UNIVERSITY OF KWAZULU-NATAL

ECOLOGICAL BENEFITS OF *BRACHIARIA* GRASSES IN INTEGRATED CROP-LIVESTOCK PRODUCTION SYSTEMS IN RWANDA

MUTIMURA MUPENZI

2016

ECOLOGICAL BENEFITS OF *BRACHIARIA* GRASSES IN INTEGRATED CROP-LIVESTOCK PRODUCTION SYSTEMS IN RWANDA

By

Mutimura Mupenzi

(Eng. Agric. –Animal Production, UR; MSc Agric. – Grassland Science, UKZN)

A thesis submitted in partial fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

IN

ANIMAL SCIENCE

SCHOOL OF AGRICULTURAL, EARTH AND ENVIRONMENTAL SCIENCES

COLLEGE OF AGRICULTURE, ENGINEERING AND SCIENCE

UNIVERSITY OF KWAZULU-NATAL

PIETERMARITZBURG

South Africa

March 2016

DEDICATION

This thesis is dedicated to my wife Henriette Mukansonera and my daughters Anela Beza Mutimura, Bessy Asābe Mutimura and Caera Sheja Mutimura

ABSTRACT

A study was conducted with the broad objective to evaluate ecological benefits of *Brachiaria* grasses in integrated crop-stall-fed livestock production systems in humid and semi-arid region of Rwanda. The specific objectives of the study were: (1) To identify factors that determine household feed resource supply and willingness to plant improved fodder in humid and semi-arid regions of Rwanda; (2) To determine nutritive values of available feed resources used by smallholder farmers in Rwanda; (3) To determine biomass and nutrient productivity as well as cutting management of promising *Brachiaria* genotypes for semi-arid ecologies in Rwanda (4) To determine nutritional value of *Brachiaria* species, on stall-fed replacement dairy heifers with or without concentrate supplements; (5) To examine the biophysical and physiological basis that make *Brachiaria* grass a more palatable and nutritious forage with impact on lactation in dairy cows relative to Napier grass.

A structured questionnaire was administered to 204 households of semi-arid and humid environments and used to determine major livelihood options and characterise integrated crop-livestock production systems. Farming was the major livelihood strategy among households in semi-arid and humid areas. The diversity of livestock species including, dairy cattle among households were more in semi-arid than in humid environments. Milk yield was higher in Jersey than in other dairy cows under smallholder farm prevailing conditions. Logistic regression analysis showed that age, level of education and experience in livestock rearing of household head significantly influenced adoption of planted forages in smallholder farms in both areas. Farmers in semi-arid area were twice more likely to establish improved fodder species in farmland than those from humid areas. Napier grass and a variety of crop residues were the major feed resources in both the rainy and dry seasons in both areas.

Feed resource inventorying depicted a wide (n=24) species diversity from both on-farm and off-farm source five of which were unique to semi-arid areas. Chemical composition, contents of metabolisable energy (ME), organic matter digestibility (OMD) and neutral detergent fibre digestibility (NDFd) and rumen fermentation characteristics partitioning factor (PF) were highly variable, depicting variability in their efficiencies of utilisation in microbial functions and post-ruminal nutrient supply for maintenance and production.

Brachiaria genotype and cutting management study involved an evaluation of five cultivars (cv.) of *Brachiaria brizantha*, one cultivar of *B. humidicola*, two cultivars of *Brachiaria* hybrid and one cultivar of *Brachiaria decumbens* against Napier grass (*Pennisetum purpureum*) in an on-farm trial in a completely randomised block design (RCBD) with four replicates. Forage samples were collected at 60, 90 and 120 days after planting (DAP). Samples of each cultivar and age of cutting were analysed for concentration of dry matter (DM), crude protein (CP), organic matter (OM), neutral detergent fibre (NDF), minerals, *in vitro* apparent degradable dry matter (ivADDM), metabolisable energy (ME) and *in vitro* gas production (GP) kinetics. The DM, CP, OM, ivADDM and digestible OM increased from 60 to 90 DAP and declined thereafter. The NDF contents increased while CP contents decreased consistently with increase in age. Macro and micro-nutrient concentrations were also higher at 90 DAP. The ME differed ($P<0.05$) among grasses and between DAP. The GP of grasses cut at 90 DAP was higher than the other two DAP. The highest yield cultivars were Basilisk, Marandú and Piatá. The optimum age of cutting was species specific, but overall cutting at 90 DAP was recommended.

In a study on changes in growth performance of crossbred dairy heifers under cut-and-carry feeding system, sixteen crossbred (Ankole × Jersey) heifers (Average body weight 203±35 kg) were randomly allocated to two dietary treatments. *Brachiaria* hybrid cultivar Mulato II with 2 kg/day of commercial concentrates (MCC) and Napier grass (*Pennisetum purpureum*) with the same supplement (NCC) were fed to heifers for 12 weeks. Feeds, mineral lick and water were provided *ad libitum*. Absolute daily dry matter intake (g DM/day) and relative intake (g/kg of metabolic body weight - $BW^{0.75}$) were higher in heifers fed on MCC than in heifers fed on NCC ($P<0.001$). Feed conversion ratio was lower

(P<0.001) in MCC than NCC diets. Final body weight (FBW) and body weight gain (BWG) did not differ between the two groups of heifers (P>0.05). Average daily weight gain (ADWG), also not differed significantly (P>0.05).

To determine biophysical factors affecting quality of *Brachiaria* sp. and impact on performance in crossbred dairy cattle, a feeding trial was conducted using 40 lactating crossbred (Ankole × Holstein Friesian) in second parity and in 10–15 days in milk in collaboration with 40 farm households. Experimental diets were *Brachiaria brizantha* (cv. Piatá) and Napier grass (*Pennisetum purpureum*–used as control) as sole or mixed forage with *Desmodium distortum* (70:30 w/w fresh basis). Chemical analysis showed that Napier was low in DM, OM, and CP, but higher in NDF and ADF than the test *Brachiaria* (P<0.001). The composition varied with duration of the experiments (P<0.05) but not across farms (P>0.05). Voluntary intake did not differ across diets (P>0.05) but was consistently higher in Piatá-based than in the Napier-based diets. Average milk production with higher in cows fed on the test *Brachiaria*-based than in the Napier-based diets (P<0.001). Cows fed grass-legume mixes recorded higher milk than sole grass diets. Digesta flows and degradation rates were also rapid in grass-forage than in sole grass diets (P<0.001).

The most promising cultivars identified from this study were cv. Basilisk, cv. Marandú and cv. Piatá, because of its nutritional characteristics as well as nutrient yields which were higher and more comparable with Napier grass than other grass cultivars. The feeding trial with replacement dairy heifer proved that depriving these animals the nutritional advantage associated with selectivity in forages did not compromise the nutritional value cv. Mulato II; hence, this cultivar can effectively be used as quality fodder for cut-and-carry dairy system. Digestive physiology of Piatá-based diet provided a strong, but indicative evidence of the differences in palatability, voluntary intake and impact on lactation between cv. Piatá and Napier grass. These differences might have associated with physical effectiveness of NDF.

DECLARATION

I, Mupenzi Mutimura declare that the results reported in this thesis, except where otherwise indicated, are my original research in partial fulfilment for the award of Doctor of Philosophy in Animal Science. I conducted the research at the University of KwaZulu-Natal, and in semi-arid and humid zones of Rwanda under principal supervision of Professor Ignatius V. Nsahlai, and co-supervision of Dr Cyprian Ebong of Rwanda Agriculture Board (RAB) and Dr Idupulapati M. Rao of International Centre for Tropical Agriculture (CIAT).

This thesis has not been submitted for any degree or examination at any other university. It does not contain other persons' data, picture, graphs or other information, unless specifically acknowledged as being sourced from other persons. It does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and the references sections.

Signed………………………………… Date……………..…./……..…../2016
Mupenzi Mutimura (Candidate)

Signed………………………………… Date………………../…..……../2016
Professor Ignatius V. Nsahlai (Supervisor)

Signed………………………………… Date………......…../…………../2016
Dr. Cyprian Ebong (Co-Supervisor)

Signed………………………………… Date………....…../…………..../2016
Dr. Idupulapati M. Rao (Co-Supervisor)

ACKNOWLEDGEMENTS

Almighty God to Him comes all intellects and blessings.

I would like to express my gratitude to those who contributed to the achievement of this thesis:

My acknowledgement goes to the Swedish International Development Agency (Sida) for financial support under "*Brachiaria* grass for improving livestock production in east Africa- Funded project" through the Biosciences for Eastern and Central Africa (BecA), International Livestock Research Institute (ILRI-BecA), Nairobi, Kenya.

I thank the Rwanda Agriculture Board (RAB) for study leave to pursue this PhD degree programme.

I would like to express my sincere grateful to Professor Ignatius Verla Nsahlai, who accepted to supervise this thesis. His guidance, thorough scientific quality and humility have anchored and created in me an encouragement which culminated not only in finishing this thesis but also in my further career development.

I cannot get words to express my gratitude to Dr. Idupulapati M. Rao, who helped me to get PhD fellowship from the Sida funded project and accepted to co-supervise this thesis. Thank you so much for your kindness and humility. Dr. Rao together with Dr. Segnet Kelemu, the Director General of International Centre for Insects Physiology and Ecology (ICIPE), and Dr. Appolinaire Djikeng, the Director of BecA, thank you so much for giving me this PhD opportunity.

I would like to express my gratitude from the bottom of my heart to Dr. Cyprian Ebong, who mentored me in animal nutrition, especially rumen physiology and accepted to co-supervise this thesis. His humility and attitude for hard work provided me the impetus to carry on against odds and has set my present and future career development.

I thank my brother Dr. Gatarayiha Mutimura Celestin, who introduced me for the first time at the University of KwaZulu-Natal where I completed my postgraduate studies. His encouragements have assisted me to achieve this PhD thesis.

I am in debt to Rwandese colleagues at UKZN, especially Dr. Milindi Sibomana and Mr. Faustin Habyarimana, who helped me whenever I came to the University.

I thank my colleagues in the department of Animal Science, especially Mr. Nourou Abdou and Mr. Sylvester Fomum for their encouragements during our studies.

I thank Dr. Nasleldine Basha and Dr. Fabian Fon, for demonstrating to me how to use automated gas production and Dr. Titus Zindove, for assisting me in survey data analysis.

Thank you very much Ms. Sithembile Ndlela for assisting me in minerals and markers analysis using ICP machine. Your time in operating the ICP has contributed to this achievement.

I would like to express my sincere gratitude to Mr. Pierre Celestin Hitimana, Mr. Andre Birasa Lussa and Mr. Joseph Gasana my colleagues at RAB, who helped me during the on-farm experimental establishment and data collection. Thank you so much Mr. Hitimana for helping me in markers' administration and faecal sample collection.

I am indebted to farmers who accepted me, provided the animals and premises for research, and time to take records on feeds and milk on their farms. Without these contributions, this thesis would not be completed in time.

Finally, I cannot get words to express gratitude to my wife Henriette Mukansonera who, in taking care of our family during my stay at the University gave me the moral stamina which prevailed above the stressful of thesis writing and being away from home. My daughters Anela Beza Mutimura, Bessy Asābe Mutimura and Caera Sheja Mutimura, thank you very much for your smile and love which gave me the fortitude to finish this thesis. I promise you that I will never leave you again for such a long period.

Benefaciat vobis Deus omnia!
(May God bless you all!)

Mupenzi Mutimura

THESIS OUPUTS

Published and under review papers

1. Mupenzi Mutimura, Cyprian Ebong, Idupulapati Madhusudana Rao and Ignatius Verla Nsahlai, 2015. Nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. Tropical Animal Health and Production, 47, 1131–1137.
2. Mupenzi Mutimura, Cyprian Ebong, Idupulapati Madhusudana Rao and Ignatius Verla Nsahlai, 2016. Change in growth performance of crossbred (Ankole × Jersey) dairy heifers fed on forage grass diets supplemented with commercial concentrates. Tropical Animal Health and Production, 48, 741–746.
3. M. Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai, 2015. Effect of cutting time on agronomic and nutritional characteristics of nine commercial cultivars of *Brachiaria* compared with Napier grass during establishment under semi-arid conditions in Rwanda. Grassland Science (Under review, Manuscript ID: GRS-2015-0077).

Conference abstracts

1. M. Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai, 2015. Improving cut-and-carry forage feeding systems in Rwanda: Intake and body weight change of crossbred (Ankole × Jersey) dairy heifers fed on *Brachiaria* grass and Napier grass based diets. Presented at 48th South African Society of Animal Science (SASAS) Congress. From 21 – 23rd September 2015, Empangeni, KwaZulu-Natal Province. Book of Abstract, pp, 48.
2. M. Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai, 2015. Factors influencing current and future prospects for intensive dairy production in Rwanda. The XXIII International Grassland Congress at Delhi NCR, India, from 20–24th November 2015. Abstract, No. 851.
3. M. Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai, 2015. Agronomic and nutritional characteristics of selected *Brachiaria* hybrids and varieties harvested at three stages of

growth. The XXIII International Grassland Congress at Delhi NCR, India, from 20 – 24th November 2015. Abstract, No. 972.

To be submitted

1. M. Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai. Effect of supplementing *Brachiaria brizantha* cultivar Piatá and Napier grass with or without *Desmodium distortum* on intake, kinetic passage rate and milk production of crossbred dairy cows.
2. M. Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai. Seasonal variation of livestock feed resources in semi-arid and humid environments.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1: Introduction

1.1. Background and Justification

Rwanda is a land locked country situated in Eastern Africa. With its population of 10.5 million and area of 26,338 km^2 and average density is 310 persons per km^2 in 2012, the country is the most highly populated nation in the sub-Saharan Africa (NISR, 2012a). It has a tropical climate with average temperatures of 19.8°C in 1971 and 20.7°C in 2007 during the day and 15^{o}C at night. Most of the country receives a bimodal rainfall in excess of 1,000 mm where the long rains occur in March–May and short rains in September–December.

Rwanda is a predominantly agrarian economy where agriculture contributes about 39% of the gross domestic product (GDP), approximately 80% of foreign exchange earnings and employs about 88% of the population, especially women. This scenario is typical of Africa nations where the sector contribution to GDP is estimated at 40%, and approximately 75% of the population depend exclusively on income from agriculture and agribusiness (Machuka, 2003). Livestock agriculture is the most important agricultural land use system in the world with grasslands covering 25% of land surface and contributing to the livelihoods of more than 800 million people (Steinfeld et al., 2006). Forage/grassland based crop-livestock systems represent about 70% of agricultural land use in the tropics. Over the past 30 years, meat and milk consumption in developing countries has grown three times as fast as in developed countries with an additional market value of US$155 billion. Smallholder mixed crop-livestock systems provide over 50% of the world's meat and over 90% of its milk. Smallholder crop-livestock systems are the most important livestock systems in developing countries (Herrero et al., 2010). One major dichotomous constraint to livestock production in developing countries in the tropics is inadequate quantity and quality of forages to feed livestock. Poor grazing land management and a lack of productive and adapted forage species to biotic (pests and diseases) and abiotic (edaphic and climatic) stress factors (Miles et al., 2004) are the other challenges. Nutrient depletion and improper management of forage options lead to reduced livestock production, accentuates the impacts of climate change.

Mindful of arable land resource constraints, the government of Rwanda has adopted intensification and crop-livestock integration as the driving paradigm for agricultural development to meet current and future food and nutrition security in sustainable production systems. Two major programmes for intensification are the "Crop Intensification Programme (CIP) and One cow per poor family–GIRINKA". CIP focuses on the major staple crops including cereals and non-grain starchy staples (root and tuber crops and bananas). GIRINKA focuses on dairying for household nutrition and income security. A recent programme on Livestock Intensification Programme (LIP) in the formative stage envisages a wholesome integration where commensurate investments will be directed all livestock commodity value chains to meet the national transformative growth of the economy. However, all indications are that cattle will remain the dominant feature of the livestock subsector in Rwanda for a foreseeable future. These policy initiatives translate into enormous challenges for feed resource development to produce sufficient fodder to meet the demand for the current and future livestock numbers that the country will require for meeting the domestic and export market demands for livestock products from smallholdings. Currently, land holdings do not exceed 0.5 ha on average (Mpyisi et al., 2003). Crop cultivation is progressively encroaching on grazing areas with increasing human pressure. This expansion is not likely to displace cattle because, since 2006 the Government of Rwanda has been distributing dairy cows to poor family under "One cow per poor family programme". It was planned that by the end of year 2012; 368,400 dairy cows would have been distributed to poor farmers for milk and manure production (MINAGRI, 2006). Even without these policies and programme, intensification remains a pertinent issue. This is because according to the Boserup theorem of autonomous intensification, livestock biomass expansion is a self-actualising process that is catalysed by human population growth and expansion of arable agriculture. In the context of animal source food production, intensification implies exploiting the attributes of available plant genetic resources (PGR) and animal genetic resources (AnGR) in order to maximise land use efficiency in food and feed production and feed efficiency in meat and milk production.

Hence, the key research agenda is to develop the optimal combinations of feed and animal genetic resource bases that ensure sufficient production of meat and milk in Rwanda to meet current and future demands in the domestic and export market, while ensuring sustainable environmental health of the country.

1.2. Problem statement

The world's agricultural system faces a great balancing act. By 2050, it should simultaneously produce far more food to feed a population expected to reach 9.3 billion, provide economic opportunities for millions of rural poor, especially women who depend on agriculture, and reduce environmental footprints associated with efforts to sustain food and nutrition security. Those impacts include the conversion of natural ecosystems and high greenhouse gas (GHG) emissions. While the urgency to address these concerns vary from one country to another, Rwanda can no longer afford to increase agricultural production by expanding the area under cultivation (Mugabo et al., 2013 unpublished). Therefore, the government has adopted CIP and crop-livestock integration in order to produce increasingly more plant and animal-source food from increasingly less land. Implementation of CIP has enabled the agricultural sector to achieve targets for millennium development goals (MDG), in consonance with comprehensive Africa agriculture development (CAADP) and Vision 2020 including good governance and efficient State, skilled human capital, vibrant private sector, world -class physical infrastructure and modern agriculture and livestock which are oriented towards competitive regional and global markets (GoR, 2000). However, the gap between protein and lipid intakes and World Health Organisation (WHO) recommendation needs to be improved (World Bank, 2011).

Despite impressive success, especially since 2006, poverty remains a very pertinent problem to tackle in Rwanda. Poverty levels still differ among provinces, among districts within provinces and among households in a district. No significant poverty reduction was recorded in 17 out of 30 districts. Overall more than 4.5 million people lived below minimum (USD113.6 /year) consumption threshold of USD 161.6 in 2011. The poorest income groups are farmers and those dependent on providing agricultural labour for livelihood (NISR, 2012b).

In the context of poverty, livestock, particularly ruminants are controversial items in the agricultural development agenda. They are accountable for several dimensions of environmental degradation ranging from de-vegetation, desertification, erosion of soil, genetic diversity, to global warming through GHG emissions (carbon dioxide, methane and nitrous oxide). However, the economic and social benefits of livestock to poor people outweigh the negative impacts on the environment; and most of which can be mitigated through improved forage options and animal husbandry practices. Therefore, an alternative thesis advocates for integration of livestock and entire Animal Genetic Resources into environmental service sector as "insurance covers" for the unpredictable future.

The role of livestock in poverty reduction programmes premises on projected increase in consumption of livestock products and services during the 21st century, especially in developing countries including sub-Saharan Africa (Delgado et al., 1999). The key drivers in consumption include the consistent increases in population size, urbanisation and disposable incomes. The key challenge is how to enable resource poor livestock owners respond to the market incentives and exit from poverty.

The most critical technological challenge to livestock production in sub-Saharan Africa is how to establish and maintain a sustainable forage resource base to accommodate the desired livestock units and meet the increasing market demands in milk and meat products. Feed resource constraints are severe in arid and semi-arid ecologies as well as intensive crop-livestock systems on small land holdings in humid areas. The problem is aggravated by the progressive increases in global temperatures and climate variability. Projections indicate that the impact of global warming will be severe in the arid and semiarid ecologies in East and Central Africa, especially the transition hotspots in the highlands and the most affected people will be the resource poor households with limited capacity to adapt to climate change and variability (Thornton et al., 2007).

Intuitively, crop-livestock integration is the logical strategy for sustainable food futures in Rwanda because integration promotes reciprocal nutrient flows between crop and livestock when manure feeds crops and crop residues feed animals. However, with emphasis on cereals under CIP, the quality of crop residues is low. Fermentation of poor quality roughages promotes enteric methane emission, which over-compromises the low nutritional benefit to animals. In dry areas of Rwanda, crop failures are eminent, but unpredictable due to climate variability. Therefore, overdependence on crop residues will compromise efforts towards sustainable food futures. Reciprocating nutrient flows between crops and livestock are in themselves inherently unsustainable because of nutrient losses in animal and crop off-takes outside the production system. Therefore, alongside crop residues, improved forage species, including *Brachiaria* grasses, will remain indispensable components of the feed value chain in the country.

Because of their importance in the provision of high quality feeds to the animal, forages can be regarded as crops of importance among conventional food crops (Mulama, 2009). Of pivotal importance is the utilisation of forage crops tolerant to temperature and water stress, quality attributes including yields and nutritional values, and feed efficiency and reduction of enteric methane emissions while sequestrating significant amounts of carbon in soil (Bodas et al., 2008).

Improved *Brachiaria* grasses offer an advantage of sequestering large amounts of carbon on a scale similar to that of forests with the possibility of reducing emissions of N_2O and CH_4 per unit of livestock product. In addition, some of improved *Brachiaria* grasses (e.g. cultivar Mulato II) have ability to sustain productive growth in areas of prolonged dry period in comparison to other grasses (Cardoso et al., 2015). If these grasses are widely integrated into mixed crop-livestock systems, the mainstay of sustainable food futures of these practices could reduce trade-off between food security and environmental costs associated with rising livestock production and consumption in the developing world. Although African food shortages are widely publicised worldwide with the unpleasant and often derogatory sentiments of the continent, the association of food insecurity and feed insecurity for animals have largely been a perfunctory issue. This neglect is partially responsible for the endemic food and nutrition insecurity, especially in sub-Saharan Africa.

Farmer participatory evaluations conducted on feed resources in Rwanda indicated that livestock activities were shared between genders, but certain activities (e.g. milking cows, animal shed construction) were intended for males due to the cultural beliefs and number of cattle and the type of cattle owned by farmers. These were the important factors for wealth ranking and status among the community (Mutimura and Everson, 2012a, b). The farmer preference rankings confirmed that overall Napier grass was the major fodder crop used followed by some indigenous species and crop residues. Scores for availability, quality and quantity of feeds showed a shortage of livestock feed resources indicating a need for suitable forage species to be integrated in mixed crop-livestock farming systems. Although major feed resources used by smallholder farmers in wet and dry seasons have been inventoried (Lukuyu et al., 2009; Mutimura and Everson, 2011; Kamanzi and Mapiye, 2012; Mutimura et al., 2013a Klapwijk et al., 2014), there was, however, no information on nutritive values of these feeds to inform decisions on the choices of combinations feed items for optimal animal performance across seasons of the year.

Brachiaria grasses provide opportunities to address the challenges of shortages of quality of animal feed. However, there is need to identify the most productive and adapted *Brachiaria* grass among a wide range of genotype and determine the most appropriate cutting management for integration in the intensive livestock system. Most of the information on the quality of *Brachiaria* sp. and cultivars has been generated from open grazing trials where selectivity for most nutritious botanical fractions is not compromised by chopping and restricted feeding to save feed. There is no empirical evidence that this inhibition does not compromise voluntary intake and value for animal production that is associated with *ad libitum* feeding (Zemmelink and t'Mannetje, 2002). Studies have shown high farmers' preference of *Brachiaria* species and cultivars in Rwanda based on real or perceived attributes of palatability and improved lactation performance (Mutimura and Everson, 2012a) and these perceptions have not been empirically validated. High crude protein (CP) and low neutral and acid detergent fibres (NDF and ADF) and high mineral contents are good indicators of forage quality. Nevertheless, the comparison of chemical analyses often show similar range of nutrient profiles in *Brachiaria* and Napier grasses. This observation suggests that better palatability, voluntary intake and improved performance in animals fed *Brachiaria* sp. than in animals fed Napier grass is associated with other factors than the concentrations for chemical constituents. Forage legumes are ideal supplements for high milk yielding cows because the low nitrogen found in most tropical grasses seems to be a limiting factor in livestock production (Abreu et al., 2004; Mupangwa et al., 2010). A number of leguminous forages have been evaluated and found adapted to different regions in Rwanda (Mutimura et al., 2013b). Nutrient dynamics, which refer to nutrients required and absorbed for increasing animal productivity (Dijkstra et al., 2008) differ among legume species (Tibayungwa, 2010). Therefore, there is need to provide support tools for choice of *Brachiaria* grasses and legume combinations that optimises nutrient dynamics for sustainable livestock productivity.

1.3. Objectives

The goal of the study was to increase the contribution of *Brachiaria* grasses to food, nutrition and income security through poverty reduction. The purpose was to increase milk yield through increases in quantity and quality of feeds in the smallholder dairy farms. The strategic objective was to evaluate ecological benefits of *Brachiaria* grasses that are integrated into crop-livestock production system through individual livestock farmers or communal dairy feedlots. The specific objectives were:

1. To determine factors that determine household feed resource supply and willing to plant improve fodder;
2. To identify/inventory types, sources and nutritional values of ruminant feeds in the humid and semi-arid ecologies of Rwanda;
3. To determine biomass and nutrient productivity as well as cutting management of promising *Brachiaria* genotypes for semi-arid ecologies on Rwanda;
4. To determine nutritional value of *Brachiaria* sp., on stall-fed replacement dairy heifers with or without concentrate supplements*;*
5. To determine the biophysical and physiological factors associated with voluntary intake and lactation performance of crossbred dairy cattle fed *Brachiaria* grass and Napier grass as sole feed or mixed with forage legume.

1.4. Thesis structure

This thesis is structured in eight chapters. The first chapter describes the background and justification of this study. Chapter 2 deals with review of the literature, especially on the crop-livestock integration, feeds and feeding systems in smallholder farms as well as dairy production on tropical grass. Chapter 3 describes seasonal variation of livestock feed resources in semi-arid and humid environments of Rwanda. Chapter 4 shows the nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. Chapter 5 deals with agronomic and nutritional characteristics of nine selected *Brachiaria* hybrids and varieties at different harvesting ages. Chapter 6 shows change in intake and growth performance of crossbred dairy heifer fed on *Brachiaria* grass in comparison with Napier grass as basal diets under cut-and-carry feeding system. Chapter 7 shows the effect of supplementing *Brachiaria* grasses and Napier grass with or without *Desmodium distortum* on kinetic passage rates and milk yield of crossbred dairy cows under smallholder farm prevailing conditions. Finally, chapter 8 gives general discussion, conclusions and recommendations.

Chapter 2: Literature review

2.1. Introduction

The ever-increasing human population and their high demand for animal protein, especially from meat and milk will depend on better utilisation of available feed resources by the ruminant livestock for improving household food security and income (Kabi and Bareeba, 2008). Among feed resources, forage crops, especially grasses have shown unique characteristics in different agricultural systems. They can be grown in harsh environments, utilised as functional components in providing environmental services in soil erosion control and greenhouse gas emission mitigation efforts (Bear and Green, 1994) and income generation as basic animal feed (Sanderson et al., 1996; Wright and Turhollow, 2010). Perennial grasses, including *Brachiaria* grasses can accumulate up to 1.1 Mg/ha/year of carbon stock in the soil (McLaughlin and Walsh, 1998), which improves soil productivity and nutrient cycling and mitigate emissions impacts of GHG (McLaughlin and Kszos, 2005; Vagen et al., 2005). Grasses are the most important vegetation in the plant kingdom, with more than 600 genera and 7,500 species (Bear and Green, 1994). They can adapt to diverse ecologies, especially tropical grasses due to their physiology and root systems. Most tropical grasses are C_4 plants with photosynthetic pathway for efficiency for water utilisation, and enhanced tolerance to drought as well as pests and diseases through symbiotic association with fungal endophytes (Malinowski and Belesky, 2000).

In smallholder farms, perennial grasses are important for erosion control and provision of fodder for stall-fed ruminants. When well established, grasses reduce the cycle of replanting which causes soil loss and degradation (McLaughlin and Walsh, 1998). These are important ecologically benefits of plants in farming systems because they are components of “win-win” packages for climate smart intensification for sustainable livestock agriculture.

Historically, sustainability has been regarded as an economic issue where sustainable systems were considered as profitable production units of affordable foods and agricultural products. This sustains the incentive to produce and the willingness to buy which are the key factors that fosters the relationships between producers and consumers. However, current states of knowledge depict sustainable production system as socially equitable, economic viable, and ecologically sustain units of production and consumption (Bauman and Copper, 2011; Jaeger-Erben et al., 2015; Haileslassie et al., 2016). Critical researches on the sustainability of resource management have been conducted in integrated cropping system where cereal-legume-food staples are planted in rotation for derive soil improvement from nitrogen (N) fixation in sub-Saharan Africa (Sanginga et al., 2003; Singh et al., 2003). Vanlauwe and Giller (2006) contested the hyped importance of such interventions for sustainable production because of imbalances in trade-offs in unrecoverable nutrient losses in the harvested grains for food. Except a few cases where forages have been used in smallholder farms of Southeast Asia and West Africa (Roothaert et al., 2003; Singh et al., 2003), there is little evidence of benefits, contested or otherwise, from forage grass like *Brachiaria* grasses in mixed crop-livestock farming systems in sub-Saharan Africa. With the controversy on the importance of conservation agriculture on labour productivity in smallholder farms (Giller et al., 2009), real value of grasses can be perceived in the context of their contribution in erosion control; functionality in the provision of environmental services, and feed for ruminants and coprophagic livestock.

2.2. Farming systems

In Rwanda, more than 60% of the households cultivate less than 0.5 ha of land, and more than a quarter cultivate less than 0.2 ha and most of the land is acquired by inheritance (Mpyisi et al., 2003). The standard of living is strongly related to the size of landholding, with those holding the least land generally being the poorest (MINECOFIN, 2007). With the inherent low soil fertility coupled with intense erosion, it is not easy to cope but this will require major strategies for improving nutrient cycling. To achieve this objective, crop-livestock systems are considered as one of the best options (Stangel, 1993).

Agricultural productivity needs to increase income of poor rural farmers while supplying food to the growing urban population in the developing countries (Upton, 2004). Due to an increase in human population, demand for livestock products will be increased (Thornton, 2010). In Rwanda, the livestock sub-sector contributes up to 12% of national GDP (NISR, 2012a). Livestock activity has increased from 2005 to 2013 (Figure 2.1 a, b), where number of livestock has increased as well as livestock products (Figure 2.1c, d; NIRS, 2014). The tremendous increase in milk yield (Figure 2.1c) is due to increased dairy cows imported and distributed to poor farmers by government institutions and NGOs under "one cow per poor family programme" introduced since 2006 by the government of Rwanda (RARDA, 2006).

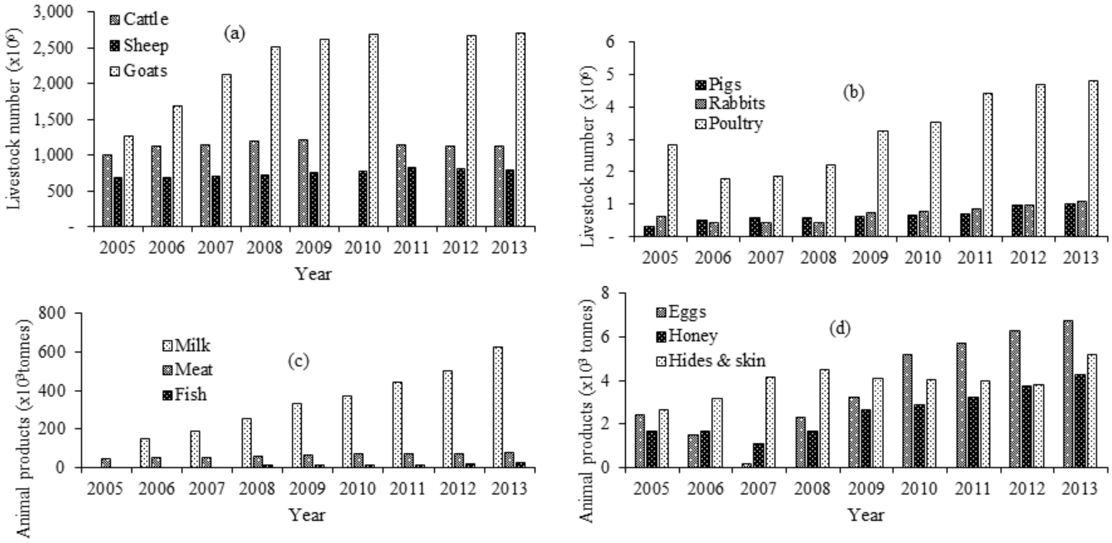

Figure 2.1: Trends of ruminant (a) and mono-gastric (b) livestock number as well as animal products (c, d) in Rwanda from 2005 to 2013 (Adapted from NISR, 2014)

2.2.1. Agricultural production

In sub-Saharan Africa, agricultural production is the lead source of income that the population depends on and the most production being with crops (Schlenker and Lobell, 2010). Crop production in the tropics is hindered by over cultivated land and removal of soil nutrients during crop harvesting. It is expected that fertiliser utilisation in Africa will increase to 6.9 MT of N, P_2O_5 and K_2O by 2020 for crop productivity to increase annually (Vlek et al., 1997). In Rwanda, agriculture contributes up to one third of the country's GDP and it is the major economic activity for many rural families. Mindful of arable land resource constraints, the Government of Rwanda has adopted crop intensification programme (CIP) as the paradigm for agricultural development.

The two major foci of agricultural production are CIP and dairy production. Dairy production needs good quality feed resources to be available although these are not easily affordable by smallholder farmers practising zero grazing where cattle are fed by cutting and carrying forages to a cowshed from small land size (RARDA, 2006). For this reason, in Rwanda, crop cultivation is progressively encroaching on grazing areas due to increasing human pressure.

2.2.2. Livestock production

Globally, agriculture provides livelihood more than any sector. The livestock sub-sector contributes to livelihoods of approximately one billion people, especially in the developing countries with 40% of agricultural outputs (Peters et al., 2012). For the last five years, livestock is the faster growing subsector of the economy in developing countries where it contributes up to 33% of the GDP (Thornton, 2010). Livestock have been important in sustaining crop production in different agricultural production systems, especially in infield and outfield of Western Europe and in other areas of the world (Schiere et al., 2002). This is because draught power and manure were used for land cultivation and crop fertilisation, respectively. In many countries of Asia, livestock contribute in increasing crop production, income as well as maintaining sustainability of cropping systems (Devendra and Thomas, 2002).

Since the last 20 years, milk production has been increasing, and countries like India ranked second world wide (FAOSTAT, 2011) through crop-livestock integration. This practice mitigates the impact of arable agriculture expansion and reduce grazing land by increasing the efficiency of land and nutrient use for improved crop and livestock productivity while reducing nutrient losses (Swanson and Miller, 2008).

Livestock production is a prominent agricultural land use in the world with grasslands covering 25% of land surface and contributing to the livelihoods of more than 800 million people (Steinfeld et al., 2006). Forage grassland based crop-livestock systems represent about 70% of agricultural land use in the tropics. Over the past 30 years, meat and milk consumption in developing countries has grown three times as fast as in developed countries with an additional market value of US$155 billion. Smallholder mixed crop-livestock systems provide over 50% of the world's meat and over 90% of its milk. These are the most important livestock systems in developing countries (Herrero et al., 2010).

A major constraint to livestock production in smallholder farms in the tropics is the inadequate quantity and quality of forage produced. Poor grazing land management and lack of suitable forage options that are better adapted to biotic (pests and diseases) and abiotic (edaphic and climatic) stress factors contribute to low productivity (Miles et al., 2004). Nutrient depletion and inadequate management of forage options and grazing lands lead to reduced livestock production, particularly in the face of climate change. Although livestock have a poor image of increasing global warming through methane (CH_4) emissions, pastures grown to feed livestock could mitigate CO_2 emissions by increasing carbon accumulation in plant and soil up to the same level as forests (World Bank, 2010).

2.3. Feeds and feeding in smallholder farms

In many developing countries including sub-Sahara African countries, land scarcity has dictated the adoption of mixed crop-livestock as the agricultural farming system. In this system, quantity and quality of animal feed decrease because of shrinking of grazing land (Delve et al., 2001). In small farms of developing countries, the fibrous by-products resulting from crop cultivation constitute a major source of nutrients for animal production (Table 2.1) and they form the principal feed of livestock during the dry seasons (Williams et al., 1997). In Rwanda, livestock has become labour intensive as the land for grazing is devoted to cropping. Dairy animals are sharply increasing while beef sector development is beginning to attract policy attention. In the face of climate change, these two production domains are threatened by the lack appropriate feeds and water, especially during the dry season. During this period, livestock owners utilise non-conventional feeds like banana stems, local brewer residues just to name few as coping strategies (Mutimura and Everson, 2011).

Table 2.1: Livestock production systems and animal feed resources in selected countries and areas

Production systems	Areas	Grassland/ Rangeland	Fodder crops	Crop residues	Concentrates
Livestock-grassland (temperate zones, tropical highlands)	Mongolia, Parts of China, South America, East Africa	●●●			
Livestock-grassland (humid/sub humid tropics)	Latin America and the Caribbean (lowlands)	●●●			
Livestock-grassland (arid, semiarid tropics)	Parts of sub-Saharan Africa, West Asia-North Africa	●●●		●	
Mixed crop-livestock (rain-fed, temperate zones, tropical highlands)	Northeast Asia, Parts of East Africa, Andean Latin America and the Caribbean (Ecuador, Mexico)	●	●●	●●	●
Mixed crop-livestock (rain-fed, humid, sub-humid tropics)	Southeast Asia, Latin America and the Caribbean, sub-Saharan Africa	●	●	●●●	●
Mixed crop-livestock (rain-fed arid, semi-arid tropics)	West Asia-North Africa, West Africa, South Asia northeast Brazil	●●	●	●●●	●
Mixed crop-livestock (irrigated, temperate zones, tropical highlands)	East Africa, Parts of China	●	●●	●●	●
Mixed crop-livestock (irrigated; humid/sub-humid tropics)	Parts of southeast Asia (Philippines, Vietnam)		●	●●●	
Mixed crop-livestock (irrigated, arid, semiarid tropics)	West Asia-North Africa, South Asia, Mexico		●●	●●●	

Source: Adapted from Seré et al. (1995)

●: The number of dots indicates the degree of importance of each animal feed resource in different countries and areas

In Rwanda, status of feed resources has depicted a diversity of feedstuffs farmers use to feed their animals. The major feed is Napier grass (*Pennisetum purpureum*) which makes up to 20% of feeds fed to cattle while crop residues, especially maize stovers, are also among major feed resources (Mutimura et al., 2013a). Napier grass has also been reported to be a major feed resource in smallholder farms of Kenya where it is grown largely on small plots and contour bands to protect soil erosion (Nyaata et al., 2000). In many east African countries, farmers rely on rains and little on feed conservation and it is practised by only a few farmers. This creates shortage of feed, especially during the dry season (Njarui et al., 2011). In semi-arid areas, crop residues are abound due to cereal production. However, many smallholder farmers do not know how to treat and use crop residues. In West Africa countries like Niger, supplementing millet stovers with groundnut haulms improved weight gain of sheep (Abdou et al., 2011).

Crop residues are high in neutral detergent fibre (NDF) and acidic detergent fibre (ADF) which induce low digestibility, hence, low dry matter and energy intakes for animal productivity (Leng, 1990). In Bangladesh, the traditional way of feeding livestock is through rice straw. During the dry season, farmers harvest natural pastures in which quality and quantity fluctuate from season to season (Khan et al., 2009). Feed shortage in many developing countries is caused by shortage of land, high number of livestock per unit area and poor management of feed resources (Njarui et al., 2011). In south Asian countries like India, fodder for livestock is limited. Crop residues are the main sources of fodder, especially in irrigated areas for crop production. In this case, the price of green forage has substantially increased to high levels (SAPPLPP, 2011).

It is important to face poverty and chronic food shortages, exacerbated by natural and man-made disasters, by increasing livestock productivity through good quality feed and feeding practices. Although low quality feed is not used as basal diet in temperate countries (Khan and Chaudhry, 2011), in tropical countries, especially in smallholder farms, low quality feeds are used as basal diet and in some cases are not supplemented or treated to meet the requirements of livestock (Smith, 2002). One of the options for smallholder farmers to address feed challenges is to integrate good quality forage options into crop-livestock systems which will provide feed and regenerate depleted soil for crop production.

2.4. Mixed crop-livestock production systems

High increase of human population with subsequent pressure on food is the main preoccupation driving agriculture towards intensification (Singh et al., 2004). Literature is awash with information on mixed crop-livestock systems (Stangel, 1993; Schiere et al., 2002; Thomas et al., 2002; Singh et al., 2004; Wilkins, 2008; Ryschawy et al., 2012) but little attention is paid to improved grass options for smallholder farms. In many areas of Africa including Rwanda, crop intensification is based on crop-livestock integration system (Figure 2.2). Farmers who practise this farming system produce a half of the world's food on small land holding (Herrero et al., 2010). This is because livestock is raised on grass, browses and non-conventional feed; and is fed on crop residues where manure is used for further crop production. The use of manure from crop residues fed to ruminants is much more efficient in N cycling in soil than the use of crop residues as direct soil amendment (Delve et al., 2001). To get N available in soil using vegetation composts is very laborious and protracted because it needs mixing of household wastes with tree leaves to reach better amending (Kaboré et al., 2010). Nitrogen excreted in urine or in faeces is evacuated in the environment. Increase of N in urine is caused by highly degradable feeds, especially concentrates fed to an animal. While some N in the urine is volatilised, the remained one is also leached in soil. Conversely, N excreted in the faeces is from low degraded feed where N content in faeces is slowly degraded in soil and can be utilised by plant hence, recycled (Powell and Williams, 1995). In the case of mixed farming system in Rwanda (Figure 2.2), the N excreted in urine may not be high as most farmers feed ruminant livestock with poor quality roughage. This indicates that more N is available in faeces. However, Stangel (1995) reported that in sub-Saharan Africa the loss of N in farms is four times higher than the fertiliser used in the region and only one half of the worldwide average level.

For better management of manure-crop residues, models for crop-livestock integration have been developed to enhance farm productivity without affecting sustainability of the system (Singh et al., 2004). In Rwanda, CIP coupled with land consolidation where farmers consolidate land and grow one crop (Cantore, 2012), a grass like *Brachiaria* as soil fertility regenerator can be integrated in the crop-livestock system to increase soil carbon and milk yield.

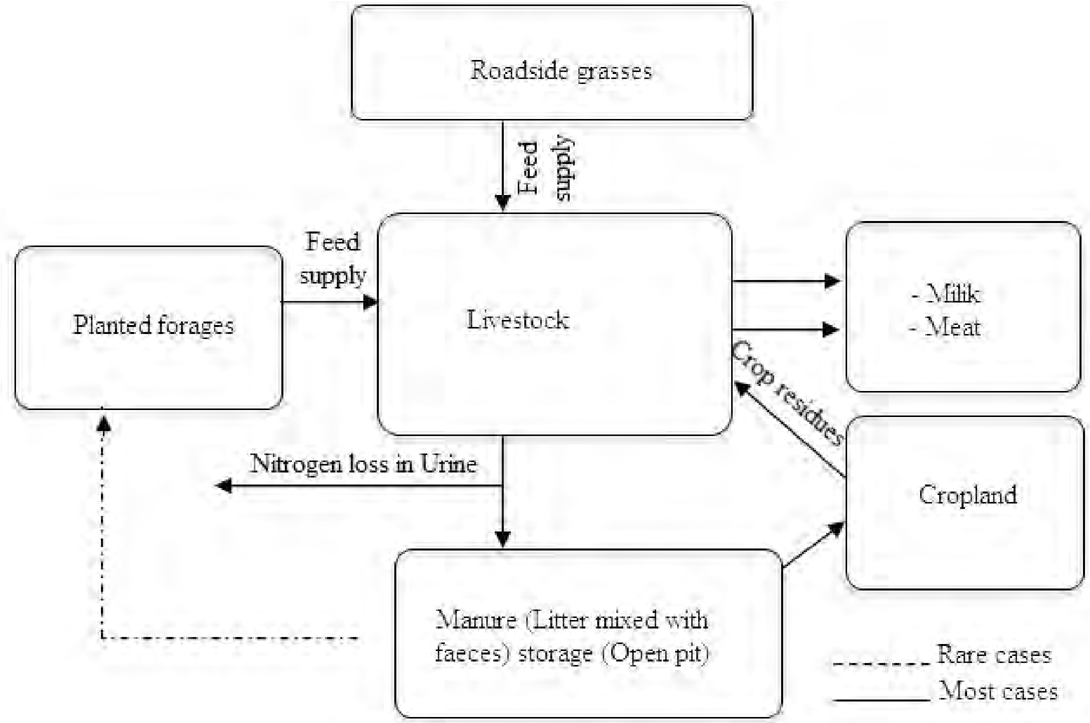

Figure 2.2: Schematic representation of farming system and nutrient cycling in smallholder farms in Rwanda

Crop-livestock integration has been a model of farming system since the last 30 years. In developed countries particularly in Europe, intensification of agriculture to increase productivity was applied but could deteriorate the environment and undermine economic viability (Wilkins, 2008). Currently, mixed crop-livestock systems in France are seen at farm level as a good alternative for sustainability of the agricultural intensification system (Ryschawy et al., 2012). In south eastern United States of America, forage crop integrated with grazing animals and food crops was the main farming system (Franzluebbers, 2007). This integration would increase benefit both to production and to environment where crop rotations, cover cropping, intercropping and conservation tillage were applied. Except income from crop production, when farmers face hard times, live animals or animal products are sold for income generation (Herrero et al., 2010). In south Asia, where land holding is also small, farmers increase livestock productivity by adopting mixed crop-livestock systems (Thomas et al., 2002). In this system, related technologies have been adopted because there was no aspect of the socio-economy and policy taken into consideration. Conversely, in Indonesia, China and Vietnam, studies have shown that crop-livestock integration was a source of income when beef production was introduced and supported. It was also considered as role player between crop-livestock and natural resource base (Winter, 2011).

In sub-Saharan Africa and South Asia, crop residues are used to feed livestock, especially during long dry seasons. This imparts on cropping land because crop residues are not used as mulch (Valbuena et al., 2012). South-East Asian countries are similar to sub-Saharan African countries including Rwanda where smallholder farmers have small land and practise crop-livestock system. Dominant in this system is the zero grazing system where livestock is fed by cutting and carrying of forage. Planted forages are supplemented by roadside grasses. However, some farmers may have small plot of land for grazing animal and during the evening grazing supplemented by planted forage (Lapar and Ehui, 2004). Considering the farming system whereby grazing land has sharply shrunk, the development of a dairy production is the option of developing and integrating grasses with high yield and high intake potential (Clark et al., 2007).

2.5. The role of improved forages in smallholder farmers

Since the last decade some forage technologies have been disseminated in smallholder farms in South-East Asia to increase feed resource and environmental protection (Peters et al., 2001). The introduced forage options into mixed crop-livestock helped farmers to increase income whilst protecting their land (Stür et al., 2002). Tropical forage-based system has different role to play in the agriculture. In Latin America and the Caribbean, cattle are reared on planted pastures while in Western Africa natural pastures are used to graze cattle. In contrast, most livestock owners in the eastern-central Africa and tropical Asia, cut–and–carry of forage is a major practice to feed cattle (Peters et al., 2012). In east Africa, most livestock farmers utilise Napier grass as the main feed resource to feed lactating cows. However, according to Lukuyu et al. (2012), Napier grass alone can achieve milk yield of 7 kg/day/cow while it can achieve milk yield of 12 kg/day/cow when supplemented with forage legume. Recently, in east Africa including Rwanda and Uganda, Napier grass was found to be affected by Napier grass stunt and smut diseases (NSSD) which can damage up to 100% of the grass (Nyiransengimana et al., 2013; Kawube et al., 2015). Although efforts to control the diseases are being made (ILRI, 2013), it is also imperative to provide to smallholder farmers other forage options of choice (Nyaata et al., 2000).

Planted pastures are not only sources of animal feeds, but also contribute to maintain/improve the natural resource base by reducing erosion, restoring soil fertility and degraded lands while improving biodiversity. In many countries, smallholder farmers are practising and sharing green manure to reduce inorganic fertiliser usage whilst improving the sustainability of forage-food crop production systems (Bunch, 2012). Pasture grasses like *Brachiaria* grasses have shown its importance in many aspect of the agriculture. Integrated with sorghum, *Brachiaria brizantha* cultivar Piatá produced high biomass, high crude protein and high *in vitro* digestibility of organic matter at the age of 70 days after its establishment (Quintino et al., 2013).

Brachiaria grasses originated from Africa and some genotypes have been improved in Latin America and are adapted to different prevailing local conditions in tropics (Miles et al., 2004; Rao et al., 1998). In Thailand, *Brachiaria* hybrids cultivar Mulato and Mulato II were evaluated and found that Mulato had higher crude protein (17.5%) in leaf than Mulato II (14.6%) at the first harvest of seeds. However, Mulato II had a high dry matter of 2,337 kg/ha compared to Mulato which had 1,971 kg/ha (Hare et al., 2007). The frequency of seed harvesting was increasing DM while CP content was decreasing. In north-east Thailand *Brachiaria brizantha* cv. Toledo, cultivars Mulato and Mulato II showed a high yield of DM during the dry season compared to *Brachiaria ruziziensis, Paspalum atratum* and *Panicum maximum* (Hare et al., 2009). In Rwanda, some improved *Brachiaria* grasses were also evaluated in the acidic soils and low rainfall areas. Mulato II and hybrid BR02/1485 had CP content of 14% and 15%, respectively in the whole plant. High DM content was found in *Brachiaria brizantha* cultivar Toledo and indigenous *Brachiaria decumbens* (Mutimura and Everson, 2012a). The DM yield of improved *Brachiaria* grasses Toledo, Marandú, indigenous *Brachiaria* and Mulato II was higher than that of naturalised *Cenchrus ciliaris* both in the wet and dry seasons. In Madagascar, *Brachiaria* grass cv. Mulato was evaluated in monoculture and intercropped with perennial peanut and it was found that when intercropped, it produced high DM in the first cuts while there was no difference in the third cut (Rahetlah et al., 2012). Many researches worked on *Brachiaria* hybrids and varieties on agronomic aspects including abiotic (drought, acidic soils coupled with aluminium toxicity) and biotic (diseases and pests, physical defoliation) stress conditions (Hare et al., 2009).

In animal production, many studies on *Brachiaria* grasses were oriented on grazing (Gonzalez et al., 2012; Vendramini et al., 2012) and few have been done on smallholder farms in the integrated crop-livestock systems where land holding is limited and livestock are fed on cut and carried forages. In Latin American countries, like Honduras, *Brachiaria* grasses, especially variety Toledo, Mulato and *Brachiaria decumbens* are planted on large scale and harvested for making hay and used during the dry season which last between six to seven months (Reiber et al., 2012). In Kenya, most strategies for coping mechanisms applied by smallholder farmers during the dry season are the use of fodder banks and purchase of fodder from other farmers (Njarui et al., 2011). As rain-fed agriculture is the main crop production source that many sub-Saharan African farmers practise (Cooper et al., 2008), forages adapted to drought are the source of feed that should be promoted to smallholder livestock owners.

2.6. Adaptation of forage grasses to different agro-ecologies

The adaptation of a plant depends on the climatic and edaphic conditions for a given area (Pitman, 2001). Grasses in particular are adapted to various areas with different types of soils because of characteristics that they have acquired in their environment (Serrao and Simao, 1975). In many areas of the tropics, each grass species grows on a particular soil. For example, *Cenchrus ciliaris* is adapted to dry and fertile soil while the genera of *Andropogon* and *Brachiaria* are adapted to infertile and acidic soils (Pitman, 2001). A range of high quality grasses including *Chloris gayana*, *Panicum maximum*, *Eragrostris curvula* and *Digitaria eriantha,* have been identified to be adapted to different stress conditions in Zimbabwe (Mapiye et al., 2006). The adaptation of forage grasses to specific environmental conditions has interested researchers in the evaluation of potential grasses for different agro-ecological zones

(Gray, 1984). This evaluation has made it possible to rank grasses best adapted for specific conditions and to use them to feed animals either by grazing or by cut and carry forage. Experiments testing the production of tropical and temperate grasses growing on soil with low nutrient content have shown that tropical grasses grew better than temperate grasses (Wilson and Haydock, 1971). The ability to grow in various agro-ecological zones has given the small farmers an opportunity to appreciate, to select and use them for erosion control and in animal feeding (Roothaert et al., 2003). Furthermore, grasses evaluated on acidic soil containing toxic levels of aluminium and manganese in Colombia and on salty soil in Pakistan showed that grasses have the mechanisms to adapt to these stress conditions (Hameed et al., 2009; Rao et al., 1996). Apart from these abiotic stress conditions, other factors that grasses are able to tolerate and to adapt are the biotic factors like insect injury that can cause serious loss of yield (Fikru, 2001).

Grasses are found everywhere in rangelands, meadows as well as pastures and there are more than 10,000 species (Kretschmer and Pitman, 2001). They are the main component of the diet of herbivores. They also can protect soil by retaining water run-off (Popp et al., 2009). This is why many studies on their adaptation affirmed their adaptability and their importance on the environment and animal feeding. For example, *Brachiaria* species have been evaluated in many regions: humid lowlands of tropical America (Pedro and Keller-Grein, 1996), savannah of tropical America (Pizarro et al., 1996), sub-Saharan Africa (Ndikumana and Leeuw, 1996) and in Asia, the south Pacific, and Australia (Stür et al., 1996). Any form of their genetic improvement was based on their capacity to adapt to the harsh environment and forage breeders can improve their persistence under abiotic and/or biotic stress conditions (Vogel and Lamb, 2007). In addition, the adaptation implies better mechanism to reproduce. Many authors affirm that the genera of grasses like *Brachiaria* and *Panicum* possess the apomictic character that is a mechanism of reproduction by the seed without fertilisation (Miles and do Valle, 1996) and this apomixis is possessed by few plants in the plant kingdom. Thanks to the genetic recombination through apomixis, the hybrids of *Brachiaria* can also be propagated by the mechanism of seeds (Miles and do Valle, 1996). Other positive attributes of *Brachiaria* are their ability to withstand dry conditions, successive cutting, fire and shade (Ghebrehiwot, 2004; Wilson et al., 1980). Considering all these aspects of adaptability, their development under different environments will be a substantial achievement (Kretschmer and Pitman, 2001) for better livelihoods of smallholder farmers practising crop-livestock farming systems.

2.7. Nutrient requirements of dairy cows

Ruminant livestock require balanced diets to attain their maximum performance particularly in milk and meat production (Rim et al., 2008). Balancing diets to meet ruminant's nutrient requirements should be done without compromising animal and environment welfare as the ruminant nutrition is a complex aspect (NRC, 2001).

The purpose of feeding cattle is to balance diets nutritionally by providing favourable rumen environment which maximises development and active rumen microorganisms (Ishler et al., 1996). Feeding cattle requires feeding both the animal and rumen microbes (Table 2.2). Requirements for a dairy animal are water; energy for maintenance, activity, pregnancy, milk production and for gaining body condition; protein; fibre for rumen function and reduce start and low fibre; vitamins and minerals (macro and micro minerals; Moran, 2005). One of the main factors causing low milk production in a dairy cow like Holstein Friesian is the diet offered to the animal during lactation (Dillon et al., 2003). These authors stated that although a dairy cow might produce high amount of milk, it should be put on the good forage during its early lactation to achieve greater milk yield.

Beside the nutrient content of a feed, other factors influencing the ruminal environment are particle size of a feed and the volatile fatty acids (VFA; Montoro et al., 2013). VFAs are important factors because they are synthesised into glucose which is a sugar needed for milk production and for central nervous system of an animal (Knowlton et al., 2003). However, the quality of VFA depends on the nutrient supply. High supply of cellulose, hemicelluloses and water soluble carbohydrate increase non glucogenic VFA (acetic acid and butyric acid) while glucogenic VFA (propionic acid) which increases milk yield will be in small amount (Dijkstra et al., 2008). In general, fatty acids are important in ruminant nutrition. They are used by the animal to increase energy in lactating cows by reducing negative energy balance, increase milk yield and improve fertility (Moate et al., 2004; Sinclair and Garnsworthy, 2010). Knowing fatty acids profile of microbial lipids in ruminant nutrition is of great importance because it helps to understand the level at which an animal is fed and eventually the animal products (Or-Rashid et al., 2007). The latter authors argued that many conjugated linoleic acids (CLA) are more associated with rumen protozoa than other rumen microbes. Much of CLA and other unsaturated fatty acids in animal are from rumen protozoa.

All feeds eaten by animal are not digested and the parts which are not digested leave the gastrointestinal tract (GIT) as faeces. The digested part can be expressed as a percentage of the total intake. The percentage digested is called digestibility coefficient and the feeding value of a feed is particularly estimated by its energy and protein content (Pandey and Voskuil, 2011). Digestibility of a feed is a crucial factor for the quality of feed. Low quality forages are described as forages whose digestibility is below 55% and crude protein is less than 8% (Leng, 1990).

In smallholder farms quality and availability of feed resources vary seasonally and it is a crucial problem to feed livestock, especially during the dry season (Abegaz et al., 2007). A dairy cow requires nutrients for body growth, maintenance and production. The requirements for maintenance and lactation have higher impact for absorbed nutrients than the other production traits (Shaver and Howard, 1988). In this case, reproduction can be affected by feeding practices and the type of feed offered to the animal. Most feed resources used by small holder farmers, particularly during the dry period are crop residues which are generally low in crude protein and high in fibre, thus requiring some level of supplementation or treatment to support acceptable livestock performance (Bogale et al., 2008).

Table 2.2: Supply of essential nutrients to cow and rumen microbes

Nutrients	Cow	Rumen microbes
Energy	Glucose from volatile fatty acids (VFA)	Carbohydrate fibres, non-fibre carbohydrates, amino acids
Protein	Amino acids, microbial protein	Ammonia, amino acids, peptides
Minerals	Dietary	Dietary
Vitamins	Dietary, bacterial	Dietary, synthesised

Source: Adapted from Ishler et al. (1996).

In east Africa, the highest amount of feed used in dairy animals is from Napier grass. During the dry season crude protein of Napier grass drops to 4.8% from 12% in wet season (Lanyasunya et al., 2006). Study on feeds fed to livestock by smallholder farmers in Rwanda, showed that most feed used were low in crude protein to support requirements of a dairy cattle (Klapwijk et al., 2014) and some farmers harvest branches of tree legumes, especially *Calliandra* sp. and *Leucaena* sp. to feed animals. These trees are established on contour bands primarily for erosion control and for producing stakes for climbing bean (Bucagu et al., 2013; Mutimura et al., 2013a).

Nutritive values of plants vary according to location, season and plant species. Low crude protein content in some grasses like Napier grass, *Brachiaria brizantha*, *Cynodon dactylon*, *Perotis pantens*, *Digitaria eriatha*, *Cynodon nlemfluensis* and *Hyperthelia dissolute* has been reported in Zimbabwe during the dry season (Tavirimirwa et al., 2012). Balancing proteins in animal nutrition is most critical if it is to achieve the potential production of a ruminant (Table 2.3). According to Doepel and Lapierre (2006), to meet metabolisable protein requirements of a dairy cow, a balance between rumen undegradable protein (RUP) and rumen degradable protein (RDP) should be taken into consideration when making rations. This allows the optimisation of the efficiency of utilisation of nitrogen intake whilst reducing the cost of feed and nitrogen excretion to the environment.

Table 2.3: Nutrient requirements of dairy cows depending on body weight, level of milk yield and total digestible nutrient (NRC, 2001)

Milk (kg)	Fat (%)	True Protein (%)	DMI (kg)	LW change (kg)	NEl (Mcal)	RDP (g)	RUP (g)	CP (%)	LW (kg)
10	4.0	3.0	12.4	0.9	15.3	1240	230	11.9	454
15	4.0	3.0	9.9	-0.4	20.4	1110	480	16.0	454
20	4.0	3.0	16.0	1.0	22.7	1680	560	14.0	454
25	3.0	2.5	19.6	1.0	26.0	1940	620	13.1	680
30	3.0	2.5	14.0	-0.6	29.2	1570	860	17.4	680
35	3.0	2.5	22.7	1.3	32.2	2370	820	14.1	680
40	3.0	2.5	16.0	-1.2	35.3	1760	1230	18.7	680

DMI = dry matter intake; LW = live weight; NEl = net energy for lactation; RDP = rumen degradable protein; RUP = rumen undegradable protein; CP = crude protein

The most challenging of the protein balancing is not proteins themselves but the amino-acids (AA) which make protein and in most cases lysine and methionine (Doepel and Lapierre, 2006). When amino-acids do not match, they become free in blood and when they reach the liver, they are deaminated and urea synthesised is partly excreted in urine (Knowlton et al., 2003).

2.8. Kinetics of passage of feed in animals

Kinetics of passage is a fundamental principle in modern feed evaluation, especially for ruminants. This has been a lacking component for knowing the characteristics of a feed for ruminant production (Warner et al., 2013). In addition, rumen passage kinetics of a feed can be used to determine the retention time (RT) in the rumen based on extrinsic and intrinsic factors. Kräme et al. (2013) reported that the total mean retention time (MRT) decrease from feed fibre to concentrate fibre and to liquid.

Digestibility of a feed depends on two mechanisms, the fermentative digestion and passage. The two compete with each other and their kinetics is important in ruminant nutrition (Huhtanen et al., 2006; Meng et al., 1999). This is because it helps to predict the extent to which protein, carbohydrates, microbial protein are digested, absorbed and supply energy and protein to the animal (Fox et al., 2004). According to Huhtanen et al. (2006), prediction of DM intake depends on the retention time of feed in the GIT.

These authors argued that the increase of retention time of particles in the rumen will increase digestibility but it will decrease intake. Different factors influence the mean retention time (MRT) of a feed in the GIT. The major factors are the body weight, pregnancy and lactation, which increase the passage rate of digesta (Van Weyenberg et al., 2006).

The determination of passage rate of particles is of major concern if it is to predict dry matter intake of a feed in animal (Uden et al., 1982). The extent of digestion of a feed is controlled by the relationship between passage rate (k_p) and digestibility rate (k_d). Percentage of a nutrient digested (ND) in the rumen is calculated as follows: $ND = \frac{k_{d1}}{(k_{p1} + k_{d1})}$ while percentage of a nutrient passing (NP) from the rumen is calculated: $NP = \frac{k_{p1}}{(k_{p1} + k_{d1})}$ where k_{d1} and k_{p1} are digestibility rate in the rumen and passage rate from the rumen, respectively (Figure 2.3). Indigestible markers can be used to estimate k_p. Different solid or liquid phase markers have been evaluated and used to determine the digesta rate of passage in herbivore. Most of these markers are external, however, there exist other markers which are internal including among others carbon isotope, especially the stable carbon isotope ^{13}C (Warner et al., 2013).

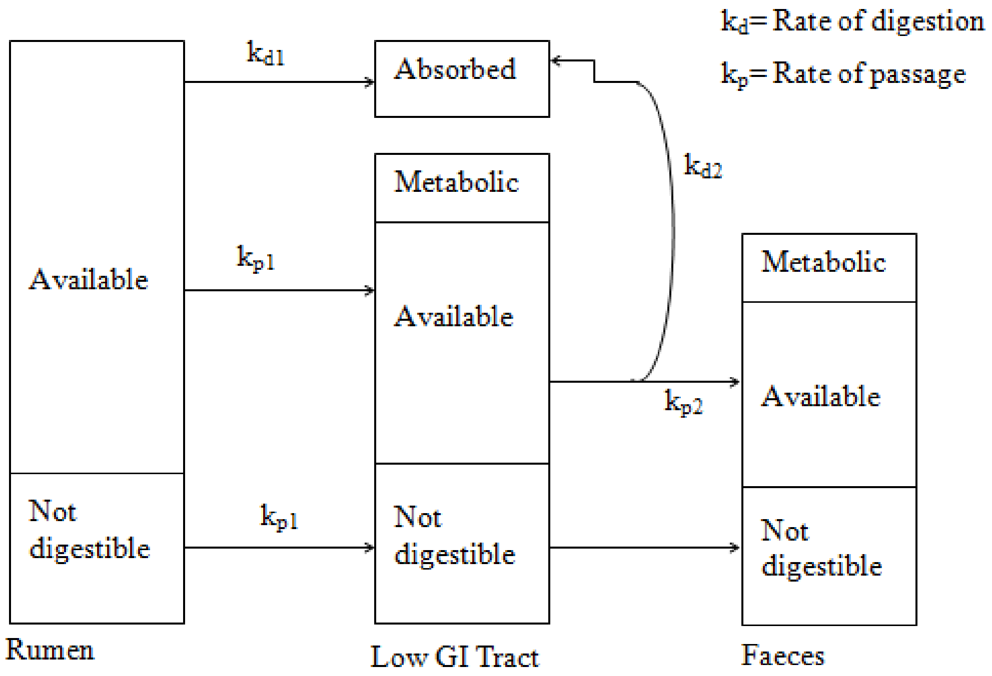

Figure 2.3: Process of a feed degradation in gastrointestinal tract

Investigation of chromium (Cr), Cerium (Ce) and Cobalt as markers showed that Cr was suitable for a solid phase marker while Cobalt- ethylenediaminetetraacetic acid (Co-EDTA) and Chromium- ethylenediaminetetraacetic acid (Cr-EDTA) were suitable for liquid phase marker but with caution in regard to animal species (Uden et al., 1980). However, the choice and usage of a marker remains to be at the discretion of individual researchers (Titgemeyer, 1997). The movement of digesta in the gastrointestinal tract (GIT) requires the use of a specific marker. For example, the marker used for fluid phase include Cr-EDTA and Co-EDTA whereas Cr- mordanted fibre, ytterbium chloride ($YCl_3.6HO_2$) and rare earth labelled fibres are used for the particulate phase (Robbins, 1993).

2.9. Dairy production on tropical forage grass based diet

Grass pastures constitute the basal diet up to 70% of dairy farms (Chapman et al., 2008). In tropical areas, the major factor limiting animal production, especially during the dry season is a pasture system (Poppi and McLennant, 1995). While milk production in developed countries like Australia and New Zealand will rely on irrigated pasture

(Clark et al., 2012), in sub-Saharan Africa, the milk production will increase through efficient use of available feed resources including the use of improved planted pastures (Olaloku and Debre, 1992). Milk production is influenced by different factors mainly breed, parity, season of calving, geographic region and management factors (nutrition, frequency of milking). Feeding dairy cows is costly if it is to optimise genetic merit for milk production. However, according to Clark et al. (2007), opportunities to reduce feed cost exist and these include among others the use of improved pasture. Low milk production from tropical grass depends upon the management applied to the grass. High milk yield of 20 litres per day per cow raised on elephant grass (*Pennisetum purpureum*) has been reported in Brazil. This is because the grass had a higher crude protein content of 18.5% due to high (50 kg) application of nitrogen (N) per hectare as fertiliser to the elephant grass (Danes et al., 2013). However, for smallholder farmers, it is rare that N is applied to fodder crop because even if it is available it is used for food crop production.

On the other hand, in Brazil, dairy heifers fed on *Brachiaria decumbens* alone achieved 624 g of body weight gain (BWG) daily during rainy season and 387 g of BWG daily during the dry season. This BWG achievement was lower than that of heifers fed on *Brachiaria decumbens* mixed with tree legumes that had 722 g of BWG during the rainy season (Paciullo et al., 2011). Tropical forage grasses, especially *Panicum maximum* mixed with a forage legume, *Arachis pintoi*, was reported to increase the body weight gain (BWG) of steers up to 950 g daily in Hawaii lowland conditions (Mathews et al., 2000). Body weight gain depends on the supply of protein and energy in the diet. The largest supply of these nutrients comes from grasses which are consumed and digested by ruminants (Chapman et al., 2008). Digestibility of grasses and their efficient utilisation depends on the level of protein and energy content in the feed and the protein deficiency in a feed can cause low ruminant production. However, Hess et al. (2003) reported that the increase of forage legume in feed composed of grasses increase organic matter and protein degradation. In addition, even cereal crop can be improved by supplementing with forage legumes. According to Hymes et al. (2013), the incorporation of alfalfa (*Medicago sativa*) in maize silage based diet increased milk yield to 30.9 kg per day per Holstein cows in the United States of

America. Also, in supplementation, the addition of grain in diet of forage grass mixed with legume based diet increases the level of fat and protein while increasing milk yield. This also decreases gross energy intake in faeces and urine in dairy cows (Williams et al., 2013).

Tropical grasses are not only important in animal production but also for environmental protection. Kennedy and Charmly (2012), reported that methane emissions from enteric fermentation of cattle fed on tropical grasses and browser tree legumes were low compared to other feed resources. In Hawaii, tropical grasses like *Brachiaria mutica* and *Pennisetum purpureum* were the most productive and suitable for nutrient recycling in the dairy production system (Valencia-Gica et al., 2011).

2.10. Anti-nutritional factors in tropical forage grasses

Anti-nutritional factors found in tropical forages are the toxins and tannins. Plant toxins and tannins are compounds that plants use to protect themselves from pests and herbivores. Toxins in forage grasses include carboline alkaloid (found in *Phalaris* sp.), cyanogenic glycosides (found in sorghums), oxalates, nitrates and saponins (found in tropical grasses). However, tannins and cyanogens are more aboundant in legumes than in grasses (Gleadow and Woodrow, 2002).

Cyanogens are glycosides containing in a sugar with certain enzymes. It can be hydrolysed to release cyanide (HCN). The hydrolytic mechanism can happen in the rumen by rumen microbial activity releasing CN which becomes toxic to ruminants. Toxicity occurs when cyanide ion blocks adenosine triphosphate (ATP) formation and the body tissues undergo starvation from lack of energy leading to death (Whittier, 2011). Cyanogenic glycosides in forage plant like *Dysphania glomulifera* was found to be a cause of death of 40 cattle grazing the plant in Springure, central Queensland, Australia (Mckenzie et al., 2007).

Saponins are found in *Brachiaria* sp. and *Panicum* sp. and can induce photosensitization in grazing animals (De Oliveira et al., 2013). *Brachiaria decumbens* and *B. brizantha* had higher concentration of saponine than *Andropogon gayanus*

(Moreira et al., 2009; Pires et al., 2002). *Brachiaria decumbens* causes hepatotoxic, which is an outbreak caused by steroidal saponins, the jaundice and photosensitivity; and these are clinical signs of hepatotoxic in ruminants (Ajwad and Noordin, 2012). Although *Brachiaria* grasses, especially *B. decumbens, B. brizantha, B. humidicola* and *B. ruziziensis* are the most important grasses for ruminants in countries like Brazil, their use in feeding systems is limited by hepatogenous photosensitisation (Beatriz et al., 2011; Hasiah et al., 2000).

Anti-nutritional factors of grasses can also be associated with fungal toxin secretion and nitrate concentration in feeds (Smitha et al., 2013; Westwood, 2008). Fungal toxins are mainly from fungal endophytes. Endophytic toxins in grasses include ergot alkaloids (Cheeke, 1995). Endophytic fungus has been identified in *B. brizantha* (Kelemu et al., 2011). Although this fungal strain has been reported as economically important, this can cause photosensitisation in sheep, goats and cattle. Toxicity affects much younger than adult ruminants (Ajwad and Noordin, 2012). For nitrates poisoning, this affects cattle and it occurs when high nitrate ($N\bar{O}_3$) is accumulated in the rumen and is reduced into nitrite (NO_2). The latter is absorbed into blood via rumen wall and is fixed to haemoglobin and ultimately blocks the fixation and circulation of the oxygen in the body. The animal can die due to asphyxiation if there is no immediate treatment (Neale, 2006).

Furthermore, some tropical grasses contain soluble oxalates in good concentration which can cause toxicity. The concentration of oxalates induce the deficiency of calcium in ruminants (Rahman et al., 2006). Some of these grasses include *Digitaria decumbens*, *Setaria sphacelata* and *Pennisetum clandestinum* (Smitha et al., 2013). Toxicity occurs when oxalates react with calcium and reduce the absorption of calcium leading to hypo-calcium. Grasses like *Pennisetum purpureum* contains a limited amount of oxalates, however, if the grass is fed to a ruminant for long period, it can be toxic (Rahman et al., 2010). The accumulation of oxalates in grasses can be reduced by fertiliser application in grown or grazing land pasture (Rahman and Kawamura, 2011).

2.11. Prediction of feed intake in dairy cows

Predicting feed intake in animal nutrition is of great importance if it is to increase animal performance while enhancing health of the environment (Rim et al., 2008). Before the 21st century most methods used to feed animal were based on chemical composition of feeds (Blake, 2010). Recent feeding methods in animal nutrition are based on models which involve both chemical and biological factors.

Several investigations in animal nutrition have been conducted for predicting dry matter intake (DMI; Shem et al., 1995; Blümmel et al., 1997; Brown et al., 1977; Holter et al., 1997; Hayirli et al., 2003; West et al., 2003; Nsahlai and Apaloo, 2007). Most researchers were interested in predicting nutrients intake based on models which predict DMI (Ellis et al., 2006). It is very important to accurately predict DMI as it is the basis for formulating rations depending on physiological status of an animal. Currently, research work on DMI prediction is towards reticulo-rumen fill and physiological mechanisms whilst considering environmental factors (Grant and Tylutki, 2011). Prediction of feed intake, chemical composition and digestibility are related to degradability, intake rate, palatability and animal characteristics. The ability of cows to process the intake and satiety should be considered. Most of limiting satiety is expressed as feed intake capacity. The latter can be predicted based on physiological states of a cow which are mainly parity, days in milk (DIM) and days of pregnancy (Zom et al., 2012).

Feed intake is measured by dry matter intake. This aspect is of great importance because it is the most important factor influencing livestock productivity. Models to predict DMI for the management of dairy cow grazing on grass should be applied (O'Neill et al., 2013). DMI is a tool to measure animal performance. Depicting the availability of nutrients in a feed and their interactions is the core aspect in animal nutrition. This is because, it helps to understand and formulate a ration for dairy cow as the latter is sensitive to the profile of nutrients absorbed (Mertens, 1997). Feed intake is mainly influenced by feed characteristics and the animal itself. For the animal, body weight, stage of lactation, milk yield, stage of lactation, BWG and body condition score are major characteristics (Hayirli et al., 2003). Furthermore, feed characteristics are mainly digestibility and fibre content. These two latter aspects affect rumen fill which determines feed intake. However, studies have shown that a cow may stop eating before reaching the fill capacity of the rumen (Taweel et al., 2006). This aspect has been attributed to metabolic regulation which might be considered when predicting feed intake. Ruminal NDF is concerned with physical intake regulators (Oba and Allen, 1999) while energy concentration is also an indirect variable determining DMI (Rabelo et al., 2003).

Intake of tropical grasses varies according to animal, plant species and maturity level. For example in tropical areas of Mexico, high DMI for *Brachiaria brizantha* was observed because it had low NDF and lignin contents (Juarez et al., 1999). According to Forbes (2003), the prediction of intake by considering observed effects of animal and feed factors are useful within the range of condition in which data are collected, however, it is not recommended to predict the intake outside the range.

2.12. Summary

Integrated crop-livestock farming is a major socio-economically viable and sustainable agricultural system for smallholder farmers. The increase of animal production especially milk and meat in developing countries cannot be achieved by feeding crop residues alone and there is great need for using improved forage grasses. Improved grasses have shown multiple benefits in the sustainability of the agricultural system by having high nutrient composition and improving soil productivity. The evaluation of benefits of *Brachiaria* grasses within existing mixed crop-livestock farming system in Rwanda is of great interest. This is because, on-farm *Brachiaria* grass feeding will increase the willingness of farmers to adopt the forage technologies through the achievement of milk yield from their dairy cows and ultimately increase of household food security and welfare. In the long run, use of improved forage technologies could improve food and nutrition security for the ever-increasing human population on the limited arable land.

Literature is awash with information on tropical forages on aspects related to chemical composition, fertiliser recommendations, persistence and management of forage production. However, there has been lack of adoption of forages by farmers because most of the research on forages was conducted on-station and the use of results in dairy production is scarce (Thomas and Sumberg, 1995). The reason might be attributed to the complexity of on-farm research which needs involvement of multidisciplinary techniques and the need for high labour and time (Tanaka et al., 2008) while the main challenge is the lack of farmers' initiative to participate (Gwaze et al., 2011). Although language has been identified by the latter authors as one of the barriers for on-farm research, Goma et al. (2001) argued that the information that farmers are asked to provide should be translated into their local language. Conducting on-farm research with the participation of farmers was found to be the most appropriate as a way for faster dissemination of technologies (Engstrom et al., 2010). However, on-farm research conditions are typically less controlled and therefore critical attention should be paid in experimental design before trials are being set up.

Chapter 3: Seasonal variation of livestock feed resources in semi-arid and humid environments

Abstract

In most of sub-Saharan African countries, including Rwanda, the predominant agricultural production is from a mixed crop-livestock farming system because of small size land holding. The objective of this study was to assess the seasonality of livestock feed resources in semi-arid and humid environments of Rwanda. Structured questionnaire was designed and administered to 102 households from each environment (Totalling 204) practising mixed crop-livestock farming system. Humid environment had more other activities than farming compared to semi-arid. Semi-arid area had more households with dairy cows than humid environment. Household heads above 40 years and uneducated were more likely to establish fodder species for livestock. Farmers in humid environments were more likely to apply fertiliser on forages as one of the management practices than in semi-arid areas. Household heads with above 20 years of experience in livestock rearing and uneducated household heads were also more likely to apply fertiliser on forages. Farmers in semi-arid environments were two times more likely to establish forages in farmland than in humid environments. Various feed resources were identified in both environments. However, Napier grass was the most frequent feed resource across all season in both areas. Its availability differed ($P<0.01$) between the two environments during the rainy season and during the dry season ($P<0.05$). In addition, various crop residues were also used in both areas during the rainy and dry seasons. We conclude that the high use of crop residues in both areas during both seasons can lead to feed shortage.

Keywords: Crop-livestock integration, household characteristics, fodder species, niches, dairy cows

3.1. Introduction

Information and knowledge on farm diversity can provide a way of improving farm productivity based on differences among farms and disseminate agricultural innovations from individual farms to a level of farm population (Cortez-Arriola et al., 2015). In most sub-Saharan African countries including Rwanda, agricultural production is from a mixed crop-livestock farming system which is most likely due to small size of land holding because of population pressure as well as climate variability (IAASTD, 2009). In addition, other key mutually reinforcing agricultural development and food security issues include plant, animal and feed resources in the context of soil improvement (Mutimura et al., 2014). The sustainability of this system will depend upon the management of crop-livestock integration. Bell et al. (2014) reported that crop-livestock integration can increase benefits when annual pastures are replaced with perennial pastures in crop rotation. Such integration increases water balance in the soil, improves soil fertility as well as sequestrate carbon and increase livestock productivity through the availability of feed resources.

In smallholder farms with limited land holding, feeds for cattle compete with conservation agriculture (CA). This is because crop residues and herbages are fed to cattle instead of being used as mulch (Naudin et al., 2015; Turmel et al., 2015) and in this case the practice of conservation agriculture can be impeded (Hellin et al., 2013). To increase nutrient availability in smallholder farms for viable agriculture in Africa, feeding cattle with crop residues should be reduced (Baudron et al., 2014), and more crop residues be retained in the field for green manure (Castellanos-Navarrete et al., 2015). In the context of Rwanda, particularly in the semi-arid and humid areas with acidic soils, farmers use different feed resources to sustain livestock production particularly for dairy cows fed under cut-and-carry forage system (Mutimura and Everson, 2011). Although some feed resources have been identified, information on their availability for utilisation across seasons, however, is not documented. Furthermore, as the dry season together with acidic soil conditions impact negatively on year-round livestock feeds availability, smallholder farmers have evolved ways to cope with the situation. This includes the use of various feedstuffs including nonconventional feed resources (Negesse et al., 2009). Additionally, other coping mechanisms including livestock herd reduction and feed conservation have been reported in different areas.

In the small-scale farms where land is more devoted to cropping than to livestock production, feed conservation is rare due to limited forage production. Studies have shown that farmers in East Africa produced forage in different landscapes mainly from farm boundaries and along with contours that are used to control soil erosion (Franzel et al., 2014). The forage technology commonly applied are exotic fodder trees which have been disseminated for more than two decades (Roothaert and Paterson, 1997) and planted fodder grasses which has been practised for about 100 years in Africa (Lenné and Wood, 2004). However, there are gaps in available information on "niches" in the smallholder farms in Rwanda, especially in areas constrained by prolonged drought spells, acidic soils and aluminium toxicity. The objective of the study was to determine the seasonality of livestock feed resources in semi-arid and humid environments of Rwanda and factors that affect willingness to plant improved fodder species. Both environments are characterised by integrated crop-livestock farming system on smallholdings.

3.2. Materials and methods

3.2.1. Study site

A survey on crop-livestock integration was conducted to identify the type of livestock production and feed resources and their seasonal variation in smallholder farms under contrasting environments. The survey was also aimed at understanding household characteristics of semi-arid (Bugesera district) and humid (Nyamagabe district) Rwanda. These two districts have contrasting climatic conditions. Bugesera district is located in the eastern Province of the country where climate is drier with less rainfall (Bazimenyera et al., 2014). This district is classified (Köppen classification; $AW_{3\text{-}4}$) as semi-arid with rainfall varying between 650–900 mm per annum and a temperature ranging from 24^0C to 28^0C. On the other hand, Nyamagabe district is located in southern Province of Rwanda and is classified (Köppen classification; $CW_{2\text{-}3}$) as humid. It has an average annual rainfall of 1800 mm and an average temperature of 16.5^0C (Stainback et al., 2012). The area is also characterised by acidic soil with aluminium toxicity (Mutimura and Everson, 2012a).

3.2.2. Sampling and data collection procedures

A structured questionnaire (see Appendix) was used targeting 204 households that practised mixed crop-livestock farming system. In semi-arid areas, the interview targeted 26 households per sector (Local administration division under the district) where four sectors were selected totalling at least 102 households. Also, 102 households from two sectors of Nyamagabe district (humid zone) were selected for interview. The two selected sectors in humid area were equivalent to four sectors in semi-arid area in size of population. Before the survey, enumerators including scientists *cum* extension workers were trained to conduct the interview which was administered in the local language (Kinyarwanda). Households were sampled using snowball technique (Patton, 1990). This helped to collect data on household characteristics, frequency distribution of dairy breeds, planted fodder species, willingness to grow forages and farmer' preferences on landscapes for growing forage species.

3.2.3. Statistical analysis

Data collected from survey were analysed statistically as non-parametric using SAS system 9.3 (2010). Data on household characteristics and frequency distribution of dairy breeds between semi-arid and humid environments were analysed using PROC FREQ procedures of SAS and the comparison between household characteristics and environments was done using Chi-square. In addition, all data on ranking and number of livestock owned by household in both environments were analysed using PROC GLM procedures of SAS (2010). Furthermore, ordinal logistic regression (PROC LOGISTIC procedures) of SAS (2010) was used to estimate the probability of farmers being familiar with planted fodder species, willingness to grow forages and their management as well as farmer' preferences on landscapes for growing forage species. These procedures were also used to understand choices of farmers in landscapes for planting forages. The logit model fitted predictors such as environment, gender, age, education and experience of farmers in livestock rearing were used. The logit model used was as follows:

$$\ln\left(\frac{\pi}{1-\pi}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots \beta_t X_t + \varepsilon$$

Where π: is the probability of being familiar with planted fodder species, willingness to grow forages, their management and landscapes for planting forages; $\frac{\pi}{1-\pi}$: Odds ratio which referred to the odds of being familiar with planted fodder species, willingness to grow forages, their management and landscapes for planting forages; β_0 : Intercept; $\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots \beta_t X_t$: Regression coefficients of environment, gender, age, education and experience of farmers in livestock rearing; ε : Random residue error. During the computing of each predictor $(\beta_1 \ldots \beta_t)$, the odds ratio was interpreted, for examples, as the proportion of farmers having planting fodder species versus those who did not do it. In addition, a similar model was used for other binary data set recorded in the study.

3.3. Results

3.3.1. Household characteristics

Household characteristics (gender, age, education and major activities of farmers) in semi-arid and humid environments are shown in Table 3.1. Household head did not differ (P>0.05) between gender across both environments. However, within each environment, a majority of households were headed by males. The level of education among household heads was not significantly different (P>0.05). In addition, age of household head did not differ (P>0.05) between environments but between categories of age, high percentage of farmers are more than 40 years old.

Furthermore, major activities carried out by household differed (P<0.05) between semi-arid and humid environments. Although farming seemed to be the major activity in both areas, however, humid environment had more other activities than farming compared to semi-arid. Formal employment and casual labour were among other activities carried by household head in humid environment. However, in both areas, experience in livestock rearing did not differ (P>0.05). In addition, in both environments, a majority of households had less than 20 years of experience in livestock rearing (Table 3.1) suggesting that some farmers might not be able to handle challenges related to livestock husbandry including feeds and feeding.

Table 3.1: Socio-economy characteristics of households in semi-arid and humid environments

Class	Semi-arid (n= 101)	Humid (n= 102)	χ^2
Household head	%	%	0.88^{NS}
Males	38.9	36.5	
Females	10.8	13.8	
Education of household head			2.40^{NS}
Not attended school	13.9	19.3	
Primary school	30.2	26.2	
Secondary school	5.5	4.9	
Age of household head			0.32^{NS}
Less than 40 years old (<40)	10.5	8.9	
More than 40 years old (≥40)	39.3	41.3	
Major activity			10.64*
Farming	48.8	43.4	
Self-employed	2	2.9	
Formal employment	-	2.9	
Casual labour	-	1.9	
Farmers' experience in livestock rearing			1.21^{NS}
Less than years (<20)	32	35.9	
More than 20 years (≥20)	17.7	14.3	

χ^2 : Chi-Square; NS: Not significant (P>0.05); *: Significant at P<0.05.

3.3.2. Livestock enterprises

Number and type of livestock owned by a household in semi-arid and humid environment are presented in Table 3.2. Eight livestock enterprises were identified in both environments and showed that indigenous cattle and indigenous goats differed (P<0.05) between the two environments. Households in the semi-arid zone owned more than one cattle and three indigenous goats compared to the humid area. Conversely, both environments differed (P<0.05) in pigs owned. A majority of household in humid environment owned many pigs (11 pigs) compared to semi-arid area (2 pigs). However, the rest of livestock enterprises did not differ (P>0.05) between these identified environments.

Table 3.2: Number (Mean ± Standard error) of livestock enterprise owned by individual households in semi-arid and humid environments

Class	Semi-arid	Humid	P-value
Indigenous cattle	2±0.1	1±0.1	0.0477
Indigenous chickens	6±0.8	4±0.9	0.1565
Indigenous goats	3±0.3	2±0.3	0.0492
Indigenous sheep	2±0.4	2±0.3	0.5647
Rabbit	5±2.9	5±2.3	0.9221
Pigs	2±1.2	11±3.2	0.0151
Exotic cattle	2±0.1	1±0.12	0.1260
Exotic goats	2±2.1	4±1.1	0.4076

Cattle ownership by smallholder farmers in both environments is much more oriented towards dairying. These animals are kept in a shed and fed on cut-and-carry forage system than other livestock species. Figure 3.1 shows percentage distribution of dairy breed categories in semi-arid and humid environments. The two environments differed (P<0.05) in dairy cattle breed types where the semi-arid had higher percentage of cattle than the humid area environment.

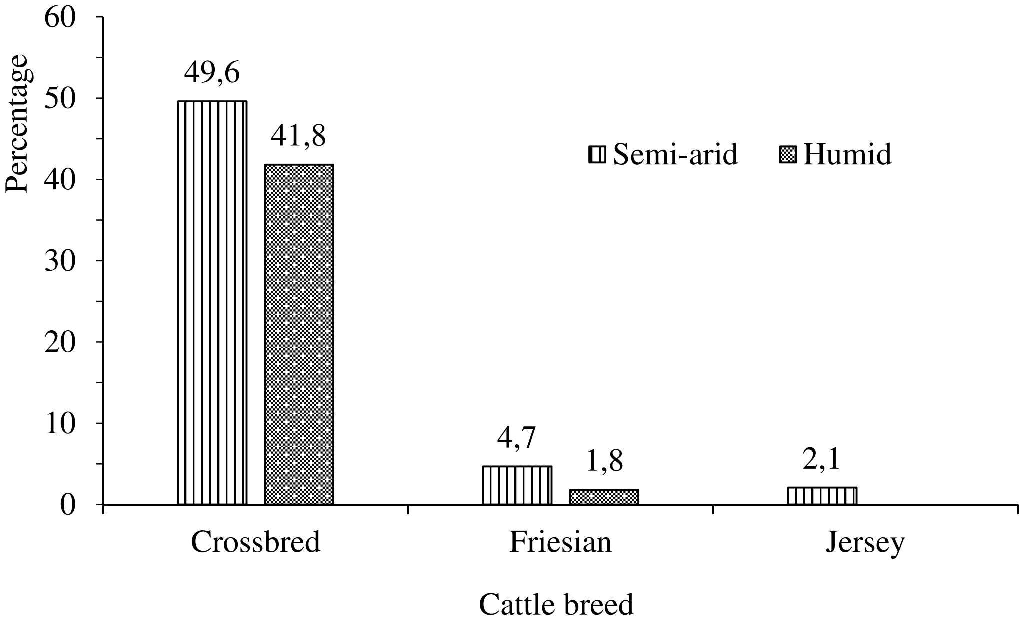

Figure 3.1: Percentage distribution of dairy breeds in semi-arid and humid environments (Chi-square= 9.31; P= 0.0095)

Milk yield of different cow genotypes differed (P<0.05) among cow genotypes, however, effects of environment and interaction of breed and environment did not differ (P>0.05; Table 3.3). Jersey cows had higher milk yield than the other cattle genotypes.

Table 3.3: Daily milk yield (Mean±Standard errors) per cow in semi-arid and humid areas

Breeds	Milk yield (L/day)
Friesian	6.7±0.7^{b}
Friesian ×Ankole	6.2±0.5^{b}
Ankole	3.3±0.6^{c}
Jersey	10.8±1.6^{a}
Significance:	
Breed	***
Environments[1]	NS
Breed ×Environment	NS

NS: P>0.05; ***: P<0.001; ^{abc}: Means in the same column with the same uppercase letter are not significantly different at P<0.05; [1] Semi-arid and humid environments.

3.3.3. Importance of feed resources in smallholder farms

Estimated conditional odds ratio suggested that farmers less than 40 years of age were less likely to plant fodder species than those more than 40 years old (Table 3.4). In addition, educated farmers are less likely to plant fodder species than uneducated farmers. Furthermore, all predictors of willingness to plant fodder species did not show significance different (P>0.05). With respect to the management of fodder species, semi-arid environment was far less likely to apply fertiliser than humid environment. In addition, educated farmers were less likely to apply fertiliser than educated ones. In addition, farmers with less than 20 years of experience in livestock rearing were less likely to apply fertiliser on fodder species than those above 20 years of experience.

Table 3.4: Odds ratio estimates and profile-likelihood confidence intervals of household experiencing shortage of planted fodder species

Predictor	Odds	LCI	UCI
Planted fodder species			
Environment (Semi-arid vs Humid)	0.50^{ns}	0.19	1.31
Gender (Males vs Females)	0.67^{ns}	0.19	2.29
Age of household head (<40 vs ≥40 years)	0.23**	0.09	0.62
Education of household head (Educated vs Uneducated)	0.34*	0.13	0.90
Experience in livestock rearing (<20 vs ≥20 years)	0.42^{ns}	0.14	1.20
Willingness to plant fodder species			
Environment (Semi-arid vs Humid)	1.61^{ns}	0.70	3.68
Gender (Males vs Females)	0.96^{ns}	0.34	2.73
Age of household head (<40 vs ≥40 years)	0.87^{ns}	0.32	2.35
Education of household head (Educated vs Uneducated)	1.43^{ns}	0.56	3.65
Experience in livestock rearing (<20 vs ≥20 years)	0.42^{ns}	0.14	1.20
Fertiliser application			
Environment (Semi-arid vs Humid)	0.18**	0.06	0.53
Gender (Males vs Females)	1.52^{ns}	0.50	4.65
Age of household head (<40 vs ≥40 years)	0.90^{ns}	0.28	2.90
Education of household head (Educated vs Uneducated)	0.32*	0.12	0.88
Experience in livestock rearing (<20 vs ≥20 years)	0.25*	0.07	0.83

LCI: Low confidence interval; UCI: Up confidence interval; ns: Not significant at P<0.05; *: Significant at P<0.05; **: Significant at P<0.01; Higher value of odds ratio estimates indicate greater difference in preference between levels of predictors.

3.3.4. Landscape preferences for fodder production

Odds ratios of landscape (niche) preferences including farmland, terraces and farm boundary are presented in Table 3.5. Estimated odds ratios showed that farmers in semi-arid area were two times more likely to plant fodder species on farmland than in humid area (estimated odds ratio 2.01 with 95% confidence interval 1.07; 3.77).

Table 3.5: Odds ratio estimates and profile-likelihood confidence intervals of household growing fodder on different niches (landscapes)

Predictor	Odds	LCI	ULI
Farmland			
Environment (Semi-arid vs Humid)	2.01*	1.07	3.77
Gender (Males vs Females)	1.13^{ns}	0.54	2.37
Age of household head (<40 vs ≥40 years)	1.09^{ns}	0.46	2.61
Education of household head (Educated vs Uneducated)	1.02^{ns}	0.52	2.02
Experience in livestock rearing (<20 vs ≥20 years)	0.97^{ns}	0.49	1.95
Terraces			
Environment (Semi-arid vs Humid)	0.61^{ns}	0.31	1.20
Gender (Males vs Females)	0.86^{ns}	0.39	1.89
Age of household head (<40 vs ≥40 years)	0.75^{ns}	0.30	1.89
Education of household head (Educated vs Uneducated)	0.71^{ns}	0.34	1.49
Experience in livestock rearing (<20 vs ≥20 years)	1.67^{ns}	0.78	3.55
Farm boundary			
Environment (Semi-arid vs Humid)	0.45^{ns}	0.15	1.33
Gender (Males vs Females)	1.07^{ns}	0.32	3.55
Age of household head (<40 vs ≥40 years)	1.67^{ns}	0.38	7.43
Education of household head (Educated vs Uneducated)	2.04^{ns}	0.69	5.98
Experience in livestock rearing (<20 vs ≥20 years)	0.33^{ns}	0.10	1.04

LCI: Low confidence interval; UCI: Up confidence interval; ns: Not significant at $P<0.05$; *: significant at $P<0.05$; Higher value of odds ratio estimates indicate greater difference in preference between levels of predictors.

3.3.5. Ranking of major planted fodder species in smallholder farms

Smallholder farmer ranked the availability of forage species using four levels, namely: (1) poor, (2) moderate, (3) high and (4) very high (Figure 3.2). In semi-arid and humid areas five major fodder species were identified and ranked. Fodder species did not differ ($P>0.05$) within an environment but differed ($P<0.05$) between semi-arid and humid environments. Napier grass was ranked high and moderate in semi-arid and humid environments, respectively. However, ranks of the rest of fodder species were similar in the semi-arid and humid areas. None of the fodder grasses was ranked high in humid and no fodder was ranked very high in the semi-arid zone (Figure 3.2).

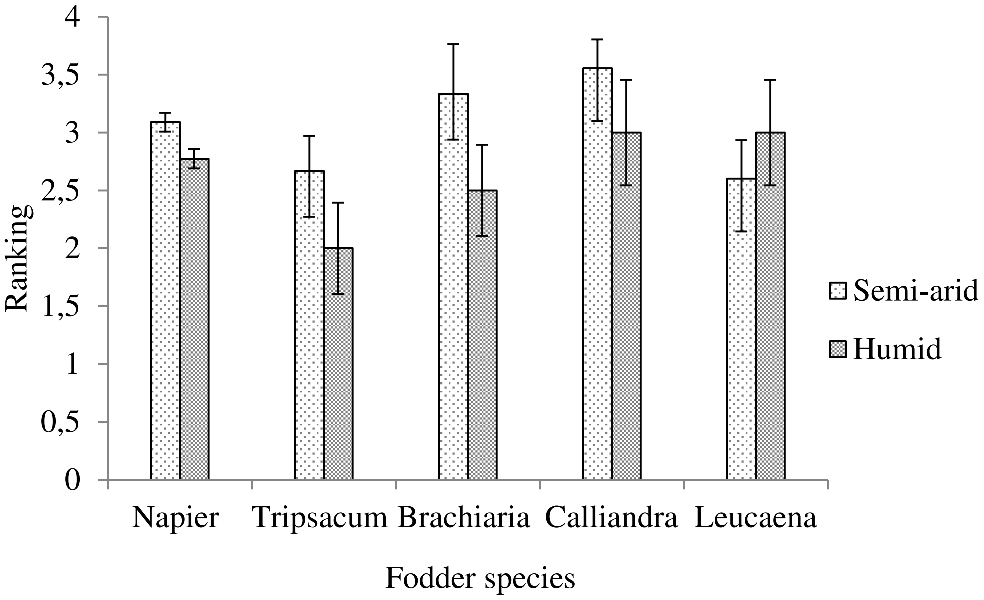

Figure 3.2: Levels of farmer's acceptability of planted forages (1= Poor; 2= Moderate; 3= High and 4= Very high) in semi-arid and humid environments of Rwanda.

Six and eight major feed resources were identified in semi-arid and humid environments, respectively (Table 3.6). Ranking of these feed resources showed that Napier grass was the most common all seasonal feed resource available to households from both areas. This grass ranked the first in the rainy and dry seasons across the two environments. However, its availability differed (P<0.01) between the two environments during the rainy season and during the dry season (P<0.05). Napier grass was more available in the humid than the semi-arid environment (Table 3.6). Furthermore, roadside grass was more (P<0.05) available in humid than in the semi-arid areas during the rainy season. Although other feed resources did not differ (P>0.05) between environments and seasons, humid area showed much more diversity in feed resources than in semi-arid area.

Table 3.6: Farmers' estimates of major feed resource availability (kg of fresh per day) in the dry and rainy seasons in semi-arid and humid environments

	Rainy			Dry		
Feed resources	Semi-arid	Humid	Sign.	Semi-arid	Humid	Sign
Banana peels	21.6 (5)	30 (8)	NS	26.2 (5)	27.5 (8)	NS
BPS	-	36.6 (5)	-	22.5 (6)	41.6 (5)	NS
Bean haulms	6 (6)	50 (3)	NS	-	60 (3)	-
Maize stovers	52.5 (2)	45 (4)	NS	75 (2)	60 (2)	NS
Rice straw	-	30 (7)	-	-	30 (7)	-
SPV	22.5 (4)	33.7 (6)	NS	30 (4)	35.6 (6)	NS
Napier grass	139.3 (1)	1261 (1)	**	111 (1)	557 (1)	*
Roadside grass	24.2 (3)	50.3 (2)	*	37.1 (3)	51.3(4)	NS

The higher the mean rank the more importance of availability of feed resource in the season; BPS: Banana pseudo-stem; SPV: Sweet potato vines; NS: Not significant at P<0.05; **: Significant at P<0.01; *: Significant at P<0.05.

3.4. Discussion

Household characteristics including gender, education and experience in livestock rearing of household head did not differ between semi-arid and humid environment. This suggests that these characteristics were not affected by agro-ecology. However, major activities done by household head differed between the two agro-ecologies. Many major activities were found more in humid environment than in semi-arid. This could be attributed to climatic conditions where variation of different production system could create other employments. Similar observations were identified in the sub-humid where farmers have much employment due to variable resources compared to semi-arid areas (Zindove and Chimonyo, 2015). Furthermore, another reason could be the limited land holdings which compelled farmers to diversify activities more than in the semi-arid area. Nonetheless, farming activity was the first major activity found in both areas. Other studies have reported that agriculture is the most common sector which contributes to poverty reduction (Christiaensen et al., 2011; Wu et al., 2014) in smallholder low-income farms in developing countries.

Types of livestock enterprises in semi-arid and humid were similar. However, farmers owned higher numbers of indigenous cattle and goats in the semi-arid than in the humid zone. Differences in the number of indigenous cattle and goats owned by farmers between the two agro-ecologies could be justified by the farmers' preference based on the climatic conditions. Semi-arid area is more prone to dry spells which over the years has compel farmers to raise only tolerant animal to harsh environment, in deed indigenous cattle and goats are more preferable in this area because of their role in the food security of households (Msangi, 2014; Salama et al., 2014; Kumar et al., 2015; Zindove and Chimonyo, 2015). In addition, ownership of pigs was different between semi-arid and humid environments. Household in humid area owned 5 times more pigs than in semi-arid area. This could be attributed to climatic conditions including cool weather and food crop allowing good health of pigs (Berton et al., 2015). Other livestock enterprises did not show differences between the two agro-ecologies and it is suggested that both environments consider livestock as valuable assets for household income generation.

Furthermore, among livestock enterprises, cattle fall among the most important enterprises being promoted by the government of Rwanda under an especial programme "One cow per poor family–GIRINKA" (RARDA, 2006). A previous study showed that the main reason for smallholder to keep cattle was milk production for primarily home consumption and secondly for cash through milk sales (Kamanzi and Mapiye, 2012). Dairy cattle were more in the semi-arid than humid areas. This might be due to the historical fact that the semi-arid areas used to be pastoral areas while the humid zone was mainly for stall-feeding. As human population pressure increased, grazing land became scarce compelling farmers in the semi-arid area to reduce cattle numbers for stall feeding system. This reduction of cattle herd was coupled with planting of forages that are adapted to cut and carry system for feeding. In addition, a high percentage of these cattle are crossbreds with Friesian and Jersey or with unknown breeds. High number of these crossbreds could be due to the use of artificial insemination (AI; Wurzinger et al., 2006) though some farmers still use bulls for natural service resulting to unknown cattle genotypes because farm records are lacking.

Milk yield differed among cattle genotype but not between semi-arid and humid environments, suggesting that the management and type of breed are major factors affecting milk yield in smallholder farms of Rwanda. In the context of Rwandan climate and smallholder farmers prevailing conditions, Jersey cows have shown high milk yield than the rest of these breeds. This is because Jersey can tolerate heat stress, consume more feed (Igono et al., 1992; Muller and Botha, 1993; Rhoads et al., 2009) and have low whole animal maintenance needs (I.V. Nsahlai, pers. comm.). It is suggested that under "GIRINKA programme" increase number of Jersey can contribute to increase milk yield, thus increasing smallholder farmers' income. However, the achievement of this production depends on improving feeds and feeding under farm conditions.

Odds ratio estimates on importance of planted fodder species revealed that semi-arid and humid environments did not differ. Also, gender and experience of farmers in livestock rearing did not affect the planting of fodder species. However, age and education level of household head in both environments highly differed. High estimated odds ratio showed that farmers above 40 years old were likely to have planted fodder species. This could be linked to the importance that older farmers give to livestock husbandry, especially concerning feeds and feeding. Also, another reason might be the mixed crop-livestock farming system practised in both environments which compels farmers to use some improved fodder as a way of soil fertility management. It was reported that forage legumes have been used for many years to improve soil fertility and increase crop output (Wanapat, 2009). In addition, fodder species are established, especially in areas with steep slopes to stabilise soils (Kagabo et al., 2013). Furthermore, high estimated odds ratio for uneducated household heads suggested that educated farmers carried out activities other than livestock farming. Furthermore, high estimated odds ratio suggests that farmers in humid environment are more likely to apply fertilisers as one of management practices for sustainable forage production than those from semi-arid zone. This could be linked to land tenure and intensive farming which obliges farmers to fertilise crop. This agrees with Davis and D'Odorico (2015) who reported that farmers practise intensive livestock farming system to maximise production on small land holding. These differences of forage management between the two environments could also be attributed to soil fertility level. Unlike semi-arid, the humid area is prone to acidic soils and aluminium toxicity (Mutimura and Everson, 2012a) and these abiotic factors hinder any crop production including forages. In addition, odds ratio estimates for level of education suggest that uneducated farmers are likely to apply fertiliser on forages. This again could be attributed to the fact that these farmers are mainly involved in farming. As the major activity of interviewed farmers was farming, many studies have reported that soil management including application of fertilisers, especially manure is the core concern for smallholder farmers (Turmel et al., 2015). This is also shown by the high odds ratio estimates for experience in livestock rearing where farmers with more than 20 years are likely to apply fertiliser on forages compared to less experienced farmers.

On the other hand, establishment of forages was associated with farmers' preferences of landscapes in semi-arid and humid environments. This is shown by higher estimated odds ratio for farmland in semi-arid than in humid areas. This could be because of land availability in semi-arid compared to humid area (Mutimura and Everson, 2012b). It might also be to the "One cow per poor family programme - GIRINKA" which requires farmer to have established forages to receive a dairy cow (Klapwijk et al., 2014). In addition, farmland could also be provided for planting fodder trees when the land is inappropriate for food crop production. Some studies have also reported that farmers were providing marginalised land incompatible for either crops or livestock production to establish trees (Ndayambaje et al., 2013). Furthermore, farmers in humid area are more likely to establish fodder on terraces as landscape preference than semi-arid area. The provision of land on terraces for planting forages could be explained by the topography in the area which requires the construction of terraces as means of reducing soil erosion from steep slopes.

The ranking of major planted forages showed that Napier grass differed between semi-arid and humid environments. This suggests that, although Napier grass is the most used fodder in livestock feeding system, especially in dairying across East Africa (Rudel et al., 2015; Asudi et al., 2015), its appreciation is based on local climatic conditions. Furthermore, the appreciation of other fodder species was similar across these two environments. This could be linked to the fact that some of these fodder species are collected on roadside and others are planted on terraces, primarily for erosion control. Previous studies have shown that land shortage is the most important reason for low adoption of planted fodder species which can lead to feed shortage in smallholder dairy farms (Kamanzi and Mapiye, 2012).

Various feed resources which were used by farmers in semi-arid and humid environments including crop residues, natural grass and planted grass. Looking at high number of crop residues in comparison with planted grass and natural grass, it underscores shortage of feeds, especially during periods when food crops are not yet harvested. The use of a diversity of crop residues has been reported to be associated with feed shortages in a given eco-environment (Mekasha et al., 2014). Quantitative differences in availability have been observed in Napier grass and roadside grass between semi-arid and humid environments. This could be linked to the amount and longevity of rainfall in humid area which produce high biomass of these grasses. Although the quantity of Napier grass reduces during the dry season, it is still the first choice of farmers, underscoring the importance of planted forages in smallholder farmers. In addition, collecting dried natural grass for feeding animal during the dry season can hinder livestock production because it produces materials that are low in metabolisable energy to sustain the animal and ultimately decreases its production (Ortez-Arriola et al., 2014). Despite these grasses, a high number of crop residues used did not differ between the two environments. However, the use of crop residues during the rainy and dry seasons, suggests that fodder grasses are not enough to feed livestock in both environments. It has been similarly noted that when there is climate variability, farmers in sub-Saharan Africa tend to use different locally available feed resources as the coping mechanisms to sustain livestock production (Sharka et al., 2013). Among crop residues, maize stover was indicated as the second to Napier grass in both seasons, especially in semi-arid area. The use of maize stover has been reported in many regions including East-Africa where this feed is very important in livestock feeding system (Jaleta et al., 2015). Other crop residues with high importance in the semi-arid were banana pseudo-stems used during dry season whereas in humid area, bean haulms were used in both seasons. Notwithstanding the fact that these crop residues are used in livestock feeding, the resilience of feed shortage differs between the two locations.

3.5. Conclusions

Farming is one of the most important activities carried out by farmers in semi-arid and humid agro-ecologies. Agro-ecology, age and experience of household head were the most important in fodder management. In addition, farmland was the landscape preferred by livestock owners in semi-arid area to grow forages. However, the humid environment had more diversity in feed resources used in both the rainy and dry seasons than semi-arid area. Generally, seasonal feed availability showed variation in the number of feed resources in semi-arid and humid environments. Nevertheless, both areas depended on Napier grass as the main green fodder while others were crop residues. This suggests that feed availability is based on seasonal crop harvesting which can lead to feed shortage in a time of crop failure. Also, high use of crop residues can compromise livestock productivity due to low quality, suggesting the need to characterise the available feed resources in smallholder farms of semi-arid and humid environments for better choice of feed.

Chapter 4: Nutritional value of available ruminant feed resources in smallholder dairy farms in Rwanda[1]

Abstract

Smallholder dairy farmers in Rwanda use diversity of resources to cope with endemic feed shortages. However, there is inadequate farm data to support farmer decisions on choices of options. The objective of this study was to evaluate nutritional quality of feed types that farmers use in different agro-ecological zones of Rwanda. Samples of feed types were collected from 90 randomly selected households in the semi-arid and humid environments of Rwanda and analysed for chemical composition, contents of metabolisable energy (ME), organic matter digestibility (OMD) and neutral detergent fibre digestibility (NDFd). Rumen fermentation characteristics and efficiency of energy utilisation were examined by determining partitioning factor (PF). Only six out of 24 feed types were common in both environments. Chemical composition, OMD, ME, NDFd and PF of these feed types differed significantly ($P<0.05$) in their nutritional attributes. This suggests that a common feed composition table can be used as a component of the decision support tool for rational feed resource development and utilisation in smallholder farms in the selected agro-ecologies of Rwanda.

Key words: Chemical composition, feed resources, metabolisable energy, organic matter digestibility, partitioning factor

4.1. Introduction

Milk production in Rwanda has consistently increased due to policy support through the “One cow per poor family programme” (Klapwijk et al., 2014). However, per capita consumption of milk still lingers below the international standards because of inadequate nutrition and low yields, even from improved breeds (Kabirizi et al., 2013). A number of coping mechanisms to feed shortage in smallholder livestock systems has been undertaken (Garg et al., 2013). In East African countries including Rwanda,

---

[1] Published as: Mupenzi Mutimura, Cyprian Ebong, Idupulapati Madhusudana Rao and Ignatius Verla Nsahlai. Tropical Animal Health and Production, 47, 1131–1137.

change facilitators have promoted the adoption of high biomass fodder species most notably Napier grass (*Pennisetum purpureum*) as a coping mechanism to land shortage for feed production (Chapter 3; Mutimura et al., 2013a).

Feed inventories in smallholder dairy farms in Rwanda have revealed the diversity of options (Mutimura et al., 2013a) that underscore the need for support tools to facilitate decisions on choices for livestock feeding systems (Msangi et al., 2014). However, with the exception of few feed types from on-station trials (Mutimura et al., 2013b), information on nutritive values of feed types in Rwanda is grossly inadequate. The objective was to identify and to determine nutritive values of feed resources used by smallholder farmers to feed dairy cows in the semi-arid and humid environments of Rwanda.

4.2. Materials and methods

4.2.1. Location and sample collection from households

The study was conducted in two environments, which have contrasting elevations, climates and soils. Semi-arid (Bugesera District; 30°25' E, 2°30' S) is at low altitude (1,425 ml), warm (average 21.5ºC), low annual rainfall (750 mm), and with either sandy or clay soils. Humid (Nyamagabe District; 29°56' E, 2º 47' S) is cool (16.5ºC), at mid- to high altitude (1,800 - >2000 m), adequate rainfall (1,800 mm) zone, and with acidic kaolinite soils which are prone to aluminium toxicity. Samples were collected from 90 randomly selected households in four sectors (Sub-district) in Bugesera and Nyamagabe districts. In each sector five households per cell (local government administration under a sector) in three randomly selected cells per sector provided samples.

4.2.2. Sampling, sample handling and laboratory analysis

Samples from each household and feed type were divided into two parts. One part was dried at 60ºC for 48 hours and milled to pass through 1 mm screen for subsequent laboratory analyses. The other part was dried at 105ºC for determination of DM (AOAC, 1990; method ID 9420.5), OM (AOAC, 1990; method ID 9420.5), CP

(AOAC, 2006; method ID 984.13) and NDF (Van Soest et al., 1991).

Using *in vitro* gas technique OMD, ME and PF were determined. Samples (≈200 mg) were accurately weighed and transferred into airtight graduated gas syringes (100 ml) for anaerobic fermentation (39±1°C; 24 h) in an oven. The media was a mixture of 1:2 of inoculum source and buffer solutions (v/v) made from solutions A, B and C (Osuji et al., 1993). The inoculum sources were rumen fluids from two surgically prepared steers according to ethical practice. These animals were fed on grass hay (*Brachiaria* hybrid cv. Mulato II). The inoculum preparation procedure was done according to Osuji et al. (1993) as modified by Mutimura et al. (2013b). Gas readings were recorded at 0, 1, 3, 5, 7, 9, 12, 16, 20 and 24 after inoculation. Syringes were removed at 24 h of incubation.

OMD and ME were calculated according to Menke et al. (1979) – Equation (1) and (2).

$$\mathrm{OMD\,(g/kg\,DM)} = 148.8 + 8.89\mathrm{G}_{24} + 4.5\mathrm{CP} + 0.651\mathrm{XA} \qquad (1)$$

Where

G_{24} = Gas volume at 24h after inoculation; and; XA = Ash content (g/100g)

$$\mathrm{ME\ (MJ/kg\ DM)} = 2.2 + 0.136\mathrm{G}_{24} + 0.057\mathrm{CP} + 0.0029\mathrm{CP}^2 \qquad (2)$$

NDFd was estimated based on Goering and Van Soest (1970) – Equation (3).

$$\mathrm{NDFd\ (g/kg\ DM)} = \frac{1000x(NDF_{feed} - NDF_{res})}{NDF_{feed}} \qquad (3)$$

Where NDF_{feed} NDF in feed; NDF_{res} was NDF in residues after refluxing in neutral detergent solution.

PF was calculated based on equation by Blümmel and Becker (1997) – Equation (4).

$$\mathrm{PF\,(mg/mL\,of\ gas\ volume)} = TOMD/IVGP\ldots.. \qquad (4)$$

Where TOMD, is true organic matter digestibility; IVGP, *in vitro* gas production

4.2.3. Statistical analysis

Cross comparisons of forage species distribution was computed using Chi-square for frequency procedure of SAS system 9.3 (2010). Chemical composition, OMD, ME and PF of feed resources were examined using Mixed Model of SAS system 9.3 (2010).

4.3. Results

4.3.1. Diversity of feed resources

Only six of 24 feed types were common across environments. In semi-arid, more than 90% of farmers used crop residues and herbage opportunistically collected from roadsides and marshland. In humid, 19% of the dairy farmers relied on crop residues. The majority of households (63%) depended on pastures from edges of cultivated land; roadside and marshlands. Napier grass was found in less than 20% of the dairy households (Table 4.1).

4.3.2. Chemical composition of feed resources

Chemical composition of feed resources is shown in Table 4.2. Feed types differed significantly in DM content ($P<0.0001$), CP ($P=0011$), NDF ($P<0.0001$), Ash and OM ($P=0002$). Banana pseudo-stem had the least DM among the feed types. Most of the feed resources (73%) did not differ significantly ($P>0.05$) in DM although the range of mean DM (161-521 g/kg) was wide (Table 4.2). There was a considerable overlap in CP among feed types expect for *Leucaena* and *Calliandra* whose CP values were clearly different ($P<0.05$) from CP in 17 other feed types.

Ash content in 16 out of 24 feed types (≈ 62%) ranged from 24 to 119 g/kg DM and did not differ ($P>0.05$) among these feeds. Banana pseudo-stem had the highest ash but it did not significantly exceed ash content of Irish potato haulms. As a derivative of ash, differences in OM among feed types were inverse reflections of differences in ash contents. In addition, banana leaves had the highest NDF which exceeded NDF values of all other feed types. Irish potato haulms had the lowest NDF which differed ($P<0.05$) from NDF in 16 feed types.

Table 4.1: Frequency (%) distribution of feed types for dairy cattle in low and mid-altitudes of Rwanda

Feed types	Botanical name	Environment	
		Semi-arid	Humid
Crop residues			
Banana peels	*Musa* sp.	3	NA
Banana pseudo-stems	*Musa* sp.	15	1
Banana leaves	*Musa* sp.	3	NA
Irish potato haulms	*Solanum tuberosum*	NA	1
Sorghum stover	*Sorghum bicolor*	1	NA
Sweet potato vines	*Ipomoea batatas* L.	3	3
Wheat straw	*Triticum* spp.	NA	3
Maize stover	*Zea mays*	1	NA
Sorghum regrowth	*Sorghum bicolor*	3	NA
Roadside grass			
Commelina	*Commelina benghalensis*	6	NA
Couch grass	*Digitaria* sp.	3	5
Cymbopogon	*Cymbopogon* sp.	1	NA
Snake weed	*Polygonum nepalense*	5	NA
Planted forages			
Napier grass	*Pennisetum purpureum*	11	8
Guinea grass	*Panicum maximum*	4	NA
Signal grass	*Brachiaria decumbens*	1	3
Timothy grass	*Setaria* sp.	NA	1
Marshland grass			
Couch grass +Cyperus	*Digitaria* sp.+*Cyperus* sp.	NA	3
Cyperus	*Cyperus latifolius*	NA	3
Multipurpose trees			
Calliandra	*Calliandra calothyrsus*	NA	1
Corn plant	*Dracaena afromontana*	1	NA
Ficus	*Ficus* sp.	1	1
Leucaena	*Leucaena diversifolia*	NA	1
Bitter leaf	*Vernonia amygdalina*	3	NA

NA: Not available

Table 4.2: Chemical composition (g/kg DM) of feed types collected from semi-arid and humid environments of Rwanda

Feed types	DM	CP	Ash	OM	NDF
Banana leaves	220±66^{c}	115±24^{bcd}	91±26^{bc}	909±26^{ab}	702±39^{a}
Banana peels	161±66^{c}	70±24^{cd}	119±26^{bc}	881±26^{abc}	477±39^{cde}
Banana pseudo-stem	55±49^{d}	63±18^{d}	239±19^{a}	761±19^{c}	638±29^{b}
Bitter leaf	236±66^{c}	166±24^{ab}	129±26^{b}	871±26^{bc}	375±39^{ef}
Signal grass	609±57^{b}	86±21^{cd}	26±22^{c}	900±22^{abc}	407±34^{ef}
Calliandra	348±94^{c}	228±35^{a}	62±37^{bc}	938±37^{ab}	495±55^{cde}
Commelina	261±42^{c}	86±16^{cd}	137±16^{b}	863±16^{bc}	544±25^{cde}
Corn plant	204±94^{c}	130±34^{abcd}	97±37^{bc}	904±37^{ab}	530±55^{cde}
Couch grass	500±41^{bc}	85±15^{cd}	83±16^{bc}	917±16^{ab}	531±24^{cde}
Couch grass+Cyperus	369±66^{bc}	97±25^{cd}	112±25.9^{bc}	888±26^{abc}	430±39^{ef}
Cymbopogon	330±94^{c}	78±34^{cd}	97±37^{bc}	903±37^{ab}	469±55de
Cyperus	243±66^{c}	71±28^{cd}	70±25.9^{bc}	931±26^{ab}	524±39^{cde}
Ficus	357±66^{c}	153±24^{ab}	124±26^{b}	876±26^{bc}	458±39^{e}
Guinea grass	500±54^{bc}	91±20^{cd}	125±21^{b}	876±21^{bc}	469±32de
Irish potato haulms	894±94^{a}	95±35^{cd}	207±37^{ab}	793±37^{c}	295^{f}
Leucaena	334±94^{c}	233±35^{a}	71±37^{bc}	929±37^{ab}	527±55^{cde}
Maize stover	935±94^{a}	40±34^{d}	24±37^{c}	977±37^{a}	395±55^{ef}
Napier grass	249±25^{c}	97±10^{cd}	126±10^{b}	874±10^{bc}	553±15^{bcde}
Snake weed	294±47^{c}	116±17^{bcd}	98±18^{bc}	902±18^{abc}	335^{ef}
Sorghum regrowth	213±66^{c}	141±24^{abc}	122±26^{b}	877±26^{abc}	371^{ef}
Sorghum stover	521±94^{bc}	66±34^{cd}	60±36^{bc}	940±37^{ab}	424±39^{ef}
Sweet potato vines	214±47^{c}	99±17^{bcd}	91±18^{bc}	909±18^{ab}	495^{cde}
Timothy grass	196±94^{c}	106±35^{bcd}	140±37^{b}	860±37^{bc}	562±55^{bcde}
Wheat straw	884±66^{a}	31±25^{d}	52±26^{c}	948±26^{a}	580±39^{bcd}

Means in the column with the same uppercase letter are not significantly different at $P<0.05$.

4.3.3. *In vitro* gas production

Feed types differed significantly in OMD ($P<0.0001$), NDFd ($P<0.0001$), ME ($P<0.0001$) and PF ($P<0.0001$) (Table 4.3). The range of mean OMD (270–498 g/kg DM) was wide and contiguous. Only sweet potato vines, sorghum regrowth and maize stover had significantly (P<0.05) higher OMD than those of 15 feed types. On the other end, only four feed types had significantly lower OMD than OMD in 11 other feeds.

Banana leaves had the highest NDFd but did not differ significantly (P>0.05) from NDFd in banana pseudo-stem and wheat straw (P>0.05). Eleven feed types had the least NDFd but they did not differ significantly (P>0.05) in NDFd from banana peels and *Calliandra*. *Commelina*, Napier grass and Timothy grass constituted a category of feeds whose NDFd was lower than the NDFd value of banana leaves, but higher than NDFd in 21 feed types. Sorghum regrowth and sweet potato vines had the highest ME. However, the energy value did not differ significantly (P>0.05) between maize stover and *Leucaena. Cyperus* and *Cymbopogon* had the lowest but similar ME with nine feed types. Snake weed, *Ficus*, *Calliandra* and sorghum stover had ME values which were lower than ME in seven feed types.

Cymbopogon had higher PF values (P<0.05) than all other feeds except *Cyperus* sp., *Calliandra* and banana leaves. Eight feedstuffs recorded the lowest PF values (2–3 g TDOM/ml 24h gas) which were lower than PF values of eight other feeds (4–7 g TDOM/ml of gas). PF values of 14 feedstuffs (3–6 g TDOM/ml 24h- gas) were contiguous and similar.

Table 4.3: Organic matter digestibility (OMD; g/kg DM), NDF digestibility (NDFd; g/kg DM), metabolisable energy (ME; MJ/kg DM) and partitioning factor (PF; mg DOM/ml) of feed types in semi-arid and humid areas of Rwanda

Feed types	OMD	NDFd	ME	PF
Banana leaves	274 ± 45^{c}	695 ± 39^{a}	5 ± 1^{cd}	5 ± 1^{ab}
Banana peels	408 ± 32^{ab}	472 ± 39^{de}	7 ± 1^{cd}	4 ± 1^{bc}
Banana pseudo-stem	394 ± 24^{b}	632 ± 29^{ab}	6^{cd}	2^{c}
Bitter leaf	414 ± 32^{ab}	371 ± 39^{e}	8 ± 1^{ab}	3 ± 1^{bc}
Signal grass	390 ± 27^{bc}	402 ± 34^{e}	6^{cd}	4^{b}
Calliandra	282 ± 45^{c}	488 ± 55^{de}	7 ± 1^{c}	6 ± 1^{ab}
Commelina	428 ± 20^{ab}	539 ± 25^{b}	7^{bc}	3^{c}
Corn plant	277 ± 45^{c}	525 ± 55^{c}	5 ± 1^{cd}	5 ± 1^{b}
Couch grass	344 ± 20^{bc}	525 ± 24^{bc}	6^{cd}	5^{b}
Couch grass+*Cyperus*	373 ± 32^{bc}	423 ± 39^{e}	6 ± 1^{cd}	4 ± 1^{bc}
Cymbopogon	285 ± 45^{c}	463 ± 55^{e}	5 ± 1^{d}	7 ± 1^{a}
Cyperus	270 ± 32^{bc}	518 ± 39^{cd}	4 ± 1^{d}	6 ± 1^{ab}
Ficus	$365\pm32_{bc}$	452 ± 39^{e}	7 ± 0.5^{c}	4 ± 1^{bc}
Guinea grass	374 ± 26^{bc}	464 ± 32^{e}	6^{cd}	4^{bc}
Irish potato haulms	448 ± 45^{ab}	293 ± 55^{e}	8 ± 1^{bc}	3 ± 1^{bc}
Leucaena	365 ± 45^{bc}	520 ± 55^{cd}	8 ± 1^{ab}	3 ± 1^{bc}
Maize stover	500 ± 45^{a}	388 ± 55^{e}	8 ± 1^{ab}	3 ± 1^{c}
Napier grass	447 ± 12^{ab}	547 ± 15^{b}	7^{b}	2^{c}
Snake week	386 ± 23^{bc}	330 ± 28^{e}	7^{c}	4^{bc}
Sorghum regrowth	499 ± 32^{a}	365 ± 39^{e}	9 ± 1^{a}	2 ± 1^{c}
Sorghum stover	420 ± 45^{ab}	417 ± 55^{e}	7 ± 7^{c}	3 ± 1^{bc}
Sweet potato vines	494 ± 22^{a}	489 ± 28^{d}	8^{a}	2^{c}
Timothy grass	427 ± 45^{ab}	558 ± 55^{b}	7 ± 1^{bc}	3 ± 1^{c}
Wheat straw	388 ± 32^{bc}	575 ± 58^{ab}	6 ± 1^{cd}	3^{bc}

Means in the column with the same uppercase letter are not significantly different at $P<0.05$.

4.4. Discussion

Overall in the two niches cattle farmers relied on crop residues (35%), planted pasture (33%) assorted weeds (30%) for feed. At feed item level, the diversity of the feed resource base is wide. However, their relative contribution to the feed resource differed between the agro-ecologies. Napier grass and banana pseudo-stem were the most common feed items encountered during the survey followed by weeds and cereal straws. Mutimura et al. (2013a) reported three classes of feed as the major feeds in smallholder dairy farmsteads which included Napier grass as the major feed resource. This slight disparity can be due to seasons of the year in relations to crop and forage phenology. It is noteworthy that low altitude zone had more feed types than mid-altitude. For reasons that were not clear in this study, farmers in mid-altitude did not use banana peels and banana leaves, even when they used banana pseudo-stem. This observation is contrary to Klapwijk et al. (2014) who reported banana leaves among roughages farmers use to feed to cattle in mid-altitude zone. While a number of forage species encountered in this study are familiar feeds, *Commelina, Cyperus, Cymbopogon,* snake weed, bitter leaf and corn plant were non-conventional materials that have not been earnestly considered as livestock feeds. *Commelina* is occasionally fed deliberately or inadvertently to ruminant livestock, pigs and poultry (Kavana and Kakengi, 2014). There is considerable paucity of information on bitter leaf and corn plant compared to information on pharmacological attributes. However, both *Commelina* and snake weed, these feeds were found to be common among cattle feed resources that are worth considering among major feed types in Rwanda. Apart from wheat straw in the mid-altitude, cereal straws and leguminous fodder species are items in the household feed resource basket.

Dry matter (DM) contents of these different feed types varied drastically between species. Several factors influence the chemical composition of feeds including genotype, environmental and postharvest handling. DM of these feed types except cereal straws were beyond the expected range of 190–250 g/kg DM found in some grasses (Santos et al., 2014) most likely due to age of the plant and postharvest handling. Nevertheless, the DM content of *B. brizantha* cv. Toledo (316 g/kg) is similar to the values observed under grazing system in Brazil (Gracindo et al., 2014) while DM value of multipurpose trees was lower than that reported by Singh et al. (2014).

The global average for CP content was comparable with CP contents in most feed types except for Irish potato haulms and sweet potato vines, where the CP were 7– 8 percent units lower than the global average. These low values in this study could be attributed to age of these plants that were harvested by farmers to feed their cattle. However, CP contents of sweet potato vines were similar to the CP content in the stem fraction of the vines (Kambashi et al., 2014). The CP content of the maize stover recovered from smallholder dairy households in Rwanda was similar to the values reported from China (Li et al., 2014). Other authors (Kambashi et al., 2014) have reported higher CP than we observed. However, Menardo et al. (2015) reported much lower CP content (24 g/kg DM) than we observed. A plausible reason for a combination of low fibre and low CP in maize stover would be the choice of topmost internodes for feeding cattle. Information on nutritional value of bitter leaf is scarce. Woyessa et al. (2013) and Bonsi et al. (1995ab) reported results on CP which was similar (226 g/kg DM vs 168 g/kg DM) when we consider the wide variability in quality across samples from households. In addition, information on the CP content of feed types including Irish potato haulms is rare. The likely CP content was 126 g/kg DM (Saleh et al., 2014) depending on the soil fertility status and this was higher than we observed.

Because of the inconsistency in fibre systems used in this study and reports in Feedipedia, we could compare NDF contents for only nine out of 24 feed types. Except in *Leucaena* and sweet potato vines NDF contents in all these feed types were lower than the global average. The observation corroborates the inference that the herbaceous materials that farmers used were relatively young. Among feed materials that we could not match with the Feedipedia database, the NDF contents of banana leaves and banana pseudo-stem were higher than reported in other studies (Oliveira et al., 2014).

Organic matter digestibility (OMD), NDFd and ME were low in banana leaves, corn plant, *Calliandra and Cyperus.* This is attributed to tannins, in *Calliandra* and banana leaves (Oliveira et al., 2014), saponin in corn plant (Shukla et al., 2014). These compounds interfere with microbial activity and they confer an apparently increased efficiency in the microbial biosynthesis in the rumen, hence high PF values. There were high and positive correlations between rates of gas production, OMD (Figure 4.1a) and ME contents (Figure 4.1b) but a negatively curvilinear relationship between gas production rate and PF (Figure 4.1c). These relationships were expected because, while gas production is a proxy indicator of microbial growth, the efficiency of energy utilisation for microbial growth depends on the synergies of energy and nitrogen availability for microbial biosynthesis. Most of these feed types had the required PF values (3–4 mg/ml) for efficient rumen microbial growth. Nevertheless, PF values for *Calliandra, Cyperus, Cymbopogon* and corn plant were likely overestimated due to interference of secondary compounds which could not be validated using gravimetric methods, hence the curvilinear relationship (Figure 4.1c).

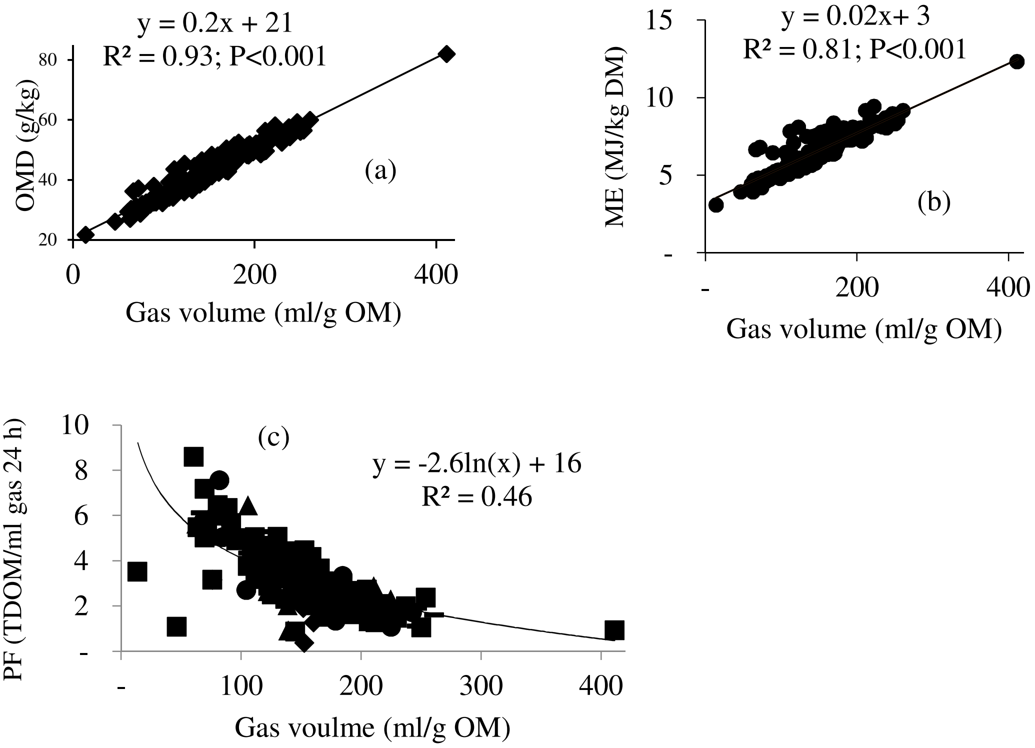

Figure 4.1: Relationships between gas production rates (ml/24h- gas volume) and organic matter digestibility (a), metabolisable energy (b) and partitioning factor (c) of household feed resources in Rwanda

4.5. Conclusions

Environment and its associated climate and soil attributes affected available options and coping mechanisms to feed shortage in Rwanda. Nutritional values of feed resources that respond rational use, are likely to be diverse and highly customised to local farm situations. This study also revealed a number of potentially valuable non-conventional indigenous forage species which can be integrated into national forage germplasm development. Nonetheless, the evaluation and integration of improved forage grass to support the existing feed resources is a crucial for increased forage options among livestock farmers.

Chapter 5: Effect of cutting time on agronomic and nutritional characteristics of nine commercial cultivars of *Brachiaria* compared with Napier grass during establishment under semi-arid conditions in Rwanda[2]

Abstract

A study was conducted to identify the most productive cultivars and their cutting management for optimum nutrient productivity in semi-arid areas of Rwanda. Five cultivars of *Brachiaria brizantha*, one cultivar of *B. humidicola*, two cultivars of *Brachiaria* hybrid and one cultivar of *Brachiaria decumbens* were evaluated against Napier grass (*Pennisetum purpureum*) in an on-farm trial in a Complete Randomised Block Design with four replicates. Forage samples were collected at 60, 90 and 120 days after planting (DAP). At each cutting time, samples of each cultivar were taken and analysed for dry matter (DM), crude protein (CP), organic matter (OM), neutral detergent fibre (NDF) and minerals. The nutritional values were also estimated using *in vitro* gas production (IVGP) and its kinetic parameters, *in vitro* apparent degradable dry matter (ivADDM), digestible organic matter (DOM), metabolisable energy (ME), partitioning factor (PF) and degradable efficiency factor (DEF). The DM, CP, OM, ivADDM and DOM increased from 60 to 90 DAP and declined thereafter. The NDF contents increased with increase in age. The macro and micro-nutrient concentrations were also higher at 90 DAP. The GP of grasses cut at 90 DAP was higher than the other two DAP. The ME differed among grasses and DAP. Furthermore, degradability parameters (A, B, C) and half time ($T_{1/2}$) differed among grasses and between cutting times. The PF and DEF were corrected and both correlated with ME. Yields (kg/ha) of DM, CP and ME increased with age up to 120 DAP. The most promising cultivars were Basilisk, Marandú, Piatá and Mulato II because of their nutritional characteristics as well as nutrient yields which were higher and more comparable with Napier grass.

Key words: Chemical composition, metabolisable energy, degradability parameters, degradation efficiency factor, nutrient yield.

---

[2] Submitted to Grassland Science as: Mupenzi Mutimura, C. Ebong, I.M. Rao and I.V. Nsahlai. Effect of cutting time on agronomic and nutritional characteristics of nine commercial cultivars of *Brachiaria* compared with Napier grass during establishment under semi-arid conditions in Rwanda. Grassland Science (Under review, Manuscript ID: GRS-2015-007).

5.1. Introduction

Intensification of ruminant livestock production is gaining momentum in a number of sub-Saharan African countries due to increasing population pressure and decline in grazing areas (Thornton and Herrero, 2014). Even farmers with access to open grazing land experience increasingly frequent feed shortage (Chirat et al., 2014) due to climate change and variability. Feeds and feeding which underpin most of the livestock production, especially dairy cows (Logue and Mayn, 2014), is a critical issue for smallholder farmers in Rwanda, mostly during the dry season (Chapter 3). In the tropics, grasses are the most ecologically reliable and economically justifiable feed resources (Pedreira et al., 2011) because of their morphological characteristics which enable efficient water use, and rapid recovery after periods of drought (Batistoti et al., 2012). In Rwanda, planting these grasses along contours is encouraged for erosion control (NISR, 2013; Klapwijk et al., 2014). Therefore, improved tropical forages are valuable resources for environmental protection and sustainable livestock feed and food futures for livestock and people (Peters et al., 2003; Baudron et al., 2015).

Brachiaria grasses are among the most important tropical grasses that originated from Africa, improved in Americas through agronomic selection and breeding (Miles et al., 2004) and demonstrated to be highly productive, nutritive and socially acceptable in Asia and Africa for different livestock production systems (Mutimura and Everson, 2012a; Pizarro et al., 2013; Vendramini et al., 2014). However, nutritional attributes of forage depend on plant management. In tropical areas with respect to phenology, soil fertility, moisture conditions, light intensity and temperature (Campos et al., 2013; Danes et al., 2013), the most sensitive attributes to management and environment are metabolisable energy (ME) and crude protein contents as well as macro and micro-minerals. These attributes can compromise milk yields of cows fed on forages grown in warm-environment, including Napier grass (*Pennisetum purpureum*; Dijkstra et al., 2008; Mutimura et al., 2013a; Klapwijk et al., 2014; Ul-Allah et al., 2014; Mutimura et al., 2015). To meet the animals' requirements, farmers have adopted diversification of feed options to cope with feed and nutrient shortages (Chapter 4; Negesse et al., 2009; Mutimura et al., 2015), particularly for domestic herbivores which are the most efficient converters of plant energy and protein into meat and dairy products (Soussana and Lemaire, 2014).

Improved *Brachiaria* grasses are commonly grown in Latin America (Rao et al., 1998; Miles et al., 2004; Cezário et al., 2015). These include *B. brizantha* cv. MG-4, *B. brizantha* cv. Piatá, *B. brizantha* cv. Marandú, *B. brizantha* cv. Xaraes, *B. humidicola* cv. Llanero, *B. humidicola* cv. Humidicola and *B. decumbens* cv. Basilisk which are in general well-adapted to other tropical agro-ecologies. They have recently been introduced, and are being evaluated and disseminated in East Africa (Djikeng et al., 2014). Results on dry matter production and nutritional quality of some of these grasses have been reported under different cutting regimes (Ortega-Gomez et al., 2011). However, the effect of cutting age on nutritional attributes of mentioned *Brachiaria* cultivars including commercial hybrids (cv. Mulato and cv. Mulato II) during establishment in semi-arid environment in Rwanda has not been determined. The objective of the current study was to identify the best-bet *Brachiaria* cultivars based on cutting age for optional nutrient characteristics and productivity in Rwanda.

5.2. Materials and methods

5.2.1. Site description

A field experiment on evaluation of tropical forage grass cultivars was established on-farm (Field trial was established in October 2013 and data recorded until February 2014) in Bugesera district, in the eastern Province (semi-arid area) of Rwanda. Bugesera district lies between 30°25’ E and 2°30’ S with an average altitude of 1,400 m.a.s.l. (Munyemana, 2001). The climate is semi-arid with a long (4–5 months) dry season (Munyemana, 2001; Figure 5.1). Annual rainfall ranges between 650 and 900 mm, with the average temperature of the coldest month is lower than 18°C.

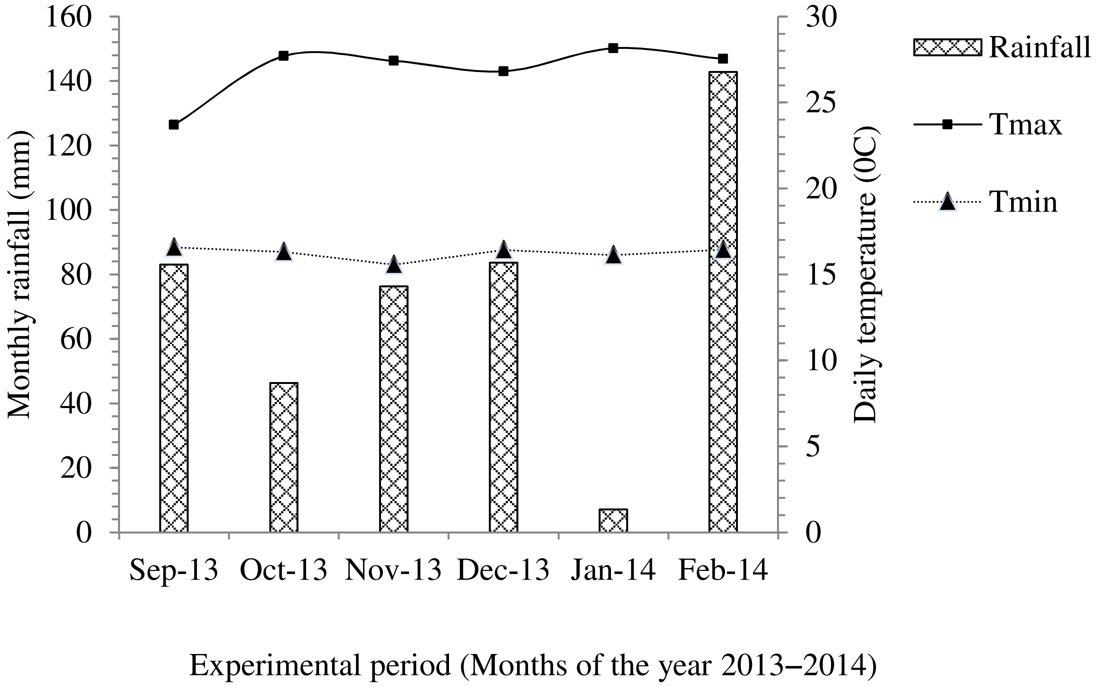

Figure 5.1: Total monthly rainfall and average daily temperature during the experimental period (Source: Data from Bugesera district weather station)

5.2.2. Land preparation and experimental design

The field trial included a set of nine *Brachiaria* cultivars (*B. brizantha* cv. MG-4, *B. brizantha* cv. Piatá, *B. brizantha* cv. Marandú, *B. brizantha* cv. Xaraes, *B. humidicola* cv. Llanero, *B. humidicola* cv. Humidicola, *B. decumbens*, cv. Basilisk, *Brachairia* hybrid cv. Mulato and *Brachiaria* hybrid cv. Mulato II) together with Napier grass which was used as control. Detail information on each cultivar was presented in Table 5.1. The trial was established at on-farm in a completely randomised block design (RCBD) with four replicates. Plot of land used, was planted before to *Lablab purpureus*. The plot was prepared using a hoe, then the plot was divided into sub-plot of 3×3 m. Grasses were established without fertiliser application using seeds and cuttings (for Napier grass) on continuous rows to the rate of 8 kg/ha with spacing of 50 cm between rows. The experimental design was a split–plot where *Brachiaria* cultivars and Napier grass were the main plots and cutting age (60, 90 and 120 days) after planting (DAP) were subplots. Soil samples were taken and analysed for total nitrogen (N) and soil organic carbon (SOC) contents before planting. Analysis of soil

(AOAC, 2006; method ID 984.13) revealed N and SOC contents were 0.3±0.2% and 1.5±0.7%, respectively.

5.2.3. Parameters

The key parameters of the study were chemical composition, neutral detergent fibre (NDF), *in vitro* gas production (GP) and *in vitro* dry matter digestibility (ivDMD) as proxy indicators of nutritive values of test cultivars.

Table 5.1: List of tropical forage grasses used for field evaluation

Species	Cultivar name	Accession number
Brachiaria brizantha	MG-4	CIAT 26646
Brachiaria brizantha	Marandú	CIAT 6294
Brachiaria brizantha	Xaraes	CIAT 26110
Brachiaria brizantha	Piatá	CIAT 16125
Brachiaria decumbens	Basilisk	CIAT 606
Brachiaria hybrid	Mulato	CIAT 36061
Brachiaria hybrid	Mulato II	CIAT 36087
Brachiaria humidicola	Llanero	CIAT 6133
Brachiaria humidicola	Humidicola	CIAT 679
Pennisetum purpureum	Napier grass/Elephant grass	-

5.2.3.1. Chemical composition and fibre analyses

Above ground biomass was harvested at each DAP from 1 m^2 quadrat and fresh weight was recorded. Harvested samples of each cutting age were divided into two portions; one portion was dried at 105^0C for 24 h to calculate dry matter (DM) contents (AOAC, 1990; method ID 9420.5); and organic matter contents by incineration at 550°C for 8 h (AOAC, 1990; method ID 9420.5). The second portion of these samples was dried at 60^0C for 48 h and then milled to pass through 1 mm screen for subsequent analysis. Crude protein (CP) expressed as 6.25 x Kjeldahl Nitrogen (N/kg DM) content in the feed (AOAC, 2006; method ID 984.13) using automated systems (Büchi Labortechnik AG, CH-9230 Flawil 1/Switzerland, Type: K-360). Neutral detergent fibre (NDF) was determined according to Van Soest et al. (1991). Macro-nutrients (Ca, P, Na, Mg and K) and micro-nutrients (Mn, Cu, Zn and Fe) in DM were analysed using Inductively Coupled Plasma (ICP) Optical Emission Spectrometer, Varian 720-ES Series which is available at the University of KwaZulu-Natal, Department of Chemistry, Pietermaritzburg Campus.

5.2.3.2. *In vitro* digestibility and gas production

In vitro gas production (GP) kinetics was measured using automatic-computerised gas production systems (Pell and Schofield, 1993). Ground forage samples (1 g) incubated at 39°C with buffered rumen fluid (100 ml) in Duran bottles (250 ml). The buffer solutions A and B were prepared according to Osuji et al. (1993). Solution A consisted of sodium hydrogen carbonate ($NaHCO_3$; 19.6 g), di-sodium hydrogen orthophosphate anhydrous (Na_2HPO_4; 7.4 g); potassium chloride (KCl; 1.14 g); sodium chloride (NaCl; 0.94 g); magnesium chloride hexahydrate ($MgCl_2.6HO_2$; 0.26 g) and distilled water (2 L). Solution B was calcium chloride dihydrate ($CaCl_2.2HO_2$; 2.65 g) dissolved in distilled water (50 ml). An aliquot (2 ml) of solution B was added to solution A. Ammonium sulphate ($(NH_4)_2SO_4$; 5.8 g) was added to the buffer to eke nitrogen requirement for normal rumen microbial function with CO_2.

Two fistulated cows fed *ad libitum* veld hay and Lucerne supplement (2 kg/day) provided rumen liquor. The rumen content was macerated in a plastic bucket under CO_2 flux. The rumen fluid was squeezed through four layers of cheesecloth. The resultant liquor was transferred into a warm vacuum flask for delivery to the laboratory within 20 minutes. The final inoculum was made by adding the buffer solution (67 ml) and rumen liquor (33 ml) to the sample (1 g) in the Duran bottle (250 ml) under continuous CO_2 flux. Pressure readings were recorded at 20 minutes interval for 72 h. These bottles were removed and their contents transferred into Beckman bottles for centrifugation (BECKMAN$_{TM}$, JLA-16.250, Max 16000 RPM, S/N 13U5193) at 16,000 rpm for 15 minutes at 4^0C. Supernatants were discarded and pellets were quantitatively recovered for DM determination by oven drying to constant weight at 60^0C for 72 hours (Castells et al., 2012).

5.2.4. Statistical analysis

Cumulative gas volumes were computed for each channel of pressure sensor as the difference between the readings at time (t_i) and the initial reading (t_0), adjusted for control readings (Blank) at corresponding recording times. To determine kinetics of gas volume production combined models (Schofield et al., 1994; Equation 1) described by Campos et al. (2004) were used.

$$W = \frac{G}{1 + e^{[2+4c(lt-t)]}} \quad (1)$$

W : Total gas volume at time t; G : Maximum gas volume at $t = \infty$; c : Degradation rate (h^{-1}); lt : Bacteria colonisation or lag time.

Maximum rate of GP at the point of inflection was calculated from the cumulative gas production (GP) while the time taken to produce half of gas volume ($T_{½}$) was estimated based on Sahoo et al. (2010)-Equation 2. Rumen degradability efficiency factor (DEF) was also calculated based on Ouda and Nsahlai (2009)-Equation 3.

$$T_{1/2}\ (h) = lt + 1/(2 \times c) \quad (2)$$

$$DEF = \frac{2PF}{T_{1/2}} \quad (3)$$

Where PF is a partitioning factor

The model was run using NEWAY1.SAS (SAS, 2010) model which also estimated asymptotic gas production as proxy indicators for organic matter degradability. Organic matter degradability (OMD) and metabolisable energy (ME) values were estimated from *in vitro* digestibility using the following equations (Menke et al., 1979; Equation 4 and 5):

OMD (g/kg DM) $=14.88+0.889V_{24}+0.45CP+0.0651Ash$ (4)

ME (MJ/kg DM) $=2.2+0.136V_{24}+0.057CP+0.0029CP^2$ (5)

Where V_{24} = gas volume (ml) at 24 h; CP: crude protein (%). *In vitro* apparent digestible dry matter (ivADDM) was calculated as follows (Equation 6):

ivADDM (g/kg DM) = [Feed incubated−(Residue–Blank)]*1000/Feed incubated (6)

Differences in chemical composition and in biological measures among forage cultivars and cutting ages were statistically examined using the model (Equation 7):

$$Y_{ijk} = \mu + B_i + F_j + H_k + FH_{jk} + \varepsilon_{ijk} \qquad (7)$$

Y_{ijk} = variable dependent; μ= overall mean; B_i = effect of block; F_j = effect of forage grass species; H_k = effect of cutting age; FH_{jk} = effect of interaction of $F \times H$; ε_{ijk} = residual error.

A relationship was established between PF and DEF; and ME of these grasses, using regression procedures.

5.3. Results

5.3.1. Chemical composition

Dry matter (DM) of tested grasses was different (P<0.001) among grass cultivars across cutting age and at the interaction between cutting age and grass cultivars (Table 5.2). The DM increased up to 90 DAP and declined at 120 DAP. *Brachiaria* hybrid cv. Mulato II had the highest and Napier grass had the lowest DM contents (Table 5.2). A cluster of three cultivars (MG-4, Basilisk and Piatá) had the second highest DM contents which were not different (P>0.05) within the same cluster. Cultivars Marandú and Llanero had the second lowest DM contents but not different (P>0.05) from DM contents in *B. brizantha* cv. Mulato, Humidicola and Xaraes (Table 5.2).

Organic matter content also differed (P<0.001) among grasses and between cutting ages. However, no difference (P>0.05) existed among grasses at the interaction between harvesting period and grass genotypes (Table 5.2). Organic matter content increased from 60 DAP to 90 DAP and declined at 120 DAP. This trend was consistent in all except three entries (MG-4, Mulato and Napier grass), where OM contents increased with increase in DAP (Table 5.2). In addition, CP content differed (P<0.01) among grasses, between cutting ages (P<0.001) as well as the interaction. The CP contents between Napier grass and among two cultivars of *Brachiaria* were very strong (P<0.001). *Brachiaria brizantha* (cv. Humidicola, and Piatá) had the highest but similar CP contents to three cultivars of *Brachiaria* (Marandú, Llanero and Basilisk) (Table 5.2). *Brachiaria* hybrid cv. Mulato II had the least but similar (P>0.05) CP contents to *Brachiaria* hybrid cv. Mulato and Napier grass. The other entries were cultivars with intermediate CP contents (Table 5.2).

Crude protein contents declined with DAP and this effect was highly significant (P<0.001). However, these responses were dependent on the cultivars and the interaction effect (P<0.05). This interaction effect showed that cv. Humidicola, cv. Llanero, cv. Mulato and Napier grass lost more CP between 60 and 90 than they did between 90 and 120 DAP (Figure 5.2). Conversely, cv. Basilisk, cv. Marandú, cv. MG-4 and cv. Mulato II, cv. Piatá and cv. Xaraes lost more CP between 90 and 120 DAP than they did between 60 and 90 DAP.

Table 5.2: Dry matter (DM), OM, CP and NDF (g/kg DM) of Napier grass and *Brachiaria* cultivars when harvested at 60, 90 and 120 days after planting in semi-arid zone

DAP	Grass cultivars	DM (g/kg)	OM	CP	NDF
60	Basilisk	133	873	182	349
	Humidicola	153	851	211	310
	Llanero	140	843	187	419
	Marandú	139	852	170	265
	MG-4	147	861	170	300
	Mulato	206	871	173	398
	Mulato II	257	899	147	345
	Napier grass	123	850	182	273
	Piatá	161	886	192	269
	Xaraes	148	877	161	294
90	Basilisk	324	907	167	321
	Humidicola	223	902	152	335
	Llanero	257	889	152	409
	Marandú	279	889	159	275
	MG-4	342	904	156	224
	Mulato	201	882	138	429
	Mulato II	279	916	137	412
	Napier grass	153	890	137	358
	Piatá	291	901	166	334
	Xaraes	281	904	143	382
120	Basilisk	255	901	112	297
	Humidicola	280	865	131	353
	Llanero	227	880	146	444
	Marandú	208	890	138	339
	MG-4	239	905	133	323
	Mulato	240	883	122	440
	Mulato II	304	894	114	457
	Napier grass	191	909	120	367
	Piatá	249	899	133	378
	Xaraes	228	901	120	449
	SEM	3.2	2.7	2.2	5.7
	Grass cultivars	***	***	**	***
	DAP	***	***	***	***
	DAP × Grass cultivars	***	NS	*	***

DAP: Days after planting; DM: Dry matter; OM: Organic matter; CP: Crude protein; NDF: Neutral detergent fibre; SEM: Standard error of the means; NS: Not significant (P>0.05); ***: Significant (P<0.001); **: Significant (P<0.01); *: Significant (P<0.05).

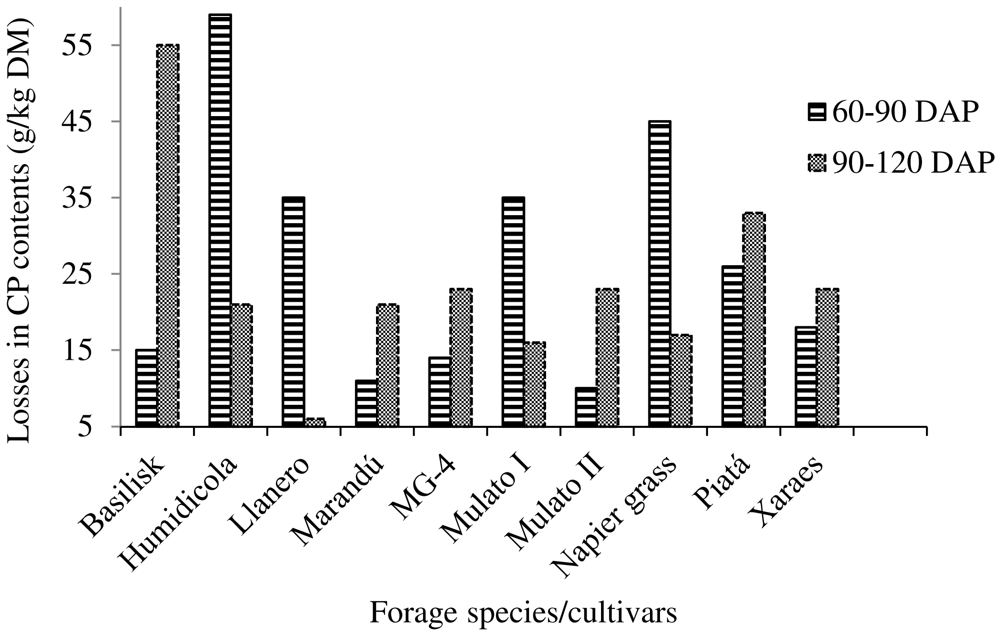

Figure 5.2: Effect of the age of the plant on losses in CP contents in different cultivars of *Brachiaria* and Napier grass

Neutral detergent fibre (NDF) of tested grasses differed (P<0.001) among grass cultivars, across cutting age and at the interaction between cutting age and grass cultivars. The NDF contents differed highly (P<0.001) between Napier grass and among *Brachiaria* cultivars. However, cv. Llanero, cv. Mulato and cv. Mulato II had the similar (P>0.05) NDF contents and these values were higher than those of Napier grass and other *Brachiaria* cultivars, followed by cultivar Xaraes (Table 5.2). Neutral detergent fibre contents also increased with DAP (P<0.001). However, the magnitude of change depended on the cultivar. In one cultivar (Basilisk), NDF content decreased by 7–8% with DAP from 60 to 120. There was a slight (2%) decrease in cultivar Llanero between 60 and 90 days, thereafter it increased slightly (9%). In cultivar MG-4, NDF content decreased by approximately 25% from 60 DAP to 90 DAP and rebounded by 44% from 90 DAP to 120 DAP, which making a net gain of approximately 7% from the NDF content at 60 DAP to 120 DAP. Napier grass, Mulato II, Piatá and Xaraes gained (19-30%) large fibre content between 60 and 90 DAP compared to subsequent increases at 120 DAP. Successive increases in fibre contents in other cultivars were small (Table 5.2).

Macro-elements analysed in tested grasses showed that there were differences ($P<0.001$) among tested grasses for Ca, K, Na and Mg. In addition, differences were observed at stages of growth for Ca ($P<0.01$), K ($P<0.001$), Mg ($P<0.001$) and P ($P<0.001$). There were also large differences ($P<0.001$) among grasses at the interaction between age at harvest and grass genotypes for Ca ($P<0.001$), K ($P<0.05$) and Mg ($P<0.001$). However, all grasses had similar ($P>0.05$) P. There was also no difference ($P<0.05$) in the effect of age at harvest of grasses for Na. There was no interaction effect of age and genotypes ($P>0.05$) for Na and P (Table 5.3). Trends for most grasses showed that macro-nutrient content reduced as the age of these grasses increased. However, Ca content in Piatá and Mulato did not change substantially with the age.

On micro-nutrients (Table 5.4), the effect of grass genotype was strong for Fe ($P<0.01$), Zn ($P<0.05$), Cu ($P<0.05$) and Mn ($P<0.001$). The effect of age at harvest was highly different ($P<0.001$) for these micro-minerals. Furthermore, the interaction effect of age and grass genotype also showed some differences in Fe ($P<0.05$), Zn ($P<0.05$), Cu ($P<0.01$) and Mn ($P<0.001$).

5.3.2. The ivADDM, OMD and ME of tested grasses

There was no difference ($P>0.05$) in ivADDM among grass cultivars although the tendency ($P=0.051$) was very strong at 90 DAP with cultivar Piatá being the highest in ivADDM. However, the DAP ($P<0.001$) and the effect of the interaction between DAP and genotypes affected ivADDM. Generally, although there was no effect ($P>0.05$) of grass genotypes the trend showed that ivADDM increased from 60 to 90 DAP, then decreased to 120 DAP.

Organic matter digestibility content differed ($P<0.001$) among grass genotypes (Table 5.5). The effect of DAP was also high ($P<0.001$) whereas the effect of the interaction between DAP and grass genotypes was evident ($P<0.05$). In all grasses except cv. Humidicola, OMD increased from 60 to 90 DAP and substantially decreased at 120 DAP. At 90 DAP cv. Piatá had the highest OMD but similar to other grasses except cv. Xaraes and cv. Marandú. In addition, ME of tested grasses differed among grasses and among DAP ($P<0.001$). Also, the effect of interaction between DAP and grass genotypes was evident (P<0.05; Table 5.5). At 90 DAP, most grasses had similar ME except cv. Piatá and cv. Xaraes which had the highest and lowest levels, respectively.

Table 5.3: Macro-nutrient concentration (g/kg DM) in the tested grasses at different days after planting

DAP	Grass cultivars	Ca	K	Na	Mg	P
60	Basilisk	27.3	27.5	3.5	44.2	12.1
	Humidicola	33.9	29.2	8.2	28.6	24.5
	Llanero	30.8	28.1	4.0	56.2	22.9
	Marandú	29.1	31.0	3.1	35.7	20.9
	MG-4	31.1	28.4	4.7	51.1	14.5
	Mulato	30.4	22.8	3.9	38.1	22.8
	Mulato II	30.3	18.7	5.4	23.2	20.3
	Napier grass	35.1	30.0	9.0	30.0	10.6
	Piatá	26.8	27.3	3.4	42.7	20.4
	Xaraes	24.3	25.8	3.4	32.2	21.9
90	Basilisk	25.4	23.8	3.1	36.8	13.9
	Humidicola	15.9	20.5	6.2	22.5	11.8
	Llanero	19.2	25.4	3.6	36.2	13.0
	Marandú	29.0	26.2	4.0	31.3	15.1
	MG-4	27.8	23.9	4.0	42.0	16.8
	Mulato	29.8	24.5	4.0	32.1	16.0
	Mulato II	42.4	16.0	6.6	39.8	16.1
	Napier grass	28.5	27.6	4.7	16.7	13.5
	Piatá	27.3	22.4	3.0	35.1	13.0
	Xaraes	26.2	23.8	3.1	31.9	13.8
120	Basilisk	24.4	18.9	3.1	32.8	10.8
	Humidicola	24.9	18.6	4.6	25.8	10.7
	Llanero	25.4	24.2	4.0	35.8	13.3
	Marandú	31.2	23.7	4.9	30.5	14.6
	MG-4	31.9	20.0	4.5	40.7	11.7
	Mulato	28.5	20.2	3.8	32.0	11.8
	Mulato II	38.8	14.2	5.7	43.9	8.4
	Napier grass	31.1	20.0	4.8	15.3	10.5
	Piatá	23.4	20.8	3.5	32.6	9.8
	Xaraes	22.2	20.8	3.0	25.8	11.9
	SEM	0.5	0.4	0.3	0.7	1.1
	Grass cultivars	***	***	***	***	NS
	DAP	**	***	NS	***	***
	DAP × Grass cultivars	***	*	NS	***	NS

DAP: Days after planting; SEM: Standard error of the means; NS: Not significant (P>0.05); ***: Significant (P<0.001); **: Significant (P<0.01); *: Significant (P<0.05).

Table 5.4: Micro-nutrient concentration (mg/kg DM) in the tested grasses at different days after planting

DAP	Grass cultivars	Fe	Zn	Cu	Mn
60	Basilisk	7.8	0.46	0.13	0.88
	Humidicola	11.2	0.37	0.11	0.89
	Llanero	15.0	0.48	0.12	0.77
	Marandú	11.0	0.38	0.09	0.93
	MG-4	6.9	0.42	0.11	0.67
	Mulato	12.5	0.26	0.07	0.61
	Mulato II	11.4	0.29	0.07	0.91
	Napier grass	13.7	0.43	0.13	0.87
	Piatá	5.0	0.35	0.09	1.09
	Xaraes	5.4	0.33	0.08	0.74
90	Basilisk	1.8	0.3	0.09	0.78
	Humidicola	2.2	0.3	0.06	0.9
	Llanero	3.0	0.24	0.05	0.76
	Marandú	2.6	0.27	0.08	0.87
	MG-4	2.1	0.22	0.07	0.58
	Mulato	4.2	0.25	0.1	0.63
	Mulato II	2.7	0.26	0.06	0.92
	Napier grass	1.5	0.28	0.08	0.81
	Piatá	3.0	0.28	0.07	1.24
	Xaraes	2.0	0.27	0.08	0.89
120	Basilisk	3.3	0.25	0.05	0.94
	Humidicola	19.8	0.29	0.03	1.48
	Llanero	9.6	0.29	0.06	1.21
	Marandú	8.5	0.26	0.07	0.92
	MG-4	5.3	0.28	0.06	0.84
	Mulato	9.2	0.25	0.07	0.9
	Mulato II	8.7	0.2	0.04	1.27
	Napier grass	3.1	0.24	0.06	0.84
	Piatá	4.6	0.28	0.06	0.82
	Xaraes	3.9	0.28	0.07	0.65
	SEM	0.6	0.01	0.003	0.01
	Grass cultivars	**	*	*	***
	DAP	***	***	***	***
	DAP × Grass cultivars	*	*	**	***

DAP: Days after planting; SEM: Standard error of the means; ***: Significant ($P<0.001$); **: Significant ($P<0.01$); *: Significant ($P<0.05$).

Table 5.5: Mean values of ivADDM (g/kg DM), OMD (g/kg DM) and ME (MJ/kg DM) for the tested grasses at different days after planting

DAP	Grass cultivars	ivADDM at 72 hours	OMD	ME
60	Basilisk	251	417	6.9
	Humidicola	378	480	8.2
	Llanero	313	537	8.7
	Marandú	349	422	6.8
	MG-4	364	466	7.5
	Mulato	507	537	8.7
	Mulato II	318	493	7.8
	Napier grass	336	445	7.3
	Piatá	334	469	7.8
	Xaraes	320	447	7.2
90	Basilisk	524	523	8.4
	Humidicola	550	467	7.4
	Llanero	508	489	7.7
	Marandú	465	437	7.0
	MG-4	412	510	8.1
	Mulato	495	494	7.7
	Mulato II	457	509	8.0
	Napier grass	351	453	7.1
	Piatá	564	550	9
	Xaraes	455	433	6.8
120	Basilisk	318	352	5.4
	Humidicola	400	470	7.3
	Llanero	433	427	6.7
	Marandú	337	369	5.9
	MG-4	445	410	6.5
	Mulato	348	474	7.3
	Mulato II	490	416	6.4
	Napier grass	486	378	5.9
	Piatá	429	397	6.3
	Xaraes	296	378	5.9
	SEM	24.6	12.1	0.2
	Grass cultivars	NS	***	***
	DAP	***	***	***
	DAP × Grass cultivars	*	*	**

DAP: Days after planting; ivADDM: *In vitro* apparent degradable dry matter; OMD: Organic matter digestible; ME: Metabolisable energy; SEM: Standard error of the means; NS: Not significant ($P>0.05$); ***: Significant ($P<0.001$); **: Significant ($P<0.01$); *: Significant ($P<0.05$).

5.3.3. Gas production characteristics of tested forage grasses

Cumulative GP was different ($P<0.01$) among grasses and highly ($P<0.001$) among DAP (Table 5.6); however, interaction between grass cultivars and DAP was not different ($P>0.05$). GP of grasses cut at 90 DAP was higher than at 60 and 120 DAP.

Degradability showed similar ($P>0.05$) quickly degradable fraction (A) among tested grasses but differed ($P<0.001$) among different DAP. Thus grass harvested at 60 and 90 DAP had highest A compared to grass cut at 120 DAP. Furthermore, there was no ($P>0.05$) interaction between cultivars and DAP on A and B. Conversely, slowly degradable fraction (B) differed modestly ($P<0.01$) among grasses and highly ($P<0.001$) among DAP. In addition, the rate of degradation (C) of B differed modestly ($P<0.01$) among grass cultivars and highly ($P<0.001$) among DAP. The interaction between grass cultivars and DAP affected ($P<0.01$) the rate of degradation. Higher rates of degradation of tested grasses were observed at 60 DAP while the lowest were observed at the age of 120 DAP.

Furthermore, half-life ($T_{1/2}$) differed ($P<0.01$) among grass cultivars and highly ($P<0.001$) among DAP. The interaction between grass cultivars and DAP affected ($P<0.01$) $T_{1/2}$ at 120 DAP while $T_{1/2}$ of 60 DAP did not differ from that of 90 DAP.

Table 5.6: *In vitro* digestion parameters of experimental grasses cut at 60, 90 and 120 days after planting

DAP	Grass cultivars	GP (ml/g DM)	A (g/kg DM)	B (g/kg DM)	C (%/h)	$T_{1/2}$
60	Basilisk	168	60	108	0.031	23
	Humidicola	182	73	110	0.039	20
	Llanero	199	50	149	0.033	24
	Marandú	163	58	106	0.036	22
	MG-4	211	71	140	0.028	21
	Mulato	222	74	147	0.03	20
	Mulato II	215	86	129	0.035	20
	Napier grass	196	62	134	0.032	23
	Piatá	212	69	143	0.03	23
	Xaraes	197	68	129	0.31	23
90	Basilisk	240	70	170	0.033	20
	Humidicola	216	61	155	0.033	22
	Llanero	253	86	168	0.028	21
	Marandú	188	65	124	0.028	22
	MG-4	234	87	148	0.028	20
	Mulato	253	96	155	0.029	19
	Mulato II	243	66	177	0.029	19
	Napier grass	243	65	178	0.028	26
	Piatá	266	69	197	0.032	20
	Xaraes	210	50	160	0.025	23
120	Basilisk	182	36	147	0.028	29
	Humidicola	243	51	192	0.027	23
	Llanero	255	53	201	0.023	23
	Marandú	163	37	130	0.031	27
	MG-4	190	47	143	0.03	25
	Mulato	224	52	172	0.027	20
	Mulato II	198	46	152	0.027	23
	Napier grass	198	39	164	0.032	28
	Piatá	192	40	152	0.029	26
	Xaraes	198	30	169	0.021	29
	SEM	8.4	5.3	7.6	0.001	0.5
	Grass cultivars	**	NS	**	**	***
	DAP	***	***	***	***	***
	DAP × Grass cultivars	NS	NS	NS	**	**

DAP: Days after planting; GP: Gas production; A: intercept (quick degradable fraction); B: Potential degradable (slow degradable fraction); C: rate of degradability of B; $T_{1/2}$ (h): half time (time taken to produce half of gas volume); ***: Significant ($P<0.001$); **: Significant ($P<0.01$); NS: Not significant ($P>0.05$).

Partitioning factor (PF) and rumen degradability efficiency factor (DEF) showed correlation ($R^2= 0.86$; $R^2=0.89$) with metabolisable energy (ME; Figure 5.3a,b) of tested grass cultivars. Also, there was a very strong positive correlation ($R^2= 0.96$) between DEF and PF (Figure 5.3c).

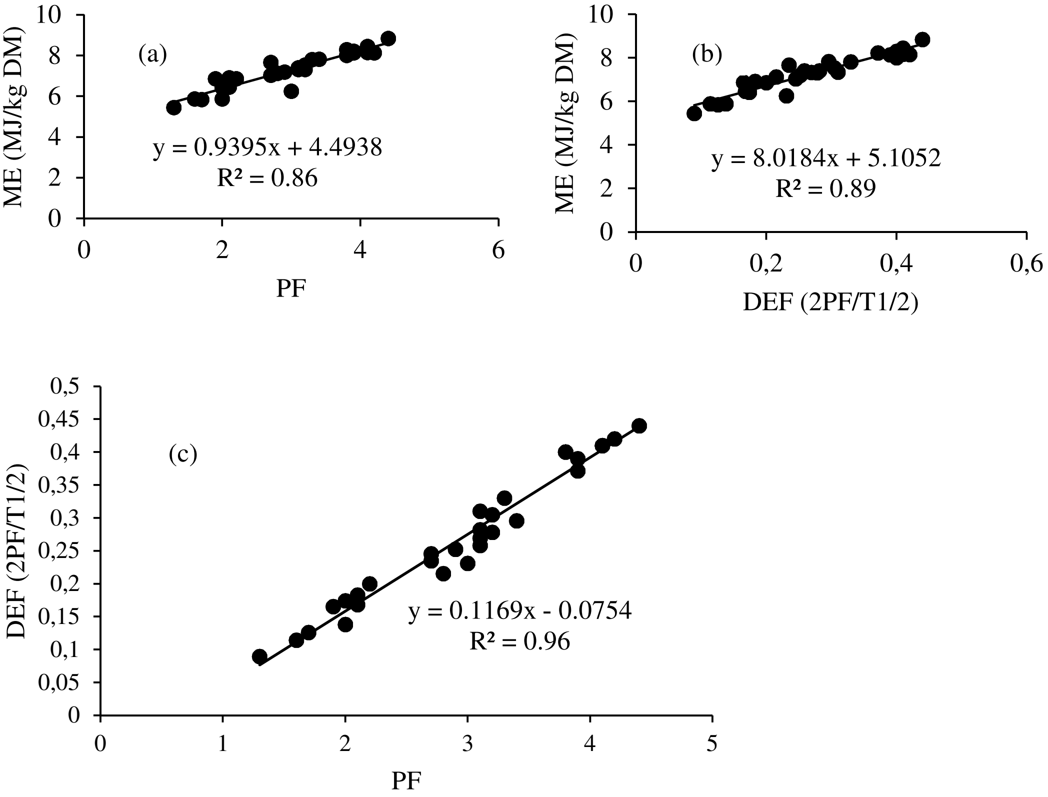

Figure 5.3: Relationship between ME and PF (a), between ME and DEF (b) and between DEF and PF (c) of tested grass cultivars

5.3.4. Nutrient yields of experimental grasses

Yield of DM (kg/ha), CP (kg/ha) and ME (MJ/ha) differed highly ($P<0.001$) among grass cultivars and DAP. The interaction effect between grass cultivars and DAP was also highly significant ($P<0.001$). Napier grass had the highest DM, CP and ME which were similar ($P>0.05$) to cv. Basilisk, cv. Marandú and cv. MG-4 (Table 5.7). Cultivar Mulato had the lowest DM, CP and ME yields but had similar DM content with *Brachiaria* cv. Mulato II and cv. Humidicola.

Changes in yields of DM, CP and ME in these grass cultivars with DAP depended on grass species and cultivars. Generally, between 60 and 90 DAP yields of DM, CP and ME increased by 4-7 folds across the grass cultivars, thereafter incremental DM yield decreased. The increase of DM between 60 and 90 DAP was very high in cv. Humidicola (21-fold) and cv. Llanero (11-fold) compared to other grass cultivars

(Table5.7). Although the CP and ME increased with DAP for most grasses, values for cv. Basilisk, cv. Marandú, MG-4 and cv. Piatá decreased at 120 DAP.

Table 5.7: Yields of dry matter (DM), crude protein (CP) and metabolisable energy (ME) of different grass cultivars of *Brachiaria* in comparison with Napier grass at different days after planting

DAP	Grass cultivars	DM (kg/ha)	CP (kg/ha)	ME (MJ/ha)
60	Basilisk	1,247	520	8,605
	Humidicola	116	56	954
	Llanero	455	244	3,956
	Marandú	1,544	720	11,582
	MG-4	1,136	479	7,724
	Mulato	346	170	2,695
	Mulato II	539	290	4,691
	Napier grass	1,677	746	12,245
	Piatá	1,281	601	9,994
	Xaraes	952	425	6,853
90	Basilisk	9,388	4,910	78,861
	Humidicola	2,539	1,186	18,786
	Llanero	5,392	2,637	41,520
	Marandú	9,797	4,997	79,359
	MG-4	6,482	2,833	45,375
	Mulato	2,437	1,240	19,496
	Mulato II	3,002	1,483	23,117
	Napier grass	9,155	4,147	64,997
	Piatá	6,717	3,694	60,455
	Xaraes	5,894	2,552	40,081
120	Basilisk	12,153	4,278	65,627
	Humidicola	5,537	2,602	40,418
	Llanero	7,287	3,111	48,820
	Marandú	12,033	4,934	78,216
	MG-4	7,374	2,721	43,507
	Mulato	2,156	897	13,799
	Mulato II	7,487	3,549	54,652
	Napier grass	16,648	6,293	98,224
	Piatá	8,919	3,541	56,188
	Xaraes	8,818	3,333	52,025
	SEM	323	132	2,073
	Grass cultivars	***	***	***
	DAP	***	***	***
	DAP × Grass cultivars	***	***	***

DAP: Days after planting; SEM: Standard error of the means; ***: Significant (P<0.001).

Analysis of variance showed that the content of all chemical components varied across species and cultivars due to difference in genetic make-up of each cultivar. Changes in chemical composition with maturity are well documented in literature. However, the magnitude and pattern are grass cultivar specific. Pearson's correlation showed that content of DM, OM, CP and NDF were correlated with maturity depicting strong linear trends in all component across grass cultivars. In some cases, the linear trend was not significant (Table 5.8). As expected CP contents were negatively correlated with age at harvest in all grass cultivars. The correlation was not significant in cv. Marandú due to high standard error and lack of difference in CP contents across levels.

Table 5.8: Grass cultivar mean and Pearson correlations among chemical composition with age of maturity in tested grasses

	DM (g/kg)			OM (g/kg DM)			CP (g/kg DM)			NDF (g/kg DM)		
Cultivars	Mean	R^2	Sign	Mean	R^2	Sign	Mean	R^2	Sign	Mean	R^2	Sign
Basilisk	237.2	0.62746	*	864.9	0.7162	**	154.1	-0.92627	****	322.4	-0.49031	NS
Humidicola	218.8	0.96612	****	846.1	0.67842	*	164.7	-0.89647	****	332.3	0.64591	*
Llanero	208.3	0.70513	*	844.8	0.79359	**	161.5	-0.88665	***	424.0	0.33786	NS
MG-4	242.6	0.45572	NS	855.6	0.78217	**	153.0	-0.80603	**	282.3	0.16252	NS
Marandú	208.9	0.47232	NS	836.4	0.74303	*	155.8	-0.57319	NS	293.1	0.73186	**
Mulato	215.5	0.5706	NS	854.6	0.53286	*	144.3	-0.80383	*	422.2	0.46209	NS
Mulato II	279.7	0.49429	NS	874.0	0.51551	*	132.8	-0.74021	**	404.7	0.80655	*
Napier grass	155.5	0.82217	**	847.3	0.86712	***	146.5	-0.89862	****	332.8	0.77072	*
Piatá	233.9	0.6413	*	866.5	0.76861	**	163.6	-0.92876	****	326.6	0.85904	***
Xaraes	219.0	0.58447	*	861.3	0.79971	**	141.3	-0.75022	**	374.8	0.83159	***

DM: Dry matter; OM: Organic matter; CP: Crude protein; NDF: Neutral detergent fibre; NS: Not significant (P>0.05); *: Significant (P<0.05); **: Significant (P<0.01); ***: Significant (P<0.001).

5.4. Discussion

Dry matter of a feed is one of the most important attributes in forage evaluation because nutrient intake is a function of voluntary DM intake, nutrient density/concentration in dry matter and bioavailability in the animal (McDonald et al., 2011). It is also important in guiding the choice of forages according to expected yield per unit area of land. Fresh herbage with high DM contents translates into high DM productivity per unit area of land and the optimal timing of harvest to maximise DM yield. Dry matter content in most tested forage grasses increased from 60 to 90 DAP and declined at 120 DAP for cv. Humidicola, cv. Mulato, cv. Mulato II and Napier grass. At 90 DAP where grasses had higher DM contents, cv. MG-4, cv. Basilisk and cv. Mulato II had greater values. Previous researchers have reported that DM content is much influenced by genetic makeup of the plant, weather and postharvest handling. For example, the DM of Napier grass obtained at 60 DAP was much lower than that reported in the same grass at the same growth stage (Zetina-Córdoba et al., 2013; Lounglawan et al., 2014). This difference might be due to the fact that the grass in Thailand was grown with fertiliser application (NPK, 15-15-15; kg/ha) whereas in our experiment, tested grasses were established without any fertiliser application. The DM content observed at 90 DAP in this study was similar to that reported on forage cereal crops in eastern China (Qu et al., 2014). The DM of tested grasses revealed that a good time for high DM concentration was at 90 DAP. For warm-season grass, temperatures below 15°C can decrease growth of the grass (Moreno et al., 2014). Temperatures throughout our experiment were above 15°C. For this reason, high DM obtained at 90 DAP might be influenced by the low moisture as the samples at this age were collected during dry season compared to other DAP. However, Napier grass which is the most popular forage cultivar used by farmers in east Africa including Rwanda to feed cattle (Klapwijk et al., 2014; Mutimura et al., 2013a) had the lowest DM at 90 DAP. This suggests that tested *Brachiaria* cultivars might offer more advantages on nutritional characteristics than Napier grass at 90 DAP.

Crude protein is one of the major criteria for determining the nutritional quality of a feed. This is because as level of CP increases, the DM intake by livestock and rumen microbial growth would also increase (Chanthakhoun et al., 2012). However, increase of CP level in a feed should come from conventional feed resources (Baluch-Gharaei et al., 2015). The CP content of most grasses decreased with advancing age of plants. These differences in CP losses within cultivars among DAP were large in cv. Basilisk, cv. Humidicola, cv. Llanero and Napier grass than other cultivars within DAP. This implies some forage cultivars (e.g. cv. Humidicola, cv. Llanero and cv. Mulato) should be harvested earlier than the other (e.g. cv. Basilisk, cv. Marandú, cv. MG-4 and cv. Mulato II) to maximise forage CP. It would be better to harvest cv. Piatá and cv. Xaraes between 60 and 90 DAP than other cultivars, especially cv. Basilisk. The CP at 90 DAP ranged between 137 and 167 g/kg DM and were much higher than the CP content (109 g/kg DM) reported from Brazil in *Brachiaria brizantha* when the grass was intercropped with soybean (Crusciol et al., 2014). These results obtained for CP content on cv. Piatá, cv. Marandú and cv. Xaraes were also higher than those reported in Brazil when these grasses were subjected to cutting heights of 10, 20 and 30 cm above the soil (de Pinho Costa et al., 2014). However, our results were similar to those Maia et al. (2014) reported when inorganic fertiliser (nitrogen and phosphorus) was applied to same grasses after corn was harvested. In addition, the CP content in cv. Marandú were much higher (170 g/kg DM) than those reported in Brazil where cv. Marandú (66 g/kg DM) was harvested at 60 DAP and fed to steers (Morais et al., 2011). This might be due to the soil structure, management practices and weather conditions which are major factors that influence nutritional quality of grasses. The CP values obtained in Napier grass were much higher than CP values (112 g/kg DM) of the grass reported in Taiwan at 60 days of growth (Zetina-Córdoba et al., 2013). In addition, at 60 days of age, cv. Humidicola had higher CP (211 g/kg DM) than the rest of these grasses. This could be due to its low germination rates and slower growth under cooler environment (Meena et al., 2014) which might influence its CP in leaves at 60 DAP. At 90 DAP cv. Piatá and cv. Basilisk had high values of CP of 166 and 167 g/kg DM, respectively. This could satisfy the daily CP requirement of a lactating cow producing 20–30 litres of milk per day (NRC, 2001). Our findings suggest that tested *Brachiaria* grasses, in the short run, can be a good source of CP to cattle without any fertiliser application in local farm prevailing conditions.

The NDF content in feed is one of the major criteria to predict DM intake (DMI) in animal, especially for grazing animals. This is because high NDF content in a feed leads animal to eat less feed (Lardner et al., 2015) and hence affects animal productivity. The NDF content in tested grasses increased with DAP. Cultivars Llanero, Mulato and Mulato II showed higher NDF contents than the rest of these grasses across the three DAP. The NDF content observed in most grasses within each DAP was much lower than values reported in other grasses like *Lilum* sp. (Fukushima et al., 2015). The NDF reported in Taiwan on Napier grass was much higher (710 g/kg DM) (Zetina-Córdoba et al., 2013) when compared to our results (Table 5.2). Cultivars Piatá, MG-4, Xaraes and Marandú showed lower NDF content at all three DAP than values reported in Brazil when these grasses were harvested during four seasons of the year (de Pinho Costa et al., 2014). When comparing cutting ages, NDF was much higher (385 g/kg DM) at 120 DAP, however, these values are in the range of 300–400 g/kg DM which is the recommended NDF content in feed for good DMI by ruminant livestock (McDonald et al., 2011). Furthermore, OM content of forage grasses used in this study increased from 60 to 90 DAP. However, except cv. Basilisk, cv. Humidicola, cv. Llanero and cv. Mulato II, OM content of the rest of the tested grasses declined at 120 DAP (Table 5.2). Generally, the mean OM content of tested grasses at 90 DAP was higher (898 g/kg DM) than that of 60 DAP (866 g/kg DM) and 120 DAP (893 g/kg DM). These values of OM content in tested grasses were similar to those reported in meadow grasses (91.3%) in Armenia (Khachatur, 2006). However, OM values of Napier grass were similar (891 g/kg DM) to those reported in Taiwan on Napier grass at the age of 60 days of growth (Zetina-Córdoba et al., 2013).

Mineral nutrients play major roles in the body function of the animal including skeletal development and maintenance, energy, milk production and body function (Rasby et al., 2011). Concentrations of mineral nutrients in a plant are affected by environment, management applied to the plant and maturity stage (El-Nashaar et al., 2009). Values for Ca and P reported elsewhere (Crusciol et al., 2014; Mutimura and Everson, 2012a) were lower than observed, however, K and Mg values were almost similar to our observations, except for K values at 120 DAP (Table 5.3). Furthermore, micronutrients contents were lower than those reported in Fescue (Johns et al., 2003). In consideration of micro-nutrients measured in tested grasses, these nutrients might not meet the requirements of a lactating dairy cow of 680 kg of live weight producing 20–30 litres of milk daily. Conversely, based on macro-nutrients requirements of dairy cows (NRC, 2001), the level of all studied macro-nutrients are likely to satisfy a lactating cow of 680 kg of live weight producing 20-30 litres of milk daily.

Dry matter digestibility is one of many factors influencing animal productivity (Mathison et al., 1995). This is also influenced by the availability of the degradable materials of the feed. The ivADDM of tested grasses differed at 90 and 120 DAP. High ivADDM of these grasses was obtained at 90 DAP. This might be due to the high DM content at this age of harvest. At 120 DAP, ivADDM decreased except for cv. MG-4, Napier grass and cv. Mulato II. Most grasses showed low ivADDM with values below 50% except for cv. Piatá, cv. Humidicola, cv. Basilisk and cv. Mulato which had 564; 550; 524 and 508 g/kg DM, respectively at 90 DAP. Similar results were reported on *Saccharum officinarum* and *Panicum maximum* by Singh et al. (2012), but these were lower than results reported in Brazil using the same *Brachiaria* cultivars (Maia et al., 2014). Our results on ivADDM from Napier grass were lower than reported by Singh et al. (2014). In addition, OMD increased with cutting age of these grasses until 90 DAP and declined at 120 DAP. These same grasses had high OMD at 90 DAP. The high OMD in cv. Piatá, cv. Basilisk and cv. MG-4 could be explained by their high CP contents (Sampaio et al., 2010) at 90 DAP with reasonable values of NDF content in grasses. Other researchers have reported high OMD (>64%) in cv. Mulato II and cv. Cayman (Vendramini et al., 2014). The OMD in cv. Humidicola was higher than that reported by Nogueira Filho et al. (2000) in the same grass but lower than in Napier grass. Furthermore, ME in tested grasses at 60 and 90 DAP did not differ. However, high ME (9 MJ/kg DM) was obtained in cv. Piatá cut at 90 DAP followed by cv. Basilisk, cv. MG-4 and cv. Mulato II (Table 5.5). The ME values observed in these grasses were higher than those reported on available forage grasses in smallholder farms in Rwanda (Mutimura et al., 2015). Instead, these grasses showed similar ME content compared to some temperate grass cultivars (Fulkerson et al., 2007). The Napier grass which is considered as control had similar ME content reported by latter authors. Although there was variation in ME content among tested grasses, some of these grasses might not satisfy the ME requirement for dairy cow with live weight of 450 kg producing 20–30 litres of milk per day (NRC, 2001). Nevertheless, cv. Piatá can meet the daily ME requirement for dairy cow of 650 kg live weight producing 16 litres per day (Geraghty et al., 2010) if it can eat 17 kg of DM per day. Moreover, grasses with ME above 7 MJ/kg DM might be better to supply energy to ruminant livestock based on dairy dry matter intake (Datt et al., 2008).

Gas production parameters of a feed are crucial factors in animal nutrition because they can be used to predict dry matter intake by the animal. Gas production (GP), rate of degradability and half time ($T_{1/2}$) of grasses were higher at 90 than at 60 and 120 DAP. Cultivar Piatá had the highest GP at 90 DAP followed by Mulato. This might be due to high DM content in the grass at 90 DAP. The B of cv. Piatá was also higher than that of other grasses which revealed that this grass cultivar had a high degradable fraction. Interestingly, the rate of degradation in cv. Piatá was also high although similar to cv. Basilisk and cv. Humidicola (Table 5.6). The high rate of degradation might be influenced by the high energy content of these grasses. Negrão et al. (2014) reported that the increase of rate of degradation in cv. Basilisk was influenced by increasing levels of rice bran as source of energy. The rate of degradation of cv. Mulato II and cv. Basilisk was much lower than that reported in previous research on Napier grass (Mutimura et al., 2013b). The time taken to produce half of gas volume ($T_{1/2}$) suggests that cv. Piatá, cv. Mulato, cv. Mulato II, cv. MG-4 and cv. Basilisk might serve as a good source of forage which can increase DMI by the animal. Furthermore, although Napier grass had reasonable degradable fractions, it required a longer time (26 h) to be degraded than the other grasses. This means that at this growth age the DM intake of Napier grass by a ruminant livestock might be reduced due to the extended length of time taken in the rumen (Negrão et al., 2014).

The DEF which is influenced by the time to produce half of gas volume, was correlated ME. The ME increased with increase of PF as well as with the increase of DEF. Similar trend was observed by Ouda and Nsahlai (2009) who reported the increase of DEF of grass hay when supplementation ratio of legumes was increasing. As the DEF is a proportional of PF and $T_{1/2}$, forages with small values of $T_{1/2}$ will have high values of DEF. Also, when $T_{1/2}$ remains constant, DEF increases with increase of PF. This means that high rumen degradability depicts microbial efficiency and high values of ME in a forage grass proposing the ME can be estimated using DEF and PF.

The value of forages determines the carrying capacity of land premises based on the amount of nutrients, especially CP and ME that they supply to animals. Results from the present study contributed to the identification of grass species/cultivars which are better in nutrient yield per unit area. The DM yield (kg/ha) increased with the increase of DAP. Although at 90 DAP most grasses had high percentage of DM content, this did not influence high DM yield at this harvesting period. This suggests that biomass was much more responsible for higher DM matter yield than the dry matter content. The same observation was reported by Lewandowski and Heinz (2003) who found that the delay in harvesting miscanthus grass increased DM yield resulting to decreased quality of plant. Except Mulato and Humidicola at 90 DAP, all other grasses including Napier grass had higher CP yield than observed in sweet sorghum in China (Qu et al., 2014). Nutrient yields showed that most grasses can sustain annually CP and ME requirements of a dairy cow of 450 kg producing 20 litres of milk per day (NRC, 2001). At 120 DAP, Napier grass outweighed the rest of tested grasses due to its high biomass yield. Although, this grass yielded high DM per unit area at this period of harvest, its use by ruminant livestock might be limited by degradation process which will require much time to be digested (Table 5.6). Better yields for cv. Basilisk, cv. Marandú and cv. Piatá were obtained at 90 DAP. This suggests that the age of 90 DAP can be a good time for harvesting these grasses without compromising nutritional quality. However, harvesting these grasses at 120 DAP will yield high nutrients but can compromise their nutritional quality.

5.5. Conclusions

Among 10 grasses tested there were significant differences in terms of nutritional characteristics across the cutting ages. Most grasses had slightly similar nutritive values but cv. Marandú, cv. Basilisk and cv. Piatá were superior in nutritional attributes compared to the rest of these grasses. This is because their DM contents were not higher but their ivADDM, GP, potential degradable fractions, DEF, ME and time taken for rumen degradability values were superior to the rest. Napier grass as the major feed resource of smallholder farmers in east Africa was found to be among the lowest in its nutritive value attributes among the tested grasses but it had higher CP and ME yield per unit area because of its high above ground biomass production. The ME contents decreased from 90 to 120 DAP. Yields (kg/ha) of DM, CP and ME increased consistently with DAP up to 120 DAP. Age of 90 DAP was the best harvesting time to get good quality of the grasses. The most promising *Brachiaria* cultivars identified were *B. decumbens* cv. Basilisk, *B. brizantha* cv. Marandú and *B. brizantha* cv. Piatá, because of their nutritional characteristics as well as nutrient yields which were higher and more comparable with Napier grass than the other cultivars. Although these *Brachiaria* grass have shown good nutritional quality, evaluation of their effect on livestock performance is of great importance.

Chapter 6: Growth performance of crossbred (Ankole × Jersey) dairy heifers fed on forage grass diets supplemented with commercial concentrates[3]

Abstract

Rearing heifers for dairy cow replacement is a challenge in smallholder dairy farms in the tropics due to feed shortage. The objective of this study was to evaluate *Brachiaria* hybrid cultivar Mulato II as a feed resource for improving growth performance of dairy heifers under cut-and-carry feeding system in Rwanda. Sixteen crossbred (Ankole × Jersey) heifers (Average live weight 203±35 kg) were randomly allocated to two dietary treatments viz: cv. Mulato II with 2 kg/day of commercial concentrates (MCC) and Napier grass (*Pennisetum purpureum*) with the same supplement (NCC), for a period of 12 weeks. Mineral lick and water were provided *ad libitum*. Daily feed intake and fortnightly live weight were measured. Average daily gains and feed conversion ratio (FCR) were calculated. Results showed that absolute daily dry matter intake (g DM/day) and relative intake (g/kg of metabolic body weight - $BW^{0.75}$) were higher in heifers fed on MCC than in heifers fed on NCC ($P<0.001$). FCR was lower ($P<0.001$) in MCC than NCC diets. Final body weight (FBW) and body weight gain (BWG) did not differ between the two groups of heifers ($P>0.05$). Average daily weight gain (ADWG) did not differed significantly ($P>0.05$) between treatments. Based on numerical body weight changes and nutritive values, Mulato II showed potential to be integrated into local cut-and-carry feeding systems for better heifer rearing to facilitate dairy cow replacement.

Keywords: Dry matter intakes, feed conversion ratio, *Brachiaria* grass, Napier grass

6.1. Introduction

Population growth and shrinking of grazing land have compelled farmers to shift from extensive to intensive dairy system in order to optimise milk yield per cow (Lukuyu et al., 2012). In spite of the additional stress on limited feed resources, especially during

---

[3] Mupenzi Mutimura, Cyprian Ebong, Idupulapati Madusudhana Rao and Ignatius Verla Nsahlai, 2015. Change in growth performance of crossbred (Ankole × Jersey) dairy heifers fed on forage grass diets supplemented with commercial concentrates. Tropical Animal Health and Production, 48, 741–746.

the dry season, farmers retain female calves to replace culled cows (Mohd Nor et al., 2015). In tropical areas of Asia, Africa and South American highlands, farmers lose replacement dairy stock due to limited knowledge on calf and heifer rearing. Approximately 35% of the losses can be restored using adequate feeding (Moran, 2011). In these areas, Napier grass (*Pennisetum purpureum*) is the most abundant single, year-round feed resource in smallholder dairy farms (Mutimura et al., 2013a; Rahman et al., 2015). However, total dependence of farmers on Napier grass is risky because of Napier grass stunt disease that poses threats to production of this grass throughout the East African region (Asudi et al., 2015; Kawube et al., 2015). Developing disease resistant cultivars has been identified as one possible approach to address the problem (Kawube et al., 2014). However, there is need to consider alternative fodder species to complement the search for disease resistance in the global germplasm collection and local landraces.

Brachiaria species are indigenous grasses to Africa, which have been selected for productivity and tolerance to abiotic and biotic stresses in Latin America (Miles et al., 2004). *Brachiaria* hybrid cultivar (cv.) Mulato II was introduced, evaluated and selected by farmers in Rwanda (Mutimura and Everson, 2012a; Chapter 5). However, its superiority over Napier grass in terms of animal productivity in stall-fed cattle has not been examined. Data on animal growth performance from different *Brachiaria* grass species is limited to grazing trials (Gracindo et al., 2014). The objectives of the study were (1) to determine relative intake and growth performance of crossbred dairy heifers fed on *Brachiaria* hybrid cv. Mulato II compared with Napier grass under a cut-and-carry forage feeding system in Rwanda; and (2) to assess the relationship between energy intake and energy required.

6.2. Materials and methods

6.2.1. Location

The feeding trial was conducted at Songa research station of Rwanda Agriculture Board (RAB). The station is located in the mid-altitude zone (1,471 m a.s.l) of Rwanda and it lies between $29^0 48'$ E, $2^0 25'$S. The average annual rainfall is 1,087 mm and relative humidity of 77% with an average temperature of 20.1^0C per year.

6.2.2. Management of animals

Sixteen (Ankole × Jersey) crossbred heifers (605±11 days of age and 203±35 kg body weight) were selected and divided randomly into two groups of eight animals. Animals from each group were ear tagged, randomly assigned to one of the two dietary treatments. Animals were put in individual pens in a house built for cows in the station and partitioned for stall feeding. ALBENDOZOLE (10 ml/10 kg body weight) and acaricide (Norotraz 12.5% E.C- Effective Concentration, 2 m/1 L of water; twice/week) were used to control endo and ecto-parasites, respectively. Individual pens were cleaned every morning.

6.2.3. Feeds and feeding

The dietary treatments were two different roughages: *Brachiaria* grass (*Brachiaria* hybrid cv. Mulato II) or Napier grass (*Pennisetum purpureum*) fed as basal diets. All animals received commercial concentrate supplements (2 kg/day) which was composed of maize (55%), soybean (10%), rice bran (10%), palm cakes (20%), bone powders (1.5%), salt (0.5%) and molasses (3%). Water and mineral blocks were provided *ad libitum*. These basal feeds (grasses) were harvested (15 cm above ground) from the station plots where they were planted without fertiliser application. The soil type of the plots is sandy clay with nitrogen and carbon content of 0.2±0.4% and 1.2±0.5%, respectively. The harvested herbages were chopped (10 cm length) using forage chopper (Mild steel, 7 HP of power, electric motor/diesel engine, BrazAfric Ltd) before feeding. Basal diets were given *ad libitum* based on individual body weights. After an adaptation period of 14 days, daily feed offers and refusals, respectively were weighed, recorded and sampled at 900h and 1500h for a period of 12 weeks (From 21st February to 21st May 2014). Fortnightly, individual animals were measured to the nearest 100 g using mechanical Weigh Bridge (PORTEE 1000 kg, 2x1 m, B.C, 188021, RAPPORT).

Daily feed dry matter (DM), organic matter (OM), crude protein (CP), metabolisable energy (ME), calcium (Ca) and phosphorus (P) intake were calculated as the difference between feed offer and refusal corrected for the respective contents in the original samples (Balehegn et al., 2014). Feed conversion ratio (FCR) was calculated as the slope of the linear regressions of cumulative nutrient (DM, OM and CP) intakes on growth rates. Growth rates (g/day) were estimated as the slope of the linear regressions of weekly body weights on days of feeding. Daily ME requirement for growing heifers was calculated based on– Equation 1, 2, 3, 4, 5 and 6 (AFRC, 1993).

$$E_m (MJ/day) = 0.396W^{0.73} \tag{1}$$

$$E_g (MJ/day) = \Delta w(6.28 + 0.0188W)/(1 - 0.3\Delta w) \tag{2}$$

Where E_m is the net energy for maintenance; W is the live weight; Δw is the live weight change; E_g is the net energy required for weight gain.

$$k_f = 0.042M/D + 0.006 \tag{3}$$

$$k_m = 0.019M/D + 0.053 \tag{4}$$

$$k_{mp} = ((NE_m + NE_g)/NE_m)/(1/(k_m + (NE_m + NE_g/NE_m) - 1)/k_f) \tag{5}$$

Where k_f is the efficiency of utilisation of metabolisable (ME) for weight gain; M/D is the ME (MJ/kg DM) of a diet; k_m is the efficiency utilisation of ME for maintenance; k_{mp} is the efficiency utilisation of ME for maintenance and production; NE_m is the net energy for maintenance; and NE_g is the net energy for growth.

The predicted ME required for maintenance and production was calculated as:

Predicted ME required = $(E_m + E_g)/k_{mp}$ (6)

6.2.4. Chemical composition of feeds used

Samples of feed offered and refusals were collected daily. Weekly samples were mixed and two samples were taken and analysed for chemical composition. The official protocol were used to the determine DM, Ash and OM (AOAC, 1990; method ID 9420.5) and CP (AOAC, 2006; method ID 984.13). Macro and micronutrients were determined using Atomic Absorption and Flame Emission Spectrophotometer (PerkinElmer, Inc., Precisely, A. Analyst 200).

6.2.5. Statistical analysis

Chemical compositions of feeds over 12 weeks were analysed using General Linear Model (GLM) procedures of the Statistical Analysis System (SAS, 2010). Means were compared using PDIFF option of SAS. Data from experiments on feed intake and body weight gain were subjected to analysis of variance (ANOVA) in a completely randomised design using GLM procedures of the Statistical Analysis System (SAS, 2010) based on the following model (Equation 6):

$$Y_{ij} = \mu + H_i + F_j + e_{ij} \qquad 6$$

Where Y_{ij} = variable dependent; μ= overall mean; H_i = animal effect; F_j = effect of feed; e_{ij} = residual error.

Initial body weight of heifers was used as a covariate in analysis of the effect of diets on body weight gain. Individual and group animal differences between means were separated using least significance difference (LSD) at $P<0.05$ level of significance.

6.3. Results

6.3.1. Feed composition

Chemical composition of the feeds used in this experiment is given in Table 6.1. Ash contents of the roughages were higher than in concentrates ($P<0.05$). *Brachiaria* hybrid cv. Mulato II had less ash content than Napier grass ($P<0.05$). Commercial concentrates had more OM and CP than roughages ($P<0.05$). OM and CP in Napier grass was lower than those of Mulato II ($P<0.05$). The roughages and concentrates did not differ in Ca contents ($P>0.05$) but the roughages had lower contents of P than the concentrates ($P<0.05$; Table 6.1).

Table 6.1*:* Chemical composition of feed used in the experiment

Parameters	Feed types			
	Commercial concentrates	Mulato II	Napier grass (Control)	Mineral block
DM (g/kg)	910^{a}	320^{b}	270^{c}	–
Ash (g/kg DM)	72±4^{c}	110±32^{b}	147±20^{a}	–
CP (g/kg DM)	172±9^{a}	131±17^{b}	85±12^{c}	–
OM (g/kg DM)	928±4^{a}	890±32^{b}	854±20^{c}	–
Calcium (Ca; g/kg DM)	5±1^{a}	5±1^{a}	5±1^{a}	39
Phosphorus (P; g/kg DM)	8^{a}	2±1^{b}	2^{b}	43
ME (MJ/kg DM)	13.1	8.1	7.2	–
Magnesium (Mg; g/kg DM)	–	–	–	4
Potassium (K; g/kg DM)	–	–	–	2
Sodium (Na; g/kg DM)	–	–	–	187
Iron (Fe; mg/kg DM)	–	–	–	6
Zinc (Zn; mg/kg DM)	–	–	–	4
Copper (Cu; mg/kg DM)	–	–	–	0.01
Sulphur (S; mg/kg DM)	–	–	–	0.3

DM= Dry matter; CP= Crude protein; OM= Organic matter; ^{abc} Means in the same row with the same uppercase letter are not significantly different at P<0.05; ME: Metabolisable energy; –: Parameter not determined.

6.3.2. Feed intake

Absolute (kg or g/day) and relative (kg or g/kg metabolic body weight - $BW^{0.75}$) daily intake of DM, OM, CP and Ca were significantly ($P<0.01$; Table 6.2) higher in animals fed Mulato II supplemented with CC (MCC) than Napier grass supplemented with concentrates (NCC) as basal diets. However, P intake was higher in NCC than in MCC diets.

Table 6.2: Effect of roughage on intake of feeds and its nutrients by crossbred heifers

	Treatments			
Intakes	NCC	MCC	SEM	P- Value
Absolute intake:				
DMI (kg/day)	4.3^{b}	5.4^{a}	0.03	<.0001
OMI (kg/day)	3.8^{b}	4.9^{a}	0.03	<.0001
CPI (kg/day)	0.5^{b}	0.8^{a}	0.003	<.0001
ME intake (MJ/day)	41.8^{b}	52.9^{a}	0.23	<.0001
Ca intake (g/day)	21.5^{b}	27^{a}	0.0001	<.0001
P intake (g/day)	19.5^{b}	21.7^{a}	0.0001	<.0001
Relative intake:				
DMI (g/kg $BW^{0.75}$)	76^{b}	82^{a}	0.0005	<.0001
OMI (g/kg $BW^{0.75}$)	67.3^{b}	74.1^{a}	0.0004	<.0001
CPI (g/kg $BW^{0.75}$)	9.2^{b}	11.8^{a}	0.05	<.0001
Ca intake in the diet (g/kg $BW^{0.75}$)	0.38^{b}	0.41^{a}	0.002	<.0001
P intake in the diet (g/kg $BW^{0.75}$)	0.34^{a}	0.33^{b}	0.001	0.0094

SEM: Standard errors of the mean; DMI: Dry matter intake; CP: Crude protein intake; OM: Organic matter intake; ME: Metabolisable energy; $BW^{0.75}$: Metabolic body weight; ^{ab} Means in the same row with the same uppercase letter are not significantly different at $P<0.05$; MCC: Mulato II with commercial concentrates; NCC: Napier grass with commercial concentrates.

6.3.3. Body weight gain and feed conversion ratio

Results from body weight gain (BWG) and feed conversion ratio (FCR) are shown in Table 6.3. The final body weight (FBW), and average body weight gain (ABWG) were similar ($P>0.05$) between the two roughages. Although, there was no difference

(P>0.05) between dietary groups, average daily weight gain (ADWG) of heifers fed on MCC diet was numerically higher than those fed on NCC diet. Feed conversion ratio (FCR) for DM, OM and CP was significantly different (P<0.001) between MCC and NCC diet. This suggests that high numerical body weight gain observed in MCC diet was due to higher FCR.

Table 6.3: Body weight gain and feed conversion ratio of crossbred dairy heifers fed on MCC in comparison to NCC diet

	Treatments			
	NCC	MCC	SEM	P- Value
Body weight gain:				
IBW (kg)	190^a	215^a	12	0.16
FBW (kg) after 12 weeks	218^a	266^a	16.5	0.06
ABWG (kg) after 12 weeks	28^a	50^a	8	0.06
ADWG (g/day)	375^a	580^a	127.4	0.32
Feed conversion ratio (FCR; kg/kg BW gain)				
DM	11.5^a	9.3^b	0.06	<.0001
CP	1.4^a	1.3^b	0.01	<.0001
OM	10.2^a	8.4^b	0.06	<.0001

SEM: Standard errors of the mean; IBW: Initial body weight; ^{ab} Means in the row with the same uppercase letter are not significantly different at P<0.05; MCC: Mulato II with commercial concentrates; NCC: Napier grass with commercial concentrates.

6.3.4. Energy intake versus energy required

Observed metabolisable energy intake (MEI) and predicted ME for growing dairy crossbred dairy heifers showed a very strong relationship. The observed MEI from both diets was higher than the predicted ME (Figure 6.1). However, observed MEI from Mulato II offered with commercial concentrates (MCC) was higher than that of Napier grass supplemented with commercial concentrates (NCC).

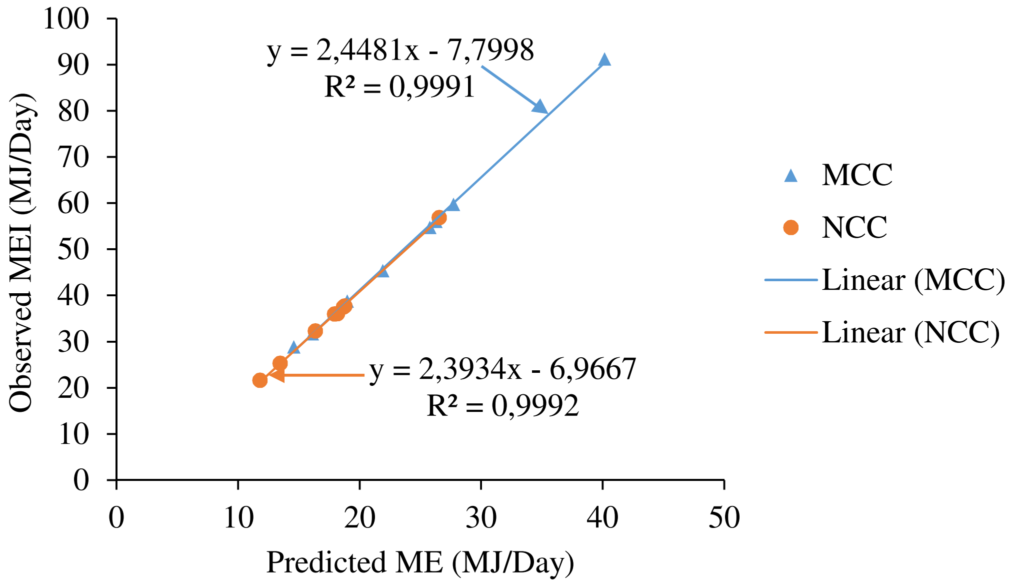

Figure 6.1: Relationship between metabolisable energy (ME) intake calculated and metabolisable energy predicted (ME predicted) for the two dietary groups of growing crossbred dairy heifers

6.4. Discussion

Dry matter intake (DMI) and contents of nutrients in feeds are major factors determining feed quality and animal productivity (McDonald et al., 2011). In the present study, we found that Mulato II was better than Napier grass as potential source of protein and energy. Although diets offered to crossbred dairy heifers differed in CP and OM, no variation in P and Ca was observed. Higher values of OM and CP in Mulato II than in Napier grass were reported in previous studies (Mutimura et al., 2015; Maia et al., 2014). DM and nutrient intakes were higher in MCC diet than in NCC diet. In this respect Mulato II had comparative advantage in DM intake than Napier grass because of its leafiness and thinner stems than Napier grass (Maass et al., 2015). Therefore, these animals could eat more Mulato II than Napier grass. Also high DMI in MCC diet might have influenced by high CP content in the diet. This observation is in agreement with Malisetty et al. (2014) who reported that DMI increases with an increase of CP content in a diet. Morais et al. (2014) also reported that when quality of supplement and supplementation frequency remain the same, the difference in weight gains of an animal will be based on the quality of roughage. As the two groups of crossbred dairy heifers had received the same amount of the commercial concentrates, the major factor which influenced differences in DMI would be the quality of roughages where MCC had higher CP and OM content than NCC.

High CP intake was observed in MCC diet and this diet had high CP. This suggests that CP content in feed influenced its intake. This agrees with Singh et al. (2015) who reported increase of CP intake when CP was increased in a feed. The CP intake of 0.8 kg/day was slightly higher than results reported on CP intake from corn meal supplemented with jatropha and fed on Holstein heifers (da Silva et al., 2015). However, our results were higher than those reported in a feeding trial when Tho-tho male cattle were fed on tree leaves based ration (Das et al., 2011). Relative DM and nutrient intakes were higher in MCC than in NCC diet. Similar findings were reported by Ngim et al. (2011) and suggested that grass with high relative intake should be integrated in livestock feeding system. Generally, the trend showed that diet with high nutrient content had higher intake of these nutrients, however, this trend was different for minerals. This is because both diets had similar P content but higher P intake was observed in NCC diet. Although the explanation of this observation seems complicated, however, previous studies have reported similar trend where Ca and P intakes did not correlate with their concentration in a diet (Sinha et al., 2011).

Body weight changes from the two groups were not statistically different, but numerically average daily weight gain (ADWG) of heifers fed on MCC exceeded those fed on NCC. Ngim et al. (2011) reported similar results on cattle fed on Mulato II as the basal feed in comparison with other grass in Thailand. In addition, differences in CP, OM and ME intakes between the two dietary groups are attributable to increased ADWG in MCC diet.

Observed metabolisable energy intake was much higher than predicted either for MCC heifers or to NCC heifers. A positive strong correlation between the observed ME intake and ME predicted was obtained in both MCC and NCC diet. However, higher MEI was observed in MCC than in NCC diets. This means that high ME consumed in MCC was translated into superior growth performance of 35.3% more than in heifers fed on NCC diet. It is not curtained why the predicted ME requirements was not a perfect match of the observed. We speculated a likelihood of errors being incurred in the determination of ME value of used feeds, and possibly breed specific disparities in the equations used to estimate energy required for live weight gain and maintenance. The results on ADWG of heifers fed on MCC were slightly higher than those reported on crossbred (Friesian × Boran) heifers (532 g/day) and on Bhadawari buffalo heifers (330 g/day) fed on hay and wheat straw supplemented with commercial concentrates, respectively (Gojjam et al., 2011; Singh et al., 2015). Furthermore, FCR values were different between the two dietary groups of heifers. FCR showed that for the heifer to gain 1 kg of live weight per day it should eat 9.3 and 11.5 kg of DM in MCC and NCC diets, respectively. Similar value for FCR (9.5 kg of DM/kg ADWG) was reported when steers were grazing on smooth bromegrass (Lardner et al., 2015).

Diets with low CP and ME had poor FCR. A similar observation was reported when cows were fed on low and high level of protein (Fiems et al., 2015; Wang et al., 2014). It has been reported that a good FCR value is influenced by environment, feed type and high energy intake (Fiaz et al., 2012; Singh et al., 2015). This suggest that diets should be selected based on their quantity and quality.

6.5. Conclusions

Daily body weight gain of heifers fed on MCC diet showed no statistical difference but numerically exceeded those fed on NCC diet. Considering DM and nutrient intakes as well as the quality attributes of Mulato II, this forage grass can be integrated into cut-and-carry feeding system in smallholder farms to feed heifers predestined for dairy mature cow replacement. In spite of good feed conversion ratio and body weight gain, it is also crucial to examine the biophysical and physiological basis that make *Brachiaria* grass a more palatable and nutritious forage with an impact on lactation in dairy cows.

Chapter 7: Effect of supplementing *Brachiaria brizantha* cultivar Piatá and Napier grass with or without *Desmodium distortum* on feed intake, kinetic passage rate and milk production of crossbred dairy cows

Abstract

On-farm agronomic trials and laboratory experiments have identified several *Brachiaria* grass species as potential alternatives to Napier grass *(Pennisetum purpureum*) for intensive dairy in Sub-tropical Africa. A few studies have indicated that chemical composition of Napier grass and *Brachiaria* sp. are similar, but animals prefer and perform better when fed *Brachiaria* grass than when fed on Napier grass. The objective of this study was to examine the biophysical and physiological basis that make *Brachiaria* grass a more palatable and nutritious forage with impact on lactation in dairy cows than Napier grass. Forty lactating Ankole × Friesian crossbred cows, were stall-fed on *Brachiaria brizantha* cv. Piatá and Napier grass mixed with a forage legume (*Desmodium distortum* = DD; at 70% Grass + 30% DD) or without the legume, all fed at fresh matter basis. Results showed that cv. Piatá had more contents of DM, CP and OM, but lower NDF and ADF than Napier grass ($P<0.001$). Supplementation increased CP and NDF, but decreased ADF content in grass based diets. The legume supplement did not affect DM intake ($P>0.05$), but it affected CP and ME intakes ($P<0.001$) with higher effect on cows fed Piatá than on cows fed Napier grass. Average daily milk yield was lower on Napier grass than on Piatá based rations ($P<0.001$). The passage rate of small particles did not differ across the basal diets ($P<0.05$), but the difference between treatments with legume supplements were significant ($P<0.05$). Gut retention was longer on Napier grass (83.1 h) than Piatá (62.8 h). The difference between the two basal diets was not significant when fed with legume supplements. We concluded that hind gut retention time was more limiting on intake in Napier grass than in Piatá due to differences in the physical effectiveness of their fibres (peNDF).

Key words: Chemical composition, nutrient intake, grass-legume, retention time

7.1. Introduction

Napier grass (*Pennisetum purpureum*) has been recognised as one of the fodder grasses that has contributed to sustainable climate smart agricultural intensification through its sparing effect of land and push-and-pull technology in integrated pest management (Pretty et al., 2011). *Brachiaria* species share the same attributes with Napier grass (Pickett et al., 2014) with an additional advantage of inhibiting nitrous oxide emission from soil nitrogen through biological nitrification inhibition (Subbarao et al., 2009). Currently, in many areas of sub-Saharan Africa (SSA), increase of population pressure and expansion of arable agriculture are often perceived as threats to livestock agricultural as livelihood assets. However, a study has in accordance with Boserup hypothesis of autonomous intensification, ruminant animal livestock biomass has been increasing alongside human population growth and arable agriculture expansion in SSA (Bourn and Wint, 1994). Traditionally, this phenomenon occurs where the management of nutrient and energy flows enable crop and livestock components to reciprocate in supporting each other as a coherent farming system (Andrieu et al., 2015). These authors, reported that applicable livelihood strategies in this system include, crops residues which are used for animal feed, animal waste for manure and draught for crops cultivation and transport, fodder for livestock feed and erosion control as well as biological nitrogen fixation and fuel wood for energy. However, this synergy is compromised when farmer prefer to use land for crops and crop wastes for mulching (Homann-Kee Tui et al., 2015), underscoring the need for cultivated fodder for sustainable intensification (Dijkstra et al., 2008).

Chemical analyses that have compared *Brachiaria* grass with Napier grass have consistently ranked the two forages according to their nutritional quality (Mutimura et al., 2015). However, a few feeding trials and farmers' perceptions have indicated that animals and farmers preferred *Brachiaria* grass to Napier grass because of real or perceived palatability and better animal response to the grass (Mutimura and Everson, 2012a; Rao et al., 2015; Chapter 6). Comprehensive reviews have corroborated the evidence that voluntary dry matter intake (DMI) in ruminants was a function gut fill restriction. This is moderated by rates of physical and biochemical feed particle degradation and outflow rates from the reticulo-rumen of the animal (Nsahlai and Apaloo, 2007; Zebeli et al., 2012). However, most adversely affected are animals with high performance fed on low quality, high-fill roughages (Niu et al., 2014). In forage based rations, dry matter intake is the major limiting factor for livestock productivity, especially in dairy cattle (Hills et al., 2015). We examined this phenomenon in crossbred lactating dairy cows as a basis to compare the nutritional superiority of *Brachiaria brizantha* cv. Piatá and potential replacement of Napier grass in stall-fed dairy cattle. The trial was conducted under farmers' management to enhance the relevance and likelihood of adoption of this forage grass option (Rudel et al., 2015).

7.2. Materials and methods

7.2.1. Study site, animals and management

This study was carried out in smallholder farms in semi-arid area of Rwanda from December 2014 to April 2015. The choice of farms in this area was based on easy accessibility and closeness to Kamara research station of the Rwanda Agriculture Board (RAB). This is because the experiment necessitated harvesting of fresh forage legume (*Desmodium distortum*) from the research station and supplying it to these farms. In addition, the experimental animals were Ankole Longhorn × Holstein Friesian crossbred cows in second parity with 319±14 kg of live weight and in early lactation (10–15 days in milk; DIM). These cows were chosen from other dairy cattle genotypes because of a national dairy improvement which emphasises the use of Holstein Friesian sires and indigenous landrace (Ankole) as dam lines in crossbreeding programmes. For this purpose, a significant number of these crossbreds are widely distributed among smallholder dairy farmers in Rwanda (Rutamu, 2009). These animals are owned by farmers, and they were stall-fed in individual pens in the cowsheds.

7.2.2. Digesta flow markers and marker preparation

Fluid and particulate phase markers were Cobalt ethylene diamine tetraacetic acid (Co-EDTA) and Ytterbium oxide (Yb_2O_3), respectively. Co-EDTA was prepared according to Uden et al. (1980) and modified by Nsahlai (1991). It involved dissolving and gently heating (while stirring) Na-EDTA (297.2 g), $CoCl_2.6H_2O$ (190.4 g) and NaOH (32.0 g) in distilled water (1600 ml). Additional NaOH pellets (6.8–7 g) were added to ensure complete solubilisation. The solution was allowed to cool to room temperature; 160 ml hydrogen peroxide was added and allowed to stand at room temperature for 4 hours before adding 95% ethanol (v/v; 2400 ml). The solution was stored under refrigeration overnight for crystal formation. Crystals were filtered, repeatedly washed with 80% ethanol (v/v) and dried overnight at 100^0C.

7.2.3. Feed, experimental design and data collection

Basal diets were fresh *Brachiaria brizantha* (cv. Piatá) and Napier grass (*Pennisetum purpureum*) harvested at farmers' field where they were established without fertiliser application. Either one of these grasses was fed with or without forage legume (*Desmodium distortum*) used as supplement. This legume was established without fertilizer application and harvested at 90 days after regrowth from the Karama Research station of RAB and supplied to cows at on-farm. Fresh forage, water and mineral block (Vitamin A: 100,000 IU; Vitamin D3: 20,000 IU; Vitamin E: 40,000 UI; Calcium: 40,000 mg; Phosphorus: 50,000 mg; Magnesium: 5,000 mg; Iron: 2,000 mg; Cobalt: 50 mg; Iodine: 50 mg; Manganese: 2,000 mg; Zinc: 1,000 mg; Selenium: 10 mg) were provided *ad libitum*.

Four diets (Table 7.1) were compared in this experiment. Ten cows corresponding to 10 farms were randomly assigned to each dietary treatment in a completely randomised block design (CRBD). Fourteen days for feed adaptation were allotted to individual cows. Before feeding, fresh feed and refusals were also weighed. Feed sampling in each farm was done twice a week for a period of 17 weeks. Milk recording was done daily and summarised weekly. Milking was done twice daily, in the morning between 700h and 800h, and in the evening between 1600h and 1800h for 17 weeks. Forage grasses and legume were chopped manually at 10 cm length before feeding by using machete. Daily feed dry matter (DM), crude protein (CP) and metabolisable energy (ME) intakes were calculated as the difference between feed offered and refusal corrected for their respective contents (Balehegn et al., 2014). Initial data on body weight was recorded and used as covariates during statistical analysis of feed intake and milk yield data.

Table 7.1: Experimental details on diet composition and number of animals and farms used in the study

Treatments	Diet composition	Animals /farms
Treatment 1	Napier grass (NG; 100%): NG (Control)	10 cows (10 farms)
Treatment 2	NG (70%) + *D. distortum* (30%) = NDD	10 cows (10 farms)
Treatment 3	Piatá alone (P; 100%) = Piatá	10 cows (10 farms)
Treatment 4	P (70%) + *D. distortum* (30%)= PDD	10 cows (10 farms)

To ensure accuracy in data collection, farmers recorded data every morning and evening offers and refusals of each forage type on fresh weight basis. The data were validated the farmers' records during weekly test-day visits and sampled feed offers and orts for chemical analysis. Farmers also recorded daily milk yields, which were validated during the test day visits. Farmers and scientists jointly participated in measuring animal body weights at the beginning and end of the experiments on each farm.

7.2.4. Markers administration, sampling and laboratory analysis

Four dairy cows in each dietary group of 10 lactating cows were selected (based on easy access to the farm and distance between farms) for the administration of external markers. Because animals used were not fistulated, markers were administrated orally. Ytterbium oxide (600 mg) was weighed and mixed with small amount of feed and ensured total ingestion of the marker. Co-EDTA (20 g) was dissolved in water (1 L) for the same reason (Huhtanen and Kukkonen, 1995). Four animals from each dietary group were used. Faecal samples were taken from the rectum during the following times: 0, 2, 4, 8, 10, 12, 24, 27, 30, 33, 36, 48, 54, 60, 72, 96, 120 and 144 hours post marker administration. Faecal samples were kept in cool box (4^0C) and delivered to the laboratory. Frozen rectal grab samples of faeces were dried in forced-air oven (105^0C) for 24 hours. Dried samples were ground to pass through 1 mm and 1 g of each sample was ignited at 550^0C in a muffle furnace for 8 hours to get ash. Ash samples were analysed for Yb and Co concentrations in faeces using Inductively Coupled Plasma (ICP) Optical Emission Spectrometer, Varian 720-ES Series at the University of KwaZulu-Natal (UKZN).

7.2.5. Chemical composition of feeds used

Samples were divided into two portions, one part was dried at 60^{0}C in air-forced oven for 48 hours and grounded to pass through 1 mm screen and kept for subsequent analysis. The other part was used to determine contents of DM (g/kg), OM and ash (AOAC, 1990; method ID 9420.5). Crude protein (CP) content (g/kg DM) was calculated as 6.25 × N (Kjeldahl nitrogen) content in the feed. The N content was determined by sequential processes of macro-Kjeldahl digestion, automated ammonia release using NaOH (40% w/v) steam distillation into boric acid (Büchi Labortechnik AG, CH-9230 Flawil 1/Switzerland, Type: K–360) and back titration from boric acid using 0.01M HCl standard solution (AOAC, 2006; method ID 984.13). Fibre components (NDF and ADF) were determined according to Van Soest et al. (1991). Feed samples (1 g) transferred into Fibretech bags, and refluxed (1 h) in neutral detergent solution. These bags and contents were rinsed with hot distilled water and acetone in water solution (70% v/v) and dried (105^{o}C) overnight, weighed and incinerated at 550^{o}C (8 h). The fibre content (g/kg DM) was computed as the weight of the OM loss after incineration as a fraction (g/kg DM) of initial weight of sample.

7.2.6. Passage rate calculations

The passage outflows (k_1 and k_2) and transit time (TT) were calculated based on the model (Equation 1) developed by Blaxter et al. (1956) and cited by Nsahlai (1991).

$$Z = A(e^{-k_1(t-TT)} - e^{-k_2(t-TT)})\ ;\ t \geq TT;\quad Z = 0 \text{ for } t < TT; \tag{1}$$

Where Z and A are the marker concentrations in the faecal dry matter; k_1 and k_2 are passage rate constants; TT is the estimated time for the first appearance of marker in faeces while t is the time of sampling after a single marker had been administered.

For each marker, the natural logarithm (ln) of marker concentration in the dried faeces was plotted against time with the regression analysis produced on the linear portion of the descending slope. The regression coefficient and Z-intercept correspond to the slowest rate constant (k_1) and A_1, respectively. Fitted values were estimated for all collection times that corresponded to the ascending phase and the peak portions of the curve. Then, the anti-logarithm of the fitted values minus the actual concentrations measured at these times gave residuals. Regression analysis involving the natural logarithm of the residual concentrations and the collection time would give the Z-intercept A_2 and the second slowest rate constant (k_2). The two lines intersect at the point (TT, A) helped to calculate TT (Equation 2).

$$TT = \frac{(A_2 - A_1)}{(k_2 - k_1)} \tag{2}$$

A_1 and A_2 in this equation are the derivatives of natural logarithm. Then, total mean retention time (MRT; h) that represents the mean retention time of particles in the whole digestive tract was calculated as the reciprocal of the natural logarithmic of slopes of descending and ascending phase of the curve ($1/k_1+1/k_2$) plus the transit time (TT; Equation 3).

$$TMRT\ (h) = \left(\frac{1}{k_1} + \frac{1}{k_2}\right) + TT \tag{3}$$

7.2.7. Statistical data analysis

Data on chemical compositions of diet were analysed using General Linear Model (GLM) procedures of the Statistical Analysis System (SAS, 2010). The model used is given as follows (Equation 4):

$$Y_{ijk} = \mu + G_i + L_j + P_k + (G \times L)_{ij} + (G \times L \times P)_{ijk} + \varepsilon_{ijk} \tag{4}$$

Where Y_{ijk}: Variable dependent; μ: Overall mean; G_i: Effect of grass; L_j: Effect of forage legume; P_k: Effect of period of the experiment (Weeks); $(G \times L)_{ij}$: Interaction between grass and forage legume; $(G \times L \times P)_{ijk}$: Interaction effect of grass-legume-experimental period; ε_{ijk} : Random residual error.

In addition, DMI, ME and CP intakes, and milk yield were subjected to a two-way analysis of variance (ANOVA) in a randomised complete block design using GLM procedures of SAS and differences between diet means were detected using pairwise *t*-test (PDIFF option of SAS). The model for the ANOVA is given as follows (Equation 5):

$$Y_{ijk} = \mu + \mathrm{B}_0 + G_i + L_j + P_k + (G \times L)_{ij} + (G \times L \times P)_{ijk} + \varepsilon_{ijk} \tag{5}$$

Where Y_{ijk} : Variable dependent; μ: Overall mean; B_0 is initial body weight of the cows, used as covariate; G_i: Effect of grass; L_j : Effect of forage legume; P_k: Effect of lactation period; $(G \times L)_{ij}$: Interaction between grass and legume; $(G \times L \times P)_{ijk}$: Interaction of grass, legume and lactation period; ε_{ijk} : Random residual error.

Kinetics passage rate (k_1 and k_2), transit time (TT) and mean retention time (MRT) data were analysed using the GLM procedures of SAS (2010). The model of ANOVA is given as equation 6 and pairwise *t*-test (PDIFF option of SAS) was used to separate the means.

$$Z_{ij} = \mu + G_i + L_j + (G \times L)_{ij} + \varepsilon_{ij} \tag{6}$$

Where Z_{ij} : Variable dependent; μ: Overall mean; G_i: Effect of grass; L_j: Effect of forage legume; $(G \times L)_{ij}$: Interaction between grass and legume; ε_{ij} : Random residual error.

7.3. Results

7.3.1. Chemical composition

Chemical compositions of rations differed significantly across treatment farms (Table 7.2). DM was higher in Piatá than in Napier grass based diets. Napier-Desmodium had higher DM content than Napier grass alone. However, Piatá sole fed had similar DM to Piatá-Desmodium. Organic matter and CP contents were significantly higher in cv. Piatá than in Napier grass. Within grass diets, supplementation with Desmodium improved the CP content (P<0.001). However, supplementation did not improve OM in Napier grass and it suppressed this parameter in Piatá. The fibres (NDF and ADF) were lower in Piatá than in Napier grass. However, supplementation with Desmodium increased NDF and decreased ADF in both grass based diets. The NDF content in grass based diets was higher in farms with supplements than in farms without supplements (Table 7.2). This pattern was consistent across the period of treatment except CP whose content varied with period of feeding. The interaction showed that the change in CP with period of feeding was grass species and supplement dependent.

Table 7.2: Chemical composition (g/kg DM) of diets used in on-farm feeding trial

	Treatments[1]							
	Napier grass		Piatá			Significance[2]		
Parameters	0	1	0	1	RMSE	Grass	DD	Grass × DD
DM	156.6	196.1	238.5	241.4	37.4	***	***	***
CP	124.5	153.1	157.9	169.1	11.7	***	***	***
OM	861.7	862.4	882.3	872.8	12.3	***	***	***
NDF	386.3	431.0	329.3	426.6	39.8	***	***	***
ADF	372.6	300.0	323.8	300.7	32.6	***	***	***

DM: Dry matter; CP: Crude protein; OM: Organic matter; NDF: Neutral detergent fibre; ADF: Acid detergent fibre; RMSE: Root means square error; [1]Napier grass (0= Napier grass fed without *Desmodium distortum*; 1= Napier grass fed with *Desmodium distortum*); Piatá (0= Piatá fed alone; 1= Piatá + *Desmodium distortum*); [2] Grass: Effect of Napier grass and Piatá; [2]DD: Effect of *Desmodium distortum*; Grass × DD: Interaction effect grass-*Desmodium distortum*; ***: P<0.001.

7.3.2. Nutrient intake and milk yield

Initial body weight of cows used as covariate showed difference for dry matter intake (DMI; estimate of 7.96 g; standard error of 1.1; t-value of 7.16; P<0.001), crude protein intake (CPI; estimate of 1.14 g; standard error of 0.16; t-value of 7.04; P<0.001), metabolisable energy intake (MEI; estimate of 67.4 KJ; standard error of 9.4; t-value of 7.18; P<0.001) and milk yield (estimate of 13.4 g; standard error of 1.2; t-value of 11.01; P<0.001). Relative to Napier grass, Piatá increased DMI (P<0.05), CPI (P<0.001), MEI (P<0.001) and as such promoted higher milk yield (P<0.001). Desmodium had no effect on DMI (P>0.05) but increased CPI (P<0.001), MEI (P<0.001) and daily milk yields (P<0.05). No other effect was significant (P>0.05).

Table 7.3: Daily DMI, MEI and milk yield of dairy cows fed on different diets at on-farm

	Treatments[1]							
	Napier grass		Piatá			Significance[2]		
Parameters	0	1	0	1	RMSE	Grass	DD	Grass × DD
DMI (kg/day)	8.3	8.2	9.1	9.2	2.1	**	NS	NS
CPI (kg/day)	1.0	1.2	1.4	1.5	0.3	***	***	NS
MEI (MJ/day	59.6	71.7	81.9	88.7	18.0	***	***	NS
Milk (L/day)	5.4	7.1	8.1	9.0	1.5	***	*	NS

DMI: Dry matter intake; CPI: Protein intake; MEI: Metabolisable energy intake; RMSE: Root mean standard error; [1]Napier grass (0= Napier grass fed without *Desmodium distortum*; 1= Napier grass fed with *Desmodium distortum*); Piatá (0= Piatá fed alone; 1= Piatá + *Desmodium distortum*); [2]Grass: Effect of Napier grass and Piatá; DD: Effect of *Desmodium distortum*; Grass × DD: Interaction effect grass-*Desmodium distortum*; *: P<0.05; **: P<0.01; ***: P<0.001; NS: P>0.05.

Both DMI and MEI parameters were affected by diets across the period of feeding (Figures 7.1 and 7.2). Also, milk yield was dependent on the diets and trends in average weekly milk yield depicted clear differences across diets (Figure 7.3).

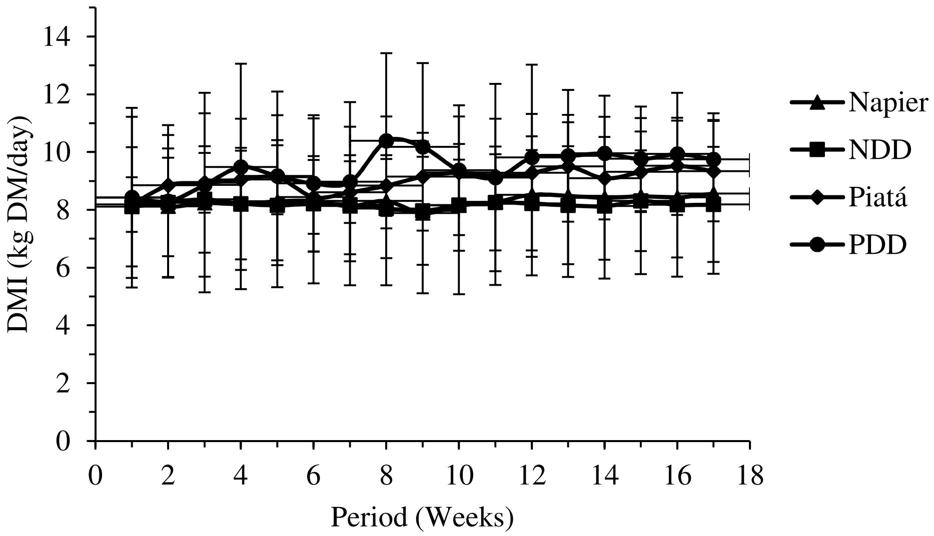

Figure 7.1: Dry matter intake (DMI) of diets (NDD= Napier grass+ *Desmodium distortum*; PDD= Piatá + *Desmodium distortum*) during the period of experiment

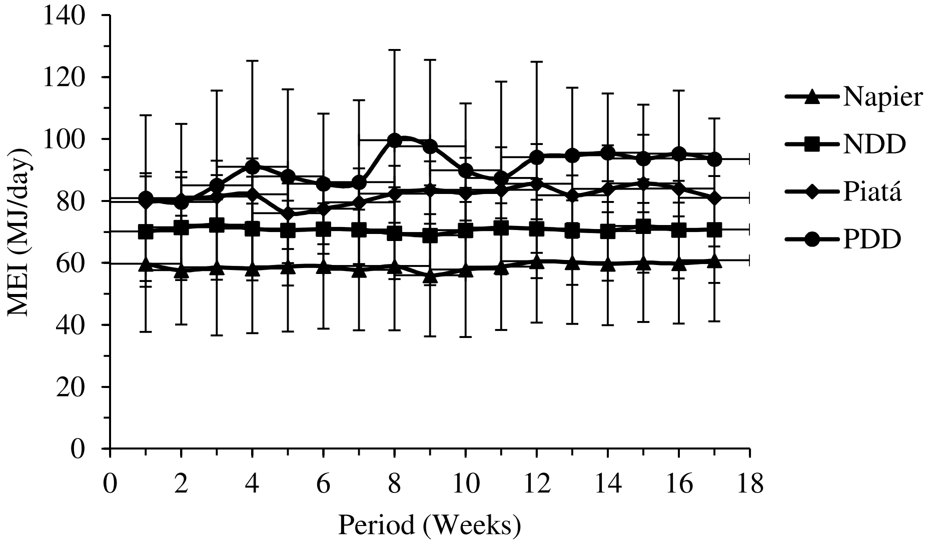

Figure 7.2: Dietary ME intake (NDD= Napier grass + Desmodium; PDD= Piatá + Desmodium) during the period of experiment

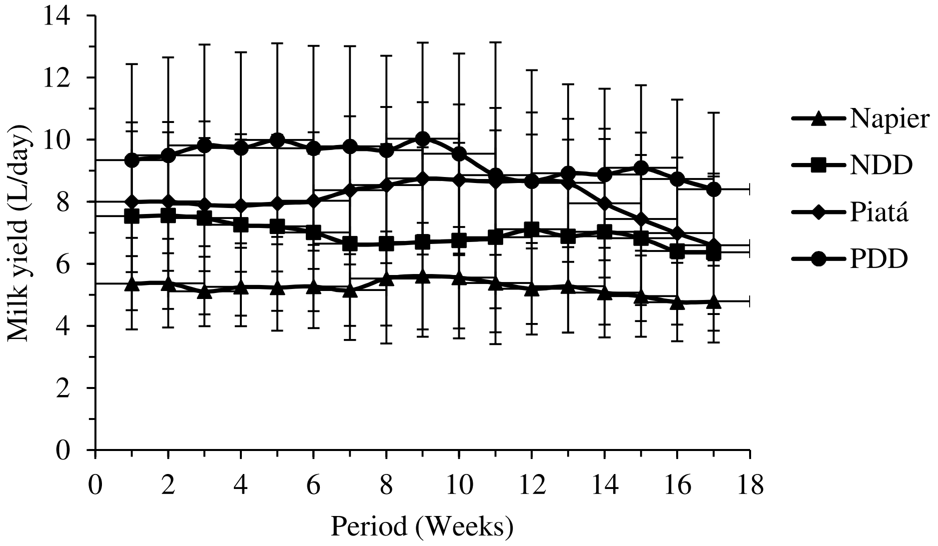

Figure 7.3: Effect of diets (NDD= Napier grass+ *Desmodium distortum*; PDD= Piatá + *Desmodium distortum*) on milk yield for the period of experiment

7.3.4. Kinetics passage rate

Grass did not affect kinetic variables for both liquid and solid particles, except that Napier grass had longer ($P<0.05$) total MRT of particles than Piatá (Table 7.4). Desmodium increased the rate of passage of liquid ($P<0.05$) and solids ($P<0.01$) resulting to shorter MRT for liquid ($P<0.05$) and solid particles ($P<0.001$). Desmodium increased the rate of passage of liquid in Napier grass diets than in Piatá diets with an effect on the interaction ($P<0.05$). The interaction of grass-Desmodium on total MRT of solids was significant, showing pronounced reductions in Napier grass diets than in Piatá diets. No other effect was significant.

Table 7.4: Fractional rate of passage from the rumen (k_1) and hind gut (k_2), transit time (TT) and mean retention time (MRT) of Co-EDTA and Yb digesta in the gut of dairy lactating cows fed on Piatá and Napier grass supplemented with or without *Desmodium distortum*

	Treatments[1]							
	Napier grass		Piatá			Significance[2]		
Parameters	0	1	0	1	RMSE	Grass	DD	Grass × DD
Co-EDTA:								
k_1 (%/h)	0.038	0.041	0.037	0.047	0.006	NS	*	NS
k_2 (%/h)	0.06	0.11	0.15	0.09	0.046	NS	NS	*
TT (h)	2.5	0.7	1.1	2.0	1.59	NS	NS	NS
TMRT (h)	46.5	35.4	37.6	34.7	5.26	NS	*	NS
Yb:								
k_1 (%/h)	0.023	0.034	0.026	0.033	0.005	NS	**	NS
k_2 (%/h)	0.034	0.060	0.058	0.060	0.017	NS	NS	NS
TT (h)	2.4	2.1	1.8	2.3	2.19	NS	NS	NS
TMRT (h)	83.1	49.7	62.8	50.7	7.77	*	***	*

RMSE: Root mean standard error; TT: Transit time; TMRT: Total mean retention time; k_1: is proportion per hour at which particles pass out of the rumen; k_2: is proportion per hour at which large particles are reduced to small particles within the rumen; [1]Napier grass (0= Napier grass fed without *Desmodium distortum*; 1= Napier grass fed with *Desmodium distortum*); Piatá (0= Piatá fed alone; 1= Piatá + *Desmodium distortum*); [2] Grass: Effect of Napier grass and Piatá; DD: Effect of *Desmodium distortum*; *: P<0.05; **: P<0.01; ***: P<0.001; NS: P>0.05.

7.4. Discussion

This study compared the effects of *Brachiaria brizantha* (cv. Piatá) in comparison with existing feed resource (Napier grass) used by dairy farmers and both grasses were supplemented with or without a forage legume, *Desmodium distortum* on ruminal passage rate of particles and milk production under smallholder farm conditions. The study provided a worthy insight into quality forage grass that should be used for increasing intake thereby improving milk production. Additionally, the study also presented an opportunity to use available and affordable forage legume as a feed supplement in lactating dairy cows' diets. Furthermore, it also contributed to improved understanding of the relationship between outflow rate of digesta, nutrient intake and animal production that govern animal nutrition for any given production system.

In comparison with other studies CP and OM concentrations in Napier grass were higher than those published in a number of reports (Rahman et al., 2013; Lounglawan et al., 2014; Mutimura et al., 2015; Rahman et al., 2015). Nonetheless, Salgado et al. (2013) reported similar CP content, but higher NDF and ADF concentrations in Napier grass than we observed in this experiment. Although management influences chemical composition of grasses (Jampeetong et al., 2014; Lounglawan et al., 2014), DM, CP, NDF and ADF of the Napier grass and Piatá differed significantly across farms due to supplementation with Desmodium. Differences in chemical composition across grass-legume diets were also reported in other studies and their increase or decrease depend on a type of forage legume (Avilés-Nieto et al., 2013). The chemical composition of Piatá was similar with values reported by Epifanio et al. (2014), but higher than those in other *Brachiaria brizantha* reported under grazing conditions (Gracindo et al., 2014). Napier grass and Piatá based grass differed in nutritional compositions. These differences were expected because nutritive values vary among grass types. The chemical composition of these grasses and legume changed across periods of feeding as expected, with maturity (Kozloski et al., 2005).

This study aimed at validating the hypothesis that less fill value of *Brachiaria brizantha* (cv. Piatá) could partly explain the perceived palatability (Mutimura and Everson, 2012a), higher dry matter intake and better performance by cattle fed *Brachiaria* grass than by cattle fed Napier grass (*Pennisetum purpureum;* Chapter 6). Feed and animal factors that influence intake of roughages are the chemical composition and gut fill, respectively. Extensive reviews have validated that, fibre components of roughages impose physical constraints on intake but improved NDF digestibility increases intake and milk yield in dairy cattle (Oba and Allen, 1999). Contrary to expectations, DMI in cows fed mixed grass-legume was not significantly higher than the DMI in cows fed sole grass. However, large differences between DMI of Napier grass and Piatá as sole diets (8.8%) and between mixed Napier-legume and Piatá-legume (10.9%) are based on grass effect. Compared to Piatá, voluntary intake in cows fed Napier grass did not respond to additional proteins from *Desmodium distortum*, but DMI increased by approximately 1.1% in cows fed Piatá. Alstrup et al. (2014) report higher increment in DMI more than we observed when protein content in the dairy rations was increased from 14 to 16% of the total mixed. Furthermore, high CP contents moderate the effect of gut fill on voluntary intake of roughages (Gebrehawariat et al., 2010; Zetina-Córdoba et al., 2013; Riaz et al., 2014; Singh et al., 2015). This suggested that the evidence in favour of low gut fill potential in sole grass fed was lacking, but it could be considered as biologically important because cows fed on grass-legume diet accommodate more NDF intake than cows fed sole grass diets. This agrees with other reports, which showed that DMI increased when CP was increasing, and that NDF and ADF content were lower in feeds (Balehegn et al., 2014; Gusha et al., 2015). Conversely, high CP and ME intakes were observed in Piatá-Desmodium and Piatá sole fed which had high CP and ME. Unlike DMI, effect of legume supplementation was highly significant on ME and CP intake. Similar observations on increased CP intake and ME intake were made when levels of these nutrients were increased in diets (Singh et al., 2015).

The likelihood of biological significance of higher DMI in cows fed Piatá is illustrated in the significantly and consistently higher mean milk yield. Cows fed sole Piatá had 33.3% more milk than cows fed sole Napier diets. In mixed grass-legume forage cows on Piatá-legume diets produced approximately 21.1% more milk than cows fed on Napier-legume diet. The milk production recorded in this study is typical of *Bos taurus-Bos indicus* crossbreds in East and Central African region. The levels of milk yield depended on the level of exotic blood and parity, but rarely exceed 15 L/day (Abate et al.; 1993; Galukande et al., 2010). This result is consistent with reports that forage grass supplemented with legume increased milk yield in dairy lactating cows (Halmemies-Beauchet-Filleau et al., 2014).

Although it was used as a proxy indicator for small particle dynamics in the rumen and hind gut, Co-EDTA effectively determined the fluid phase dynamics of the gut content. However, the higher rumen outflow rate of small particles (k_{1Co}) than large particles (k_{1Yb}) was expected (Clauss and Lechner-Doll, 2001). Our values of k_{1Co} are similar to values reported in Jersey cow during lactation between 6 and 14 weeks (Aikman et al., 2008). The high values in Piatá-Desmodium and Napier-Desmodium diets might be attributed to supplementation effect of forage legumes, which are known to have faster passage (Kammes and Allen, 2012) and fermentation rates in the rumen (Hebel et al., 2011). Conversely, k_{2Co} and k_{2Yb} values for small and large particles did not differ either in cows fed Piatá or in the cows fed Napier grass. However, shorter MRT of both small and large particles and higher DMI of Piatá-legume or sole feed were observed. This agrees with Schwarm et al. (2008) and Gorniak et al. (2014) who demonstrated the associations of particle size reduction through physical and digestive functions. This relationship is based on the fundamental property of physical effectiveness of forage NDF, which varies with sources and not contents of NDF (Zebeli et al., 2012). We therefore postulate that differences in nutritional attributes of *Brachiaria brizantha* cv. Piatá and Napier grass are associated with the biophysical attributes.

7.5. Conclusions

Higher CP and lower fibre (NDF and ADF) indicated that *Brachiaria brizantha* cv. Piatá was more nutritious than Napier grass (*Pennisetum purpureum*). Higher dry matter intake and milk yield confirmed that the nutritional value of cv. Piatá was better than the nutritive value of Napier grass. Higher dry matter intake, particle degradation and outflow rates from the rumen were observed in the Piatá than Napier grass diets. Differences in particle dynamics, intake and lactation, suggest that the test cv. Piatá and Napier grass differed in nutritional characteristics for rumen retention, hence physical effectiveness of NDF.

Chapter 8: General discussion, conclusions and recommendations

8.1. General discussion

With the increase of human population, food and nutrition security is a major concern. While numerous efforts are being put to increase food crops production for this galloping population, feed for grazing livestock has not received the attention it deserves. Under smallholder farms, which are the majority of farms in sub-Saharan Africa and Asia, the challenge associated with feed scarcity is accentuated by the expansion of arable agriculture, which often takes priority over grazing. Therefore, to achieve food and nutrition security, it is an imperative to integrated crop and livestock farming systems, especially in the smallholder farms.

The general objective of this research was to evaluate ecological benefits of improved *Brachiaria* grass under smallholder local farm conditions. The evaluation consisted of a baseline characterisation of livelihood assets, role and challenges associated with feed, determining agronomic and nutritional characteristics of several species and cultivars of *Brachiaria* grass using both laboratory and feeding trials. The evaluation also involved understanding unique physiochemical attributes that make *Brachiaria* grass better forage than Napier grass, which is the major fodder for intensive dairy in the East African region including Rwanda (Kamanzi and Mapiye, 2012; Kawube et al., 2014; Asudi et al., 2015; Kawube et al., 2015). However, the future of the current status of Napier grass in the feed resource base is threatened by Napier stunt disease (NSD), which can cause extensive damage and reduce forage productivity (Kawube et al., 2015). Although efforts to contain and manage the disease are being taken (Asudi et al., 2015), identification and evaluation of an alternative grass that is adapted to local farm conditions is a justifiable pre-emption to forestall consequences of NSD to sustainable development of the livestock subsector in the region. Under such circumstances *Brachiaria* grass is among popular grass genus which composes most of pastureland in tropical Africa. This grass has been genetically improved in Latin America for quality, quantity as well as for its abiotic and biotic stress tolerance. Currently, it is sown on many hectares in South American countries for beef production enterprises. Recently, this improved *Brachiaria* grass has been taken to Africa, its home of origin (Maass et al., 2015), especially East Africa and it is being evaluated on-farm due to farmers' participation (Djikeng et al., 2014). Participatory approaches have been identified by many studies as the best way to evaluate a crop-livestock based technology in east Africa farm conditions and this should be integrated into existing farming system for profits and sustainability (Waldman et al., 2014; Coromaldi et al., 2015).

The wide diversity of species and sources of feeds across seasons of the year was strongly indicative of limited capacity of farm household to produce enough fodder (Chapter 3). Feed shortage was found to be more precarious during the dry season across both semi-arid and humid environments. In this period farmers cope with this shock by collecting feeds from different locations including roadside and marshland. This unavailability of feed is increasingly due to decreasing of grazing land where land use is more devoted to food production. This common trend shows that a coping strategy for farmers struggling to get enough feed resources is by collecting different plant species and crop residues to maintain livestock, especially cattle (Mekasha et al., 2014; Jaleta et al., 2015). This situation has compelled farmers to adopt mixed crop-livestock system as a way of improving livelihood of household (Mouri and Aisaki, 2015) and a better management of this agricultural synergy, can lead to a sustainable agriculture production (Baudron et al., 2014). In view of the above scenario, this study identified niches for fodder production and three types of landscape were used by farmers to produce fodder. Depending on soil topography, along terrace banks, farmland and farm boundaries were niches used for fodder production. This suggests that the type of fodder produced should be adapted to a given niche. A majority of farmers planted Napier grass/Elephant grass and some fodder trees on the mentioned landscapes. Grown-erected habit of these fodders is appreciated by smallholder farmers because they occupy less land (Franzel et al., 2014). However, most households in semi-arid areas prefer to plant fodder species in farmland whereas in humid areas, they prefer to establish forages on terraces. Although fodder is being produced on different landscapes, incorporating forage crops into grain-crop and/or crop legume is not practised by farmers. This might be another opportunity for farmers to increase feed availability because it has been reported that the incorporation of forage into existing grain-cropping system would increase profits (Komarek et al., 2015).

Feed resources used in smallholder farms in Rwanda varied according to agro-ecologies. Nutritional characteristics of these feeds also varied among plant species and within species (Chapter 4). The variability within species can be attributed to soil type and age at which farmer harvested plants and storage conditions of feed resources. Identified feed resources were dominated by Napier grass which farmers prefer because of erect growth habit (Franzel et al., 2014) thus, underscoring protein under nutrition as a limiting factor to livestock productivity, especially in farms which are highly depended on fibrous crop residues. Nonetheless, some crop residues and weeds have better nutrients content and degradability which translated into acceptable metabolisable energy (ME; Table 4.3). These values were better than those reported in Ethiopia and Kenya under smallholder farm conditions (Baudron et al., 2014). However, the nutrient availability of these feed resources is limited by their quantity which fluctuates seasonally. Looking at the variability in nutritional status of feed resources used by smallholder farmers, some feeds can be selected and integrated into local landraces used and, germplasm collection and development. As the quality of feed resources also varied with the location, eco-environmental aspect should be considered in decision making for an alternative fodder resource development (Mekasha et al., 2014).

Study on agronomic and nutritional characteristics of nine selected *Brachiaria* grass cut at different ages (Chapter 5) showed differences among cultivars and ages of harvest. The importance of this study was to determine the best-bet *Brachiaria* cultivars in comparison with most existing grass used by livestock owners. As plant species and age influence its nutritional quality (Tikam et al., 2015; Särkijärvi et al., 2012; Waramit et al., 2012), most of evaluated grasses showed better nutritional attributes at the age of 60 days after planting (DAP). However, high dry matter, *in vitro* apparent dry matter degradability (ivADMD), gas production (GP), potential degradable fraction (b) and rate of degradability (c) were observed at 90 DAP. Degradability of feed in the rumen is influenced by the microbial growth due to available energy contents in the feed

(Yahaghi et al., 2014). High *in vitro* degradability of these grasses observed at 90 DAP might be due to high crude protein and low fibre contents which are responsible for energy production and rumen microbial growth. *Brachiaria brizantha* cv. Piatá, cv. Marandú and *Brachiaria decumbens* cv. Basilisk were better in degradability characteristics and ME contents. A very strong correlation between ME and degradability efficiency factor (DEF) and between ME and PF revealed that the two factors can be a good estimate of feed ME.

Furthermore, the use of these grasses at farm level is subjected to the amount of CP and ME that can be produced on available land (t/ha) in order to sustain a given livestock production. Most tested grasses obtained high yield of these nutrient at 120 DAP. At this age, Napier grass outweighed other grasses in terms of yield of CP (t/ha) and ME (MJ/ha). This is because Napier grass had high biomass yield at 120 DAP due to its high and heavy stems. However, all high biomass may not be available for livestock as the DM intake can be decreased by high NDF content in Napier grass harvested at this age (Table 5.2). This observation is consistent with reports that nutrient concentration in Napier grass declines with increased harvest age (Tikam et al., 2015; Waramit et al., 2012) and its DM intake decreased due to high fibre content (Neto et al., 2015).

Evaluation of *Brachiaria* grass on livestock production comprised of two studies. The first study looked at change in growth performances of dairy heifers fed on cv. Mulato II in comparison with Napier grass under cut-and-carry system of forage (Chapter 6). The second study was on the effect of *Brachiaria* grass and Napier grass based diets supplemented with or without *Desmodium distortum* (forage legume) on milk yield and passage rate kinetics in dairy lactating cows (Chapter 7). Results from both studies revealed the importance of improved *Brachiaria* grass in dairy farms.

Brachiaria hybrid cv. Mulato II fed to heifers showed high absolute and relative nutrient intakes (Table 6.2). This was influenced by higher nutritive values, especially crude protein and metabolisable energy contents observed in Mulato II than in Napier grass based diets. Nutrient intakes of cv. Mulato II by dairy heifers were translated into remarkable average daily weight gain (ADWG) in comparison with those fed on Napier grass. Although there was a strong correlation between observed metabolisable energy

(ME) intake and ME predicted for both diets, high ME intake was observed in dairy heifers fed to Mulato II supplemented with commercial concentrates. This shows the importance of Mulato II in comparison with Napier grass diets. In spite of this, our results on ADWG were greater than those observed in crossbred dairy heifer recipients of embryos raised under a grazing system (de Carvalho Fernandes et al., 2015).

Brachiaria brizantha cv. Piatá was selected based on its nutritional attributes and used as basal diet for lactating dairy cows in comparison with Napier grass which is the major feed resource available in large and smallholder dairy farms (Mutimura et al., 2013a). Supplemented with or without forage legume (*Desmodium distortum*), Piatá-fed cows had more milk yield (8.1 L/day) than cows fed Napier grass (5.4 L/day). The differences were associated with high intakes of DM, CP and ME in Piatá relative to Napier grass. Grass-legume based diets also influenced milk yield, which was associated with faster rates of passage and consequently low rumen-fill (Kammes and Allen, 2012). Passage rates were accelerated by *Desmodium distortum* in the grass-legume diets. Results on nutrient intake, passage rate kinetics of particles and milk yield in dairy cows from Piatá in comparison with Napier grass suggest that the former grass can be an alternative for increasing milk production.

8.2. Conclusions

Crop-livestock integration describes predominantly the agricultural production system in Rwanda. It is an evolutionary phenomenon that is reinforced by favourable biophysical (Climate) and socio-economic factors (notably, availability of family labour; social stratification in terms of gender and age, and access to input and output markets). Feed shortage, especially during the dry season was one of challenges that impede livestock development in smallholder farms. Although there are some off-farm livelihood options, intensive cropping and livestock farming are considered as major livelihood options in semi-arid and humid environments of Rwanda.

An agro-ecological zone through its associated climate and soil attributes can affect available options and coping mechanisms to feed shortage in smallholder farms. Feed resources that are used by smallholder farmers were diverse in their nutritional values.

Nonetheless, a number of potentially valuable indigenous forage species were identified in this study.

Significance variation in chemical composition and *in vitro* digestibilities were observed in improved *Brachiaria* grasses evaluated on-farm under semi-arid condition in Rwanda. Cultivars Marandú, Basilisk and of Piatá were superior in their nutritional attributes compared to other grasses. Their ivADDM, GP, potential degradable fractions, ME and time taken for rumen degradability values were superior to the rest of these grasses. Napier grass as the major feed resource in smallholder farmers in east Africa was found to be among the lowest in its nutritive attributes. However, its CP and ME yield per unit area were higher than the rest of grasses. Generally, age of 90 DAP was the best harvesting age for better quality and quantity of these grasses. The most promising *Brachiaria* cultivars identified were *B. decumbens* cv. Basilisk, *B. brizantha* cv. Marandú and *B. brizantha* cv. Piatá, because of their nutritional characteristics and nutrient yields which were higher and more comparable with Napier grass than the other cultivars.

Absolute (kg/day) and relative (kg/BW$^{0.75}$) nutrient intakes confirmed that *ad libitum* feeding of Mulato II was better than feeding Napier grass for intensive rearing of dairy replacement heifers. This is because numerically the daily body weight gain of heifers on MCC diet exceeded that on NCC diet. Considering the quality attributes of cv. Mulato II, it can be integrated into cut-and-carry feeding system for intensive dairy production.

Significance differences in chemical composition as well as passage rate kinetics between *Brachiaria brizantha* cv. Piatá and Napier grass supplemented with or without *Desmodium distortum* were observed. Piatá-Desmodium diet increased nutrients availability, intake, ruminal passage rate of particles and milk yield than grass fed alone. The higher NDF is Napier grass than in Piatá suggest faster degradation rate for Piatá than for Napier, resulting to increased absolute flow rate of nutrients to the lower digestive tract for the former. This suggests that Piatá can be used to increase milk yield more than the existing Napier grass in smallholder farms. The integration of this

Brachiaria cultivar in the local and similar farm prevailing conditions in the tropics can increase livestock productivity.

8.3. Recommendations and further research

In this study, crop-livestock farming system was identified as the major options for livelihood. Among livestock enterprises, dairy cattle were the most strategic option to increase home income. This shows that feed shortage should be taken thoughtfully into consideration. In this case, forage interventions that mitigate land use challenges in mixed crop-livestock systems can greatly improve quality feed availability and compatible food-forage intercrops including forage grasses and legumes that fix atmospheric nitrogen or protect crops from pests.

The diversity of feed resources and their discrepancies in nutritive values were identified in the study area and showed their importance in livestock feeding system. It is recommended that these feed resources with high nutritive values be selected and developed for their availability throughout the year. This will not only increase livestock productivity but will also offer farmers' choices for better farm production. Nutritional characteristics of locally available feed resources were based on chemical compositions and *in vitro* digestibilities. With these techniques, a feed might have good *in vitro* characteristics but *in vivo* studies are needed to estimate the impact of these feeds on livestock production. This should comprise, improving quality of available feed resources (e.g. crop residues) and evaluate their economic status in mixed crop-livestock production system. These should also include quantifying nitrogen retention and excretion as well as estimating methane emission for better mitigation of enteric fermentation.

Improved *Brachiaria* grasses have shown competence in agronomic and nutritive value characteristics over Napier grass. These *Brachiaria* grasses are also known for their capability to improve soil fertility by sequestering large amount of CO_2 and N_2O for greenhouse gas emission mitigation. In addition to agronomic and nutritional aspects, evaluation of these grasses for soil microbial growth is needed for soil quality improvement. Moreover, together with the evaluation of soil microbial growth under

Brachiaria grass and N excretion, further studies are needed to determine their impact on nutrient flow in crop-livestock production system for better management of natural resource base. This will help to understand whole farm production under crop-forage production in smallholder farms, especially in tropical areas prone to dry spells.

Brachiaria hybrid cv. Mulato II and *Brachiaria brizantha* cv. Piatá showed their significance contribution as valuable feed for dairy cows. Their quality attributes increased body weight and milk yield of crossbred heifers and lactating dairy cows, respectively. Although, a good number of parameters were assessed in this study, the use of nitrogen from these grasses was not assessed. Therefore, N retention and excretion as well as milk fat and protein should be considered for further studies in order to fully understand the benefit of *Brachiaria* grass under tropical conditions. This study also showed that nutritional benefits of *Brachiaria* grass over Napier grass was associated with difference in intake. It is proposed that the effect of potentially effective NDF content on voluntary intake and productivity of forage be evaluated, validated and integrated in the forage evaluation protocols.

9. References

Abate, A., Dzowela, B.H. and Kategile, J.A. 1993. Intensive animal feeding practices for optimum feed utilization. Proceedings of the Workshop held at Kadoma Ranch Hotel, Zimbabwe, from 20 – 23rd July, 1992.

Abdou, N., Nsahlai, I.V. and Chimonyo, M., 2011. Effects of groundnut haulms supplementation on millet stover intake, digestibility and growth performance of lambs. Animal Feed Science and Technology, 169, 176–184.

Abegaz, A., van Keulen, H. and Oosting, S.J., 2007. Feed resources, livestock production and soil carbon dynamics in Teghane, Northern Highlands of Ethiopia. Agricultural Systems, 94, 391–404.

Abreu, A., Carulla, J.E., Lascano, C.E., Diaz, T.E., Kreuzer, M. and Hess, H.D., 2004. Effects of *Sapindus saponaria* fruits on ruminal fermentation and duodenal nitrogen flow of sheep fed a tropical grass diet with and without legume. Journal of Animal Science, 82, 1392–1400.

AFRC (Agricultural and Food Research Council), 1993. Energy and protein requirements of ruminants. A manual prepared by AFRC advisory Technical committee on responses to nutrients. CAB International, Wallingford, UK, 159 p.

Aikman, P.C., Reynolds, C.K. and Beever, D.E., 2008. Diet digestibility, rate of passage, and eating and rumination behaviour of Jersey and Holstein cows. Journal of Animal Science, 91, 1103–1114.

Ajwad, A.M.A and Noordin, M.M., 2012. Toxicity of Signal Grass (*Brachiaria decumbens*): A Review Article. Journal of Advanced Medical Research, 2, 18–39.

Alstrup, L., Nielsen M.O., Lund, P., Sehested, J., Larsen, M.K. and Weisbjerg, M.R., 2015. Milk yield, feed efficiency and metabolic profiles in Jersey and Holstein cows assigned to different fat supplementation strategies. Livestock Science, 178, 165–176.

Andrieu, N., Vayssières, J., Corbeels, M., Blanchard, M., Vall, E. and Tittonell, P., 2015. From farm scale synergies to village scale trade-offs: Cereal crop residues use in an agro-pastoral system of the Sudanian zone of Burkina Faso. Agricultural Systems, 134, 84–96.

AOAC (Association of Official Analytical Chemists), 2006. Total nitrogen, Official Methods of analysis, 984.13, 18th edition. Association of official analytical chemists, Washington, DC.

AOAC, 1990. Association of official Analytical chemists. Official methods of analysis. 15th edition. A.O.A.C. Arlington Virginia, USA.

Asudi, G.O., van den Berg, J., Midega, C.A.O., Pittchar, J., Pickett, J.A. and Khan, Z.R., 2015. Napier grass stunt disease in east Africa: Farmers' perspectives on disease management. Crop Protection, 71, 116–124.

Avilés-Nieto, J.N., Valle-Cerdán, J.L., Castrejón-Pineda, F., Angeles-Campos, S. and Vargas-Bello-Pérez, E., 2013. Digestibility of buffel grass (*Cenchrus ciliaris*)-based diets supplemented with four levels of *Gliricidia sepium* hay in hair sheep lambs. Tropical Animal Health and Production, 45, 1357–1362.

Balehegn, M., Eik, L.O. and Tesfay, Y., 2014. Replacing commercial concentrate by *Ficus thonningii* improved productivity of goats in Ethiopia. Tropical Animal Health and Production, 46, 889–894.

Baluch-Gharaei, H., Rouzbehan, Y., Fazaeli, H. and Rezaei, J., 2015. Effect of deep-stacking broiler litter on pathogenic bacteria, intake, digestibility, microbial protein supply and rumen parameters in sheep. Animal Feed Science and Technology, 199, 73–83.

Batistoti, C., Lemppa, B., Jank, L., das Morais, M.G., Cubas, A.C., Gomes, R.A., and Ferreira, M.V.B., 2012. Correlations among anatomical, morphological, chemical and agronomic characteristics of leaf blades in *Panicum maximum* genotypes. Animal Feed Science and Technology, 171, 173–180.

Baudron, F., Mamo, A., Tirfessa, D. and Argaw, M., 2015. Impact of farmland exclosure on the productivity and sustainability of a mixed crop-livestock system in the Central Rift Valley of Ethiopia. Agriculture, Ecosystems and Environment, 207, 109–118.

Baudron, F., Jaleta, M., Okitoi, O. and Tegegn, A., 2014. Conservation agriculture in African mixed crop-livestock systems: Expanding the niche. Agriculture, Ecosystems and Environment, 187, 171–182.

Bauman, D.E. and Capper, J.L., 2011. Sustainability and dairy production: challenges and opportunities. Proceedings 2011 Cornell Nutrition Conference for Feed Manufacturers, 73rd Meeting, October 18–20, 2011 Doubletree Hotel, East Syracuse, New York, pp, 136–153.

Bazimenyera, J.D., Qiang, F. and Niragire, T., 2014. Seasonal Variation of Major Elements in South Lake Cyohoha, Rwanda. Journal of Northeast Agricultural University (English Edition), 21, 56–63.

Beard, J.B. and Green, R.L., 1994. The role of Turf grasses in environmental protection and their benefits to humans. Journal of Environmental Quality, 23, 1–16.

Beatriz, R.C., Castro, M.B., Lemos, R.A.A., Gabriela, R.C., Mustafa, V. and Franklin, R.C., 2011. *Brachiaria* sp. poisoning of ruminants in Brazil. Brazilian Journal of Veterinary Research, 31, 183–192.

Bell, L.W., Moore, A.D. and Kirkegaard, J.A., 2014. Evolution in crop–livestock integration systems that improve farm productivity and environmental performance in Australia. European Journal of Agronomy, 57, 10–20.

Berton, M.P., de Cássia Dourado, R., de Lima, F.B.F., Rodrigues, A.B B., Ferrari, F.B., do Carmo Vieira, L.D., de Souza, P.A. and Borba, H., 2015. Growing-finishing performance and carcass yield of pigs reared in a climate-controlled and uncontrolled environment. International Journal of Biometeorology, 59, 955–960.

Blake, J., 2010. Practical consideration of feed evaluation systems for dairy cows. In: Garnsworthy, C.P. and Wiseman, J. (Eds). Recent advances in animal nutrition 2009. Nottingham, University Press, pp, 99–113.

Blaxter, K.L., Graham, McC. And Wainman, F.W., 1956. Some of observations on the digestibility of food by sheep, and on related problems. British Journal of Nutrition, 10, 69–91.

Blümmel, M. and Becker, K., 1997. The degradability characteristics of fifty-four roughages and roughage neutral-detergent fibres as described by *in vitro* gas production and their relationship to voluntary feed intake. British Journal of Nutrition, 77, 757–768.

Blümmel, M., Makkar, H.P.S., Chisanga, G., Mtimuni, J. and Becker, K., 1997. The prediction of dry matter intake of temperate and tropical roughages from in vitro digestibility/gas-production data, and the dry matter intake and in vitro digestibility of African roughages in relation to ruminant live weight gain. Animal Feed Science Technology, 69, 131–141.

Bodas, R., Lopez, S., Fernandez, M., Gracia-Gonzalez, R., Rodriguez, A.B., Wallace, R.J. and Gonzalez, J.S., 2008. *In vitro* screening of the potential of numerous plant species as anti-methanogenic feed additives for ruminants. Animal Feed Science and Technology, 145, 245–258.

Bogale, S., Melaku, S. and Yami, A., 2008. Potential use of crop residues as livestock feed resources under smallholder farmers' conditions in Bale highlands of Ethiopia. Tropical and Subtropical Agro-ecosystems, 8, 107–114.

Bonsi, M.L.K., Osuji, P.O., Tuah, A.K. and Umunna, N.N., 1995a. *Vernonia amygdalina* as a supplement to teff straw (*Eragrostis tef.*) fed to Ethiopian Menz sheep. Agroforestry Systems, 31, 229–241.

Bonsi, M.L.K., Osuji, P.O. and Tuah, A.K., 1995b. Effect of supplementing teff straw with different levels of *Leucaena* or *Sesbania* leaves on the degradabilities of teff straw, Sesbania, Leucaena, *Tagasaste* and *Vernonia* and on certain rumen and blood metabolites in Ethiopian Menz sheep. Animal Feed Science and Technology, 52, 101–129.

Bourn, D. and Wint, W., 1994. Livestock, land use and agricultural intensification in sub-Saharan Africa. Pastoral Development Network Paper 37a Overseas Development Institute, London. http://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/5411.pdf. Retrieved 26-11-2015.

Brown, C.A., Chandler, P.T. and Holter, J.B., 1977. Development of predictive equations for milk yield and dry matter intake in lactating cows. Journal of Dairy Science, 60, 1739–1754.

Bucagu, C., Vanlauwe, B., Van Wijk, M.T. and Giller, K.E., 2013. Assessing farmers' interest in agroforestry in two contrasting agro-ecological zones of Rwanda. Agroforest System, 87,141–158.

Bunch, R., 2012. Restoring the soil: A guide for using green manure/cover crops to improve the food security for smallholder farmers. Canadian Food grains Bank, 94 p.

Campos, F.P., Sarmento, P., Nussio, L.G., Lugão, S.M.B., Lima, C.G. and Daniel, J.L.P., 2013. Fibre monosaccharides and digestibility of Milenio grass under N fertilisation. Animal Feed Science and Technology 183, 17–21.

Campos, F.P., Sampaio, A.A.M., Bose, M.L.V., Vieira, P.F. and Sarmento, P., 2004. Evaluation of in vitro gas production of roughages and their mixtures using the curves subtraction method. Animal Feed Science and Technology, 116, 161–172.

Cantore, N., 2012. The crop intensification programme in Rwanda: A sustainability analysis. Consultancy report, Kigali, Rwanda, 34 p.

Cardoso, J.A., Pineda, M., Jimenez, J.C., Vergara, M.F. and Rao, I.M., 2015. Contrasting strategies to cope with drought conditions by two tropical forage C_4 grasses. AoB PLANTS, 7, 1–15.

Castellanos-Navarrete, A., Tittonell, P., Rufino, M.C. and Giller, K.E., 2015. Feeding, crop residue and manure management for integrated soil fertility management – A case study from Kenya. Agricultural Systems, 134, 24–35.

Castells, L., Bach, A., Araujo, G., Montoro, C. and Terré, M., 2012. Effect of different forage sources on performance and feeding behaviour of Holstein calves. Journal of Dairy Science, 95, 286–293.

Cezário, A.S., Ribeiro, K.G., Santos, S.A., de Campos Valadares Filho, S. and Pereira, O.G., 2015. Silages of Brachiaria brizantha cv. Marandú harvested at two regrowth ages: microbial inoculant responses in silage fermentation, ruminant digestion and beef cattle performance. Animal Feed Science and Technology, 208, 33–43.

Chanthakhoun, V., Wanapat, M. and Berg, J., 2012. Level of crude protein in concentrate supplements influenced rumen characteristics, microbial protein synthesis and digestibility in swamp buffaloes (*Bubalus bubalis*). Livestock Science, 144, 197–204.

Chapman, D.F., Kenny, S.N., Beca, D. and Johnson, I.R., 2008. Pasture and forage crop systems for non-irrigated dairy farms in southern Australia. 1. Physical production and economic performance. Agricultural Systems, 97, 108–125.

Cheeke, P.R., 1995. Endogenous toxins and mycotoxins in forage grasses and their effects on livestock. Journal of Animal Science, 73, 909–918.

Chirat, G., Groot, J.C.J., Messada, S., Bocquier, F. and Ickowicz, A., 2014. Instantaneous intake rate of free-grazing cattle as affected by herbage characteristics in heterogeneous tropical agro-pastoral landscapes. Applied Animal Behaviour Science, 157, 48–60.

Christiaensen, L., Demery, L. and Kuhl, J., 2011. The (evolving) role of agriculture in poverty reduction—An empirical perspective. Journal of Development Economics, 96, 239–54.

Clark, D., Malcolm, B. and Cobs, J.Ja., 2012. Dairying in the antipodes: recent past, near prospects. In: Proceedings of the 5th Australasian Dairy Science Symposium. November 13–15, 2012, Airport Convention Centre & Motel Melbourne, Australia, pp, 93–106.

Clark, D.A., Caradus, J.R., Monaghan, R.M., Sharp, P. and Thorrold, B.S., 2007. Issues and options for future dairy farming in New Zealand. New Zealand Journal of Agricultural Research, 50, 203–221.

Clauss, M. and Lechner-Doll, M., 2001. Differences in selective reticulo-rumen particle retention as a key factor in ruminant diversification. Oecologia, 129, 321–327.

Cooper, P.J.M., Dimes, J., Rao, K.P.C., Shapiro, B., Shiferawa, B. and Twomlo, S., 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? Agriculture, Ecosystems and Environment, 126, 24–35.

Coromaldi, M., Pallante, G. and Savastano, S., 2015. Adoption of modern varieties, farmers' welfare and crop biodiversity: Evidence from Uganda. Ecological Economics, 119, 346–358.

Cortez-Arriola, J., Rossing, W.A.H., Améndola Massiotti, R.D., Scholberg, J.M.S., Groot, J.C.J. and Tittonell, P., 2015. Leverages for on-farm innovation from farm typologies? An illustration for family-based dairy farms in north-west Michoacán, Mexico. Agricultural Systems, 135, 66–76.

Crusciol, C.A.C., Nascente, A.S., Mateus, G.P., Pariz, C.M., Martins, P.O. and Borghi, E., 2014. Intercropping soybean and palisade grass for enhanced land use efficiency and revenue in a no till system. European Journal of Agronomy, 58, 53–62.

da Silva, L.D., Pereira, O.G., Valadares Filho, S.C., Ribeiro, K.G., Valadares, R.F.D., Silva, T.C. and Santos, S.A., 2015. Intake, digestibility, and nitrogen efficiency in Holstein heifers fed treated jatropha (*Jatropha curcas* L.) kernel cake. Livestock Science, 178, 100–107.

Danes, M.A.C., Chagas, L.J., Pedroso, A.M. and Santos, F.A.P., 2013. Effect of protein supplementation on milk production and metabolism of dairy cows grazing tropical grass. Journal of Dairy Science, 96, 407–419.

Das, K.C., Haque, N., Baruah, K.K., Rajkhowa, C. and Mondal, M., 2011. Comparative nutrient utilization, growth, and rumen enzyme profile of mithun (*Bos frontalis*) and Tho-tho cattle (*Bos indicus*) fed on tree-leaves-based ration. Tropical Animal Health and Production, 43, 209–214.

Datt, C., Datta, M. and Singh, N.P., 2008. Assessment of fodder quality of leaves of multipurpose trees in subtropical humid climate of India. Journal of Forestry Research, 19, 209–214.

Davis, K.F. and D'Odorico, P., 2015. Livestock intensification and the influence of dietary change: A calorie-based assessment of competition for crop production. Science of the Total Environment, 538, 817–823.

de Carvalho Fernandes, C.A., Palhao, M.P., Figueiredo, A.C.S., Ribeiro, J.R., e Silva, F.F. and Viana, J.H.M., 2015. Weight gain potential affects pregnancy rates in bovine embryo recipients raised under pasture conditions. Tropical Animal Health and Production (in press), DOI: 10.1007/s11250-015-0926-0.

De Oliveira, C.H.S., Barbosa, J.D., Oliveira, C.M.C., Bastianetto, E., Melo, M.M., Haraguchi, M., Freitas, L.G.L., Silva, M.X. and Leite, R.C., 2013. Hepatic photosensitization in buffaloes intoxicated by *Brachiaria decumbens* in Minas Gerais state, Brazil. Toxicon, 73, 121–129.

de Pinho Costa, K.A., da Costa Severiano, E., Simon, G.A., Epifanio, P.S., da Silva, A.G., Guedes Fonseca Costa, R.R., Santos, C.B. and Rodrigues, C.R., 2014. Nutritional characteristics of *Brachiaria brizantha* cultivars subjected to different intensities of cutting. American Journal of Plant Sciences, 5, 1961-1972.

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

Delve, R.J., Cadisch, G., Tanner, J.C., Thorpe, W., Thorne, P.J. and Giller, K.E., 2001. Implications of livestock feeding management on soil fertility in the smallholder farming systems of sub-Saharan Africa. Agriculture, Ecosystems and Environment, 84, 227–243.

Devendra, C. and Thomas, D., 2002. Crop–Animal interactions in mixed farming systems in Asia. Agricultural Systems, 71, 27–40.

Dijkstra*,* J., Kebreab, E., Bannink, A., Crompton, L.A., Lopez, S., Abrahamse, P.A., Chilibroste, P., Mills, J.A.N. and France, J., 2008. Comparison of energy evaluation systems and a mechanistic model for milk production by dairy cattle offered fresh grass-based diets. Animal Feed Science and Technology, 143, 203–219.

Dillon, P., Buckley, F., O'Connor, P., Hegarty, D. and Rath, M., 2003. A comparison of different dairy cow breeds on a seasonal grass-based system of milk production. Livestock Production Science, 83, 21–33.

Djikeng, A., Rao, I.M., Njarui, D., Mutimura, M., Caradus, J., Ghimire, S.R., Johnson, L., Cardoso J.A., Ahonsi, M. and Kelemu, S., 2014. Climate-smart *Brachiaria* grasses for improving livestock production in East Africa. Tropical Grasslands – Forrajes Tropicales, 2, 38–39.

Doepel, L. and Lapierre, H., 2006. Challenges in protein nutrition for dairy cows. WCDS Advances in Dairy Technology, 18, 57–67.

Ellis, J.L., Qiao, F. and Cant, J.P., 2006. Prediction of dry matter intake throughout lactation in a dynamic model of dairy cow performance. Journal of Dairy Science, 89, 1558–1570.

El-Nashaar, H.M., Griffith, S.M., Steiner, J.J. and Banowetz, G.M., 2009. Mineral concentration in selected native temperate grasses with potential use as biofuel feedstock. Bioresource Technology, 100, 3526–3531.

Engstrom, M., Sanchez, W., Stone, W. and St-Pierre, N.R., 2010. Applications of population data analysis in on-farm dairy trials. Journal of Animal Science, 88, 25–31.

Epifanio, P.S., Costa, K.A.P., Severiano, E.C., Cruvinel, W.S., Bento, J.C. and Perim, R.C., 2014. Fermentative and bromatological characteristics of Piatá palisadegrass ensiled with levels of meals from biodiesel industry. Ciências Agrárias, 35, 491–504.

FAOSTAT, 2011. FAO statistics database on the World Wide Web.

Fiaz, M., Abdullah, M., Javed, K., Babar, M.E., M. Nasir, Pasha, T.N. and Jabbar, M.A., 2012. Effect of varying dietary energy levels during the last trimester of pregnancy on subsequent first lactation performance in Sahiwal heifers. Tropical Animal Health and Production, 44, 975–981.

Fiems, L.O., De Boever, J.L., Ampe, B., Vanacker, J.M., De Campeneere, S. and Sonck, B., 2015. Effect of energy restriction and dietary protein level during the re-alimentation period on feed efficiency in double-muscled Belgian Blue cows. Livestock Science, 174, 46–52.

Fikru, H.J., 2001. Drought stress, insects, and yield loss. In: Peterson, R.K.D. and Higley, G.L. (Eds). Biotic stress and yield loss. CRC press, New York, Washington, D.C., pp, 117–130.

Forbes, J.M., 2003. The multifactorial nature of food intake control. Journal of Animal Science, 81, 139–144.

Fox, D.G., Tedeschi, L.O., Tylutki, T.P., Russell, J.B., Van Amburgh, M.E., Chase, L.E., Pell, A.N. and Overton, T.R., 2004. The Cornell Net Carbohydrate and Protein System model for evaluating herd nutrition and nutrient excretion. Animal Feed Science and Technology, 112, 29–78.

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J. and Wambugu, C., 2014. Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. Current Opinion in Environmental Sustainability, 6, 98–103.

Franzluebbers, A.J., 2007. Integrated crop–livestock systems in the Southeastern USA. Agronomy Journal, 99, 361–372.

Fukushima, R.S., Kerley, M.S., Ramos, M.H., Porter, J.H. and Kallenbach, R.L., 2015. Comparison of acetyl bromide lignin with acid detergent lignin and Klason lignin and correlation with in vitro forage degradability. Animal Feed Science and Technology, 201, 25–37.

Fulkerson, W.J., Neal, J.S., Clark, C.F., Horadagoda, A., Nandra, K.S. and Barchia, I., 2007. Nutritive value of forage species grown in the warm temperate climate of Australia for dairy cows: Grasses and legumes. Livestock Science, 107, 253–264.

Galukande, E.G., Mulindwa, H., Wurzinger, M., Okeyo, M.A., Mpairwe, D. and Solkner, J., 2010. On-farm comparison of milk production and growth of purebred Ankole and crossbred Friesian-Ankole cows in South-Westerrn Uganda. Dissertation Zur Elangung des Doktorgrades Des Univeristat fur Bodenkultur, pp, 60–85.

Garg, M.R., Sherasia, P.L., Bhanderi, B.M., Phondba, B.T., Shelke, S.K. and Makkar, H.P.S., 2013. Effects of feeding nutritionally balanced rations on animal productivity feed conversion efficiency, feed nitrogen use efficiency, rumen microbial protein supply, parasitic load, immunity and enteric methane emissions of milking animals under field conditions. Animal Feed Science and Technology, 179, 24–35.

Gebrehawariat, E., Tamir, B. and Tegegne, A., 2010. Feed intake and production parameters of lactating crossbred cows fed maize-based diets of stover, silage or quality protein silage. Tropical Animal Health and Production, 42, 1705–1710.

Geraghty, T., O'Grady, L. and Mulligan, F.J., 2010. An investigation into reduced milk production following dietary alteration on an Irish dairy farm. Irish Veterinary Journal, 63, 689–694.

Ghebrehiwot, H.M., 2004. The effects of burning and mowing on microclimate and soil resources and implications for species change in the southern tall grassveld of Kwazulu-Natal. MSc. Thesis, UKZN, 150 p.

Giller, K.E., Witter, E., Corbeels, M. and Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research, 114, 23–34.

Gleadow, R.M. and Woodrow, I.E., 2002. Constraints on effectiveness of cyanogenic glycosides in herbivore defense. Journal of Chemical Ecology, 28, 1301–1313.

Goering, H.K. and Van Soest, P.J., 1970. Forage fibre analyses (Apparatus, Reagents, Procedures, and Some Applications). USDA. Agricultural Research Service. Agricultural Handbook No. 379.

Gojjam, Y., Tolera, A. and Mesfin, R., 2011. Management options to accelerate growth rate and reduce age at first calving in Friesian–Boran crossbred heifers. Tropical Animal Health and Production, 43, 393–399.

Goma, H.C., Rahim, K., Nangendo, G., Riley, J. and Stein, A., 2001. Participatory studies for agro-ecosystem evaluation. Agriculture, Ecosystems and Environment, 87, 179–190.

Gonzalez, M.A., Valles de la Mora, B., Díaz, M.A.A., Gallegos, E.C., Zavaleta, E.O. and Rodriguez, J.J., 2012. Effect of grazing *Cratylia argentea* associated with *Brachiaria brizantha*-Toledo on quality pasture and weight gain in Holstein × Zebu Heifers. Tropical and Subtropical Agroecosystems, 15, 1–11.

GoR (Government of Rwanda), 2000. Rwanda Vision 2020. MINECOFIN, Kigali, 28 p.

Gorniak, T., Hüther, L., Meyer, U., Lebzien, P., Breves, G., Südekum, K.H. and Dänicke, S., 2014. Digestibility, ruminal fermentation, ingesta kinetics and nitrogen utilisation in dairy cows fed diets based on silage of a brown midrib or a standard maize hybrid. Archives of Animal Nutrition, 68, 143–158.

Gracindo, C.V., de Castro, M.B., Louvandini, H., Riet-Correa, F. and Barbosa-Ferreira, M., 2014. Performance of sheep grazing in pastures of *Brachiaria decumbens*, *Brachiaria brizantha*, *Panicum maximum* and *Andropogon gayanus* with different protodioscin concentrations. Tropical Animal Health and Production, 46, 733–737.

Grant, R.J. and Tylutki, T.P., 2011. Influence of social environment on feed intake of dairy cattle. Proceedings 2011 Cornell Nutrition Conference for Feed

Manufacturers, 73rd Meeting, October 18–20th, 2011 Doubletree Hotel, East Syracuse, New York, pp, 86–100.

Gray, N.N., 1984. The production potential of tropical pastures in the drier phase of the highland sourveld of Natal. Journal of Grassland Society of Southern Africa, 1, 1–19.

Gusha, J., Halimani, T.E., Ngongoni, N.T. and Ncube, S., 2015. Effect of feeding cactus-legume silages on nitrogen retention, digestibility and microbial protein synthesis in goats. Animal Feed Science and Technology, 206, 1–7.

Gwaze, F.R., Mwale, M. and Chimonyo, M., 2011. Challenges encountered in conducting farmer-oriented livestock research among resource-limited farmers of Sub-Saharan Africa: A review. African Journal of Agricultural Research, 6, 4840–4851.

Haileslassie, A., Craufurd, P., Thiagarajah, R., Kumar, S., Whitbread, A., Rathor, A., Blummel, M., Ericsson, P. and Kakuman, K.R., 2016. Empirical evaluation of sustainability of divergent farms in the dryland farming systems of India. Ecological Indicators, 60, 710–723.

Halmemies-Beauchet-Filleau, A., Vanhatalo, A., Toivonen, V., Heikkilä, T., Lee, M.R.F., and Shingfield, K.J., 2014. Effect of replacing grass silage with red clover silage on nutrient digestion, nitrogen metabolism, and milk fat composition in lactating cows fed diets containing a 60:40 forage-to concentrate ratio. Journal of Dairy Science, 97, 3761–3776.

Hameed, M., Ashraf, M. and Naz, N., 2009. Anatomical adaptations to salinity in cogon grass [*Imperata cylindrical* (L.) Raeuschel] from the salt range. Plant and Soil, 322, 229–238.

Hare, M.D., Tatsapong, P. and Phengphet, S., 2009. Herbage yield and quality of *Brachiaria* cultivars, *Paspalum atratum* and *Panicum maximum* in north-east Thailand. Tropical Grasslands, 43, 65–72.

Hare, M.D., Tatsapong, P. and Saipraset, K., 2007. Seed production of two *Brachiaria* hybrid cultivars in north-east Thailand. Closing date defoliation. Tropical Grasslands, 41, 35–42.

Hasiah, A.H., Elsheikh, H.A., Abdullah, S.A., Khairi, H.M. and Rajion, M.A., 2000. Effect of phenobarbitone treatment against signal grass (*Brachiaria decumbens*) toxicity in sheep. The Veterinary Journal, 160, 267–272.

Hayirli, A., Grummer, R.R., Nordheim, E.V. and Crump, P.M., 2003. Models for predicting dry matter intake of Holsteins during the prefresh transition period. Journal of Dairy Science, 86, 1771–1779.

Hebel, C., Ortmann, S., Hammer, S., Hammer, C., Fritz, J., Hummel, J. and Clauss, M., 2011. Solute and particle retention in the digestive tract of Phillip's dikdik (*Modoqua saltiana phillipsi*), a very small browsing ruminant: Biological and methodological implications. Comparative Biochemistry and Physiology, Part A, 159, 284–290.

Hellin, J., Erenstein, O., Beuchelt, T., Camacho, C. and Flores, D., 2013. Maize stover use and sustainable crop production in mixed crop–livestock systems in Mexico. Field Crops Research, 153, 12–21.

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., van de Steeg, J., Lynam, J., Rao, P., Macmillan, S., Gerard, B., McDermott, J., Seré, C. and Rosegrant, M., 2010. Smart investments in sustainable food production: revisiting mixed crop–livestock systems. Science, 327, 822–825.

Hess, H.D., Monsalve, L.M., Lascano, C.E., Carulla, J.E., Diaz, T.E. and Kreuzer, M., 2003. Supplementing of a tropical grass diet with forage legumes and *Sapindurasaponaria* fruits: effects on *in vitro* ruminal nitrogen turnover and methanogenesis. Australian Journal of Agricultural Research, 54, 701–713.

Hills, J.L., Wales, W.J., Dunshea, F.R., Garcia, S.C. and Roche, J.R., 2015. Invited review: An evaluation of the likely effects of individualized feeding of concentrate supplements to pasture-based dairy cows. Journal of Dairy Science, 98, 1363–1401.

Holter, J.B., West, J.W. and McGilliard, M.L., 1997. Predicting *ad libitum* dry matter intake and yield of Holstein cows. Journal of Dairy Science, 80, 2188–2199.

Homann-Kee Tui, S., Valbuena, D., Masikati, P., Descheemaeker, K., Nyamangara, J., Claessens, L., Erenstein, O., van Rooyen, A. and Nkomboni, D., 2015.

Economic trade-offs of biomass use in crop-livestock systems: Exploring more sustainable options in semi-arid Zimbabwe. Agricultural Systems, 134, 48–60.

Huhtanen, P., Ahvenjärvi, S., Weisbjerg, M.R. and Nørgaard, P., 2006. Digestion and passage of fibre in ruminants. In: Sejrsen, K., Hvelplund, T. and Nielsen, M.O. (Eds). Ruminant Physiology: Digestion, Metabolism and Impact of Nutrition on Gene Expression, Immunology and Stress. Wageningen Press, Wageningen, the Netherlands, pp, 87–135.

Huhtanen, P. and Kukkonen, U., 1995. Comparison of methods, markers, sampling sites and models for estimating digesta passage kinetics in cattle fed at two levels of intake. Animal Feed Science and Technology, 52, 141–158.

Hymes-Fecht, U.C., Broderick, G.A., Muck, R.E. and Grabber, J.H., 2013. Replacing alfalfa or red clover silage with birdsfoot trefoil silage in total mixed rations increases production of lactating dairy cows. Journal of Dairy Science, 96, 460–469.

IAASTD (International Assessment of Agricultural knowledge, Science and Technology for Development), 2009. Agriculture Crossroads. In: Sub-Saharan Africa (SSA) report, Island Press, 1718, Connecticut Avenue, NW, Suite 300, Washington, DC 20009, 153 p.

Igono, M.O., Bjotvedt, G. and Sanford-Crane, H.T., 1992. Environmental profile and critical temperature effects on milk production of Holstein cows in desert climate. International Journal of Biometeorology, 36, 77–87.

ILRI (International Livestock Research Institute), 2013. Getting superior Napier grass to dairy farmers in East Africa, Report, Nairobi, Kenya, 6 p.

Ishler, V., Heinrichs, J. and Varga, G., 1996. From feed to milk: understanding rumen function. Extension Circular, College of Agricultural Sciences, The Pennsylvania State University, 27 p.

Jaeger-Erben, M., Rückert-John, J. and Schafer, M., 2015. Sustainable consumption through social innovation: a typology of innovations for sustainable consumption practices. Journal of Cleaner Production, 108, 784–798.

Jaleta, M., Kassie, M. and Erenstein, O., 2015. Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia. Agricultural Systems, 134, 17–23.

Jampeetong, A., Brix, H. and Kantawanichkul, S., 2014. Effects of inorganic nitrogen form on growth, morphology, N uptake, and nutrient allocation in hybrid Napier grass (*Pennisetum purpureum* × *Pennisetum americanum* cv. Pakchong1). Ecological Engineering, 73, 653–658.

Johns, J., Hemken, R. and Scharko, P., 2003. Trace mineral supplementation for Kentucky beef cows. Cooperative extension service. University of Kentucky, UK.

Juarez, L.F.I., Fox, D.G., Blake, R.W. and Pell, A.N., 1999. Evaluation of tropical grasses for milk production by dual-purpose cows in tropical Mexico. Journal of Dairy Science, 82, 2136–2145.

Kabi, K. and Bareeba, F.B., 2008. Herbage biomass production and nutritive value of mulberry (*Morus alba*) and *Calliandra calothyrsus* harvested at different cutting frequencies. Animal Feed Science and Technology, 140, 178–190.

Kabirizi, M., Zziwa, E., Mugerwa, S., Ndikumana, J. and Nanyennya, W., 2013. Dry season forages for improving dairy production in smallholder systems in Uganda. Tropical Grasslands – Forrajes Tropicales, 1, 212–214.

Kaboré, T.K.W., Houot, S., Hien, E., Zombré, P., Hien, V. and Masse, D., 2010. Effect of the raw materials and mixing ratio of composted wastes on the dynamic of organic matter stabilization and nitrogen availability in composts of Sub-Saharan Africa. Bioresource Technology, 101, 1002–1013.

Kagabo, D.M., Stroosnijder, L., Visser, S.M. and Moore, D., 2013. Soil erosion, soil fertility and crop yield on slow-forming terraces in the highlands of Buberuka, Rwanda. Soil and Tillage Research, 128, 23–29.

Kamanzi, M. and Mapiye, C., 2012. Feed inventory and smallholder farmers' perceived causes of feed shortage for dairy cattle in Gisagara District, Rwanda. Tropical Animal Health and Production, 44, 1459–1468.

Kambashi, B., Picron, P., Boudry, C., Théwis, A., Kiatoko, H. and Bindelle, J., 2014. Nutritive value of tropical forage plants fed to pigs in the Western provinces of the Democratic Republic of the Congo. Animal Feed Science and Technology, 191, 47–56.

Kammes, K.L. and Allen, M.S., 2012. Rates of particle size reduction and passage are faster for legume compared with cool-season grass, resulting in lower rumen fill and less effective fibre. Journal of Dairy Science, 95, 3288–3297.

Kavana, P.Y. and Kakengi, V.A.M., 2014. Availability of pasture for domestic and wild herbivores in grazing land of Mpanda Tanzania. Livestock Research for Rural Development. Volume 26,
Article #37. http://www.lrrd.org/lrrd26/2/kava26037.htm. Retrieved January 6, 2015.

Kawube, G., Talwana, H., Nicolaisen, M., Alicai, T., Otim, M., Kabirizi, J., Mukwaya, A. and Nielsen, S.L., 2015. Napier grass stunt disease prevalence, incidence, severity and genetic variability of the associated phytoplasma in Uganda. Crop Protection, 75, 63–69.

Kawube, G., Alicai, T., Otim, M., Mukwaya, A., Kabirizi, J. and Talwana, H., 2014. Resistance of Napier grass clones to Napier grass stunt disease. African Crop Science Journal, 22, 229–235.

Kelemu, S., White, J.F., Munoz, F. and Takayama, Y., 2001. An endophyte of the tropical forage grass *Brachiaria brizantha*: isolating, identifying, and characterizing the fungus, and determining its antimycotic properties. Canadian Journal of Microbiology, 47, 55–62.

Kennedy, P.M. and Charmley, E., 2012. Methane yields from Brahman cattle fed tropical grasses and legumes. Animal Production Science, 52, 225–239.

Khachatur, M.B., 2006. *In- vitro* digestible organic matter and energy contents in wild growing forages of Armenia. Journal of Central European Agriculture, 7, 445–450.

Khan, M.J., Peters, K.J. and Uddin, M.M., 2009. Feeding strategy for improving dairy cattle productivity in small holder farm in Bangladesh. Bangladesh Journal Animal Science, 38, 67–85.

Khan, M.M.H. and Chaudhry, A.S., 2011. A comparative study of low and high quality forages for chemical composition and *in vitro* degradability. The Journal of Animal and Plant Sciences, 21, 715–723.

Klapwijk, C.J., Bucagu, C., van Wijk, M.T., Udo, H.M.J., Vanlauwe, B., Munyanziza, E. and Giller, K.E., 2014. The 'One cow per poor family' programme: Current and potential fodder availability within smallholder farming systems in southern Rwanda. Agricultural Systems, 131, 11–22.

Knowlton, F.K., Nelson, J.M. and Dunklee, K., 2003. World of dairy nutrition. Holstein Foundation, Brattleboro, VT 05302–0816, 39 p.

Komarek, A.M., Bell, L.W., Whish, J.P.M., Robertson, M.J. and Bellotti, W.D., 2015. Whole-farm economic, risk and resource-use trade-offs associated with integrating forages into crop–livestock systems in western China. Agricultural Systems, 133, 63–72.

Kozloski, G.V., Perottoni, J. and Sanchez, L.M.B., 2005. Influence of regrowth age on the nutritive value of dwarf elephant grass hay (*Pennisetum purpureum* Schum. cv. Mott) consumed by lambs. Animal Feed Science and Technology, 119, 1–11

Krämer, M., Lund, P. and Weisbjerg, M.R., 2013. Rumen passage kinetics of forage- and concentrate-derived fibre in dairy cows. Journal of Dairy Science, 96, 3163–3176.

Kretschmer, A.E. and Pitman, W.D., 2001. Germplasm resources of tropical forage grasses. In: Sontomayor, R.A. and Pitman, W.D. (Eds). Tropical forage plants: development and use. Raton, London New York, Washington, D.C., pp, 27–40.

Kumar, A., Waiz, S.A., Goud, T.S., Tonk, R.K., Grewal, A., Singh, S.V., Yadav, B.R. and Upadhyay, R.C., 2015. Assessment of adaptability of zebu cattle (*Bos indicus*) breeds in two different climatic conditions: using cytogenetic techniques on genome integrity. International Journal of Biometeorology (in press), DOI: 10.1007/s00484-015-1080-0.

Lanyasunya, T.P., Wang, H.R., Mukisira, E.A., Abdulrazak, S.A. and Ayako, W.O., 2006. Effect of seasonality on feed availability, quality and herd performance on smallholder farms in Ol-Joro-Orok location/Nyandarua district, Kenya. Tropical and Subtropical Agroecosystems, 6, 87–93.

Lapar, A.M.L. and Ehui, S.K., 2004. Factors affecting adoption of dual-purpose forages in the Philippines uplands. Agricultural Systems, 81, 95–114.

Lardner, H.A., Damiran, D. and McKinnon, J.J., 2015. Evaluation of 3 bromegrass species as pasture: Herbage nutritive value, estimated grass dry matter intake and steer performance. Livestock Science, 175, 77–82.

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

Lenné, J.M. and Wood, D., 2004. Is there a logic of fodder legumes in Africa? Food Policy, 29, 565–585.

Lewandowski, I. and Heinz, A., 2003. Delayed harvest of miscanthus—influences on biomass quantity and quality and environmental impacts of energy production. European Journal of Agronomy, 19, 45–63.

Li, H.Y, Xu, L. and Wang, N., 2014. Assessment of the nutritive value of whole corn stover and its morphological fractions. Asian-Australian Journal of Animal Science, 27, 194 –200.

Logue, D.N. and Mayne, C.S., 2014. Welfare-positive management and nutrition for the dairy herd: A European perspective. The Veterinary Journal, 199, 31–38.

Lounglawan, P., Lounglawan, W. and Suksombat, W., 2014. Effect of cutting interval and cutting height on yield and chemical composition of King Napier grass (*Pennisetum purpureum* x *Pennisetum americanum*). APCBEE Procedia, 8, 27–31.

Lukuyu, B., Gachuiri, C., Lukuyu, M., Lusweti, C. and Mwendia, S., 2012. Feeding dairy cattle in East Africa. In: Lukuyu, B. and Gachuiri, C. (Eds), East Africa Dairy Development Project, Nairobi, Kenya, 95 p.

Lukuyu, B.A., Kitalyi, A., Franzel, S., Duncan, A. and Baltenweck, I., 2009. Constraints and options to enhancing production of high quality feed in dairy production in Kenya, Uganda and Rwanda ICRAF Working Paper no. 95. Nairobi, Kenya: World Agro-forestry Centre, 31 p.

Maass B.L., Midega, C.A.O., Mutimura, M., Rahetlah, V.B., Salgado, P., Kabirizi, J.M., Khan, Z.R., Ghimire S.R. and Rao, I.M., 2015. Homecoming of *Brachiaria*: Improved hybrids prove useful for African animal agriculture. East African Agricultural and Forestry Journal, 81, 71–78.

Machuka, J., 2003. Developing food production systems in sub-Saharan Africa. In: Chrispeels, M. and Sadava, D. (Eds). Plants, Genes, and Crop Biotechnology. American Society of Plant Biologists, ASPB Education Foundation and Jones and Bartlett Publishers, Sudbury, MA, USA, pp, 100–123.

Maia, G.A., de Pinho Costa, K.A., da Costa Severiano, E., Epifanio, P.S., Neto, J.F., Ribeiro, M.G., Fernandes, P.B., Silva, J.F.G. and Gonçalves, W.G., 2014. Yield and chemical composition of *Brachiaria* forage grasses in the offseason after corn harvest. American Journal of Plant Sciences, 5, 933–941.

Malinowski, D.P. and Belesky, D.P., 2000. Adaptations of endophyte-infected cool-season grasses to environmental stresses: Mechanisms of drought and mineral stress tolerance. Crop Science, 40, 923–940

Malisetty, V., Yerradoddi, R.R., Devanaboina, N., Mallam, M. and Mitta, P., 2014. Effect of feeding sorghum straw based complete rations with different roughage to concentrate ratio on dry matter intake, nutrient utilization, and nitrogen balance in Nellore ram lambs. Tropical Animal Health and Production, 46, 759–764.

Mapiye, C., Mwale, M., Chikumba, N., Poshiwa, X., Mupangwa, J.F. and Mugabe, P.H., 2006. A review of improved forage in Zimbabwe. Tropical and Subtropical Agro-ecosystems, 6, 125–131.

Mathews, B.W., Carpenter, J.R., Cleveland, E., Gibson, Z. and Niino-DuPonte, R.Y., 2000. Perennial forage peanut (*Arachis pintoi*) in pastures for raising replacement heifer/stocker steers in Hawaii. Journal of Hawaiian Pacific Agriculture, 11, 1–10.

Mathison, G.W., Okine, E.K., Vaage, A.S., Kaske, M. and Millingan, L.P., 1995. Current understanding of the contribution of the propulsive activities in the forestomach to the flow of digesta. In: Engelhardt, W.v., Leonhard-Marek, S., Breves, G. and Giesecke, D. (Eds) Ruminant physiology: Digestion, metabolism, growth and reproduction. Proceedings of the eighth International Symposium on Ruminant Physiology. Herstellung: Schröders, Agentur, D-14199, Berlin, pp, 23–41.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A., Sinclair, L.A. and Wilkinson, R.G., 2011. Animal nutrition. Seventh Edition, Pearson Education Limited, Edinburgh Gate, Harlow, Essex CM20 2JE, England, 692 p.

Mckenzie, R.A., Burren, B.G., Noble, J.W. and Thomas, M.B., 2007. Cyanide poisoning in cattle from *Dysphania glomulifera* (red crumb weed): using the internet for rapid plant identification and diagnostic advice. Australian Veterinary Journal, 85, 505–509.

McLaughlin, S.B. and Kszos, L.A., 2005. Development of switch grass (*Panicum virgatum*) as a bioenergy feedstock in the United States. Biomass and Bioenergy, 28, 515–535.

McLaughlin S.B. and Walsh, M.E., 1998. Evaluating environmental consequences of producing herbaceous crops for bioenergy. Biomass and Bioenergy, 14, 317–324.

Meena, H.M., Sachdev, M.S., Manjaiah, K.M. and Dotaniya, M.L., 2014. Nitrification inhibition potential of *Brachiaria humidicola*. National Academy Science Letter, 37, 113–116.

Mekasha, A., Gerard, B., Tesfaye, K., Nigatu, L. and Duncan, A.J, 2014. Inter-connection between land use/land cover change and herders'/farmers' livestock feed resource management strategies: a case study from three Ethiopian eco-environments. Agriculture, Ecosystems and Environment, 188, 150–162.

Menardo, S., Airoldi, G., Cacciatore, V. and Balsari, P., 2015. Potential biogas and methane yield of maize stover fractions and evaluation of some possible stover harvest chains. Biosystems engineering, 129, 352–359.

Meng, Q., Kerley, M.S., Ludden, P.A. and Belyea, R.L., 1999. Fermentation substrate and dilution rate interact to affect microbial growth and efficiency. Journal of Animal Science, 77, 206–214.

Menke, K.H., Raab, L., Salewski, A., Steingass, A., Fritz, D. and Scheinder, W., 1979. The estimation of digestibility and metabolisable energy contents of ruminant feedstuffs from gas production when they incubated with rumen fluid in vitro. Journal of Agricultural Science (Cambridge), 92, 217–222.

Mertens, D.R., 1997. Creating a system for meeting the fibre requirements of dairy cows. Journal of Dairy Science, 80, 1463–1481.

Miles, J.W., Valle C.B do; Rao, I.M. and Euclides, V.P.B., 2004. Brachiaria grasses. In: Moser, L.E., Burson, L.E., Sollenberger, L.E. (Eds). Warm-season (C4) grasses. Agronomy, Monograph 45. ASA, CSSA, SSSA, Madison, WI, USA, pp, 745–783.

Miles, J.W. and do Valle, C.B., 1996. Manipulation of apomixis in *Brachiaria* breeding. In: Miles, J.W, Maass, B.L. and do Valle, C.B. (Eds). *Brachiaria*: Biology, Agronomy and Improvement. CIAT, Cali, Colombia, pp, 164–177.

MINAGRI (Ministry of Agriculture and Animal Resources of Rwanda), 2006. A proposal to distribute a cow to every poor family in Rwanda. Kigali, Rwanda, 26 p.

MINECOFIN (Ministry of Economy and Finance of Rwanda), 2007. Economic Development and Poverty Reduction Strategy document, Kigali-Rwanda.

Moate, P.J., Chalupa, W., Jenkins, T.C. and Boston, R.C., 2004. A model to describe ruminal metabolism and intestinal absorption of long chain fatty acids. Animal Feed Science and Technology, 112, 79–105.

Mohd Nor, N., Steeneveld, W., Mourits, M.C.M. and Hogeveen, H., 2015. The optimal number of heifer calves to be reared as dairy replacements. Journal of Dairy Science, 98, 861–871.

Montoro, C., Miller-Cushon, K., Devries, J. and Bach, A., 2013. Effect of physical form of forage on performance, feeding behaviour, and digestibility of Holstein calves. Journal of Dairy Science, 96, 1117–1124.

Morais, J.A.S., Queiroz, M.F.S., Keli, A., Vega, A., Fiorentini, G., Canesin, R.C., Reis, R.A. and Berchielli, T.T., 2014. Effect of supplementation frequency on intake, behavior and performance in beef steers grazing Marandú grass. Animal Feed Science and Technology, 189, 63–71.

Morais, J.A.S., Berchielli, T.T., de Vega, A., Queiroz, M.F.S., Keli, A., Reis, R.A., Bertipaglia, L.M.A. and Souza, S.F., 2011. The validity of n-alkanes to estimate intake and digestibility in Nellore beef cattle fed a tropical grass (*Brachiaria brizantha* cv. Marandu). Livestock Science, 135, 184–192.

Moran, J.B., 2011. Factors affecting high mortality rates of dairy replacement calves and heifers in the tropics and strategies for their reduction. Asian-Australia Journal of Animal Science, 24, 1318–1328.

Moran, J.B, 2005. Tropical dairy farming: feeding management for smallholder dairy farmers in the humid tropics. Landlikns Press, 312 p.

Moreira, C.N., Banys, V.L., Pinto, A.S., Franco, L.A.S., Haragushi, M. and Fioravanti, M.C.S., 2009. Bovine cattle fed *Brachiaria* and *Andropogon* grasses:

performance, evaluation of the amount of spores of the *Pithomyces chartarum* fungus and saponine amounts. Brazilian Animal Science, 10, 184–194.

Moreno, L.S.B., Pedreira, C.G.S., Boote, K.J. and Alves, R.R., 2014. Base temperature determination of tropical *Panicum* spp. grasses and its effects on degree-day-based models. Agricultural and Forest Meteorology, 186, 26–33.

Mouri, G. and Aisaki, N., 2015. Using land-use management policies to reduce the environmental impacts of livestock farming. Ecological Complexity, 22, 169–177.

Mpyisi, E., Weber, M., Shingiro, E. and Loveridge, S., 2003. Changes in allocation of land holdings, production and farm size in the Rwandan smallholder sector over the period 1984/1990 to 2002. Agricultural Policy Synthesis, 8 p.

Msangi, J.P., 2014. Role of small-stock in safeguarding food security in dry lands: Case in Namibia. In: Msangi, J.P. (Ed) Food security among small-scale agricultural producers in Southern Africa, pp, 105–127.

Msangi, S., Enahoro, D., Herrero, M., Magnan, N., Havlik, P., Notenbaert, A. and Nelgen, S., 2014. Integrating livestock feeds and production systems into agricultural multi-market models: The example of IMPACT. Food Policy, 49, 365–377.

Mulama, J., 2009. Livestock vital for rural livelihood. Agriculture-Africa. Nairobi March 17 (IPS*)*.

Muller, C.J.C. and Botha, J.A., 1993. Effect of summer climatic conditions on different heat tolerance indicators in primiparous Friesian and Jersey cows. South African Journal of Animal Science, 23, 98–103.

Munyemana, J.M.V., 2001. Evaluation of some agroforestry species for resistance to the termites on the grounds of Bugesera: Case of the Kayovu hill. Memoir, National University of Rwanda (NUR), Faculty of Agriculture, Butare, Rwanda.

Mupangwa, J.F., Niyireba R.T., Ebong C., Uwimana G. and Musoni, A., 2010. Effect of supplementing Napier grass with *Mucuna pruriens* on milk production and milk composition from the crossbred cows of Rwanda. In: Enhancing food and nutrition security and integrated pest management in developing countries. Proceedings of the 3rd International Scientific Research Conference. From 2nd to 4th November 2010. National University of Rwanda, Huye, Southern Province, Rwanda.

Mutimura, M., Ebong, C., Rao, I.M. and Nsahlai, I.V., 2015. Nutritional values of available ruminant feed resources in smallholder dairy farms in Rwanda. Tropical Animal Health and Production, 47, 1131–1137.

Mutimura, M., Dusengemungu, L., Musana, B., Gahakwa, D. and Ebong, C., 2014. Household characteristics and livelihood strategies in pilot sites for beef enterprise development in Eastern Province of Rwanda. Journal of Animal and Veterinary Advances, 13, 644–651.

Mutimura, M., Lussa, A.B., Mutabazi, J., Myambi, C.B., Cyamweshi, R.A. and Ebong, C., 2013a. Status of animal feed resources in Rwanda. Tropical Grasslands, 1, 109–110.

Mutimura, M., Myambi, C.B., Gahunga, P., Mgheni, D.M., Laswai, G.H., Mtenga, L.A., Gahakwa, D., Kimambo, A.E. and Ebong, C., 2013b. Rumen liquor from slaughtered cattle as a source of inoculum for *in vitro* gas production technique in forage evaluation. Agricultural Journal, 8, 173–180.

Mutimura, M. and Everson, T.M., 2012a. On-farm evaluation of improved *Brachiaria* grasses in low rainfall and aluminium toxicity prone areas of Rwanda. International Journal of Biodiversity and Conservation, 4, 137–154.

Mutimura, M. and Everson, T.M., 2012b. The role of gender in livestock rearing in the low rainfall and acidic soil prone areas of Rwanda. Agricultural Journal, 7, 152–159.

Mutimura, M. and Everson, T.M., 2011. Assessment of livestock feed resource-use patterns in low rainfall and aluminium toxicity prone areas of Rwanda. African Journal of Agricultural Research, 6, 3461–3469.

Naudin, K., Bruelle, G., Salgado, P., Penot, E., Scopel, E., Lubbers, M., de Ridder, N. and Giller, K.E., 2015. Trade-offs around the use of biomass for livestock feed and soil cover in dairy farms in the Alaotra lake region of Madagascar. Agricultural Systems, 134, 36–47.

Ndayambaje, J.D., Heijman, W.J.M. and Mohren, G.M. J., 2013. Farm woodlots in rural Rwanda: purposes and determinants. Agroforest System, 87, 797–814.

Ndikumana, J. and Leeuw, P.N., 1996. Regional experience with *Brachiaria*: Sub-Saharan Africa. In: Miles, J.W., Maass, B.L. and do Valle, C.B. (Eds). *Brachiaria*: Biology, Agronomy, and Improvement. CIAT, Cali, Colombia, pp, 247–257.

Neale, B.D., 2006. Effects of fertiliser application and cutting interval on nitrate accumulation in Bermuda grass. M.Sc. (Agri.), Thesis, University of Tennessee at Martin, 41 p.

Negesse, T., Makkar, H.P.S. and Becker, K., 2009. Nutritive value of some non-conventional feed resources of Ethiopia determined by chemical analyses and an in vitro gas method. Animal Feed Science and Technology, 154, 204–217.

Negrão, F.M., Zanine, A.M., Cabral, L.S., de Souza, A.L., Alves, G.R., Ferreira, D.J., Dantas, C.C.O. and Lehmkuhl, A., 2014. Fractionation of carbohydrates and protein and rumen degradation kinetic parameters of Brachiaria grass silage enriched with rice bran. Revista Brasileira de Zootecnia, 43, 105–113.

Neto, S.G., Oliveira, R.L., de Lima, F.H.S., de Medeiros, A.N., Bezerra, L.R., Viégas, J., do Nascimento Jr, N.G. and de Freitas Neto, M.D., 2015. Milk production, intake, digestion, blood parameters, and ingestive behavior of cows supplemented with by-products from the biodiesel industry. Tropical Animal Health and Production, 47, 191–200.

Ngim, M.S., Pha, K., Savouth, H., Young, J. and Bush, R., 2011. Introduced forage productivity and quality in the smallholder environment. In: Young, J., Rast, L., Sothoeun, S. and Windsor, P. (Eds), Cattle health, production and trade in Cambodia. Proceedings from three ACIAR-funded projects presented at an international workshop held in Phnom Penh, Cambodia, 7–8 June 2011, pp, 14–18.

NISR (National Institute of Statistics of Rwanda), 2014. Statistical yearbook, Kigali, Rwanda, 212 p.

NISR (National Institute of Statistics of Rwanda), 2013. Seasonal Agricultural Survey Report, Kigali, Rwanda, 105 p.

NISR (National Institute of Statistics of Rwanda), 2012a. Agricultural statistics, Survey report, Kigali, Rwanda.

NISR (National Institute of Statistics of Rwanda), 2012b. The third integrated household living conditions survey (EICV 3), Main indicators report, Kigali, Rwanda, 206 p.

Niu, M., Ying, Y., Bartell, P.A. and Harvatine, K.J., 2014. The effects of feeding time on milk production, total-tract digestibility, and daily rhythms of feeding behavior and plasma metabolites and hormones in dairy cows. Journal of Dairy Science, 97, 7764–7776.

Njarui, D.M.G, Gatheru, M., Wambua, J.M., Nguluu, S.N., Mwangi, D.M. and Keya, G.A., 2011: Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. Livestock Research for Rural Development. Volume 23, Article #111. Retrieved July 30, 2013.

Nogueira Filho, J.C.M., Fondevila, M., Barrios Urdaneta, A. and Gonzalez Ronquillo, M., 2000. *In vitro* microbial fermentation of tropical grasses at an advanced maturity stage. Animal Feed Science and Technology, 83, 145–157.

NRC (National Research Council), 2001. Nutrient requirements of dairy cattle. Seventh revised edition. National Academy Press, Washington, DC., 381 p.

Nsahlai, I.V. and Apalo, J., 2007. On the suitability of Illius and Gordon's model for simulating the intake and digestibility of roughage diets by ruminants. South African Journal of Animal Science, 37, 275–289.

Nsahlai, I.V., 1991. The effect of quantity and quality of dietary nitrogen on the utilization of roughage diets by steers. PhD Thesis, University of Reading, UK.

Nyaata, O.Z., Dorward, P.T., Keatinge, J.D.H. and O’neill, M.K., 2000. Availability and use of dry season feed resources on smallholder dairy farms in central Kenya. Agroforestry Systems, 50, 315–331.

Nyiransengimana, E., Uzayisenga, B., Nsabimana, J.D., Uwimana, G., Umunezero, O., Mutimura, M., Ebong, C. and Hitimana, C., 2013. Status of Napier grass stunt disease incidence in Rwanda. Proceedings of first biannual conference on agricultural research and extension: Confronting the challenges of food insecurity in the era of climate change and variability. Kigali, Serena Hotel, 21–23rd Aug, 2013. Book of Abstracts, pp, 80.

O’Neill, B.F., Lewis, E., O’Donovan, M., Shalloo, L., Mulligan, F.J., Boland, T.M. and Delagarde, R., 2013. Evaluation of the GrazeIn model of grass dry-matter intake and milk production prediction for dairy cows in temperate grass-based production systems.1–Sward characteristics and grazing management factors. Grass and Forage Science, 68, 504–523.

Oba, M. and Allen, M.S., 1999. Evaluation of the importance of the digestibility of neutral detergent fibre from forage: Effects on dry matter intake and milk yield of dairy cows. Journal of Dairy Science, 82, 589–596.

Olaloku, E.A. and Debre, S., 1992. Research priorities for the development of appropriate feeding systems for dairy production in sub-Saharan Africa. In: Stares, J.E.S., Said, A. N. and Kategile, J.A. (Eds). The complementarity of feed resources for animal production in Africa. Proceedings of the joint feed resources networks workshop held in Gaborone, Botswana 4–8 March 1991. African Feeds Research Network. ILCA (International Livestock Centre for Africa), Addis Ababa. Ethiopia, pp, 399–407.

Oliveira, L.N., Filho, S.L.S.C., Gerasev, C., Duarate, E.R. and Abdalla, A.L., 2014. Chemical composition, degradability and methane emission potential of banana crop residues for ruminants. Tropical and Subtropical Agro-ecosystems, 17, 197–206.

Or-Rashid, M.M., Odongo, N.E. and McBride, W.B., 2007. Fatty acid composition of ruminal bacteria and protozoa, with emphasis on conjugated linoleic acid, vaccenic acid, and odd-chain and branched-chain fatty acids. Journal of Animal Science, 85, 1228–1234.

Ortega-Gomez, R., Castillo- Gallegos, E., Jarillo-Rodríguez, J., Escobar-Hernández, R., Ocaña-Zavaleta, E. and Valles de la Mora, B., 2011. Nutritive quality of ten grasses during the rainy season in hot-humid climate and ultisol soil. Tropical and Subtropical Agro-ecosystems, 13, 481–491.

Ortez-Arriola, J., Groot, J.C.J., Massiotti, R.D.A., Scholberg, J.M.S., Aguayo, D.V.M., Tittonell, P. and Rossing, W.A.H., 2014. Resource use efficiency and farm productivity gaps of smallholder dairy farming in North-west Michoacán, Mexico. Agricultural Systems, 126, 15–24.

Osuji, P.O., Nsahlai, I.V. and Khalili, H., 1993. Feed Evaluation. ILCA Manual 5. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia.

Ouda, J.O. and Nsahlai, I.V., 2009. Relevance and potential use of in vitro gas production measurements to evaluate varying ratios of roughages and protein sources for ruminants. Journal of Applied Animal Research, 35, 9–16.

Paciullo, D.S.C., Castro, C.R.T., Gomide, C.A.M., Maurício, R.M., Pires, M.F.A., Müller, M.D. and Xavier, D.F., 2011. Performance of dairy heifers in a silvopastoral system. Livestock Science, 141, 166–172.

Pandey, G.S. and Voskuil, G.C.J., 2011. Manual on improved feeding of dairy cattle by smallholder farmers. Golden Valley Agricultural Research Trust, Lusaka, Zambia, 50 p.

Patton, M., 1990. Qualitative evaluation and research methods. Beverly Hills, CA: Sage, pp, 169-186.

Pedreira, B.C., Pedreira, C.G.S., Boote, K.J., Lara, M.A.S. and Alderman, P.D., 2011. Adapting the CROPGRO perennial forage model to predict growth of *Brachiaria brizantha*. Field Crops Research, 120, 370–379.

Pedro, A.J. and Keller-Grein, G., 1996. Regional experience with *Brachiaria*: Tropical America–Humid lowlands. In: Miles, J.W., Maass, B.L. and do Valle, C.B. (Eds). *Brachiaria*: Biology, Agronomy, and Improvement. CIAT, Cali, Colombia, pp, 205–224.

Pell, A.N. and Schofield, P., 1993. Computerized monitoring of gas production to measure forage digestion *in vitro*. Journal of Dairy Science, 76, 1063–1073.

Peters, M., Rao, I., Fisher, M., Subbarao, G., Martens, S., Herrero, M., van der Hoek, R., Schultze-Kraft, R., Miles, J., Castro, A., Graefe, S., Tiemann, T., Ayarza, M. and Hyman, G., 2012. Tropical forage-based systems to mitigate greenhouse gas emissions. In: Hershey, C. (Ed.). Issues in Tropical Agriculture I. Eco-Efficiency: From Vision to Reality. CIAT, Cali, Colombia.

Peters, M., Lascano, C.E., Roothaert, R. and de Haan, N.C., 2003. Linking research on forage germplasm to farmers: the pathway to increased adoption—a CIAT, ILRI and IITA perspective. Field Crops Research, 84, 179–188.

Peters, M., Horne, P., Schmidt, A., Holmann, F., Kerridge, P.C., Tarawali, S.A., Schultze-Kraft, R., Lascano, C.E., Argel, P., Stür, W., Fujisaka, S., Müller-Sämann, K. and Wortmann, C., 2001. The role of forages in reducing poverty and degradation of natural resources in tropical production systems. Agricultural Research and Extension Network Paper No. 117, 12 p.

Pickett J.A., Woodock, C.M., Midega, C.A.O. and Khan, Z.R., 2014. Push-pull farming system. Current Opinion in Biotechnology, 26, 124–132.

Pires, V.S., Taketa, A.T.C., Gosmann, G. and Schenkel, E.P., 2002. Saponins and Sapogenins from *Brachiaria decumbens* Stapf. Journal of the Brazilian Chemical Society, 13, 135–139.

Pitman, W.D., 2001. Environment constraints to tropical forage plant adaptation and productivity. In: Sontomayor, R.A and Pitman, W.D. (Eds). Tropical forage plants: development and use. Raton, London New York, Washington, D.C., pp, 17–23.

Pizarro, E.A., Hare, M.D., Mutimura, M. and Changjun, B., 2013. *Brachiaria* hybrids: potential, forage use and seed yield. Tropical Grasslands – Forrajes Tropicales, 1, 1–5.

Pizarro, E.A., do Valle, C.B., Keller-Grein, G., Schultze-Kraft, R. and Zimmer, A.H., 1996. Regional experience with *Brachiaria*: Tropical America–Savannah. In: Miles, J.W., Maass, B.L. and do Valle, C.B. (Eds). *Brachiaria*: Biology, Agronomy, and Improvement. CIAT, Cali, Colombia, pp, 225–246.

Popp, A., Blaum, N.A.N.D. and Jeltsch, F., 2009. Ecohydrological feedback mechanisms in arid rangelands: Simulating the impacts of topography and land use. Basic and Applied Ecology, 10, 319–329.

Poppi, D.P. and McLennant, S.R., 1995. Protein and energy utilization by ruminants at pasture. Journal of Animal Science, 73, 278–290.

Powell1, J.M. and Williams, T.O., 1995. An overview of mixed farming systems in sub-Saharan Africa. In: Powell, J.M., Fernández-Rivera, S., Williams, T.O. and Renard, C. (Eds). Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, Technical Papers. Proceedings of an International Conference held in Addis Ababa, Ethiopia, 22–26 November 1993. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. 568 p.

Pretty, J., Toulman, C. and Williams, S., 2011. Sustainable intensification of African Agriculture. International Journal of Agricultural Sustainability, 9, 5–24.

Qu, H., Liu, X.B., Dong, C.F., Lu, X.Y. and Shen, Y.X., 2014. Field performance and nutritive value of sweet sorghum in eastern China. Field Crops Research, 157, 84–88.

Quintino, A.C., Abreu, J.G., Almeida, R.G., Macedo, C.M., Silva Cabral, L. and Galati, R.L., 2013. Production and nutritive value of Piatã grass and hybrid sorghum at different cutting ages. Acta Scientiarum. Animal Sciences, 35, 243–249.

Rabelo, E., Rezende, R.L., Bertics, S.J. and Grummer, R.R., 2003. Effects of transition diets varying in dietary energy density on lactation performance and ruminal parameters of dairy cows. Journal of Dairy Science, 86, 916–925.

Rahetlah, V.B., Randrianaivoarivony, J.M., Andrianarisoa, B., Razafimpamoa, L.H. and Ramalanjaona, V.L., 2012. Yield and quality of *Brachiaria hybrid* cv. Mulato-forage perennial peanut (*Arachis pintoi*) mixture in the Highlands of Madagascar. Livestock Research for Rural Development. Volume 24, Article #171. http://www.lrrd.org/lrrd24/10/rahe24171.htm, Retrieved August 4, 2013.

Rahman, M.M., Rahman, M.R., Nakagawa, T., Abdullah, R.B., Wan Khadijah, W.E. and Akashi, R., 2015. Effects of wet soya waste supplementation on the intake, growth and reproduction of goats fed Napier grass. Animal Feed Science and Technology, 199, 104–112.

Rahman, M.M., Abdullah, R.B., Embong, W.K.W., Nakagawa, T. and Akashi, R., 2013. Effect of palm kernel cake as protein source in a concentrate diet on intake, digestibility and live weight gain of goats fed Napier grass. Tropical Animal Health and Production, 45, 873–878.

Rahman, M.M. and Kawamura, O., 2011. Oxalate accumulation in forage plants: some agronomic, climatic and genetic aspects. Australian Journal of Animal Science, 24, 439–448.

Rahman, M.M., Ishii, Y., Niimi, M. and Kawamura, O., 2010. Interactive effects of nitrogen and potassium fertilisation on oxalate content in Napier grass (*Pennisetum purpureum*). Asian Australian Journal of Animal Science, 23, 719–723.

Rahman, M.M., Niimi, M., Ishii, Y. and Kawamura, O., 2006. Effects of season, variety and botanical fractions on oxalate content of Napier grass (*Pennisetum purpureum* Schumach). Grassland Science, 52, 16–166.

Rao, I., Peters, M., Castro, A., Schultze-Kraft, R., White, D., Fisher, M., Miles, J., Lascano, C., Blümmel, M., Bungenstab, D., Tapasco, J., Hyman, G., Bolliger, A., Paul, B., Van Der Hoek, R., Maass, B., Tiemann, T., Cuchillo, M., Douxchamps, S., Villanueva, C.,. Rincón, Á., Ayarza, M., Rosenstock, T., Subbarao, G., Arango, J., Cardoso, J., Worthington, M., Chirinda, N., Notenbaert, A., Jenet, A., Schmidt, A., Vivas, N., Lefroy, R., Fahrney, K., Guimarães, E., Tohme, J., Cook, S., Herrero, M., Chacón, M., Searchinger, T. and Rudel, T., 2015. LivestockPlus – The sustainable intensification of forage-based agricultural systems to improve livelihoods and ecosystem services in the tropics. Tropical Grasslands – Forrajes Tropicales, 3, 59–82.

Rao, I.M., Miles, J.W. and Granobles, J.C., 1998. Differences in tolerance to infertile acid soil stress among germplasm accessions and genetic recombinants of the tropical forage grass genus, *Brachiaria*. Field Crops Research, 59, 43–52.

Rao, I.M., Kerridge, P.C. and Macedo, M.C.M., 1996. Nutritional requirements of *Brachiaria* and adaptation to acidic soils. In: Miles, J.W., Maass, B.L. and do Valle, C.B. (Eds). *Brachiaria*: Biology, Agronomy, and Improvement. CIAT, Cali, Colombia, pp, 53–71.

RARDA (Rwanda Animal Resources Development Authority), 2006. Annual report, Kigali, Rwanda.

Rasby, R.J., Berger, A.L., Bauer, D.E. and Brink, D.R., 2011. Minerals and vitamins for beef cows. Know how, Extension materials, University of Nebraska, 7 p.

Reiber, C., Peters, M., Hoffmann, V. and Schultze-Kraft, R., 2012: Adoption and feeding of grass and legume hay in Honduras. Livestock Research for Rural Development. Volume 24, Article #192. Retrieved July 25, 2013.

Rhoads, M.L., Rhoads, R.P., VanBaale, M.J., Collier, R.J., Sanders, S.R., Weber, W.J., Crooker, B.A. and Baumgard, L.H., 2009. Effects of heat stress and plane of nutrition on lactating Holstein cows: Production, metabolism, and aspects of circulating somatotropin. Journal of Dairy Science, 92, 1986–1997.

Riaz, M.Q., Südekum, K.H., Clauss, M. and Jayanegara, A., 2014. Voluntary feed intake and digestibility of four domestic ruminant species as influenced by dietary constituents: A meta-analysis. Livestock Science, 162, 76–85.

Rim, J.S., Lee, S.R., Cho, Y.S., Kim, E.J., Kim, J.S. and Jong, K.H., 2008. Prediction of dry matter intake in lactating Holstein dairy cows offered high levels of concentrate. Asian-Australian Journal of Animal Science, 21, 677–684.

Robbins, C.R., 1993. Wildlife feeding and nutrition. Academic Press, California, 352 p.

Roothaert, R., Horne, P.M. and Stür, W.W., 2003. Integrating forage technologies on smallholder farms in the upland tropics. Tropical Grasslands, 37, 295–303.

Roothaert, R.L. and Paterson, R.T., 1997. Recent work on the production and utilization of tree fodder in East Africa. Animal Feed Science Technology, 69, 39–51.

Rudel, T.K., Paul, B., White, D., Rao, I.M., Van Der Hoek, R., Castro, A., Boval, M., Lerner, A., Schneider, L. and Peters, M., 2015. LivestockPlus: Forages, sustainable intensification, and food security in the tropics. AMBIO, 44, 685–693.

Rutamu, I., 2009. Investment opportunities in the dairy sub-sector of Rwanda. Final Report, SNV-IFAD, Kigali, Rwanda, 50 p.

Ryschawy, J., Choisis, N., Choisis, J.P., Joannon, A. and Gibon, A., 2012. Mixed crop-livestock systems: An economic and environmental-friendly way of farming? Animal, 6, 1722–1730.

Sahoo, A., Ogra, R.K., Sood, A. and Ahuja, P.S., 2010. Nutritional evaluation of bamboo cultivars in sub-Himalayan region of India by chemical composition and in vitro ruminal fermentation. Grassland Science, 56, 116–125.

Salama, A.A.K., Caja, G., Hamzaoui, S., Badaoui, B., Castro-Costa, A., Facanha, D.A.E., Guilhermino, M.M. and Bozzi, R., 2014. Different levels of response to heat stress in dairy goats. Small Ruminant Research, 121, 73–79.

Saleh, S., Lashkari, S., Abbasi, R.E. and Kamangar, H., 2014. Nutrient digestibility and chemical composition of potato (*Solanum tuberosum*) vince as alternative forage for ruminant diets. Agricultural Communications, 2, 63–66.

Salgado, P., Lecomte, P., Richard, D., Thang, V.Q., Trach, N.X., Thu, T.V. and Cuong, V.C., 2013. Oats (*Avena strigosa*) as winter forage for dairy cows in Vietnam: an on-farm study. Tropical Animal Health and Production, 45, 561–568.

Sampaio, C.B., Detmann, E., Paulino, M.F., Valadares Filho, S.C., de Souza, M.A., Lazzarini, I., Rodrigues Paulino, P.V. and de Queiroz, A.C., 2010. Intake and digestibility in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. Tropical Animal Health and Production, 42, 1471–1479.

Sanderson, M.A., Reed, R.L., McLaughlin, S.B., Wullschleger, S.D., Congcr, B.V., Parrish, D.J., Wolf, D.D., Taliaferro, C., Hopkins, A.A., Ocumpaugh, W.R., Hussey, M.A., Read, J.C. and Tischler, C.R., 1996. Switch grass as a sustainable bioenergy crop. Bioresource Technology, 56, 83–93.

Sanginga, N., Dashiella, K.E., Diels, J., Vanlauwe, B., Lyasse, O., Carskya, R.J., Tarawali, S., Asafo-Adjei, B., Menkir, A., Schulz, S., Singh, B.B., Chikoye, D., Keatinge, D. and Ortiza, R., 2003. Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savannah. Agriculture, Ecosystems and Environment, 100, 305–314.

Santos, E.M., Pereira, O.G., Garcia, R., Ferreira, C.L.L.F., Oliveira, J.S. and Silva, T.C., 2014. Effect of regrowth interval and a microbial inoculant on the fermentation profile and dry matter recovery of guinea grass silages. Jour of Dairy Science, 97, 4423–4432.

SAPPLPP (South Asia Pro-Poor Livestock Policy Programme), 2011. Dependence of livestock rearers on common lands: A scoping study, 42 p.

Särkijärvi, S., Sormunen-Cristian, R., Heikkilä, T., Rinne, M. and Saastamoinen, M., 2012. Effect of grass species and cutting time on in vivo digestibility of silage by horses and sheep. Livestock Science, 144, 230–239.

SAS, 2010. Statistics, Version 9.3. SAS Institute, Inc., Cary, NC, USA.

Schiere, J.B., Ibrahim, M.N.M. and van Keulen, H., 2002. The role of livestock for sustainability in mixed farming: criteria and scenario studies under varying resource allocation. Agriculture, Ecosystems and Environment, 90, 139–153.

Schlenker, W. and Lobell, D.B., 2010. Robust negative impacts of climate change on African agriculture. Environmental Research Letter, 5, 1–8.

Schofield, P., Pitt, R.E. and Pell, A.N., 1994. Kinetics of fibre digestion from in vitro gas production. Journal of Animal Science, 72, 2980–2991.

Schwarm, A., Ortmann, S., Wolf, C., Jürgen Streich, W. and Clauss, M., 2008. Excretion patterns of fluid and different sized particle passage markers in banteng (*Bos javanicus*) and pygmy hippopotamus (*Hexaprotodon liberiensis*): Two functionally different foregut fermenters. Comparative Biochemistry and Physiology, Part A, 150, 32–39.

Seré, C., Steinfeld, H. and Groenewold, J., 1995. World livestock systems: Current status, issues and trends. In: Gardiner, P. and Devendra, C. (Eds). Global Agenda for Livestock Research. Proceedings of a Consultation, 18th–20th January 1995, International Livestock Research Institute (ILRI), Nairobi, Kenya, pp, 11–38.

Serrao, E.A.S. and Simao, N.M., 1975. The adaptation of tropical forages in the Amazon region. Tropical forages in livestock production systems. American Society of Agronomy, Crop science and Soil science. Nevada, USA, 104 p.

Sharka, J.J., Kahaka, Z. and Okuru, F.N., 2013. Farmers' perceptions and adaptations to climate change in sub-Sahara Africa: A synthesis of empirical studies and implications for public policy in African agriculture. Journal of Agricultural Science, 5, 121–135.

Shaver, R.D. and Howard, T.W., 1988. Feeding dairy cows for efficient reproductive performance. North Central Regional, Extension Publication. N0 366, 6 p.

Shem, M.N., Ørskov, E.R. and Kimambo, A.E., 1995. Prediction of voluntary dry-matter intake, digestible dry-matter intake and growth rate of cattle from the degradation characteristics of tropical foods. Animal Science, 60, 65–74.

Shukla, A., Vats, S. and Shukla, R.K., 2014. Proximate composition, nutritive value and evaluation of antioxidant potential of stem of *Dracaena reflexa* Lam. International Journal of Pharmacy and Pharmaceutical Sciences, 6, 360–364.

Sinclair, K. and Garnsworthy, C.P., 2010. Fatty acids and fertility in dairy cows. In: Garnsworthy, C.P. and Wiseman, J. (Eds). Recent advances in animal nutrition 2009. Nottingham, University Press, pp, 1–19.

Singh, B.B., Ajeigbe, H.A., Tarawali, S.A., Fernandez-Rivera, S. and Abubakar, M., 2003. Improving the production and utilization of cowpea as food and fodder. Field Crops Research, 84, 169–177.

Singh, B.C., Larbi, A., Tabo, R. and Dixon, G.O., 2004. Trends in development of crop varieties for improved crop-livestock systems in West Africa. In: Williams, T.O., Tarawali, S.A., Hiernaux, P. and Fernandez-Rivera, S. (Eds). Sustainable crop-livestock production for improved livelihoods and natural resource management in West Africa. Proceedings of an international conference held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 19–22nd November, 2001.

Singh, S., Kushwaha, B.P., Maity, S.B., Singh, K.K. and Das, N., 2015. Effect of dietary protein on intake, nutrients utilization, nitrogen balance, blood metabolites, growth and puberty in growing Bhadawari buffalo (*Bubalus bubalis*) heifers. Tropical Animal Health and Production, 47, 213–220.

Singh, S., Anele, U.Y., Edmunds, B. and Südekum, K. H., 2014. *In vitro* ruminal dry matter degradability, microbial efficiency, short chain fatty acids, carbohydrate and protein fractionation of tropical grass-multipurpose tree species diets. Livestock Science, 160, 45–51.

Singh, S., Kushwaha, B.P., Nag, S.K., Mishra, A.K., Singh, A. and Anele, U.Y., 2012. *In vitro* ruminal fermentation, protein and carbohydrate fractionation, methane production and prediction of twelve commonly used Indian green forages. Animal Feed Science and Technology, 178, 2–11.

Sinha, D., Neog, B.N., Sarmah, S., Prakash, B., Rajkhowa, C. and Baruah, K.K., 2011. Intake, digestibility and nitrogen balance in Mithun (*Bos frontalis*) offered urea-treated paddy straw based feed blocks. Tropical Animal Health and Production, 43, 383–387.

Smith, T., 2002. On-farm treatment of straws and stovers with urea. In: Development and field evaluation of animal feed supplementation packages. Proceedings of the final review meeting of an IAEA Technical Co-operation Regional AFRA Project organized by the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture and held in Cairo, Egypt, 25–29 November 2000, pp, 15–22.

Smitha, P.P.A., Alagundagi, S.C. and Salakinkop, S.R., 2013. The anti-nutritional factors in forages–A review. Current Biotica, 6, 516–526.

Soussana, J.F. and Lemaire, G., 2014. Coupling carbon and nitrogen cycles for environmentally sustainable intensification of grasslands and crop-livestock systems. Agriculture, Ecosystems and Environment, 190, 9–17.

Stainback, G.A., Masozera, M., Mukuralinda, A. and Dwivedi, P., 2012. Smallholder Agroforestry in Rwanda: A SWOT-AHP Analysis. Small-scale Forestry, 11, 285–300.

Stangel, P.J., 1995. Nutrient cycling and its importance in sustaining crop–livestock systems in sub-Saharan Africa: An overview. In: Powell, J.M., Fernández-Rivera, S., Williams, T. O. and Renard, C. (Eds). Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, Technical Papers. Proceedings of an International Conference held in Addis Ababa, Ethiopia, 22–26 November 1993. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia, 568 p.

Stangel, P.J., 1993. Nutrient cycling and its importance in sustaining crop-livestock systems in sub-Saharan Africa: An overview. In Powell, J.M., Fermandez-Rivera, S., Williams, T. O. and Renard, C. (Eds). Nutrient cycling in mixed farming systems of sub-Saharan Africa. Proceedings of International Livestock Centre for Africa (ILCA), Technical papers, Addis Ababa, Ethiopia, pp, 37–59.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. and de Haan, C., 2006. Livestock's long shadow: environmental issues and options. Food and Agriculture Organisation of the United Nations, Rome, 390 p.

Stür, W.W., Horne, P.M., Gabunada, F.A.Jr., Phengsavanh, P. and Kerridge, P.C., 2002. Forage options for smallholder crop–animal systems in Southeast Asia: working with farmers. Agricultural Systems, 71, 75–98.

Stür, W.W., Hopkinson, J.M. and Chen, C.P., 1996. Regional experience with *Brachiaria*: Asia, the south Pacific, and Australia. In: Miles, J.W., Maass, B.L. and do Valle, C.B. (Eds). *Brachiaria*: Biology, Agronomy, and Improvement. CIAT, Cali, Colombia, pp, 258–271.

Subbarao, G.V., Nakahara, K., Hurtado, M.P., Ono, H., Moreta, D.E., Salcedo, A.F., Yoshihashi, A.T., Ishikawa, T., Ishitani, M., Ohnishi-Kameyama, M., Yoshida, M., Rondon, M., Rao, I.M., Lascano, C.E., Berry, W.L. and Ito, O., 2009.

Evidence for biological nitrification inhibition in *Brachiaria* pastures. PNAS, 106, 17302–17307.

Swanson, K. and Miller, S., 2008. Factors regulating feed efficiency and nutrient utilisation in beef cattle. In: France, J. and Kebreab, E. (Eds). Mathematical modelling in Animal Nutrition, pp, 419–441.

Tanaka, D.L., Karn, J.F. and Scholljegerdes, E.J., 2008. Integrated crop-livestock systems research: Practical research considerations. Renewable Agriculture and Food Systems, 23, 80–86.

Tavirimirwa, B., Manzungu, E. and Ncube, S., 2012. The evaluation of dry season nutritive value of dominant and improved grasses in fallows in Chivi district, Zimbabwe. Journal of Animal and Feed Research, 2, 470–474.

Taweel, H.Z., Tas, B.M., Tamminga, S. and Dijkstra, J., 2006. The role of rumen fill in terminating grazing bouts of dairy cows under continuous stocking. In: Kebreab, E., Dijkstra, J., Bannink, A., Gerrits, W. J.J. and France, J. (Eds). Nutrients digestion and utilisation in farm animals: Modelling approaches, pp, 48–53.

Thomas, D., Zerbini, E., Parthasarathy, R.P. and Vaidyanathan, A., 2002. Increasing animal productivity on small mixed farms in South Asia: A systems perspective. Agricultural Systems, 71, 41–57.

Thomas, D. and Sumberg, J.E., 1995. A review of the evaluation and use of tropical forage legumes in sub-Saharan Africa. Agriculture, Ecosystems and Environment, 54, 151–163.

Thornton, P.K. and Herrero, M., 2014. Climate change adaptation in mixed crop–livestock systems in developing countries. Global Food Security, 3, 99–107.

Thornton, P.K., 2010. Livestock production: Recent trends, future prospects. Philosophical Transactions of Royal Society B: Biological Sciences, 365, 2853–2867.

Thornton, P.K., Herrero, M., Freeman, A. and Okeyo, M., 2007. Vulnerability, climate change and livestock research opportunities and challenges for poverty alleviation. ICRISAT, 4, 1–23.

Tibayungwa, F., 2010. Simulation of modelling of cattle forage systems in smallholder dairy. PhD Thesis, Makerere University, 102 p.

Tikam, K., Phatsara, C., Sorachakula, C., Vearasilp, T., Samiprem, S., Cherdthong, A., Gerlach, K. and Südekuma, K.-H., 2015. In vitro gas production, in vivo nutrient digestibilities, and metabolisable energy concentrations for sheep of fresh and conserved pangola grass. Small Ruminant Research, 128, 34–40.

Titgemeyer, E.C., 1997. Design and interpretation of nutrient digestion studies. Journal of Animal Science, 75, 2235–2247.

Turmel, M.S., Speratti, A., Baudron, F., Verhulst, N. and Govaerts, B., 2015. Crop residue management and soil health: A systems analysis. Agricultural Systems, 134, 6–16.

Uden, P., Rounsaville, T.R., Wiggans, G.R. and Van Soest, P.J., 1982. The measurement of liquid and solid digesta retention in ruminants, equines and rabbits given timothy (*Phleum pratense*) hay. British Journal of Nutrition, 48, 329–339.

Uden, P., Colucci, P.E. and Van Soest, P.J., 1980. Investigation of chromium, cerium and cobalt as markers in digesta. Rate of passage studies. Journal of the Science of Food and Agriculture, 31, 625–632.

Ul-Allaha, S., Khan, A., Fricke, T., Buerkert, A. and Wachendorf, M., 2014. Fertiliser and irrigation effects on forage protein and energy production under semi-arid conditions of Pakistan. Field Crops Research, 159, 62–69.

Upton, M., 2004. The role of livestock in economic development and poverty reduction. PPLPI Working paper N0 10. 66 p.

Vagen,T.G., Lal, R. and Singh, B.R., 2005. Soil carbon sequestration in sub-Saharan Africa: A review. Land Degradation and Development, 16, 53–71.

Valbuena, D., Erenstein, O., Homann-KeeTui, S., Abdoulaye, T., Claessens, L., Duncan, A.J., Gérard, B., Rufino, M.C., Teufel, N., van Rooyen, A. and van Wijk, M.T., 2012. Conservation Agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. Field Crops Research, 132, 175–184.

Valencia-Gica, R.B., Yost, R.S. and Porter, G., 2011. Biomass production and nutrient removal by tropical grasses subsurface drip-irrigated with dairy effluent. Grass and forage Science, 67, 337–349.

Van Soest, P.J., Robertson, J.B. and Lewis, B.A., 1991. Methods for dietary fibre, neutral detergent fibre and non-starch carbohydrates in relation to animal nutrition. Journal of Dairy Science, 74, 3583–3597.

Van Weyenberg, S., Sales, J. and Janssens, G.P.J., 2006. Passage rate of digesta through the equine gastrointestinal tract: A review. Livestock Science, 99, 3–12.

Vanlauwe, B. and Giller, K.E., 2006. Popular myths around soil fertility management in sub-Saharan Africa. Agriculture, Ecosystems and Environment, 116, 34–46.

Vendramini, J.M.B., Sollenberger, L.E., Soares, A.B., Da Silva, W.L., Sanchez, J.M.D., Valente, A. L., Aguiar, A. D. and Mullenix, M. K., 2014. Harvest frequency affects herbage accumulation and nutritive value of *Brachiaria* grass hybrids in Florida. Tropical Grasslands – Forrajes Tropicales, 2, 197−206.

Vendramini, J.M.B., Sollenberger, L.E., Lamb, G.C., Foster, J.L., Liu, K. and Maddox, M.K., 2012. Forage accumulation, nutritive value, and persistence of ‘Mulato II’ *Brachiaria* grass in northern Florida. Crop Science, 52, 914–922.

Vlek, P.L.G., Kuhne, R.F. and Denich, M., 1997. Nutrient resources for crop production in the tropics. Philosophical Transactions of the Royal Society Biological Sciences, 352, 975–985.

Vogel, K.P. and Lamb, J.A.F.S., 2007. Forage breeding. In: Barnes, R.F., Jerry, C.N., Moore, K.J. and Collins, M. (Eds). Forages: The science of grassland agriculture. Volume II, 6th edition, Blackwell publishing, Iowa State Press, USA, pp, 427–438.

Waldman, K.B., Kerr, J.M. and Isaacs, K.B., 2014. Combining participatory crop trials and experimental auctions to estimate farmer preferences for improved common bean in Rwanda. Food Policy, 46, 183–192.

Wanapat, M., 2009. Potential uses of local feed resources for ruminants. Tropical Animal Health and Production, 41, 1035–1049.

Wang, C., Liu, J.X., Makkar, H.P.S., Wei, N-b. and Xu, Q-m., 2014. Production level, feed conversion efficiency, and nitrogen use efficiency of dairy production systems in China. Tropical Animal Health and Production, 46, 669–673.

Waramit, N., Moore, K.J. and Fales, S.L., 2012. Forage quality of native warm-season grasses in response to nitrogen fertilisation and harvest date. Animal Feed Science and Technology, 174, 46–59.

Warner, D., Dijkstra, J., Hendriks, W.H. and Pellikaan, W.F., 2013. Passage kinetics of ^{13}C-labeled corn silage components through the gastrointestinal tract of dairy cows. Journal of Dairy Science, 96, 5844–5858.

West, J.W., Mullinex, B.G. and Bernard, J.K., 2003. Effects of hot, humid weather on milk temperature, dry matter intake, and milk yield of lactating dairy cows. Journal of Dairy Science, 86, 232–242.

Westwood, C.T., 2008. Pastures for animal production: Understanding the challenges. In: Boschma, S.P., Serafin, L.M., Ayres, J.F. (Eds). Proceedings of the 23rd Annual Conference of the Grassland Society of NSW (Grassland Society of NSW Inc: Orange), pp, 43–49.

Whittier, J.C., 2011. Prussic acid poisoning. Livestock Series/Health. Colorado State University, Extension, Fact Sheet No. 1.612.

Wilkins, R.J., 2008. Eco-efficient approaches to land management: A case for increased integration of crop and animal production systems. Philosophical Transactions of the Royal Society B: Biological Sciences, 363, 517–525.

Williams, S.R.O., Clarke, T., Hannah, M.C., Marett, L.C., Moate, P.J., Auldist, M.J. and Wales, W.J., 2013. Energy partitioning in herbage-fed dairy cows offered supplementary grain during an extended lactation. Journal of Dairy Science, 96, 484–494.

Williams, T.O., Fernandez, R.S. and Kelley, T.G., 1997. The influence of socio-economic factors on the availability and utilization of crop residues as animal feeds. In: Crop Residues in Sustainable Mixed Crop/Livestock Farming Systems. CAB International in association with the ICRISAT and ILRI, Oxon.

Wilson, J.R., Ludlow, M.M., Fisher, M.J. and Schulze, E., 1980. Adaptation to water stress of the leaf water relations of four tropical forage species. Australian Journal of Plant Physiology, 7, 207–220.

Wilson, J.R. and Haydock, K.P., 1971. The comparative response of tropical and temperate grasses to varying levels of nitrogen and phosphorus nutrition. Australian Journal of Agricultural Research, 22, 573–587.

Winter, B. (Ed.), 2011. Beef production in crop–livestock systems: simple approaches for complex problems. ACIAR Monograph No. 145. Australian Centre for International Agricultural Research: Canberra, 160 p.

World Bank, 2011. Annual report. Year in review, 43 p. http://issuu.com/world.bank.publications/docs.

World Bank, 2010. The importance of livestock. www.Worldbank.org /htm/cigar/newsletter/.

Woyessa, F., Tolera, A. and Diba, D., 2013. Feed intake, digestibility and growth performance of Horro lambs fed natural pasture hay supplemented with graded levels of *Vernonia amygdalina* leaves and sorghum grain. Science, Technology and Arts Research Journal, 2, 30–37.

Wright, L. and Turhollow, A., 2010. Switchgrass selection as a ‘‘model’’ bioenergy crop: A history of the process. Biomass and Bioenergy, 34, 851–868.

Wu, N., Ismail, M., Joshi, S., Shao-liang, Y.I., Shrestha, R.M. and Jasra, A.W., 2014. Livelihood diversification as an adaptation approach to change in the pastoral Hindu-Kush Himalayan region. Journal of Mountain Science, 11, 1342–1355.

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

Yahaghi, M., Liang J.B., Balcells, J., Valizadeh, R., Jahromi, M.F., Alimon, R. and Hof, Y.W., 2014. Extrusion of sorghum starch enhances ruminal and intestinal digestibility, rumen microbial yield and growth in lambs fed on high-concentrate diets. Animal Feed Science and Technology, 189, 30–40.

Zebeli, Q., Aschenbach, J.R., Tafaj, M., Boguhn, J., Ametaj, B.N. and Drochner, W., 2012. Role of physically effective fibre and estimation of dietary fibre adequacy in high-producing dairy cattle. Journal of Dairy Science, 95, 1041−1056.

Zemmelink, G. and t’Mannetje, L., 2002. Value for animal production (VAP): a new criterion for tropical forage evaluation. Animal Feed Science and Technology, 96, 31–42.

Zetina-Córdoba, P., Ortega-Cerrilla, M.E., Ortega-Jiménez, E., Herrera-Haro, J.G., Sánchez-Torres-Esqueda, M.T., Reta-Mendiola, J.L., Vilaboa-Arroniz, J. and

Munguía-Ameca, G., 2013. Effect of cutting interval of Taiwan grass (*Pennisetum purpureum*) and partial substitution with duckweed (*Lemna* sp. and *Spirodela* sp.) on intake, digestibility and ruminal fermentation of pelibuey lambs. Livestock Science, 157, 471–477.

Zindove, J.T. and Chimonyo, M., 2015. Comparison of trait preferences of Nguni farmers located in semi-arid and sub-humid environments. Tropical Animal Health and Production, 47, 607–611.

Zom, R.L.G., André, G. and van Vuuren, A.M., 2012. Development of a model for the prediction of feed intake by dairy cows: 1. Prediction of feed intake. Livestock Science, 143, 43–53.

Appendix

Appendix: Survey questionnaire

Introduction

A survey on crop-livestock integration was conducted to identify the type of livestock and feed resources production in smallholder farmers. The survey aimed at understanding the socio-economic conditions and the current land use system in semi-arid and humid areas of Rwanda.

Before the enumerator starts the survey, he/she should explain to the respondent (farmers) the importance of the survey and the information you are seeking

Enumerator's name ___________________ Date of interview ….../……./………… (dd/mm/yy)

Start time _____________ End time _____________ Time taken _____________

A. Site

Farm Number_________

Province: ___________________ District _________________ Sector _____________

Cell ____________ Village ______________

Name and approximate distance to nearest trading/urban centre (km) Name______________ km ____

GPS Reading: Latitude-(S)--------------------------Longitude (E)--------- ------- Altitude ______ m.a.s.l

Agro – ecological Zone (AEZ) _______________

B. General Information

B/1. Name of respondent(s): _____________________________ B/2. Age (yrs) _____

B/3. Respondent(s) position in household _____ [1=Husband 2=Wife 3=Farm manager/worker 4=Son 5=Daughter]

B/4. Details of household head

(i) Name ____________________________ (ii*)* Sex ____ [1= Male 2 = Female]

(iii) Age (yrs*)* _______

(iv*)* Formal education ______ [0=none 1=Primary 2=Secondary 3=Post-secondary 4=Adult education 5=Others(Specify)]__________________________

(v) Years of farming experience (crops) ________ and (livestock) _______

(vi) Major activity of household head ______________1=farming 2=Self-employed 3=Formal employment 4=Casual labour 4=Others (specify)] ________

(vii) Minor off-farm activities ______________ [1=Farming 2=Self-employed 3=Formal employment 4=Casual labour 5=Others (specify)] __________________________

(viii) Address/Tel. No. ……………………………………………………………………………

B/5. List number of all household members* other than household head resident on the farm

Age categories (years)	Males	Females	Total
≤10			
10-18			
21-30			
31-55			
>55			
Total			

*A person is resident if they sleep in the house a majority of night per month and contribute and or consumes outputs

B/6. Main activity of adults (≥18 years) living permanently on the farm other than household head.

Occupation		Number	
		Male	Female
1	None		
2	Farming		
3	Employed (Public/private)		
4	Self Employed		
5	Other (Specify)		

C. General farm characteristics and farm activities

C/1. Type of land ownership _____ [1= Traditional/communal; 2= Freehold (with or without title deed); 3=Leased; 4=Hire; 5= Other (specify)]

C/2 Describe the land utilization below

Land allocation	Land Parcel 1	Land Parcel 2	Land Parcel 3	Land parcel 4
Size (acres) of the land				
Year the land was acquired				
Area of homestead (acres)				
How many acres are under crop production?				
How many acres are under natural pastures/bushes?				
How many acres are for cultivated fodders and pastures				

D. Livestock inventory

D/1. List the type and number of livestock kept on the farm except cattle.

	Goats		Sheep	Donkey	Bees hives	Poultry			Rabbit	Other livestock*
	Local	Dairy				Local	Layer	Broiler		
Owned by household										
Males										
Females										
Kept but not owned										
Males										
Females										
Total										

*Other livestock; Ducks, Turkeys, Geese

D/2. List the number of cattle kept on the farm.

	GENOTYPE		
	Local (zebu)	Cross (Specify)	High grade*
Owned by household			
Mature bulls			
Bull calves			
Cows			
Heifers			
Weaners (females)			
Female calves (suckling)			
Kept but not owned			
Mature bulls			
Bull calves			
Cows			
Heifers			
Weaners (females)			
Female calves			
Total			

*High grade=tending to pure. [1= Friesian 2=Aryshire 3=Guernsey 4=Jersey 5=Others (Specify)]

D/3. What is the main system of keeping various types of ruminant livestock?

Ruminant type	**System***
Local zebu	
Grade cattle	
Local goat	
Dairy goat	
Sheep	

*[1 =Only grazing 2=Only zero grazing (stall feeding) 3=Combination of grazing and stall feeding]

D/4. What is the main system of keeping various types of ruminant livestock and milk production and consumption?

Ruminant type	**System**[*]	**No being milked**	**Total milk from animal milked (L/day)**	**Household consumption (L/day)**	**Amount of milk sold (L/day)**	**Price (RWF/ L)**
Ankole						
Ankole x Friesian						
Ankole x Jersey						
Pure Jersey						
Pure Friesian						

[†] [1 = Only grazing; 2= Only zero grazing (Stall feeding); 3= Combination of grazing and stall feeding]

D/5 Indicate who is primarily responsible for carrying out the following tasks

Activities related to livestock production	**Responsibility***
1. Cleaning shed	
2. Milking	
3. Herding/grazing/feeding	
4. Spraying/dipping of cattle	
5. Fetching water for cattle	
6. Selling/transporting milk and other dairy product	
7. Selling of live animal	
8. Pay for feed supplement for cattle	

*1=Husband 2=Wife 3=Children 4=Long-term labourer 5=Casual labourer

E. Fodder/pasture production and management

E/1. Do you have planted forages/fodder on your farm currently? [**_____**] 1=Yes 2=N0
E/2. If **No** go to section **F.**

E/3. If yes, what are the forage/fodder species you have grown on your farm, niches grown, acreage and production levels.

Forages/fodder types	Niches cultivated *	Area cultivated (acres/tree numbers)	Month and Year established	Production level**	Sources of seeds (1=Neighbours, 2=Agro-vet 3= Own seed)
Pasture grasses†					
1.					
2.					
3.					
Herbaceous legumes+					
1.					
2.					
3.					
Fodder grasses#					
1.					
2.					
3.					
Fodder trees±					
1.					
2.					
3.					

*Niches cultivated [1= Along terrace bank; 2= Farm land; 3=Farm boundary; 4= Bushland]
**Production level [1= Poor; 2= Fair; 3= Moderate; 4= High; 5= Very high]
†Pasture [1=Cenchrus; 2= Rhodes grass; 3= Brachiaria; 4= Other (specify]
+Herbaceous legumes [1=Desmodium; 2= Lucerne; 3= Clitoria; 4=lablab; 5= Other (specify)]
#Fodder grasses [1=Napier grass; 2=Setaria grass; 3=Panicum; 4= Others (specify];
±Fodder trees [1=Calliandra; 2= Leucaena; 3= Sesbania; 4=other specify]

E/4. When did you start establishing improved forage/fodders in your farm (year) ___________

E/5. What dictates the area you plant fodder/forages? ______ [1= Land size; 2=Labour availability; 3=Number of livestock; 4=Amount of seed available; 5= Others (specify)] __________________________-

E/6. What is/are your criteria for choosing the forage/fodder species to grow? ______________ [1=High yielding; 2=Drought tolerant; 3=Animals likes it; 4=Animals produce more milk when fed these forage; 5=No disease and pest; 6=Easy to harvest;

7=Grow fast; 8=Advice from extension services; 9= Only one available; 10=Seeds are cheap; 11= Control erosion; 12=No selection criteria; 13=Others (specify)] _________

E/7. Who makes decision on the type of forage to plant? _________ [1=Husband; 2=Wife; 3=Both Husband and wife]

E/8. Which part of your farm do you plant or prefer to plant your forages? _________ [1= Sloppy area; 2= Flat area; 3= Area where crop perform poorly; 4= Infertile area; 5= Near the homestead; 6= Away from homestead; 7=Other (specify)]

E/9. Indicate who is primarily responsible for carrying out the following tasks in fodder/pasture production

Activities related to fodder production	**Responsibility***
1. Land preparation	
2. Sources/buy the seeds/planting material	
3. Planting of forages	
4. Weeding forages	
5. Application of manure/fertilizer to fodder	
6. Cutting forages for livestock	

*1=Husband; 2=Wife; 3=Children; 4=Long-term labourer; 5=Casual labourer

E/10. What is the soil fertility status where you grow your fodder/pastures? ______ [1=Very fertile; 2= Moderately fertile; 3= Low fertility; 4= Very infertile; 5= I do not know]

E/11. How do you identify the very infertile soils? _______1=Declining pasture productivity; 2=Changes in pasture colour; 3= Changes in soil colour; 4= presence of special weeds; 5= Others (specify) ____________

E/12. Which weeds are associated with low soil fertility?
List ____
E/13. Which weeds are associated with high soil fertility?
List ____
E/14. Do you apply fertilizer to your forages ______ [1= Yes; 2= No]
E/15. If **yes** which one? ________ [1=Inorganic; 2=Organic; 3= Both inorganic and organic]
E/16. If **no** why not? _____ [1=Lack of money; 2= High cost of fertiliser; 3=Do not know whether pastures need fertiliser 4= My land is fertile; 5= Others (specify)

E/17. How do you conserve feed for your livestock? _____________ [1=Bale hay; 2=Make silage; 3= Hay and silage; 4= None]

F: Household without planted fodders/forages

F/1. If you do not have planted forages/fodders where do you obtain feed for your livestock? _______________-
[1= Along terrace bank; 2= Weeds from crop land; 3= Farm/hedge boundaries; 4= Bushland; 5= Buy; 6= Public land (school, church compound); 7= Road reserves; 8= Others]

F/2. Why don't you have planted forages? _______________ [1=Lack of seeds; 2= Land is small; 3= Cheap to buy; 4= Lack of labour; 5= No idea of fodder types to plant; 6= Lack of knowledge; 7= Others (specify)]

G: Feed resources availability

G/1. Record when you feed your cattle the various feeds in a year. Mark **X** in the boxes which correspond to the responses.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Cultivated and natural pastures												
Planted pastures												
Fodder grasses#												
Natural pasture												
Herbaceous legumes+												
Fodder trees±												
Crop residues												
Maize stover												
Sorghum stover												
Cassava												
Sweet potatoes												
Beans haulms												
Pigeon pea												
Cowpea												
Green grams												
Others												

Commercial feeds												
Agro-industrial												
Others												

†Pasture [1=Cenchrus; 2=Rhodes grass; 3=Brachiaria; 4= other (specify]
+Herbaceous legumes [1=Desmodium; 2= Lucerne; 3= Other specify]
#Fodder grasses [1=Napier grass; 2=Setaria grass; 3=Panicumn; 4= Others (specify]
±Fodder trees [1=Calliandra 2= Leucaena 3= Sesbania; 4= Other specify]

G/2. Do you experience a shortage of feeds for your livestock ____ [1=YES; 2=NO]

G/3. Indicate general availability/scarcity of feeds in your farm. (Indicate relativity*)

Months	Short dry season		Long rains			Long dry season				Short rains		
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Now												

*[1=Adequate; 2= Moderately adequate; 3= Scarce; 4= Very scarce]

G/4 Rank the **3 major strategies** (in order of importance) you apply during the period of **scarce** and **very scarce** feed shortage

Strategy	**Scarce**	**Very scarce**
Use conserved/stored forages		
Feed less to animals		
Feed less to certain categories of animal		
Rent grazing land		
Reduce herd size		
Purchase fodder		
Purchase concentrate feed		
Feed forages not normally used		
Others (specify) ______________		

H. OTHERS

H/1 List benefit(s) of grasses other than for livestock feeds. _______________ [1=Improve soil fertility; 2= Reduce soil erosion; 3= Reduce pest; 4= Control weeds 5= Improve soil structure; 6= Increase organic matter; 7= Others (specify)]

H/2. If the forages/fodder you grow assists in controlling weeds, list the weeds _____________________________

Thank you for participating in the survey