet containing the urea-treated maize stover compared with that of the animals fed the diet containing the untreated stover. However, there was no sound difference in daily weight gain between animals fed the diet containing urea-treated maize stover and those fed the diet containing hay. With regard to carcass characteristics, no appreciable differences were noted among animals fed with the three diets.

Analyses of feeding costs indicated that each kg live weight gained by animals fed the urea treated maize stover diet was achieved at lesser expense than the weight gained by animals fed the hay diet and at reasonably higher expense than the weight gained by animals fed the untreated maize stover diet. Therefore, urea treated maize stover could be used as an alternative to natural pasture hay, and its use in general may be considered as one of the strategies that bring about an efficient utilization of crop residues for livestock feeding especially in arid and semi-arid areas where crop residues constitute the major ruminant feeds. However, its economic advantage over other alternatives must carefully be examined under the prevailing price conditions before it is implemented.

LITERATURE CITED

Alemu, Y., S. Zinash and B. Seyoum. 1991. The potential of crop residues and agro-industrial by-products as animal feed, pp. 57-64. *In* **Proceedings of the 3rd National Livestock Improvement Conference.** Institute of Agricultural Research (IAR), Addis Ababa, Ethiopia.

Anderson, D.C. 1978. Uses of cereal residues in beef cattle production systems. **J. Anim. Sci.** 46 (3): 849-861.

Anderson, P.T., W.G. Bergen, R.A. Merkel and D.R. Hawkins. 1988. The effect of dietary crude protein level on rate, efficiency and composition of gain of growing beef bulls. **J. Anim. Sci**. 66: 1990.

AOAC (Association of Official Analytical Chemists). 1990. **Official Methods of Analysis.** 15th ed. AOAC, Arlinton, Virginia.

ARC (Agricultural Research Council). 1980. **The Nutrient Requirement of Ruminant Livestock.** Commonwealth Agricultural Bureau, Slough. 351p.

ATARC (Adami Tulu Agricultural Research Center). 1998. ATARC **Thirty Years Research Experience**. ATARC, Ethiopia.

Barber, W.P., A.H. Ademson and J.F.B. Altma. 1984. New methods of forage evaluation, pp. 161-176. *In* **Recent Advances in Animal Nutrition**. Butterworth, London.

Bartle, S.J. and T.J. Klopfenstein. 1988. Non-chemical opportunities for improving crop residue feed quality: A review. **J. Prod. Agric**. 1: 356-362.

Brand, A.A., S.W.P. Cloete and F. Franck. 1991. The effect of supplementing untreated, urea-supplemented and urea-ammoniated wheat straw with maize meal and/or fish meal in sheep. **S. Afr. J. Anim. Sci.** 21 (1): 48-54.

Bui, V.C. and V.L. Le. 2001. Identification of some levels of urea applied for treatment of rice straw using as feed for dairy and growing cattle. **http://www.vcn.vnn.vn/sp_pape/spec_5_4_2001_1.htm**

Butterworth, M.H. and A.K. Mosi. 1985. Practical evaluation of crop residues and agro-industrial by-products for ruminants in developing countries with emphasis on east Africa. *In* T.R. Preston, V.L. Kossila, J. Goodwin and S.B. Reed (eds.). Better utilization of crop residues and byproducts in animal feeding: research guidelines 1**.** State of knowledge. **FAO Animal Production and Health Paper** 50. FAO, Rome.

Chairatanayuth, P. and V. Wannamolee. 1987. The composition and digestibility of threshed sorghum head residue treated with urea or NaOH, pp. 187-189. *In* R.M. Dixon (ed.). Ruminant feeding systems utilizing fibrous agricultural residues-1986. **Proceedings of the 6th Annual Workshop of the Australian-Asian Fibrous Agricultural Research Network Held in the University of the Philippines at Los Banos**. International Development Program (IDP) of Australian-Asian Universities and Colleges ltd. Canberra, Australia.

Chenost, M. and C. Kayouli. 1997. Roughage utilization in warm climates. **FAO Animal Production and Health Paper** No. 135. FAO, Rome.

Coombe, J.B. 1981. Utilization of low quality residues, pp. 319-334. *In* F.W.H. Morley (ed.). Grazing Animals. **World Animal Science** B1. Elsevier, Amsterdam, Netherlands.

CSA (Central Statistical Authority). 2001. **Agricultural Sample Survey** 2000/2001, vol. 1. Report on area and production of major crops. CSA, Addis Ababa, Ethiopia.

CSA (Central Statistical Authority). 2003**. Agricultural Sample Survey** 2002/2003, vol. 1. Report on area and production of major crops. CSA, Addis Ababa, Ethiopia.

CSA (Central Statistical Authority). 2004a. **Agricultural Sample Survey** 2003/2004, vol. 1. Report on area and production of major crops. CSA, Addis Ababa, Ethiopia.

CSA (Central Statistical Authority). 2004b. **Statistical Abstract**. CSA, Addis Ababa, Ethiopia.

De Leeuw, P.N. 1997. Crop residues in tropical Africa: trends, in supply, demand and use. *In* C. Renard (ed.). Crop residue in sustainable mixed crop/livestock farming systems. CAB international, New York. **http://www.ilri.cgiar.org/InfoServ/Webpub/Fulldocs/Cropresidues/chap%203.htm**

Devendra, C. 1982. Perspectives in the utilization of untreated rice straw by ruminants in Asia, pp. 7-26. *In* P.T. Doyle (ed.). **The Utilization of Fibrous Agricultural Residues as Animal Feeds**. University of Melbourne, Parkville, Victoria, Australia.

Dias-Da-Silva, A.A., A.M. Ferreira and C.V.M. Guedes. 1988. Effects of moisture level, treatment time and soya bean addition on the nutritive value of urea-treated maize stover. **Anim. Feed Sci. Technol.** 19: 67-77. Elsevier.

Dixon, R.M. and A.R. Egan. 1988. Strategies for optimizing use of fibrous crop residues as animal feeds, pp. 11-26. *In* R.M. Dixon (ed.). Ruminant feeding systems utilizing fibrous agricultural residues. **Proceedings of the 7th Annual Workshop of the Australian-Asian Fibrous Agricultural Residues Research Network.** IDP of the Australian Universities and Colleges Ltd., Canberra.

Doyle, P.T., C. Devendra and G.R. Pearce. 1986. **Rice Straw as a Feed for Ruminants**. IDP of the Australian Universities and Colleges Ltd., Canberra. 32p.

Durand, M. 1989. Conditions for optimizing cellulolytic activity in the rumen, pp. 66-74. *In* M. Chenost and P. Reiniger (eds.). **Evaluation of Straws in Ruminant Feeding**. Elsevier, Amsterdam.

Dyer, I.A., E. Riquelme, L. Baribo and B.Y. Couch. 1975. Waste cellulose as an energy source for animal protein production. **World Animal Review** 15: 39.

Elliott, R., H.M. Ferreiro, A. Priego and T.R. Preston. 1978a. Rice polishing as a supplement in sugar cane diets: the quantities of starch (glucose polymers) entering the proximal duodenum. **Tropical Animal Production** 3: 30-35.

Elliott, R., H.M. Ferreiro, A. Priego and T.R. Preston. 1978b. Estimates of the quantity of feed protein escaping degradation in the rumen of steers fed chopped sugar cane, molasses/urea supplemented with varying quantities of rice polishing. **Tropical Animal Production** 3: 36-39.

ESPO (Economic Study Program Office of Oromiya). 1999. **The Economy of Oromiya**. A perspective for development. Addis Ababa, Ethiopia.

FAO (Food and Agricultural Organization). 1986. Better utilization of crop residues and by-products in animal feeding: research guidelines 2**. FAO Animal Production and Health Paper** 50/2. FAO, Rome.

FAO (Food and Agricultural Organization). 1995. **FAO Year Book**, Vol. 49. FAO, Rome.

FAO (Food and Agricultural Organization). 1996. Agro-ecological Zoning Guidelines. **FAO Soils Bulletin** 73. FAO, Rome.

FAO (Food and Agricultural Organization). 2005. **World Fact Book**. FAO, Rome.

Fernandez-Rivera, S., T.O. Williams, P. Hiernaux and J.M. Powell. 1995. Faecal excretion by ruminants and manure availability for crop production in semiarid West Africa, pp. 149-169. *In* J.M. Powell, S. Fernandez-Rivera, T.O. Williams and C. Renard (eds.). Livestock and sustainable nutrient cycling in mixed farming systems in Sub-Saharan Africa. **Proceedings of an International Conference.** ILCA, Addis Ababa, Ethiopia.

Fimbres, H., G. Hernandez-vidal, J.F. Picon-Rubio, J.R. Kawas and C.D. Lu. 2002. Productive performance and carcass characteristics of lambs fed finishing ration containing various forage levels. **Small Ruminant Research** 43: 283-288. Elsevier.

Flachowsky, G. and M. Schneider. 1989. Improving the feeding value of fibrous crop residues in tropical countries. **Beitr. Trop. Landwirtsch Vet. Med.** 27: 239-247.

Gao, T. 2000. Review: Treatment and utilization of crop straw and stover in China. **http://www.fao.org/livestock/AGAP/FRG/lrrd/lrrd12/1/gao121.htm**

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analyses (apparatus, reagents, procedures and some applications), pp. 1-9. **Agriculture Handbook** No. 379. ARS, USDA, Washington, DC.

Gryseels, G. 1988. Role of livestock in mixed smallholder farms in the Ethiopian highlands. **Ph.D. Thesis**. State Agricultural University, Wageningen, Netherlands.

Guo, T. and Z. Yang. 2002. Animal production based on crop residues- Chinese Experiences. **FAO Animal Production and Health Paper** No. 149. FAO, Rome.

Hilmersen, A., F. Dolberg and O. Kjus. 1984. Handling and storing, pp. 25-44. *In* F. Sundstol and E. Owen (eds.). **Straw and other Fibrous By-products as Feed.** Elsevier, Amsterdam, Netherlands.

IFPRI (International Food Policy Research Institute). 2004. Strategies for sustainable land management and poverty reduction in Uganda. **Research Report** 133. IFPRI, Washington DC.

ILCA (International Livestock Center for Africa). 1983. **ILCA Annual Report**. ILCA, Addis Ababa.

Jackson, M.G. 1978. Treating straw for animal feeding. **FAO Animal Production and Health Paper** No. 10. FAO, Rome.

Kabatange, M.A. and A.J. Kitalyi. 1989. Constraints to cereal crop residue utilization in central Tanzania, pp. 233-238. *In* A.N. Said and B.H. Dzowela (eds.). Overcoming constraints to the efficient utilization of agricultural by-products as animal feed. **Proceedings of the 4th Annual Workshop Held at the Institute of Animal Research, Mankon Station, Bamenda, Cameroon.** Addis Ababa, Ethiopia.

Kamra, D.N. and F. Zadrazil. 1988. Microbiological improvement of lignocellulosic in animal feed production: A review, pp. 56-63. *In* F. Zadrazil and P. Reiniger (eds.). **Treatment of Lignocellulosics with White Rot Fungi**. Elsevier Applied Science, London.

Kay, M., H.B. Bowers and G. McKiddle. 1968. Protein requirements of rapidly growing steers. **Animal Production** 10: 37-42.

Kayouli, C. 1996. The role of feeding system based on cereal residues in integrated farming systems in Sub-Saharan Africa. **http://ces.iisc.ernet.in/hpg/envis/livdoc1121.html**

Kearl, L.C. 1982. **Nutrient Requirements of Ruminants in Developing Countries**. International feedstuffs institute, Utah Agricultural Experiment Station, Utah State University, Logan. 381p.

Klopfenstein, T. 1978. Chemical treatment of crop residues. **J. Anim. Sci.** 46 (3): 841-848.

Klopfenstein, T., L. Roth, S. Fernandez-Rivera and M. Lewis. 1987. Corn residues in beef production systems. **J. Anim. Sci.** 65: 1139-1148.

Klopfenstein, T. and F.G. Owen. 1981. Value and potential use of crop residues and by-products in dairy rations. **J. Dairy Sci.** 64: 1250-1268.

Kossila, V.L. 1985. Global review of the potential of crop residues as animal feed. *In* T.R. Preston, V.L. Kossila, J. Goodwin and S.B. Reed (eds.). Better utilization of crop residues and byproducts in animal feeding: research guidelines 1. State of knowledge. **FAO Animal Production and Health Paper** 50. FAO, Rome.

Kossila, V.L. 1988. The availability of crop residues in developing countries in relation to livestock production, pp. 29-39. *In* J. D. Reed, B.S. Capper and P.J.H. Neate (eds.). Plant breeding and the nutritive value of crop residues. **Proceedings of a Workshop Held at ILCA.** ILCA, Addis Ababa, Ethiopia.

Leng, R.A. 1990. Factors affecting the utilization of poor quality forages by ruminants particularly under tropical conditions. **Nutrition Research Reviews** 3: 277-303.

Li, Y., C. Gu, Y. An, R. Liu, Z. Gao and Y. Cao. 1993. Effect of untreated and treated wheat straw and maize stover on performance of cross breed cattle, pp. 210-213. *In* **Proceedings of the First International Conference on Animal Production with Local Resources.** Beijing.

Lulseged, G.H. and J. Mohammed 1989. The potential of crop residues, particularly wheat straw, as livestock feed in Ethiopia, pp. 142-154. *In* A.N. Said and B.H. Dzowela (eds.). Overcoming constraints to the efficient utilization of agricultural by-products as animal feed. **Proceedings of the 4th Annual Workshop Held at the Institute of Animal Research, Mankon Station, Bamenda, Cameroun.** ILCA, Addis Ababa, Ethiopia.

Males, J.K. 1987. Optimizing the utilization of cereal crop residues for beef cattle. **J. Anim. Sci.** 65: 1124-1130.

Martin, T.G., T.W. Perry, W.M. Beeson and M.T. Mohler. 1978. Protein levels for bulls: Comparison of three continuous dietary levels on growth and carcass traits**. J. Anim. Sci**. 47: 29.

Ma, T.K., C.X. Gu, B.C. Dai and E.R. Orskov. 1990. Effect of ammonia treatment of wheat straw and level of concentrate on performance of Chinese yellow cattle. **http://fts.sunset.se/wmiror/www.cipav.org.co/lrrd/lrrd2/3/orskovl.htm.**

McIntire, J., J.D. Reed, A. Fedla, S. Jutzi and Y. Kebede. 1988. Evaluating sorghum cultivars for grain and straw yield, pp 283-304. *In* J.D. Reed, B.S. Capper and P.J.H. Neate (eds.). Plant breeding and the nutritive value of crop residues. **Proceedings of a Workshop Held at ILCA**. ILCA, Addis Ababa, Ethiopia.

Mlay, G.I. 1986. The use of diagnostic surveys in directing on-farm research: The experience of the smallholder dairy feeding systems project in Tanzania, pp. 9-16. *In* T.R. Preston and M.Y. Nuwanyakp (eds.). Towards optimal feeding of agricultural by-products to livestock in Africa. **Proceedings of a Workshop Held at the University of Alexandria, Egypt.** ILCA, Addis Ababa, Ethiopia.

MOA (Ministry of Agriculture). 1998. **Agro-ecological Zones of Ethiopia**. Natural Resources Management and Regulatory Department, MOA, Addis Ababa, Ethiopia.

Munthali, J.T.K., C.N. Jayasuriya and A.N. Bhattachrya. 1992. Effects of urea treatment of maize stover and supplementation with maize bran or urea-molasses block on the performance of growing steers and heifers, pp. 279-286. *In* J.E.S. Stares, A.N. Said and J.A. Kategile (eds.). The complementarity of feed resources for animal production in Africa. **Proceedings of the Joint Feed Resources Networks Workshop, Gaborone, Botswana.** ILCA, Addis Ababa, Ethiopia.

Neville, W.E., R.E. Hellwig, R.J. Ritterand and W.C. Cormick. 1977. Effect of diet protein on weight gains of early weaned beef calves. **J Anim. Sci.** 44 (4): 687-693.

Nguyen, X.T. 2000. Treatment and supplementation of rice straw for ruminant feeding in Vietnam.

http://www.vcn.vnn.vn/sp_pape/spec_5_4_2001_18.htm

Nguyen, X.T., X.D. Cu, V.L. Le and F. Sundstol. 1998. Effects of urea concentration, moisture content, and duration of treatment on chemical composition of alkali treated rice straw. **Livestock Research for Rural Development** 10 (1). **www.vcn.vnn.vn/sp_pape/spec_5_4_2001_9.htm**

Nordblom, J.L. and F. Shomo. 1995. Food and feed prospects to 2020 in the West Asia-North Africa Region. International Center for Agricultural Research in the Dry Areas (ICARDA). **Social Science Paper** No. 2. ICARDA, Aleppo, Syria.

Orskov, E.R., W.J. Shand, D. Tedesco and L.A.F. Morrice. 1990. Rumen degradation of straw. 10. Consistency of differences in nutritive value between varieties of cereal straws. **Animal Production** 51: 155-162.

Orskov, E.R. 1991. Manipulation of fiber digestion in the rumen, pp. 187-196. *In* **Proceedings of the Nutrition Society** 50.

Orskov, E.R. and H.J. Flint. 1991. Manipulation of rumen microbes or fed resources as methods of improving feed utilization, pp. 123-138. *In* A.G. Hunter (ed.). **Biotechnology in Livestock in Developing Countries.** University of Edinburgh.

Owen, E. and A.A.O. Aboud. 1988. Practical problems of feeding cop residues, pp. 133-156. *In* J.D. Reed, B.S. Capper and P.J.H. Neate (eds.). Plant breeding and the nutritive value of crop residues. **Proceedings of a Workshop Held at ILCA**. ILCA, Addis Ababa, Ethiopia.

Preston, T.A. 1995. Tropical animal feeding. A manual for research worker. **FAO Animal Production and Health Paper** 126. FAO, Rome.

Preston, T.R. and R.A. Leng. 1984. Supplementation of diets based on fibrous residues and by-products, pp. 373-413. *In* F. Sundstol and E.C. Owen (eds.). **Straw and other By-products as Feed.** Elsevier, Amsterdam.

Preston, T.R. and R.A. Leng. 1986. **Matching Ruminant Production Systems with Available Resources in the Tropics and Sub-Tropics**. ILCA, Addis Ababa, Ethiopia.

Preston, T.R. and R.A. Leng. 1987. **Matching Ruminant Production Systems with Available Resources in the Tropics and Sub-Tropics**. Penambul Press, Armidale, New South Wales, Australia. 245p.

Promma, S., S. Tuikumpee, A. Ratnavanija, N. Vidhyakorn and R.W, Froemert 1985. The effects of urea treated rice straw on growth and milk production of crossbred Holstein Friesian dairy cattle. pp. 88-93. *In* P.T. Doyle (ed.). The utilization of fibrous agricultural residues as animal feeds. **Proceedings of the 4th Annual Workshop of the Australian-Asian Fibrous Agricultural Residues Research Network Held in Khon Kaen, Thailand.** IDP, Canberra.

Ramakrishna, G. and D. Assefa. 2002. An empirical analysis of food insecurity in Ethiopia. The case of Wello, pp. 127-143. **Africa Development** Vol. XXVII, Nos. 1 & 2. Council for the Development of Social Science Research in Africa.

Rehrahie, M. 2001. Biological and economical evaluation of feeding urea treated tef and barley straw based diets to crossbred dairy cows in the highlands of Ethiopia. **M.Sc. Thesis**. Uppsala.

Riquelme-Villagran, E. 1988. Feed processing technologies to increase nutritive value, pp.72-84. *In* **Proceedings of the 6th World Conference on Animal Production.** Helsinki, Finland.

Saadullah, M., M. Haque and F. Dolberg. 1981. Effectiveness of ammonification through urea in improving the feeding value of rice straw in ruminants. **Tropical Animal Production** 6 (1): 30-36.

Saadullah, M., M. Haque and F. Dolberg. 1982. Treated and untreated rice straw for growing cattle. **Tropical Animal Production** 7: 20-25.

Said, A.N. and M.M. Wanyoike. 1987. The prospect of utilizing urea treated maize stover by smallholders in Kenya, pp. 15-26. *In* D.A. Little and A.N. Said (eds.). Utilization of agricultural by products as livestock feeds in Africa. **Proceedings of a Workshop Held at Ryall's Hotel, Blantyre, Malawi.** ARNAB, ILCA, Addis Ababa, Ethiopia.

Sandford, S.1989. Crop residue/livestock relationships, pp. 169-182. *In* C. Renard, R.C. Vandenbeldt and J.F. Parr (eds.). Soil, crop and water management systems for rain-fed agriculture in the Sudano-Sahelian zone. **Proceedings of an International Workshop, 11-16 Jan. 1987, ICRISAT Sahelian Center, Niamey, Niger.** ICRISAT, Patancheru, India.

SAS (Statistical Analysis System). 2000. **The SAS System for Windows**, 8. SAS Institute Inc. Cary, North Carolina.

Seyoum. B. and S. Zinash. 1989. The composition of Ethiopian feedstuffs. **IAR Research Report** No. 6. IAR, Addis Ababa, Ethiopia.

Seyoum. B. and S. Zinash. 1998. Utilization of tef straw as livestock feed: Research review, pp. 173-185. *In* **Proceedings of the 5th Annual Conference of Ethiopian Society of Animal Production (ESAP).** IAR, Addis Ababa, Ethiopia.

Shen, H.S., F. Sundstol and D.B. Ni. 1998. Studies on untreated and urea-treated rice straw from three cultivation seasons. 2. Evaluation of straw quality through in vitro gas production and in saco degradation measurements. **Anim. Feed Sci. Technol.** 74: 193-212. Elsevier.

Sibanda, S. 1986. The use of crop residues in livestock production systems in the communal areas of Zimbabwe, pp. 140-144. *In* T.R. Preston and M.Y. Nuwanyakpa (eds.). Towards optimal feeding of agricultural by-products to livestock in Africa. **Proceedings of a Workshop Held at the University of Alexandria, Egypt.** ILCA, Addis Ababa, Ethiopia.

Smith, O.B. 1993. Feed resources for intensive smallholder systems in the tropics: the role of crop residues, pp. 1969-1976. *In* **Proceedings of the XVII International Grassland Congress.** Rockhampton, Australia.

Smith, T., C. Chakanyuka, S. Sibanda and B. Manyuchi. 1989. Maize stover as feed for ruminants, pp. 218-231. *In* A.N. Said and B.H. Dzowela (eds.). Overcoming constraints to the efficient utilization of agricultural by-products as animal feed. **Proceedings of the 4th Annual Workshop Held at the Institute of Animal Research, Mankon Station, Bamenda, Cameroun.** ILCA, Addis Ababa, Ethiopia.

SPM (Strategic Planning and Management). 1999. **SPM Document**. Agriculture and Rural Development Supreme Office, Addis Ababa, Ethiopia.

SPSS (Statistical Procedures for Social Sciences). 1999. **SPSS for Windows** 10. SPSS Institute Inc., Chicago.

Strydom, P.E., R.T. Naude, M.F. Smith, M.M. Scholtz and J.B. Van Wyk. 2000. Characterization of indigenous African cattle breeds in relation to carcass characteristics. **British Society of Animal Science** 70: 241-252.

Sundstol, F., E. Coxworth and D.N. Mowat. 1978. Improving the nutritive value of straw and other low-quality roughage by treatment with ammonia. **World Animal Review** 26: 13-21.

Sundstol, F. and E. Owen. 1984. Straw and other fibrous by-products as feed. **Developments in Animal and Veterinary Science** 14. Elsevier, Amsterdam, Netherlands.

Tesfaye, A. 1999. The role of crop residues as livestock feed resource in semi-arid areas of Adami Tullu district, Ethiopia. **M.Sc. Thesis.** Department of Range Management, University of Nairobi, Kenya.

Tesfaye, A. 2005. The potential of urea treated maize stover for growth performance of weaned calves. **Kasetsart J. (Nat. Sci.)** 39 (4).

Thole, N.S., A.L. Joshi and D.V. Rangnekar. 1988. Feed availability and nutritional status of dairy animals in western Maharaashtra, pp. 207-212. *In* K. Singh and J.B. Schiere (eds.) **Fibrous Crop Residues as Animal Feed**. Indian Council of Agricultural Research (ICAR), New Delhi.

Tilley, J.M.A. and R.A. Terry. 1963. A two-stage technique for *in vitro* digestion of forage crops. **J. Br. Grassl. Soc.** 18: 104-111.

Timothy, O.W., S. Fernandez-Rivera and G.K. Timothy. 1997. The influence of socio-economic factors on the availability and utilization of crop residues as animal feeds. **http://www.ilri.cgiar.org/InfoServ/Webpub/Fulldocs/Cropresidues/chap%202.htm**

Tran, H. and T.T. Nguyen. 2000. Effects of urea treatment of maize stover on chemical composition, intake, digestibility and growth rate. **http://www.vcn.vnn.vn/sp_pape/spec_5_4_2001_24.htm.**

Umunna, N.N., A. Dakintafo and S.N. Carew. 1980. Influence of levels of dietary protein on performance and carcass characteristics of Zebu steers fed high energy rations. **Tropical Animal Production** 5: 2.

UNDP (United Nation Development Program). 1996. UNDP Emergencies Unit for Ethiopia. **http://www.reliefweb.int/.**

Varvikko, T. 1991. Nutrition constraint to improved smallholder milk production in the Ethiopian highlands: the Selale experience, pp. 43-50. *In* **Proceedings of the 4th National Livestock Improvement Conference**. IAR, Addis Ababa, Ethiopia.

Wallace, R.J. 1994. Rumen microbiology, biotechnology and ruminant nutrition: Progress and problems. **J. Anim. Sci.** 72: 2992-3003.

Wanapat, M., S. Duangchan, S. Pongpainote, T. Anakewit and P. Tongpanung. 1986. Effects of various levels of concentrate fed with urea-treated rice straw for pure-bred American Brahman yearlings, pp. 149-153. *In* R.M. Dixon (ed.). Ruminant feeding systems utilizing fibrous agricultural residues. **Proceedings of the 5th Annual Workshop of the Australian-Asian Fibrous Agricultural Residues Research Network**. IDP, Canberra.

Wongsrikeao, W. and M. Wanapat. 1985. The effects of urea-treatment of rice straw on the feed intake and live weight gain of buffaloes, pp. 81-84. *In* P.T. Doyle (ed.). The utilization of fibrous agricultural residues as animal feeds. **Proceedings of the 4th Annual Workshop of the Australian-Asian Fibrous Agricultural Residues Research Network Held in Khon Kaen, Thailand**. IDP, Canberra.

Zaman, M.S. and E. Owen. 1995. The effect of calcium hydroxide and urea treatment of barley straw on chemical composition and digestibility. **Anim. Feed Sci. and Technol.** 51: 165-171. Elsevier, London.

Zinash, S. and B. Seyoum. 1991. Utilization of feed resources and feeding systems in the central zone of Ethiopia, pp. 129-132. *In* **Proceedings of the 3rd National Livestock Improvement Conference.** IAR, Addis Ababa, Ethiopia.

Zhang, Z. and Q. Yan. 2002. Ammoniation of crop residues. **FAO Animal Production and Health Paper** No. 149. FAO, Rome.

Zhang, W., J. Yuan and H. Tian. 1995. Comparison on the nutritive value of urea, liquid ammonia treated straw and analysis of feeding benefit at different supplement levels, pp. 266-271. *In* **Proceedings of the 2nd International Conference on Animal Production with Local Resources.** Zhanjiang.

Zou, X., X. Liang and Q. Liu. 1995. Test on feeding dairy cows with straw ammoniated by different ammonia sources, pp. 199-204. *In* **Proceedings of the 2nd International Conference on Animal Production with Local Resources.** Zhanjiang.

APPENDICES

Appendix 1 ANOVA tables for the study on urea levels and treatment durations.

1.1 ANOVA table for DM content of the treated straw.

Source	DF	SS	MS	F Value	Pr > F
A=Treat. duration	2	154.5019000	77.2509500	3.82	0.0631
B=Urea level	2	106.9882333	53.4941167	2.64	0.1251
A*B	4	103.2807667	25.8201917	1.28	0.3484
Error	9	182.2321000	20.2480111		
Corrected Total	17	547.0030000			

Coefficient of variation = 6.871990

1.2 ANOVA table for ash content of the treated straw.

Source	DF	SS	MS	F Value	Pr > F
A=Treat. duration	2	3.56457778	1.78228889	6.07	0.0214
B=Urea level	2	1.05101111	0.52550556	1.79	0.2217
A*B	4	0.99802222	0.24950556	0.85	0.5284
Error	9	2.64330000	0.29370000		
Corrected Total	17	8.25691111			

Coefficient of variation = 6.747086

1.3 ANOVA table for CP content of the treated straw.

Source	DF	SS	MS	F Value	Pr > F
A=Treat. duration	2	10.30111111	5.15055556	11.93	0.0029
B=Urea level	2	11.60777778	5.80388889	13.45	0.0020
A*B	4	5.75555556	1.43888889	3.33	0.0617
Error	9	3.88500000	0.43166667		
Corrected Total	17	31.54944444			

Coefficient of variation = 4.133604

1.4 ANOVA table for NDF content of the treated straw.

Source	DF	SS	MS	F Value	Pr > F
A=Treat. Duration	2	4.83414444	2.41707222	27.00	0.0002
B=Urea level	2	31.10631111	15.55315556	173.75	<.0001
A*B	4	2.25332222	0.56333056	6.29	0.0107
Error	9	0.80565000	0.08951667		
Corrected Total	17	38.99942778			

Coefficient of variation = 0.385738

1.5 ANOVA table for IVDMD of the treated straw.

Source	DF	SS	MS	F Value	Pr > F
A=Treat. Duration	2	15.87867778	7.93933889	23.06	0.0003
B=Urea level	2	95.99847778	47.99923889	139.44	<.0001
A*B	4	4.85265556	1.21316389	3.52	0.0493
Error	9	3.0981500	0.3442389		
Corrected Total	17	119.8279611			

Coefficient of variation = 0.991796

Appendix 2 ANOVA tables for the study on weaned crossbred calves

2.1 ANOVA table for daily roughage dry matter intake of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	5.89901175	1.96633725	16.60	<.0001
Error	17	2.01383218	0.11846072		
Corrected Total	20	7.91284393			

Coefficient of variation = 9.125843

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	4.48581618	2.24290809	18.93	<.0001
Initial weight	1	0.67052794	0.67052794	5.66	0.0293

2.2 ANOVA table for daily total dry matter intake of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	5.89901175	1.96633725	16.60	<.0001
Error	17	2.01383218	0.11846072		
Corrected Total	20	7.91284393			

Coefficient of variation = 7.383644

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	4.48581618	2.24290809	18.93	<.0001
Initial weight	1	0.67052794	0.67052794	5.66	0.0293

2.3 ANOVA table for daily roughage DM intake per 100 kg live weight

Source	DF	SS	MS	F Value	Pr > F
Model	3	1.50997679	0.50332560	10.88	0.0003
Error	17	0.78660041	0.04627061		
Corrected Total	20	2.29657720			

Coefficient of variation = 8.941829

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1.41467078	0.70733539	15.29	0.0002
Initial weight	1	0.23532564	0.23532564	5.09	0.0376

2.4 ANOVA table for daily concentrate DM intake per 100 kg live weight.

Source	DF	SS	MS	F Value	Pr > F
Model	3	0.07857930	0.02619310	121.10	<.0001
Error	17	0.00367683	0.00021628		
Corrected Total	20	0.08225614			

Coefficient of variation = 2.563553

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	0.00364066	0.00182033	8.42	0.0029
Initial weight	1	0.06864241	0.06864241	317.37	<.0001

2.5 ANOVA table for total daily total DM intake per 100 kg live weight of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1.64507842	0.54835947	12.50	0.0001
Error	17	0.74570857	0.04386521		
Corrected Total	20	2.39078699			

Coefficient of variation = 7.029855

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1.30581183	0.65290591	14.88	0.0002
Initial weight	1	0.55815948	0.55815948	12.72	0.0024

2.6 ANOVA table for daily total DM intake per kg $W^{0.75}$ of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1847.113610	615.704537	11.20	0.0003
Error	17	934.813337	54.989020		
Corrected Total	20	2781.926947			

Coefficient of variation = 7.044620

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1777.245130	888.622565	16.16	0.0001
Initial weight	1	216.763551	216.763551	3.94	0.0635

2.7 ANOVA table for daily total digestible DM intake per of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1.56412755	0.52137585	10.67	0.0004
Error	17	0.83084509	0.04887324		
Corrected Total	20	2.39497264			

Coefficient of variation = 7.737549

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1.36020068	0.68010034	13.92	0.0003
Initial weight	1	0.25840895	0.25840895	5.29	0.0344

2.8 ANOVA table for daily total digestible DM intake per kg $W^{0.75}$ of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	639.028225	213.009408	9.92	0.0005
Error	17	365.189418	21.481730		
Corrected Total	20	1004.217643			

Coefficient of variation = 7.172497

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	521.4865405	260.7432702	12.14	0.0005
Initial weight	1	70.6076055	70.6076055	3.29	0.0875

2.9 ANOVA table for daily total digestible OM intake of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1.23719443	0.41239814	9.16	0.0008
Error	17	0.76543045	0.04502532		
Corrected Total	20	2.00262488			

Coefficient of variation = 7.681879

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1.01296334	0.50648167	11.25	0.0008
Initial weight	1	0.24639407	0.24639407	5.47	0.0318

2.10 ANOVA table for daily total CP intake of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	0.79939649	0.26646550	125.25	<.0001
Error	17	0.03616727	0.00212749		
Corrected Total	20	0.83556375			

Coefficient of variation = 8.965402

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	0.78408884	0.39204442	184.28	<.0001
Initial weight	1	0.00227888	0.00227888	1.07	0.3152

2.11 ANOVA table for daily total digestible CP intake of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	636573.3159	212191.1053	168.16	<.0001
Error	17	21451.1694	1261.8335		
Corrected Total	20	658024.4853			

Coefficient of variation = 9.851929

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	615764.4266	307882.2133	244.00	<.0001
Initial weight	1	1075.1578	1075.1578	0.85	0.3689

2.12 ANOVA table for daily metabolizable energy intake of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	299.5415975	99.8471992	9.16	0.0008
Error	17	185.3211214	10.9012424		
Corrected Total	20	484.8627189			

Coefficient of variation = 7.681879

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	245.2522001	122.6261000	11.25	0.0008
Initial weight	1	59.6553541	59.6553541	5.47	0.0318

2.13 ANOVA table for daily metabolizable energy intake per kg $W^{0.75}$.

Source	DF	SS	MS	F Value	Pr > F
Model	3	112443.7006	37481.2335	7.80	0.0017
Error	17	81650.8796	4802.9929		
Corrected Total	20	194094.5802			

Coefficient of variation = 7.129910

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	89394.23447	44697.11723	9.31	0.0019
Initial weight	1	15987.02120	15987.02120	3.33	0.0857

2.14 ANOVA table for daily metabolizable energy per kg diet DM.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	5.68696852	2.84348426	908315	<.0001
Error	18	0.00005635	0.00000313		
Corrected Total	20	5.68702487			

Coefficient of variation = 0.019108

2.15 ANOVA table for final weight of calves.

Source of	DF	SS	MS	F Value	Pr > F
Model	3	4677.881447	1559.293816	55.56	<.0001
Error	17	477.070934	28.062996		
Corrected Total	20	5154.952381			

Coefficient of variation = 3.062954

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	409.208688	204.604344	7.29	0.0052
Initial weight	1	3757.500494	3757.500494	133.90	<.0001

2.16 ANOVA table for total weight gain of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	413.8814467	137.9604822	4.92	0.0122
Error	17	477.0709342	28.0629961		
Corrected Total	20	890.9523810			

Coefficient of variation = 15.55895

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	409.2086878	204.6043439	7.29	0.0052
Initial weight	1	6.9290658	6.9290658	0.25	0.6256

2.17 ANOVA table for average daily weight gain of the calves.

Source	DF	SS	MS	F Value	Pr > F
Model	3	0.04406993	0.01468998	5.86	0.0061
Error	17	0.04262702	0.00250747		
Corrected Total	20	0.08669695			

Coefficient of variation = 14.36372

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	0.04401400	0.02200700	8.78	0.0024
Initial weight	1	0.00019555	0.00019555	0.08	0.7834

2.18 ANOVA table for feed conversion efficiency of the calves.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	15.64132785	7.82066393	2.51	0.1091
Error	18	56.05234788	3.11401933		
Corrected Total	20	71.69367573			

Coefficient of variation = 12.97834

2.19 ANOVA table for average daily nitrogen intake per animal.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	11687.00879	5843.50440	524.83	<.0001
Error	9	100.20601	11.13400		
Corrected Total	11	11787.21480			

Coefficient of variation = 4.193907

2.20 ANOVA table for average daily nitrogen voided in faeces per animal.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	223.2281924	111.6140962	14.07	0.0017
Error	9	71.3892232	7.9321359		
Corrected Total	11	294.6174155			

Coefficient of variation = 11.87713

2.21 ANOVA table for average daily nitrogen voided in urine per animal.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	2873.470900	1436.735450	239.60	<.0001
Error	9	53.966704	5.996300		
Corrected Total	11	2927.437603			

Coefficient of variation = 12.93314

2.22 ANOVA table for average daily nitrogen retained per animal.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	1877.106858	938.553429	107.82	<.0001
Error	9	78.342673	8.704741		
Corrected Total	11	1955.449531			

Coefficient of variation = 7.992239

2.23 ANOVA table for daily nitrogen retained as percent of intake.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	68.0180654	34.0090327	1.38	0.3003
Error	9	221.9152276	24.6572475		
Corrected Total	11	289.9332930			

Coefficient of variation = 10.48461

2.24 ANOVA table for daily nitrogen retained as percent of digested nitrogen.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	1124.761670	562.380835	33.69	<.0001
Error	9	150.223117	16.691457		
Corrected Total	11	1274.984787			

Coefficient of variation = 5.777207

2.25 ANOVA table for DM digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	182.3251807	91.1625903	8.40	0.0087
Error	9	97.6431664	10.8492407		
Corrected Total	11	279.9683470			

Coefficient of variation = 5.352394

2.26 ANOVA table for OM digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	151.7022439	75.8511220	7.12	0.0140
Error	9	95.8971060	10.6552340		
Corrected Total	11	247.5993499			

Coefficient of variation = 5.077490

2.27 ANOVA table for CP digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	609.3785982	304.6892991	25.38	0.0002
Error	9	108.0330179	12.0036687		
Corrected Total	11	717.4116162			

Coefficient of variation = 5.108567

2.28 ANOVA table for NDF digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	182.2552678	91.1276339	11.59	0.0032
Error	9	70.7728082	7.8636454		
Corrected Total	11	253.0280759			

Coefficient of variation = 4.127466

2.29 ANOVA table for average daily roughage DM cost.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	16.90178092	8.45089046	258.21	<.0001
Error	18	0.58910753	0.03272820		
Corrected Total	20	17.49088845			

Coefficient of variation = 9.063757

2.30 ANOVA table for average daily total feed DM cost.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	16.90178092	8.45089046	258.21	<.0001
Error	18	0.58910753	0.03272820		
Corrected Total	20	17.49088845			

Coefficient of variation = 6.509694

2.31 ANOVA table for average daily total feed DM cost per kg weight gain.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	79.1492532	39.5746266	33.10	<.0001
Error	18	21.5235265	1.1957515		
Corrected Total	20	100.6727797			

Coefficient of variation = 13.79497

Appendix 3 ANOVA tables for the study on Borana bulls

3.1 ANOVA table for average daily roughage DM intake of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	14.11200240	4.70400080	15.00	<.0001
Error	17	5.33114438	0.31359673		
Corrected Total	20	19.44314679			

Coefficient of variation = 9.730934

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	10.07763206	5.03881603	16.07	0.0001
Initial weight	1	2.74260260	2.74260260	8.75	0.0088

3.2 ANOVA table for daily total DM intake of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	14.11200240	4.70400080	15.00	<.0001
Error	17	5.33114438	0.31359673		
Corrected Total	20	19.44314679			

Coefficient of variation = 7.898782

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	10.07763206	5.03881603	16.07	0.0001
Initial weight	1	2.74260260	2.74260260	8.75	0.0088

3.3 ANOVA table for daily total DM intake per kg $W^{0.75}$ of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1763.938994	587.979665	9.35	0.0007
Error	17	1069.242091	62.896594		
Corrected Total	20	2833.181085			

Coefficient of variation = 8.274333

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1753.537427	876.768714	13.94	0.0003
Initial weight	1	0.687825	0.687825	0.01	0.9179

3.4 ANOVA table for daily roughage DM intake per 100 kg weight of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1.02031212	0.34010404	8.91	0.0009
Error	17	0.64854893	0.03814994		
Corrected Total	20	1.66886105			

Coefficient of variation = 10.54684

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1.01861593	0.50930796	13.35	0.0003
Initial weight	1	0.00305542	0.00305542	0.08	0.7806

3.5 ANOVA table for daily concentrate DM intake per 100 kg weight of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	0.02624754	0.00874918	116.62	<.0001
Error	17	0.00127538	0.00007502		
Corrected Total	20	0.02752292			

Coefficient of variation = 2.000093

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	0.00043132	0.00021566	2.87	0.0841
Initial weight	1	0.02389971	0.02389971	318.57	<.0001

3.6 ANOVA table for daily total DM intake per 100 kg weight of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	0.99141447	0.33047149	8.94	0.0009
Error	17	0.62838288	0.03696370		
Corrected Total	20	1.61979735			

Coefficient of variation = 8.414026

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	0.97713676	0.48856838	13.22	0.0003
Initial weight	1	0.04404592	0.04404592	1.19	0.2902

3.7 ANOVA table for daily total digestible DM intake per bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	9.78616634	3.26205545	25.21	<.0001
Error	17	2.19974915	0.12939701		
Corrected Total	20	11.98591549			

Coefficient of variation = 7.821427

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	8.78984418	4.39492209	33.96	<.0001
Initial weight	1	1.11722344	1.11722344	8.63	0.0092

3.8 ANOVA table for daily total digestible DM intake per kg $W^{0.75}$.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1555.984562	518.661521	18.88	<.0001
Error	17	467.116132	27.477420		
Corrected Total	20	2023.100694			

Coefficient of variation = 8.424946

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1550.401250	775.200625	28.21	<.0001
Initial weight	1	1.344517	1.344517	0.05	0.8276

3.9 ANOVA table for daily total digestible OM intake of bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	8.02126262	2.67375421	21.55	<.0001
Error	17	2.10906371	0.12406257		
Corrected Total	20	10.13032633			

Coefficient of variation = 7.867156

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	7.01424009	3.50712005	28.27	<.0001
Initial weight	1	1.08618700	1.08618700	8.76	0.0088

3.10 ANOVA table for daily total digestible CP intake of bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	2012670.477	670890.159	664.27	<.0001
Error	17	17169.506	1009.971		
Corrected Total	20	2029839.983			

Coefficient of variation = 5.440535

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	2012607.581	1006303.790	996.37	<.0001
Initial weight	1	1772.268	1772.268	1.75	0.2028

3.11 ANOVA table for daily total CP intake of bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	2.55953263	0.85317754	458.01	<.0001
Error	17	0.03166719	0.00186278		
Corrected Total	20	2.59119982			

Coefficient of variation = 5.359236

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	2.55733501	1.27866750	686.43	<.0001
Initial weight	1	0.00435209	0.00435209	2.34	0.1448

3.12 ANOVA table for daily total metabolizable energy intake of bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	1942.056769	647.352256	21.55	<.0001
Error	17	510.633008	30.037236		
Corrected Total	20	2452.689778			

Coefficient of variation = 7.867156

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	1698.242920	849.121460	28.27	<.0001
Initial weight	1	262.980644	262.980644	8.76	0.0088

3.13 ANOVA table for daily total metabolizable energy intake per kg $W^{0.75}$.

Source	DF	SS	MS	F Value	Pr > F
Model	3	299378.9609	99792.9870	15.86	<.0001
Error	17	106940.3360	6290.6080		
Corrected Total	20	406319.2969			

Coefficient of variation = 8.415932

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	298553.6724	149276.8362	23.73	<.0001
Initial weight	1	204.2241	204.2241	0.03	0.8591

3.14 ANOVA table for metabolizable energy per kg diet DM.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	8.56469282	4.28234641	415712	<.0001
Error	18	0.00018542	0.00001030		
Corrected Total	20	8.56487824			

Coefficient of variation = 0.032669

3.15 ANOVA table for daily total nitrogen intake per animal.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	41930.41673	20965.20837	122.58	<.0001
Error	9	1539.27697	171.03077		
Corrected Total	11	43469.69370			

Coefficient of variation = 10.52190

3.16 ANOVA table for daily nitrogen voided in faeces.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	863.232500	431.616250	25.94	0.0002
Error	9	149.752397	16.639155		
Corrected Total	11	1012.984897			

Coefficient of variation = 12.05251

3.17 ANOVA table for daily nitrogen voided in urine.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	10248.22575	5124.11287	371.94	<.0001
Error	9	123.99119	13.77680		
Corrected Total	11	10372.21694			

Coefficient of variation = 10.12949

3.18 ANOVA table for daily average nitrogen retained.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	6291.827747	3145.913874	52.63	<.0001
Error	9	537.927686	59.769743		
Corrected Total	11	6829.755433			

Coefficient of variation = 14.36878

3.19 ANOVA table for daily average nitrogen retained as percent of intake.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	50.8484401	25.4242200	1.45	0.2844
Error	9	157.7184535	17.5242726		
Corrected Total	11	208.5668936			

Coefficient of variation = 9.463762

3.20 ANOVA table for daily average nitrogen retained as percent of digested.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	933.629616	466.814808	18.14	0.0007
Error	9	231.659673	25.739964		
Corrected Total	11	1165.289289			

Coefficient of variation = 7.929718

3.21 ANOVA table for final live weight of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	12402.60031	4134.20010	84.10	<.0001
Error	17	835.68541	49.15797		
Corrected Total	20	13238.28571			

Coefficient of variation = 2.107296

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	840.57705	420.28852	8.55	0.0027
Initial weight	1	10448.02888	10448.02888	212.54	<.0001

3.22 ANOVA table for total live weight gain of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	842.314593	280.771531	5.71	0.0068
Error	17	835.685407	49.157965		
Corrected Total	20	1678.000000			

Coefficient of variation = 14.60682

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	840.5770486	420.2885243	8.55	0.0027
Initial weight	1	1.4574504	1.4574504	0.03	0.8653

3.23 ANOVA table for average daily live weight gain of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Model	3	0.09509830	0.03169943	5.80	0.0064
Error	17	0.09298894	0.00546994		
Corrected Total	20	0.18808724			

Coefficient of variation = 14.96569

Source	DF	Type III SS	MS	F Value	Pr > F
Diet	2	0.09508074	0.04754037	8.69	0.0025
Initial weight	1	0.00042621	0.00042621	0.08	0.7835

3.24 ANOVA table for feed conversion efficiency of Bulls.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	4.86845801	2.43422901	0.67	0.5251
Error	18	65.60664170	3.64481343		
Corrected Total	20	70.47509971			

Coefficient of variation = 13.09393

3.25 ANOVA table for DM digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	276.3501949	138.1750975	52.15	<.0001
Error	9	23.8465982	2.6496220		
Corrected Total	11	300.1967931			

Coefficient of variation = 2.511547

3.26 ANOVA table for OM digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	238.6863353	119.3431676	64.44	<.0001
Error	9	16.6672264	1.8519140		
Corrected Total	11	255.3535616			

Coefficient of variation = 1.995236

3.27 ANOVA table for CP digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	599.9994814	299.9997407	90.01	<.0001
Error	9	29.9965903	3.3329545		
Corrected Total	11	629.9960717			

Coefficient of variation = 2.606275

3.28 ANOVA table for NDF digestibility coefficient.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	273.6409634	136.8204817	70.49	<.0001
Error	9	17.4678621	1.9408736		
Corrected Total	11	291.1088255			

Coefficient of variation = 1.938808

3.29 ANOVA table for average daily roughage DM cost.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	30.14981944	15.07490972	143.62	<.0001
Error	18	1.88937452	0.10496525		
Corrected Total	20	32.03919395			

Coefficient of variation = 10.79406

3.30 ANOVA table for average daily total DM cost.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	30.14981944	15.07490972	143.62	<.0001
Error	18	1.88937452	0.10496525		
Corrected Total	20	32.03919395			

Coefficient of variation = 7.757916

3.31 ANOVA table for average daily total feed cost per kg weight gain.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	84.6284179	42.3142090	28.53	<.0001
Error	18	26.6954547	1.4830808		
Corrected Total	20	111.3238727			

Coefficient of variation = 14.36228

3.32 ANOVA table for weight of bulls before fasting.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	1480.222222	740.111111	2.34	0.1777
Error	6	1900.666667	316.777778		
Corrected Total	8	3380.888889			

Coefficient of variation = 5.391594

3.33 ANOVA table for weight of bulls after fasting (slaughter weight).

Source	DF	SS	MS	F Value	Pr > F
Diet	2	1144.222222	572.111111	1.75	0.2524
Error	6	1964.666667	327.444444		
Corrected Total	8	3108.888889			

Coefficient of variation = 5.621637

3.34 ANOVA table for hot carcass weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	616.055556	308.027778	1.10	0.3924
Error	6	1683.500000	280.583333		
Corrected Total	8	2299.555556			

Coefficient of variation = 9.670019

3.35 ANOVA table for cold carcass weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	595.722222	297.861111	1.14	0.3799
Error	6	1564.833333	260.805556		
Corrected Total	8	2160.555556			

Coefficient of variation = 9.512126

3.36 ANOVA table for total lean meat weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	136.905689	68.452844	0.28	0.7675
Error	6	1484.658133	247.443022		
Corrected Total	8	1621.563822			

Coefficient of variation = 13.74361

3.37 ANOVA table for total carcass fat weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	109.0464000	54.5232000	5.54	0.0433
Error	6	59.0136000	9.8356000		
Corrected Total	8	168.0600000			

Coefficient of variation = 12.91671

3.38 ANOVA table for total bone weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	16.47075556	8.23537778	0.69	0.5374
Error	6	71.61280000	11.93546667		
Corrected Total	8	88.08355556			

Coefficient of variation = 10.92515

3.39 ANOVA table for hot carcass dressing percentage.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	30.44828183	15.22414091	2.17	0.1949
Error	6	42.01698992	7.00283165		
Corrected Total	8	72.46527175			

Coefficient of variation = 4.922557

3.40 ANOVA table for cold carcass dressing percentage.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	28.50628495	14.25314248	2.55	0.1578
Error	6	33.51114128	5.58519021		
Corrected Total	8	62.01742623			

Coefficient of variation = 4.485549

3.41 ANOVA table for lean meat to cold carcass ratio.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	9.50780555	4.75390278	0.41	0.6792
Error	6	69.08697501	11.51449583		
Corrected Total	8	78.59478056			

Coefficient of variation = 5.041392

3.42 ANOVA table for fat to cold carcass ratio.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	16.89135374	8.44567687	1.77	0.2492
Error	6	28.67344893	4.77890815		
Corrected Total	8	45.56480266			

Coefficient of variation = 15.26730

3.43 ANOVA table for bone to cold carcass ratio.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	1.37485314	0.68742657	0.11	0.8942
Error	6	36.21640555	6.03606759		
Corrected Total	8	37.59125869			

Coefficient of variation = 13.13269

3.44 ANOVA table for the ratio of lean meat to slaughter weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	8.46916584	4.23458292	0.51	0.6237
Error	6	49.70313037	8.28385506		
Corrected Total	8	58.17229621			

Coefficient of variation = 8.113236

3.45 ANOVA table for the ratio of fat to slaughter weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	7.98754614	3.99377307	4.06	0.0768
Error	6	5.90324575	0.98387429		
Corrected Total	8	13.89079189			

Coefficient of variation = 0.575025

3.46 ANOVA table for the ratio of bone to slaughter weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.23939704	0.11969852	0.07	0.9336
Error	6	10.32903032	1.72150505		
Corrected Total	8	10.56842737			

Coefficient of variation = 0.022652

3.47 ANOVA table for the lean meat to bone ratio.

ource	DF	SS	MS	F Value	Pr > F
Diet	2	0.12342693	0.06171346	0.14	0.8697
Error	6	2.59100838	0.43183473		
Corrected Total	8	2.71443531			

Coefficient of variation = 17.97279

3.48 ANOVA table for fat depth measurement.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.02666667	0.01333333	6.00	0.0370
Error	6	0.01333333	0.00222222		
Corrected Total	8	0.04000000			

Coefficient of variation = 23.57023

3.49 ANOVA table for rib-eye area measurement.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	152.8964222	76.4482111	1.53	0.2907
Error	6	300.0065333	50.0010889		
Corrected Total	8	452.9029556			

Coefficient of variation = 11.50112

3.50 ANOVA table for rib-eye area per 100 kg hot carcass weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	11.12052355	5.56026177	0.76	0.5061
Error	6	43.63983341	7.27330557		
Corrected Total	8	54.76035695			

Coefficient of variation = 7.599410

3.51 ANOVA table for tissue depth measurement.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	2.28666667	1.14333333	0.99	0.4243
Error	6	6.91333333	1.15222222		
Corrected Total	8	9.20000000			

Coefficient of variation = 21.46832

3.52 ANOVA table for omental fat measurement.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	2.73555556	1.36777778	7.28	0.0248
Error	6	1.12666667	0.18777778		
Corrected Total	8	3.86222222			

Coefficient of variation = 12.58065

3.53 ANOVA table for kidney fat measurement.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	2.08148889	1.04074444	6.67	0.0299
Error	6	0.93620000	0.15603333		
Corrected Total	8	3.01768889			

Coefficient of variation = 19.27926

3.54 ANOVA table for heart fat measurement.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.16746667	0.08373333	13.53	0.0060
Error	6	0.03713333	0.00618889		
Corrected Total	8	0.20460000			

Coefficient of variation = 10.63101

3.55 ANOVA table for carcass pH.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.20442222	0.10221111	0.55	0.6013
Error	6	1.10626667	0.18437778		
Corrected Total	8	1.31068889			

Coefficient of variation = 0.155965

3.56 ANOVA table for full GIT weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	673.555556	336.777778	5.46	0.0446
Error	6	370.000000	61.666667		
Corrected Total	8	1043.555556			

Coefficient of variation = 14.22039

3.57 ANOVA table for empty GIT weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	25.71486667	12.85743333	2.88	0.1326
Error	6	26.76233333	4.46038889		
Corrected Total	8	52.47720000			

Coefficient of variation = 9.339460

3.58 ANOVA table for liver plus bile weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.34560000	0.17280000	0.87	0.4648
Err					
Corrected Total	8	1.53340000			

Coefficient of variation = 11.96060

3.59 ANOVA table for spleen weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.02006667	0.01003333	0.34	0.7252
Error	6	0.17753333	0.02958889		
Corrected Total	8	0.19760000			

Coefficient of variation = 19.62139

3.60 ANOVA table for hind and fore legs weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.26346667	0.13173333	10.19	0.0118
Error	6	0.07753333	0.01292222		
Corrected Total	8	0.34100000			

Coefficient of variation = 2.038421

3.61 ANOVA table for head plus tongue weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	8.96888889	4.48444444	9.82	0.0128
Error	6	2.74000000	0.45666667		
Corrected Total	8	11.70888889			

Coefficient of variation = 4.220639

3.62 ANOVA table for hide plus tail weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	9.50000000	4.75000000	0.79	0.4953
Error	6	36.00000000	6.00000000		
Corrected Total	8	45.50000000			

Coefficient of variation = 10.57334

3.63 ANOVA table for lung and trachea weight.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.01555556	0.00777778	0.11	0.8935
Error	6	0.40666667	0.06777778		
Corrected Total	8	0.42222222			

Coefficient of variation = 8.808552

3.64 ANOVA table for meat moisture content.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	25.98222222	12.99111111	1.45	0.3070
Error	6	53.86000000	8.97666667		
Corrected Total	8	79.84222222			

Coefficient of variation = 4.578095

3.65 ANOVA table for meat DM percentage.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.42062222	0.21031111	1.56	0.2851
Error	6	0.80993333	0.13498889		
Corrected Total	8	1.23055556			

Coefficient of variation = 0.376782

3.51 ANOVA table for meat CP content.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	205.4630284	102.7315142	3.91	0.0818
Error	6	157.6419739	26.2736623		
Corrected Total	8	363.1050024			

Coefficient of variation = 8.125291

3.66 ANOVA table for *as is* CP percentage of carcass.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	14.14933268	7.07466634	2.67	0.1484
Error	6	15.91625471	2.65270912		
Corrected Total	8	30.06558739			

Coeff Var 7.508820

3.67 ANOVA table for meat Ether extract content.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	11.6734930	5.8367465	0.22	0.8087
Error	6	159.1865268	26.5310878		
Corrected Total	8	170.8600199			

Coefficient of variation = 14.18781

3.68 ANOVA table for *as is* EE percentage of carcass.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	3.90284388	1.95142194	0.33	0.7285
Error	6	35.04946571	5.84157762		
Corrected Total	8	38.95230959			

Coefficient of variation = 19.18010

3.69 ANOVA table for meat ash content.

Source	DF	SS	MS	F Value	Pr > F
Diet	2	0.63575556	0.31787778	1.89	0.2314
Error	6	1.01106667	0.16851111		
Corrected Total	8	1.64682222			

Coefficient of variation = 14.27554

Appendix 4 Survey questionnaire

1. General

Date----------------- H/hold No.--------- H/hold Name------------------------- Sex----
District----------------------------------- PA-----------------------------------
Family size: Male--------- Female-------- Total-----------
Occupation: Major-------------------------------- Minor---------------------------------

2. Land use

2.1 Farm size (ha)----------
2.2 Land utilization in 2004 (in ha) a) for cultivation----- b) for grazing--------
c) for Pasture crops------- d) For forest/perennial crop----- e) for others (specify)---

3. Area cropped (2003 & 2004) and crop production (2004 & 2005)

No.	Crop type	2003		2004	2004		2005
		Area Cropped (ha)	Variety used (local/ improved)	Yield (Qtl)	Area Cropped (ha)	Variety used (local/ improved)	Yield (Qtl)
1	Tef						
2	Wheat						
3	Barley						
4	Maize						
5	Sorghum						
6	Haricot bean						
7	Others (specify)						

4. Crop residue collection and storage

4.1 Indicate the collection and storage practices you undertake for each crop residues (tick):

No	The practices	Residue type						
		Tef straw	Wheat straw	Barley straw	Maize stover	Sorghum stover	H/bean haulms	Others (list)
1	Collect & store all in open air							
2	Collect & store all in shelter							
3	Collect & store only some							
4	Leave all on crop field							
5	Leave all on threshing place							
6	Leave some on crop field							
7	Others (specify)							

4.2 For those not collected & stored, which of the following are your reasons? (Rank):
a) no means of transport (-----) b) small quantity (-----) c) far from home (---)
d) lack of finance (-----) e) labour shortage (-----) f) to fertilize land (----)
g) Have no feed problem h) other (specify)-----------------------------------(------)

4.3 Which means you use to transport your crop residues you use?
a) labour----- b) Vehicle----- c) pack animals (name)----- d) others (specify)---------

4.4 Do you have crop residue storage problem? 1= No 2= Yes
If yes, indicate the major problems: 1= fire 2= rain 3= termites 4= others (name) ----

5 Crop residue handling and processing

51 Do you treat or process your crop residues before feeding to animals? 1= yes 2= No
If yes, indicate in the table which method you use for each crop residue (tick)

No	Type of residues	Chop	thresh	Soak in (name)	Chemical (name)	Spray with (name)	Bale	Others (------)
1	Tef straw							
2	Wheat straw							
3	Barley straw							
4	Maize stover							
5	Sorghum stover							
6	Haricot bean haulms							
7	Others(name)							

5.2 Indicate the presence & types of constraints to the use of crop residue processing methods (choose & fill):

Methods of improvement	Presence of constraints (present , Absent	The constraints (finance, access, labor shortage, lack of know-how, others : name)
Physical (chop, grind, etc)		
Bale		
Chemical (NaOH, Urea, Local)		
Others (name)		

6 Uses of crop residue and their left overs

6.1 For which of the following purpose you use your crop residues (rank as: 1= major, 2= moderate, 3= least):

No	Types of residues	Possible uses						
		Animal feed	fuel	Construction (name)	Mulch	Sale	mattress	Others (name)
1	Tef straw							
2	Wheat straw							
3	Barley straw							
4	Maize stover							
5	Sorghum stover							
6	Haricot bean haulms							
7	Others (list)							

6.2 Indicate the presence & uses of left over for each crop residue (Choose & fill)

	Residue type						
	Tef straw	Wheat straw	Barley straw	Maize stover	Sorghum Stove r	H/bean haulms	Others (name)
Left over presence (present, absent)							
Uses of left over (firewood, feeding, as fertilizer, not used, others :name)							

7 Livestock feed resources & feeding

7.1 When do you use the following feed resources ? (fill months for each season & tick):

No.	Feed resource	Dry season (-------------------months)	Wet season (-------------------months)
1	Natural pasture		
2	Improved pasture		
3	Crop residues		
4	Road side grazing		
5	Weeds & crop thinings		
6	Others (specify)		

7.2 Do you use supplementary feeds? 1= yes 2= no
If yes, indicate in the table the available supplementary feeds & their extent of use (1= most used, 2= moderately used, 3= least used)

No.	Type of supplement	extent of use	Names of each supplement type (in order of importance)		
			1	2	3
1	Oil seed cakes				
2	Milling by-products				
3	Forage legumes				
4	Browse plants				
5	Molasses				
6	Salt				
7	Minerals				
8	Others (specify)				

7.3 Indicate the presence & types of constraints to the use of supplementary feeds (choose & fill)

Type of supplements	Presence of constraints (present , Absent	The constraints (finance, access, labor shortage, land shortage, lack of know-how, others : name)
Oil seed cakes		
Milling by-products		
Forage legumes		
Molasses		
Others (name)		

7.4 Indicate the feeding system you employee for each crop residue (tick)

No	Feeding system	Residue type						
		Tef straw	Wheat straw	Barley straw	Maize stover	Sorghum Stove r	H/bean haulms	Other
1	Graze all in situ							
2	Collect, sore & feed alone							
3	Mix with (name under each)							
4	Spray with (name under each)							

7.5 Presence of crop residue feeding problems & type of the problems (choose & fill):

	Residue type						
	Tef straw	Wheat straw	Barley straw	Maize stover	Sorghum Stove r	H/bean haulms	Other
Presence of feeding problems (present/ absent)							
The problems (cause health problem, has bad smell, poor feeding value, others: name)							

7.6 Do you prefer one type of residue for one species of animal? 1= yes 2= No
If yes, which crop residues you prefer for each species (rank 1-3 for each species)

No	Types of residues	Rank (1= most, 3= least)			
		Cattle	sheep	Goat	Equine
1	Teff straw				
2	Wheat straw				
3	Barley straw				
4	Maize stover				
5	Sorg. stover				
6	Haricot bean haulms				
7	Others (specify)				

8. Generally, do you think you use your crop residues efficiently or there is some wastage?
   1= use efficiently 2= there is wastage
   If there is wastage what are the causes? (Rank):
   1= inability to collect (----) 2= improper storage (----) 3= nature of the residue (-----)
   4= others (name)---------------------------------- (------)

CURRICULUM VITAE

1. NAME: Tesfaye Alemu Aredo

2. BIRTH DATE: 18 January, 1963

3. BIRTH PLACE: Selale, North Shoa, Ethiopia

4. EDUCATIONAL BACK GROUND:

No.	Academic award	Place and country	year
1	Master of Science in Range Management	University of Nairobi, Kenya	1999
2	Bachelor of Science in Agriculture (Animal science)	Alemaya University of Agriculture, Ethiopia	1986
3	Ethiopian School Leaving Certificate	Fitche comprehensive high school, Selale, North Shoa, Ethiopia	1982

5. PROFESSIONAL STATUS: Agricultural researcher

6. WORK EXPERIENCE: Research planning and execution since 1986

7. OFFICE: Oromiya Agricultural Research Institute,
Adami Tulu Research Center
P. O. Box 35, Zeway
E-mail: feven563@yahoo.com