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EVALUATION OF IMPROVED *BRACHIARIA* GRASSES IN LOW RAINFALL AND ALUMINIUM TOXICITY PRONE AREAS OF RWANDA

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EVALUATION OF IMPROVED *BRACHIARIA* GRASSES IN LOW RAINFALL AND ALUMINIUM TOXICITY PRONE AREAS OF RWANDA

by

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“And I will send GRASS in your fields for your livestock that you may eat and be filled”.

Deuteronomy 11: 15 (The Holy Bible: New King James Version).

Dedicated to my wife Henriette Mukansonera and my daughter Anela Beza Mutimura

ABSTRACT

Animal feed resources remain a major constraint for livestock development in Rwanda and tropical Africa in general. The scarcity of quantity and quality forage year round, particularly in the areas constrained by low rainfall and acidic soil of Rwanda, is the main problem faced by smallholder farmers in these areas. Furthermore, with the increased density of the human population in Rwanda, land has become scarce, leading to rapid shrinking of grazing land and land devoted to cropping. The system of livestock farming changed from communal grazing to the current system whereby livestock are kept in sheds and fed by cutting and carrying of forages (zero grazing system). Traditionally in Rwanda, livestock were owned by men and most activities related to grazing animals, including cattle, were carried out by males. Because of the change to a zero grazing system, the role of gender and wealth in livestock activities may influence interventions to improve fodder resources.

A two-year study was conducted in the contrasting low rainfall (the Bugesera district) and acidic soil (the Nyamagabe district) environments of Rwanda to identify animal feed resources and to evaluate the potential of improved, indigenous *Brachiaria* grasses and *Cenchrus ciliaris* to increase fodder production under these conditions. The objectives were to (i) identify feed resource-use patterns under low rainfall, acidity and aluminium toxicity stress conditions, (ii) analyse the role of gender and wealth categories in livestock activities in the target areas, (iii) assess the production of improved, indigenous *Brachiaria* grasses and *Cenchrus ciliaris* (iv) assess the quality (dry matter, crude protein, calcium and phosphorus) of improved and indigenous *Brachiaria* grasses together with *Cenchrus ciliaris* (v) assess the farmers" perception of the new varieties and hybrids of *Brachiaria* grass and (vi) determine farmers criteria for selecting fodder species. This study tested the following hypotheses: (i) drought and aluminium toxicity tolerant varieties and hybrids of *Brachiaria* grass will produce a greater yield of dry matter and nutrient than indigenous *Brachiaria* grass and naturalized *Cenchrus ciliaris* used as forages by farmers in the Bugesera and Nyamagabe districts and (ii) the new fodder crops (*Brachiaria* varieties and hybrids) which were bred for higher production and quality under drought and aluminium toxicity will be favoured over common forages by farmers under these conditions.

Focus group discussions composed of twenty farmers per district were used during farmer participatory research (FPR). The role of gender in livestock rearing, wealth categories and feed calendar development were determined using FPR. In the low rainfall area (the Bugesera district) and acidic soil area (Nyamagabe district), some livestock activities were shared between genders. For example, both women and men were responsible for cattle herding, feeding, planting forage, cattle donation (give someone a cow as a gift) and cattle selling. However, construction of animal sheds, milking cows and animal disease treatment were men‟s activities. Sharing cattle activities between genders in terms of herding, feeding and planting forage in both districts will likely be able to lead to the adoption of the selected *Brachiaria* grasses in the study area as all members of a household can intervene in the matter of feeding animals.

Wealth ranking in both areas showed that farmers identified five wealth categories: the „very rich‟, the „rich‟, the „moderately poor‟, the „poor‟ and „very poor‟. In the low rainfall area, 75% of selected farmers were in the category of „rich‟ and 25% were in the category of „moderately poor‟. In the acidic soil area, 16.67% were „very rich‟, 25% were „rich‟ and 58.33% were „moderately poor‟. The richer wealth categories were able to get money to invest in farming activities and therefore likely to adopt the new *Brachiaria* grasses

Livestock feed resources were identified and ranked by farmers based on eight criteria (e.g. availability, palatability, increase milk yield, drought tolerance, low soil fertility tolerance). Livestock feed resources preference ranking showed that in the low rainfall area *Pennisetum purpureum* (Napier grass) *Tripsacum laxum*, *Setaria sphacelata* and banana stems were highly scored as the most used resources for feeding cattle. In the acidic soil area, The Napier grass, *Commelina benghalensis, Panicum maximum* (Panicum), maize stovers and *Albizia amygdalina* were the highest scored as the most used feeds. The high variety of feed resources (13–21) indicated that there was a shortage of livestock feeds in the areas of the study.

On-farm evaluation of improved *Brachiaria* grass involved twelve farmers per district. Eight improved *Brachiaria* grasses (five hybrids and three varieties) from the International Centre for Tropical Agriculture (CIAT) and two local grasses (indigenous *Brachiaria decumbens* and naturalised *Cenchrus ciliaris*) were used. On each farm, all ten grasses

were established individually in 2 m x 3 m plots. Biomass was harvested six times (from November 2007 to September 2008) at two monthly intervals. Dry matter (DM) was determined from all cuts, and crude protein (CP), calcium (Ca) and phosphorus (P) were determined once in the wet season and once in the dry season.

In the low rainfall and acidic soil areas, DM yield was significantly different between treatments within sites for all harvest times (Wald statistic = 429.11; df = 100; $p<0.01$). For example, in the low rainfall area, the DM of *Brachiaria brizantha* cv. Toledo (5.71 t ha^{-1}), the local *Brachiaria decumbens* (5.6 t ha^{-1}), *Brachiaria* hybrid cv. Mulato II (5.13 t ha^{-1}) and *Brachiaria* hybrid cv. Mulato (5.03 t ha^{-1}) were higher than the rest of the treatments. The lowest DM in this area was obtained for the naturalised control grass *C. ciliaris* (1.19 t ha^{-1}) for all harvest times. In the acidic soil area, *Brachiaria* hybrid Bro2/1485 produced the highest DM (5.95 t ha^{-1}).

The nutrient composition (CP, Ca and P) of tested grasses was significantly different ($p<0.05$) between treatments within sites during the wet and dry seasons. In the low rainfall area, the highest quality grass was *Brachiaria* hybrid Bro2/1485 which had a CP value of 15.69% during the wet season. This CP value was higher than that found in *B. decumbens* (control) and *C. ciliaris* (control grass) in the wet season, which had a CP value of 6.68 and 5.07% respectively in the low rainfall area. It is likely that the CP value of 15.59% for hybrid Bro2/1485 will meet the CP requirements (15% per day) of a dairy cow in lactation which can produce up to 29 litres per day. In the acidic soil area, the highest CP was obtained by the *Brachiaria* hybrid cv. Mulato II (14.29%) during the wet season. This CP value was higher than that of control grasses *B. decumbens* (local) and *C. ciliaris* in the wet season, which had a CP of 9.48% and 7.88% respectively in the acidic soil area. The CP of cv. Mulato II in the acidic soil area showed that it could meet a dairy cow‟s CP requirements. In the low rainfall area, the *Brachiaria* hybrid cv. Mulato obtained a high mean value of Ca (2.15%) whereas in the acidic soil area, cv. Marandu obtained the highest value (2.41%) during the wet and dry seasons. The Ca values of these improved *Brachiaria* were higher than those of control grasses (local *Brachiaria* and *C. ciliaris*) in the low rainfall and acidic soil areas. Although in both areas Ca of improved *Brachiaria* (e.g. cv. Marandu) was higher than that of control grasses, both of them are likely to meet the Ca requirements (0.6% per day) of a dairy cow. The cv. Toledo had high P (0.28%) compared to the other grasses (0.07–0.11%) in the low rainfall area. In this area, the P of cv. Toledo will be able to meet the P requirements (0.26% per day) of a late stage pregnant cow. In the acidic soil area, the *Brachiaria* hybrid Bro2/1485 had high P (0.53%) compared to other grasses in which P varied between 0.16 and 0.47%. This P value of hybrid Bro2/1485 was higher than that of control grasses where local *Brachiaria* had 0.47% and *C. ciliaris* had 0.16% of P in the acidic soil area. Although in the acidic soil area P of hybrid Bro2/1485 was higher than that of control grasses, both hybrid Bro2/1485 and *B. decumbens* (control) are likely to meet the P requirements (0.4% per day) of a lactating dairy cow. The hypothesis that drought and aluminium toxicity tolerant varieties and hybrids of *Brachiaria* grass produce a greater yield of DM than indigenous *Brachiaria* and naturalised grass grown forages used by farmers in selected areas was not supported. This is because *B. decumbens* yielded a DM which was not significantly different from the DM of improved *Brachiaria* grasses in both areas. However, the hypothesis that improved *Brachiaria* grasses will produce greater nutrient content (CP, Ca and P) than indigenous *Brachiaria* and naturalised grass grown forages used by farmers was supported. This is because improved *Brachiaria* grasses obtained higher CP, Ca and P than the *B. decumbens* and *C. ciliaris* control grasses in the low rainfall and aluminium toxicity areas during the wet and dry season.

Experimental results indicated that *Brachiaria* hybrid Bro2/1485, *Brachiaria brizantha* cv. Toledo, *Brachiaria* hybrid cv. Mulato II, *Brachiaria* hybrid cv. Mulato, *Brachiaria decumbens* cv. Basilisk, and *Brachiaria brizantha* cv. Marandu were the potential *Brachiaria* grasses adapted to the low rainfall and acidic soil stress conditions of Rwanda. However, in both areas, farmers highly preferred the cultivar Mulato II (CIAT 360687) because of its production of green forage year round without any input of fertilizer, hence its adaptability to low rainfall and acidic soil stress conditions. This supports the hypothesis that the new fodder crops (*Brachiaria* varieties and hybrids) will be favoured over common forages by farmers in the low rainfall and aluminium toxicity conditions.

PREFACE

The research outputs described in this thesis were carried out in the School of Biological and Conservation Sciences, University of KwaZulu-Natal, Pietermaritzburg, from 2007–2009, under the supervision of Dr Terry M. Everson.

This study is the original work of the author and has not been submitted in any form to another university or academic institution for any degree. Where the author referred to the work of others it has been duly acknowledged in the text.

DECLARATION

I, Mupenzi Mutimura declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons‟ data, picture, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons‟ writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a. Their words have been re-written but the general information attributed to them has been referenced ;
    b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.
5. 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…..…./……..../2010

Mupenzi Mutimura

Signed………………………………… Date……../…..…../2010

Dr Terry Everson (Supervisor)

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CHAPTER ONE–GENERAL INTRODUCTION

1.1 Background

Shortage of animal feed resources is a major constraint for livestock development in Rwanda. Growing of non-improved forage grass species and lack of appropriate technologies to manage natural resources contribute to the problem of fodder shortage for smallholder farmers in the tropics (Fagbola and Babayemi 2006). The deficiency in both quality and quantity of feeds has arisen from poor and shrinking pastures, poor quality of commercialised feeds, water shortage, and limited use of crop by-products (MINAGRI 2008a, Mutimura *et al.* 2009). In addition, for grazing animals, the availability of animal feeds varies with seasons and becomes severe during the dry season. The pastures in this season are low in nutrients and if not supplemented with other feed resources lead to low productivity (RARDA 2006). The problem of land and farm size is therefore central to the issue of livestock feed production and has a great influence on cattle production in Rwanda (Ndabikunze 2004). Likewise, crop production is constrained by soil fertility depletion, unaffordable inorganic fertilisers, changes of temperature, rainfall and climatic extremes (FAO 2008). One way to increase animal products and farmers‟ returns is to improve animal nutrition (Fagbola and Babayemi 2006). Livestock plays a key role in increasing the agricultural economy, providing about 1.3 billion people with employment and income from 40% of the global agricultural output. For many farmers in tropical countries, livestock is also a source of renewable energy for draft and organic fertiliser. However, livestock production strains many ecosystems by degrading grasslands and contributing around 9% of the total carbon-dioxide emissions (FAO 2007). Although some cases have reported that excess manure increases the leaching of nitrogen and phosphorus (Peterson *et al.* 2007) in Rwanda this level has not yet been reached (Drechsol and Reck 1997, Mugabo 2003).

Land scarcity has caused the establishment of zero grazing systems in Rwanda, where animals are kept in sheds and fed by cutting and carrying of forages. This system can reduce the degradation of the ecosystem. According to Coleman and Sollenberger (2007), animals, especially herbivores, can cause damage to the pasture plant through action of their hooves and overgrazing. It is likely that if animals are kept in a shed, damage will not occur. The predominant type of agriculture in Rwanda, including the Bugesera and Nyamagabe districts, is smallholder mixed crop-livestock farming systems with land holdings of ≤ 0.76 hectare for the majority of farmers (NISR 2007). According to Tarawali *et al.* (1995), this mode of farming system is common in many parts of sub-Saharan Africa including Burundi, the high plateaus of north and west Cameroon, western Kenya and Malawi. Cropping and livestock production have been closely integrated and complementary where livestock provides manure and crop residues are used as feeds. In western Kenya, crop by-products are the most important feed for livestock. Farmers use stover to feed their animals instead of using it for soil fertility replacement (Marenya and Barrett 2007). These authors conclude that the integration of crop-livestock research units for agricultural development may yield synergies (livestock provides manure and crop residues are used as feeds) for income generation in low-income tropical countries. Plant nutrients are cycled from soil to the fodder crop, and when this is grazed by animals, nutrients are returned to the soil through urine and faeces (Beetz 2002). There is an opportunity to improve crop productivity and at the same time increase feed output, by integrating high yielding forage species into existing cropping systems. This would reduce the competition for land because the same land is simultaneously used for both food crop production for human consumption and forage production for feeding livestock. The changes in pasture improvement can only be identified by studying the farming system (Humphreys 1987).

Agriculture in the Nyamagabe district is constrained by infertile, acidic, and aluminium toxic soils and in the Bugesera district by low rainfall. The problems in each district are crucial constraints for provision of animal feeds. Adapted crop and forage germplasm is therefore needed to enhance the productivity and resilience of crop-livestock systems growing under these conditions. Improved *Brachiaria* grasses are exceptionally resistant to the combination of aluminium toxicity and drought (Miles *et al.* 2004) and could play a role in smallholders‟‟ crop-livestock systems in such areas. Furthermore, high yields, quality and ease of propagation of improved *Brachiaria* grasses are central to their establishment and utilisation under smallholders‟‟ crop-livestock systems for improved milk and meat production. Evaluation of the potential and use of improved *Brachiaria* grasses together with other available forages will be of primary importance for sustainable supply of feed resources in the study sites. In Latin America, improved *Brachiaria* varieties and hybrids have been introduced decennia ago and have become commercial fodder crops (Peters *et al.* 2003). *Brachiaria* pasture is widely used in tropical America, where in Brazil many hectares are cultivated (Abello *et al.* 2008, CIAT 2007a). Here it is grown as pastures for grazing on millions of hectares in relatively large farms. In southeast Asia, the introduction of improved *Brachiaria* grasses has been more recent. Successes have been recorded of integrating *Brachiaria* grass in smallholder farms, by cultivating it in rows between other crops (Stür *et al*. 2002). In east and central Africa from 500–2300 m a.s.l, including Burundi, Democratic Republic of Congo, Kenya, Rwanda, Tanzania and Uganda, *Brachiaria* grass is an indigenous genus, but most species have not been exploited sufficiently (Thomas and Grof 1986, Roothaert *et al*. 2003). More common forage crops in east Africa are *Chloris gayana, Pennisetum purpureum*, and *Setaria sphacelata*, to name just a few. The farming systems in the two districts of Rwanda are more similar to those in southeast Asia where the farming system is mixed crop-forages (Stür *et al*. 2002), than those in Latin America where improved forages are planted in many hectares for free grazing (Albello *et al*. 2008). If improved *Brachiaria* grass is accepted by smallholder mixed farmers or livestock farmers in Rwanda, it is likely to be integrated in the existing cropping pattern and harvested in a „cut and carry" manner.

Brachiaria is predominantly an African genus with about 100 species; some of which have become commercially useful forages. Rao *et al.* (1998), stated that the adoption of *Brachiaria decumbens* cultivar (cv) Basilisk in Latin America is due to its excellent adaptation to infertile, acidic soils (pH < 5.5), but the productivity is limited by its susceptibility to xylem-feeding insects (Homoptera) known as spittlebugs. However, *Brachiaria brizantha* cv. Marandu is resistant to this insect and this has led to its adoption by farmers in tropical America in recent years. In general, many *Brachiaria* accessions held at the International Centre for Tropical Agriculture (CIAT in Spanish acronym) in the forage breeding programme are adapted to infertile, acidic soil, aluminium toxicity and drought. For the above criteria of selection, it is hypothesised that the newly selected varieties and newly bred hybrids of *Brachiaria* (e.g. *Brachiaria decumbens* cv. Basilisk*, Brachiaria brizantha* cv. Toledo*, Brachiaria brizantha* cv. Marandu*, Brachiaria* hybrid cv. Mulato*, Brachiaria* hybrid cv. Mulato II*, Brachiaria* hybrid Bro2/0465*, Brachiaria* hybrid Bro2/1452*, Brachiaria* hybrid Bro2/1485) can outperform the commonly grown forage crops in the low rainfall and aluminium toxic environmental conditions of the Bugesera and Nyamagabe districts of Rwanda respectively.

The focus of participatory forage evaluation is to develop forage technologies in partnership with smallholder farmers where forages have potential to improve livestock feeding and management of natural resources (Cramb and Purcell 2001). The desire of the improved pasture to be grown and the site selection depends on farmer‟s objectives (Humphreys 1987). Farmers will need to explore whether the „new‟ *Brachiaria* varieties and hybrids are superior to the fodder crops they are used to. „Superiority‟ needs to be defined by farmers; criteria could be related to fodder production, palatability, animal productivity, ease of management, competition with other crops, drought and aluminium tolerance, natural resource management, and other factors. The aim of the study is to determine which varieties and hybrids of *Brachiaria* produce the highest yield and are selected by farmers in the low rainfall and aluminium toxicity areas of Rwanda. The study tested the following hypotheses (i) drought and aluminium toxicity tolerant varieties and hybrids of *Brachiaria* grass will produce a greater yield of dry matter and nutrients than indigenous *Brachiaria* grass and naturalized *Cenchrus ciliaris* used as forages by farmers in the Bugesera and Nyamagabe districts and (ii) the new fodder crops (*Brachiaria* varieties and hybrids) which were bred for higher production and quality under drought and aluminium toxicity will be favoured over common forages used by farmers under these conditions. It is predicted that, due to the new policy of the government of Rwanda to keep animals in sheds, it is likely that farmers will decide to select and accept the new *Brachiaria* grass. The improved *Brachiaria* grasses (e.g. *Brachiaria* hybrid cv. Mulato*, Brachiaria* hybrid cv. Mulato II*, Brachiaria* hybrid Bro2/0465*, Brachiaria* hybrid Bro2/1452 and *Brachiaria* hybrid Bro2/1485) have an erect growth habit. This is an advantage in the cut and carry of forage system. As this system is adopted in the selected sites, the *Brachiaria* forage, which is high in quantity and quality, is likely to help smallholder farmers to strengthen their intensive farming system.

1.2 Objectives

The objectives of the study were (i) to identify the current feed resources used under low rainfall, acidity and aluminium toxicity stress conditions; (ii) to analyse the role of gender and wealth categories in livestock activities in target areas; (iii) to assess the production of improved, indigenous *Brachiaria* grasses and *Cenchrus ciliaris* on smallholder farms under low rainfall, acidity and aluminium toxicity stress conditions; (iv) to assess the quality (dry matter, crude protein, calcium and phosphorus) of improved and indigenous *Brachiaria* grasses together with *Cenchrus ciliaris* and (v) to determine farmers‟ criteria for preference of forage and assess the farmers‟ perception of the new fodder crops.

1.3 Thesis structure

This thesis is divided into six chapters: the first chapter describes the trends of farming systems in Rwanda, their constraints and opportunities, and then outlines the hypotheses and objectives of the study. The second chapter is a literature review of animal feeds and feeding systems in some countries and in the study area. The third chapter describes the areas of the study, which are the Bugesera and Nyamagabe districts of Rwanda and gives a description of indigenous *Brachiaria decumbens* and naturalized *Cenchrus ciliaris*. The fourth chapter focuses on the farmers‟ assessment of current feed resources in the low rainfall and aluminium toxicity prone areas of Rwanda. Criteria include the quantity in terms of availability and quality in terms of fodder crop species in the wet and dry seasons of the year in the Nyamagabe and Bugesera districts. The fifth chapter outlines on-farm evaluation of improved *Brachiaria* grasses in low rainfall and aluminium toxicity prone areas of Rwanda. The sixth chapter presents a general discussion and conclusion of the study and a proposal for strategies to enhance forage production in the study areas.

CHAPTER TWO–LITERATURE REVIEW

2.1 Introduction

Agriculture is the main sector that contributes one-quarter to one-half of global domestic products in low-income countries (Cain *et al.* 2007, Kelemu *et al.* 2003). In Rwanda, agriculture produces about 43% (of gross domestic products) where livestock itself contributes about 8.8 % to 12% (MINAGRI 2008a). The ever-increasing human population and their high demand for animal protein will depend on better utilisation of crop residues as ruminant feed resources for improving household food security and income in developing countries (Kabi and Bareeba 2008). Demand for global food is expected to increase by 50% over the next 25 years with 80% expected to come from sub-Saharan Africa where shortage of food is still increasing (Dar and Twomlow 2007). In addressing problems of insufficient agricultural products, researchers face multiple challenges such as variability of climate. This leads to unpredictability in available soil-moisture for better growth of plants. Most soils from sub-Saharan countries have low fertility (Dar and Twomlow 2007). However, many farmers in tropics are operating at subsistence levels, and they cannot afford to invest in development and sustainable management of natural resources. The major farmers‟ problem in the tropical region is variable climate with soil erosion. As the pressure of rising population increased, the soil erosion hazard has come greater in marginal and sloping lands (Humphreys 1994). In Rwanda, the participatory watershed management approach is now an important opportunity to address issues of low agricultural production (Laura *et al.* 2005). This watershed approach is used to capture detailed information for a selected community. It includes socio-economic issues and targets all stakeholders in the rural development to intervene in each gap identified by the community itself. In different pilot sites of watersheds in Rwanda, the livestock component is constrained by lack of animal feed. The major challenges for livestock development are land scarcity, low rainfall, infertile soils and lack of forage seeds (Mowo *et al*. 2006). Integrated crop-livestock management in farming systems that focus on livestock management and forage (quantity and quality) may be a solution to problems faced by smallholder dairy farmers in Rwanda. This chapter is an overview of mixed crop-livestock production, the importance of livestock to small-scale farmers, the relationship between wealth and livestock and the role of gender in livestock activities. It also gives an overview of the importance of forage to smallholder farmers, availability of livestock feed, the importance of using improved forage and factors that affect the adoption of new forage technology by small scale farmers.

2.2 Integrated crop-livestock farming system

There is a paucity of research on integrated crop-livestock production systems. According to Tanaka *et al.* (2008), possible reasons are that the integrated crop-livestock experiments involve many treatments and replications and require scientists of diverse training and experience to address the various aspects of these systems. The scientists also need to function as a cohesive unit or team. However, there is some evidence of successful integrated crop-livestock farming systems. According to Thornton and Herrero (2001) in the tropics, mixed crop-livestock systems constitute the backbone of agriculture. In sub-Saharan Africa, the integration of crop and livestock production is one of the major problems relating to crop and livestock development (Sumberg 1998). A large proportion of grazing lands comprise natural pasture in the tropical countries and there is very little livestock production on sown pastures (Humphreys 1987). Livestock production on natural pasture will lead to low levels of animal production because the natural pastures are low in nutrients (Thomas and Sumberg 1995).

According to Delgado *et al.* (1999), the estimation of milk consumption across the tropics will increase by about 3.2% per annum until the year 2020 whereas beef and pork consumption is expected to double in developing countries between 1993 and 2020. In many tropical countries, livestock production is limited by hilly areas with serious soil erosion (CIAT 2007a). In Asia, the integration of livestock into crop systems has resulted in more efficient resource use by small-scale farmers (Paris 2002). Furthermore, in many villages of the Indo-Gangestic plains of India, widespread ownership of livestock complements the rice and wheat-based cropping systems as the basis of rural livelihoods (Erenstein *et al.* 2007). In China particularly, the integrated crop-livestock production system addresses the agricultural needs of the Chinese population. In north-western China and the Karst region of Guizhou Province, south-western China, the integration of crop, livestock and forage are effective means of improving agricultural productivity, environmental sustainability and farmers‟ income (Hou *et al.* 2008). Once household grain production is satisfied in the lower rainfall less productive area, the remaining land is allocated to cash crop and livestock enterprises (Sharna *et al.* 2008). In developed countries like the United States of America, the lack of diversification has had negative economic, biological, and environmental consequences. Because of degradation of natural resources in North America, farmers have renewed interest to integrate crops and livestock, including the use of perennial forages to enhance both profitability and environmental sustainability of their farms and communities (Russelle *et al.* 2007). One approach is to diversify agricultural production by integrating cash grain cropping with ruminant livestock production (Sulc and Tracy 2007). In the same country, it has been found that a dairy farm model (Figure 2.1) can integrate crop and dairy cows. Perennial grasses reduced nitrogen leaching in North Florida by up to 23% (Cabrera *et al*. 2006). In Rwanda, almost livestock keeping is managed through a zero grazing system where animals are kept and fed solely in a shed. Manure collected from a shed is used to fertilise crops and planted pastures (Ndabikunze 2004). This integration has been highly recommend by Tracy and Zhang (2008) in their study on soil compaction, corn yield response, and soil nutrient pool dynamics within an integrated crop-livestock system in Illinois. They found that integration of crops with livestock had generally positive effects on crop yield and soil organic matter. Crop-livestock integration in Vietnam (Peter and Stür 1999) and in the central highlands of Kenya (Woomer *et al.* 1999) makes agriculture more sustainable. The combined systems in which nutrients are recycled are more profitable in smallholder farm than a separated system, which causes the loss of nutrients. They conclude that livestock provide a high level of profit per unit of labour input, plus valuable manure for use as fertiliser.

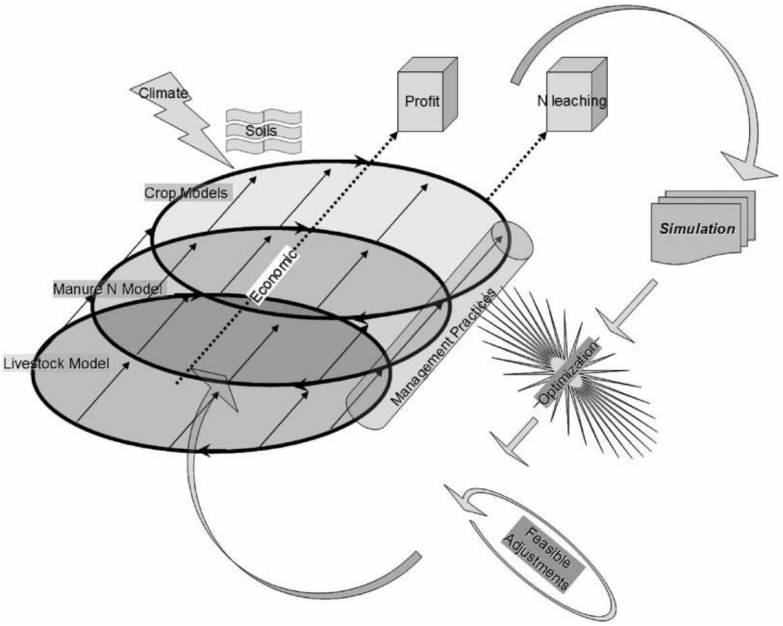


Figure 2. 1 Schematic representation of a dynamic North Florida dairy farm model (Cabrera *et al.* 2006).

2.3 Importance of livestock to smallholder farmers

Livestock production is an important component of many smallholder farming systems throughout the tropics (Pengelly *et al.* 2003). Traditionally, livestock is one of the main sources of income and protein for the poor in developing countries (Ferreira and Soares de Andrade 2004). In Africa, smallholder systems usually have different species of animals within the farm. These animals may have different purposes in the system not only by providing food (milk, meat and eggs) for the family, but also by providing cash from product sales, capital assets, provision of manure for crops and pastures, transport, and others (Herrero *et al.* 2007, Rufino *et al*. 2007). Livestock throughout the rural regions of Africa act as a store of wealth for a family or household and can be sold to provide cash in times of need (Brandt *et al.* 1997). In Ethiopia, a study on the impact of donkey ownership on the livelihoods of female peri-urban dwellers has revealed that donkey owners‟ livelihoods were improved when compared to non-donkey owners (Curran and Smith 2005). In several regions of Africa, Asia and the Americas, dairying has become an important and economically attractive enterprise for smallholder farmers.

According to Delgado *et al.* (1999), the demand for animal products is expected to grow from the current 206 million tons to 275–310 million tons or more by 2020. This will encourage smallholder farmers from developing countries to increase their income through opportunities of intensive production systems (CIAT 2007b).

In Vietnam, farmers either owned or hired livestock from livestock companies or provincial government for draught power and keep manure. In Pakistan and Kenya, cropping is the dominant agricultural activity, which contributes two-thirds of the industry"s output during both the rainy season and dry season by using irrigation. However, there is increasing recognition of the importance of livestock production, especially dairying for the major sources of livelihoods (Cain *et al*. 2007, Chinwe *et al.* 2008). In the northern Kalahari, Namibia, cattle were found to play an important role by producing milk and milk by-products for home consumption and for generating cash income within OvaHerero pastoralists (Katjiua and Ward 2007). In Rwanda, animal products are very important where milk is the major animal product followed by meat (Table 2.1). Milk and meat production have significantly increased annually between 1999 and 2007 (MINAGRI 2008b). Livestock production is one of the few options available for millions of poor people who live in arid and semi-arid areas of Africa and Asia. Livestock can be moved in response to variable rainfall conditions and can be purchased or sold in response to variable market conditions. Livestock can also supply animal traction and play key roles in the transfer and cycling of nutrients for crop production (ILRI 2008a). Donovan *et al.* (2002), in their comments on forces driving change in Rwandan smallholder agriculture from 1990–2001, stated that the decreasing crop production was due to a low provision of manure from lower livestock numbers. Hence, soil fertility is increasingly at risk. Cain *et al.* (2007) stated that the risk faced by farmers in Pakistan reduced when they practised mixed farming.

Table 2. 1 Animal products in Rwanda between 1999 and 2007 in tons

Animal products	1999	2002	2005	2007
Milk	55,577	97,981	135,141	158,764
Meat	22,807	39,126	49,861	54,780
Fish	6,433	7,612	8,180	9,655
Eggs	1,471	2,432	2,452	1,620
Honey	528	819	1,671	-
Hides	-	-	2.637	4.137

Source: MINAGRI (2008b)

In Kenya livestock small ruminants are the highest priority for smallholder and pastoral farmers, they provide a regular cash income and an insurance against emergencies (Kosgey *et al.* 2008).

2.4 Wealth and livestock

In developing countries, farming remains an important factor for livelihoods and rural people look for other opportunities for increasing their income. Farmers" assets have an impact on their activities and livelihoods. These are influenced by institutions that farmers interact with and wider money-making trends like market prices and climate disturbance such as drought (Chapman and Tripp 2004). The wealth of a household is the determinant of farmer group functions with wealthier individuals participating more in farmer groups (La Ferrara 2002). These groups are the way to transfer agricultural technology packages and policy makers and planners must understand the disparities between wealthier and poor households (Pande and Yazbeck 2003). The effect of wealth category on livestock has been widely reported in the literature.

Sieff (1999), in his study on the effects of wealth on livestock dynamics among the Datoga pastoralists of Tanzania, found that wealthy households had a low off-take rate of livestock in terms of mortality and sales. Therefore, they retain their livestock and they seek ways to increase the size of their livestock herds. According to Cramb *et al.* (2004), cattle numbers increased with increasing wealth status. Alumira (2002) classified four groups of households by wealth in the semi-arid tropics of Zimbabwe: the „very poor‟, the „poor‟, the „medium rich‟ and the „very rich‟. These two latter groups may have 10 to 200 head of cattle. By contrast, in Kenya, farmers in the “rich” and the “very rich” categories owned 3–6 head of cattle (mostly dairy cows) which were fed better quality feedstuff (Mugo *et al.* 2001). The latter authors said that although the wealthier farmers could afford the better animal feeds, farmers had indicated feed scarcity as the main constraint to keeping cattle in Kenya. Farmers tried to collect feeds in different places and when money was available, they could buy feeds (Rufino *et al.* 2007). In their study on household wealth status and natural resource use in the Kat River valley, Shackleton and Shackleton (2006) found that the “poor household” South Africans were the most significant users of non-timber forest products (NTFPs) for their livelihoods because they had less income from jobs, pensions and livestock. In Mali, poorer households were less likely to have opportunities in livestock activities, and they had less diversification of incomes, whereas the wealthier households were more likely to participate in non-cropping activities such as livestock rearing (Awudu and CroleRees 2001). This research has been supported by Bahamondes (2003) in his study on poverty-environment patterns in arid central Chile. He concluded that wealth was the most important factor influencing investment in livestock activities.

2.5 Gender roles in livestock production

The increase of gender equality and women‟s empowerment has been instrumental in poverty reduction (IFAD 2003). Many studies have stated the importance of the role of gender in agricultural and livestock production. For example, Rana *et al.* (1994), in their study on the development of a lightweight, wheel hand-hoe for farm women found that women were able to evaluate agricultural technologies. In Africa, a high percentage (70%) of women contributed to labour as well as in food production and in the rural areas, 100% were involved in food processing (Carr 1991, Kaul and Ali 1992). Even though they are involved in food production, according to ILRI (2008b), there is still a gap in food security in Africa because women‟s key role in food is limited. Bryceson and

Howe (1993) and Appleton (1994) found in their different studies on gender in agriculture that women"s technological skills and innovations are often neglected because they may relate to their domestic responsibilities or because they have low income generation. In South Africa, rural women in Limpopo Province do most of the farm activities because they are not connected to migrant casual labour like men (Dovie *et al.* 2003, Magombeyi and Taigbenu 2008). When resources generating income are placed in women"s hands, the agricultural productivity and the nutritional status are increased (Midgley 2006). However, better changes in agricultural productivity were most successful when both men and women were involved in the participatory process of resolving the problems they are facing. So far, men"s participation in agriculture is declining while women"s participation is becoming more and more dominant (ILRI 2008b). Women are hard working and contribute in disseminating new technologies. For example, in Rwanda, in recent decades women have been involved in the production and adoption of new varieties of bean. Researchers learnt the principles of involving women, which make the adopting of new seed possible (Sperling and Berkowitz 1994).

All efforts of women in rural areas of tropics are concentrated on food crop production. Despite this, women keep small stock while cattle are kept by men. The livestock and home activities that are incumbent upon women lead to low income of rural households. Empowerment of women in their activities and education for acquiring more skills is necessary in order to increase household returns (Bucyensenge *et al.* 1990). Even in good crop harvest years malnutrition can occur in vulnerable groups, especially women and children, because food intake is not balanced due to lack of animal products (e.g. milk, eggs) (Tilahun *et al.* 2004). However, in rural areas in the tropics livestock management is practised by many households with different categories of animals (e.g. small stock, cattle and buffaloes). According to ILRI (2008b), in most countries in Africa, men and women own livestock but women are facing poverty because they own small stock of low value and once sold the income is shared with all members of the household. Two-thirds of 600 million poor livestock keepers in the world are women and most of them live in rural areas (ILRI 2008b). Animal rearing is an advantage to women because it can help them to generate income for their households quicker than getting it from cropping (Persley 2004). This livestock rearing helps women to upgrade their status and increase their families‟ wealth (ILRI 2008b). However, in smallholder farming systems in the Eastern Cape Province, South Africa, Mapiye *et al.* (2009) found that cattle are owned and managed by adult males. Peter (2006) showed in his study on gender roles and relationships that men dominate in making decisions within households, but women as heads of household can assume the same roles as men. When cultivated land becomes poor, women can own an animal as a second activity and this shows the interest women put on livestock (ILRI 2008b). Among agricultural activities, Siegmund-Schultze *et al.* (2007) reported that cattle rearing was the first activity generating high income in the eastern Amazon.

In Rwanda, the population comprises 48% men and 52% women. About 28% of households are headed by women and women live longer than men though women work hard particularly in rural areas. If the households are headed by women, 91% of the households have agriculture as the main activities and 9% of households practise other activities (MINAGRI 2006). For this reason, it is important that women also own cattle so that they may increase the income within the household. ILRI (2008c) suggests that all stakeholders in agricultural development should support women livestock owners and evaluate their work for their encouragement.

2.6 Importance of forage to smallholder farmers

Forage is any plant including browse, herbage and mast that are mass harvested for feeding livestock and for better management of the environment (Stür and Horne 2001, Barnes *et al.* 2007). It also includes live grasses and legumes grazed directly by grazing animals (Grimaud *et al.* 2006), as well as cut-and-carry biomass and other forage such as hay, leaves, shredded sugarcane, chopped maize cobs, and dried cassava chips. Perennial grasses and some of the annual grasses are preferred by cattle (Kassahum *et al.* 2008). Currently there is severe loss of plant communities, including forage for livestock, which has led to poor sustainable development of livestock (ILRI 2008d). Considering the growth of high demand of animal products especially meat, milk, and milk-derived products in the next decades, there is a need of forage options capable of meeting high quality and biomass to increase livestock production (CIAT 2001). The latter propose a replacement of indigenous with exotic forage species, which are adapted to the local environment and give high nutritional value. According to Cain *et al.* (2007), in Pakistan dairy cows need a high quality and quantity of fodder in order to meet the requirement of milk production. Studies on animal feeding indicate that forage of 70% digestibility leads to feed intake of 3.3% of body weight of a ruminant and is able to increase milk production in kilograms up to ten times of its feeds intake (Waldo and Jorgensen 1981). This shows that forages are important feed resources in the world and grasses are the main feed for livestock ruminants (Holmes 1989). In the tropics, a good pasture species should have high yields of good quality, good persistence, should be easy to propagate and should have the ability to grow with a companion crop, especially a crop legume (McDowell 1972). Even if natural pasture species exist, they can be replaced by selected sown pasture species or might have other improved pastures grown with the natural pasture species (Humphreys 1987). Cultivated pasture should meet the following criteria: increase quality forage; produce high quality green forage; increase the level of animal production per unit area of land; provide hay for drought periods and provide forage throughout the year (Aucamp 2000). These characteristics of fodder crops can reduce the need for feed supplements, and raise the potential for lager herds (Rivingston *et al.* 2007). In many tropical regions, pastures are grown on infertile soils that are not suited to food crops and this leads to low forage yield for livestock (Humphreys 1987). In southern and eastern Australia where dry-land salinity is becoming a threat to the agriculture, O‟Connell *et al*. (2006), indicated that pastures tolerant of salinity could help farmers to increase agricultural productivity in these areas. Forage can be utilised as a feed resource for livestock and play an important role in maintaining the natural resource base. For example, in western Australia, *Medicago sativa* (Lucerne) has been used in crop rotation to reduce the invasion of weeds in cropping land (Doole and Pannell 2008). In southern Australia, a range of forage grown for non-irrigated farms helped farmers to feed dairy cows year-round and could be a reserve during the period of feed shortage (Chapman *et al.* 2008). It is important for farmers to exploit the synergy between crop and livestock production in order to minimise the dependence on external inputs and to enhance the overall productivity of the system (Peters *et al.* 2003). Research on animal nutrition found that the better the supply of energy in animals‟ diet the more they increased production (Roothaert *et al.* 2003). The latter authors confirmed that in the Philippines only a few farmers could succeed in satisfying the needs of their animals because they planted enough legumes for optimal production. In developing countries, most animal feeds are collected from different indigenous or introduced tropical pasture species. These indigenous pastures may have low nutritive value and lead to low livestock productivity and then hamper the sustainability of livestock production (CIAT 2007b). To overcome this problem in Mexico, farmers developed a forage seed company, for multiplying and commercialising the first hybrid *Brachiaria* cultivar Mulato. Its prime attributes were high yield and feed quality. However, its commercial success was limited by its low seed yield potential (Miles *et al.* 2004). A second hybrid *Brachiaria* cultivar Mulato II was released to the commercial market in 2005. Cultivar Mulato II has better spittlebug resistance than Mulato and is more drought tolerant but also had low seed yield. The limited seed availability of Mulato II in 2005 has been overcome and seed is commercially available in most countries of Latin America (Miles *et al.* 2007). Many other *Brachiaria* hybrids kept at CIAT‟s forage programme (e.g. Hybrid Bro2/0465, Hybrid Bro2/1485, hybrid Bro2/1452) are still under testing and their literature is limited. Their agronomic aspects are evaluated in different places in southern America, south Asia and Africa on small plots and on large-scale trial for animal production (Hayward 1999).

The interest and success of the adoption of the *Brachiaria* hybrids were due to their resistance to abiotic and biotic stress conditions (e.g. drought and diseases respectively). These new grasses were spread in Latin America and far away in the world like New Caledonia, Vanuatu and Thailand (CIAT 2007c). The latter author reported that farmers compared their indigenous grasses with the new grasses by feeding their animals and found that the new grasses were able to increase beef and milk production much more than the indigenous grasses. In addition to feeding animals, the forage species can generate income for farmers if sold for forage seed or forage biomass for animals (CIAT 2007c). Other benefits are the increase in agricultural productivity by maintaining soil fertility, reducing the need for deforestation, erosion control and mitigating climate change (Peters 2008).

2.7 Availability of feed resources

2.7.1 Crops and crop residues as feeds

Livestock productivity is constrained by poor animal nutrition especially in sub-Saharan Africa and crop residues are the most used to feed animals (Thomas and Sumberg 1995). Most agricultural crops are grown primarily for the production of grain, fibre, nuts or fruits, with about one half or more of crop production efforts resulting in residues (Unger 1994). These residues are the main component feeds in animal production (Devedra and Sevilla 2002). Furthermore, in smallholder farming systems feed resources for animals are extremely variable but usually comprise a mixture of grazing on communally owned grasslands, cut-and-carry forages from off-farm and the feeding of crop residues (Pengelly *et al.* 2003). To avoid conflicts between human food and animal feed consumption, only the wasted crop, which is defined as crop remaining after distribution, is considered as feedstock (Seungdo and Dale 2004). The feeding value of a feed (defined as its capacity to promote animal production) depends upon its ability to supply nutrients to the animal. It has three main components, the amount of feed the animal will eat, the content of nutrients in the feed and the ability of the animal to absorb and utilise the nutrients (Beer *et al.* 2000). In Europe, crop residues have been used as a feed after some chemical treatment (Owen and Jayasuriya 1989). The latter authors said that in Africa and Asia crop residues have been considered as animal feed resources for at least three decades.

The productivity of livestock in tropical countries is constrained by the lack of adequate good quality fodder, especially during the dry season. Apart from crop residues used when edible parts have been removed, forage scientists are looking for other fodder crops, which can play a dual purpose (food and fodder). The development of improved dual-purpose cowpea (*Vigna unguiculata* L.) varieties with resistance to biotic and abiotic stresses and better nutritional attributes in west Africa has shown considerable yields. For example, over 2 t ha^{-1} of grain and 3 t ha^{-1} of fodder was produced in areas with 500 mm or more annual rainfall and over 1 t ha^{-1} of grain and 1 t ha^{-1} of fodder in very dry areas with less than 300 mm annual rainfall (Singh and Tarawali 1997). Even if crop residues are the major source of animal feed in developing countries, the presence of lignin decreases the overall digestibility of residues. In addition to their low metabolisable energy (generally between 5.8 and 6.5 MJ kg^{-1} for cereal straws fed to ruminants), they are also low in protein and deficient in minerals (Vaclav 1999). Feeding residues may permit animal survival, but still results in weight loss if the animal"s diet consists solely of residues of crops (Unger 1994). The same idea is shared with Roxas *et al.* (1997) and Singh *et al.* (1997) who state that in southeast Asia, crop residues are not fully utilised as animal feed for a number of reasons, such as seasonal availability, low quality and collection and storage problems. According to Nordblom *et al.* (1997), crop residues will play an increasingly important role as feeds in the future, as human and animal populations expand in west-central Asia and north African region.

On small farms of developing countries, the fibrous by-products resulting from crop cultivation constitute a major source of nutrients for animal production (Table 2.2) and they form the principal feed of livestock during the dry seasons (Williams *et al.* 1997). In Rwanda, inadequate feed, drought and low soil fertility are important constraints to dairy cattle and crop productivity on smallholder farms (Muyekho *et al.* 2003). Native pasture and crop by-products, the major feed resources in the smallholder livestock production systems in Rwanda have insufficient nutritional value to support acceptable levels of livestock production (Hove *et al.* 2003). Many smallholder farmers attribute poor animal performance to an insufficient quantity of good-quality feed. In particular, scarcity of feed during the dry season and limited size of grazing areas have led to overgrazing. In sloping upland areas, crop production has declined, primarily because of soil erosion. This highlights the need for alternative feed sources of good quality feed to supplement the traditional sources of feeds by smallholders (Lapar and Ehut 2003). The importance of crop residues as potential livestock feed varies with the type of crops grown (e.g. cereals, grain legumes, roots and tubers), the proportion of land under food crops and with the yields of the relevant plant parts. In Rwanda, the major sources of crop residues are banana leaves and stems, roots and tubers, cereals and legumes (Leeuw 1997). The availability of these crop residues, with the exception of banana leaves and banana stems, depends upon a good harvest season.

Table 2. 2 Livestock production systems and animal feed resources in selected countries and areas

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

Source: Adapted from Seré *et al*. (1995)

X: The number of crosses indicates the importance of each animal feed resource in different countries and areas.

2.7.2 Importance of improved forages

2.7.2.1 Introduction

Many tropical grasses and legumes are of value in a wide range of tropical and subtropical farming systems. The purpose of tropical forage research and cultivar development has been to increase animal production by selecting high yielding forage species with high quality (Pengelly and Mclvor 2007). In some parts of southeast Asia, fodder crops are usually cut and carried to feed small groups of ruminants of about five dairy cows (Cain *et al.* 2007). While innovations in crop production have taken place, researchers are still facing poor management and nutrition of animals as crucial constraints to mixed crop-livestock systems (Cain *et al.* 2007). The improved forage is important not only for smallholder farming with shortage of land but also in crop-livestock farming systems to improve both crop and livestock productivity. For example, twenty commercial cultivars of *Brachiaria* species have been established in more than ten Latin American countries in the past few years (Miles *et al.* 1992). In Australia, forage legumes like *Stylosanthes* spp. have also played an important role where farmers widely adopted and used them to supplement grazing animals based on native pasture (Coates *et al.* 1997). In South Africa and Zimbabwe, improved forage legumes were introduced to improve soil nitrogen and to feed animals by supplementing maize stover and other feed of low quality (Pengelly *et al.* 2003, Ayisi *et al.* 2004). Although the improved forages give high productivity, they were strained by biotic stress like insects and other pests (Lapointe and Sonoda 2001). Native pastures are adapted to their environment and they can tolerate it better than improved pastures. However, when we come to quality and productivity, improved pastures are much more productive, higher in nutritive value and respond well to intensive management. Therefore, the first phase in intensifying forage species is to establish the most adapted pasture species to a given environment (Chandler 2001). The improved forages can help to protect land degradation that is a major ecological problem across the globe (Fatunbi and Dube 2008). Forage maintains soil fertility especially in mixed systems where its organic matter becomes fertiliser and forage legumes increase nitrogen (N) in the soil by fixing N atmospheric (Mannetje *et al.* 2007). Forage can decrease soil erosion by reducing raindrop energy, decreasing run-off, increasing water infiltration and protecting the soil surface (Karlen *et al.* 2007). Forages for feeding livestock can be produced on cropped land as well as on uncropped land or non-farm areas. Considerable differences in the opportunities for introducing forages in different agro-ecosystems and regions have been found. These include available arable land per capita, the number of crops that can be grown per year, market access, labour availability and farmers' perceptions of the risks and rewards of investing in their livestock enterprises (Steinbach 1997). Nevertheless, the introduction of forage crops is a promising way of promoting sustainable agriculture in the low input systems of resource poor farmers.

2.7.2.2 Adaptation of forage grasses to harsh environments

The adaptation of a plant depends on the climatic and edaphic conditions for a given area (Pitman 2001). The grasses in particular are adapted to the 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 reputed to be adapted to infertile and acidic soils (Pitman 2001). A range of grasses including *Chloris gayana*, *Panicum maximum*, *Eragrostris curvula* and *Digitaria eriantha,* with high quality, have been identified to be adapted to different stress conditions in Zimbabwe (Mapiye *et al.* 2006a). 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 aluminium and manganese in Colombia and on salty soil in Pakistan showed that grasses have the mechanisms to adapt to these stress conditions (Rao *et al.* 1996, Hameed *et al.* 2009). 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 the herbivores. They also can protect soil by retaining water run-off (Popp *et al.* 2009). This is why many studies on their adaptation are numerous and 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), savanna 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 to the abiotic and/or biotic stress conditions (Vogel and Lamb 2007). In addition, the adaptation implies 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 (Wilson *et al.* 1980, Ghebrehiwot 2004). Considering all these aspects of adaptability, Kretschmer and Pitman (2001) propose that their development under different environments will be a substantial achievement.

2.8 Factors affecting the adoption of new technologies by smallholder farmers

Many studies on selection and adoption of agricultural technologies found that the size of farm, unpredictable risk, human resources, lack of credit, scarcity of labour and land tenure security were the major factors which determine the adoption (Feder *et al.* 1985).

After four decades in forage research, it has been found that few farmers adopted the new forage options in southeast Asia (Roothaert *et al.* 2003). These authors said that traditional approaches to new technologies like interviews, identification of problems by development workers and development of technical solutions by researchers did not result in a spontaneous adoption. In Honduras and west Africa, farmers abandoned forage legumes for controlling weeds in maize crops when new species were introduced to control weeds (Neill and Lee 2001). In Kenya, a study was undertaken on household-level determinants of adoption of improved natural resources management practices among smallholder farmers carried out by Marenya and Barret (2007). They found that factors determining adoption were number of adults per household, farm size, level of education, gender of household head with male adoption more than female, age of household with older members less likely to adopt than younger members, non-farm income, type of enterprise on the plot and livestock holding. These factors were almost the same as those found by Mapiye *et al.* (2006b) when they assessed the constraints to adoption of forage and browse legumes by smallholder dairy farmers in Zimbabwe. They found that the large size of household and land size and higher number of dairy cattle positively affected the adoption of forage technologies whereas the lack of inputs, low yields and lack of persistence of forage species and lack of fencing material were identified as core factors limiting adoption of forage technologies. In the Bergville district of South Africa, factors affecting adoption were biophysical factors including heavy rain with hail, frost and winter, acidity of soil, and social factors including lack of knowledge and cultural belief (Sturdy 2008). Furthermore, in the KwaZulu-Natal province, South Africa, the factors driving smallholder farmers to adopt the new cotton were availability and accessibility of credit or capability of farmers to purchase inputs (Yousouf *et al.* 2002).

When Cain *et al.* (2007) assessed the critical factors affecting the viability of small-scale dairy farms in the Punjab province of Pakistan they found that the low adoption of the new plant varieties by farmers was due to low forage yields and lack of knowledge in animal nutrition. In Vietnam, the factors determining the adoption of the integrated aquaculture agriculture farming (IAA-farming) technologies were assessed by Dang *et* *al.* (2007). They found that wealth was the key factor where 60% of rich households and 6% of poor households adopted these technologies. Tuhulele *et al.* (2000) found that in southeast Asia, adoption of suitable forage technologies by smallholder farmers was achieved in six years. They confirmed that there was no plan for technology adoption, only by evaluating forage with farmer participation; it has led to more than 1700 farmers continuing with multiplying forages. Lapar and Ehut (2003) indicated that in the Philippines, the adoption of dual-purpose forages by farmers was due to the educated farmers having a higher income and more access to credit. In addition, farmers who were located in the upland where there were problems of soil erosion and deteriorating grazing land were more likely to adopt dual-purpose forages (Lapar and Ehut 2003). Wortman and Kirugu (2000) suggest that in Africa, in addition to agronomic aspects of forages, farmers‟ perception of the need of soil improvement and animal nutrition will favour the adoption. The study on adoption and impact of hybrid wheat in India carried out by Ira *et al.* (2007) found that small scale-farmers adopted this hybrid because they benefited from this hybrid more than other farmers. This is because wheat hybrid was the main important crop for farmers‟ utility. Peters and Lascano (2003) stated that there were many interventions to improve farmers‟ choice of forages as follows: (i) involve farmers at the beginning of the action; (ii) identify entry points to deal with production and natural resources management (NRM) in farming systems; (iii) identify genotypes to environmental and socio-economic area; (iv) focus on the utilisation of forages which give value–added products; (v) ease linkages between smallholders and markets; (vi) provide catalysis for the development of seed systems; and (vii) develop methods to facilitate distribution of forage by farmers and private forage seed companies.

There is enough information that highlights the importance of involving farmers in the beginning of research for development (Peters and Lascano 2003). According to Roothaert *et al.* (2003), the key to adoption of forage technologies is to allow farmers to experiment, adapt and expand. Small-scale upland farming systems are unique and have diverse priorities, which prevent mere replication of technologies. The authors continue in saying that, experiences mostly in southeast Asia and some in east Africa, have shown that participatory approaches in the development of technology are the key to integration of forages into smallholder upland farming systems.

Multi-purpose forage adoption can result in increased income for smallholder farmers and benefit NRM. However, to promote the adoption of forage based on new technologies by small and medium-scale farmers in tropical developing countries, there is a need for sustained funding of strategic research on forages, for linking on-station with on-farm research, and for farmer driven research and development (Peters *et al.* 2003). Based on an on-farm evaluation, Roothaert *et al.* (2003) reported that adoption of forage grasses by farmers was higher than forage legumes in southeast Asia. Possible reasons for this were that the farmed ruminants in southeast Asia were cattle and buffaloes, which select grass when they graze, and that improved grass species established quickly, grew rapidly and produced more biomass than legumes. Furthermore, growing grass forage was a new option for most farmers from southeast Asia and this forage provided long-term or indirect benefits (Roothaert *et al.* 2003). In contrast, in the tropics, forage planting material and/or seed has often been unavailable locally or was unaffordable. In the past, researchers have concentrated on developing forage technologies that produced high fodder biomass or maximized animal productivity. Farmer"s priorities are more complex than this; farmers" needs for forages are diverse. According to Makokha *et al.* (1999), social status of the farmers is not significant in explaining adoption behaviour but indicates that early technology adopters are likely to be those who participate in local activities that introduce and explain new approaches to agricultural innovation. This latter approach has been confirmed by Zewdu (2003) who stated that of all the factors that influence the adoption of the forage innovation, the major one is the full participation of communities. A process approach is needed to allow communities to participate in all stages of the forage development.

This literature review highlights the importance of integrated crop-livestock systems as well as fodder crops to smallholder farmers where the land has become scarce. In many countries, increase in population has led to a decrease of grazing land because land for food crop production has a higher priority than land for livestock rearing. In addition to the shortage of grazing land, there is a lack of high quality forage. In countries where grazing lands do not exist, animals are kept in a shed and are fed indigenous plants (grasses and legumes) harvested in different places including roadsides (Tanner *et al.* 2001). This zero grazing system has become more frequent in many areas of Asia (Horne and Stür 1999) and in sub-Saharan countries including Burundi, Kenya and Rwanda (Tarawali *et al.* 1995). From this confined livestock rearing, all members of a family participate in livestock activities especially searching of forage to feed animals. However, many studies have found that wealthier farmers are able to increase animal products as they can afford different feed resources for their animals as well as acquiring land for forage production (Cramb 2005, Rufino *et al.* 2007). Dar and Twomlow (2007) suggested that on-farm research should involve farmers at all stages so that they can gain knowledge of new technology. Farmers will be able to integrate crop-forage production for human and animal consumption. In addition, the forage that is intended to be integrated should tolerate prevailing farm conditions. Therefore, in the areas of Rwanda constrained by low rainfall and acidic soil new forage should tolerate these conditions. This project was designed to engage farmers in all stages of the forage development from assessing current feed resources to evaluating new forage (e.g. improved *Brachiaria* grass) adapted to acidic soil and drought stress of Rwanda.

CHAPTER THREE–STUDY AREA

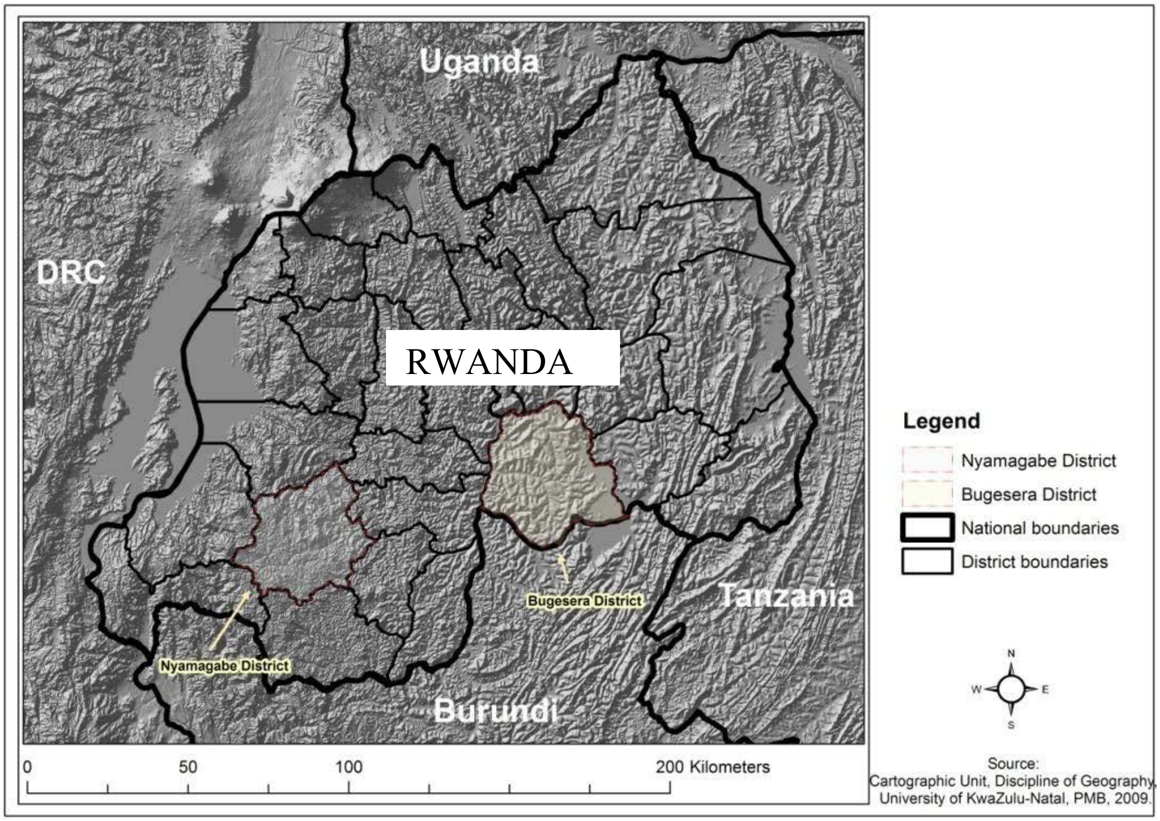
The purpose of this chapter is to give an overview of the study areas, which were the Bugesera and Nyamagabe districts. It is comprised of two main sections (1) the details of the study sites and (2) the description of two grasses: (i) a native *Brachiaria* grass which is one of the important indigenous grasses used by farmers to feed their animals and (ii) the naturalized *Cenchrus ciliaris* (Buffel grass). This study forms part of a collaborative research project between the Rwandan Agricultural Research Institute (ISAR, its French acronym) and the International Centre for Tropical Agriculture (CIAT, its Spanish acronym). The aim of the project is to improve fodder in areas subjected to drought and aluminium toxicity by introducing improved *Brachiaria* grasses that are resistant to these abiotic stresses. This study reported in this thesis focuses on the participatory and experimental evaluation of the quantity and quality of these improved and indigenous *Brachiaria* grasses in two study sites.

In 2006, the Rwandan Ministry of Local Government reformed the existing administrative authorities where the former divisions (provinces, districts, sectors and cells) were reduced in number but enlarged in area. The study area comprised two districts: a low rainfall area, which is the Bugesera district, and an area with acidic soils with high aluminium saturation, which is the Nyamagabe district (Figure 3.1). These districts were selected as the study sites as they represent the most common constraints faced by smallholder dairy farmers.

3.1 Bugesera district

3.1.1 Location and population

Bugesera district is the combination of the former districts of Gashora, Ngenda and Nyamata, which were located in the former Kigali-Ngari province. It lies between 30^{o}-30°$25^{``}$ east and 2°$05^{``}$–2°$30^{``}$ south (Munyemana 2001). It has 15 sectors (government administrative unit under the district) and is bordered in the south by the Republic of Burundi (Figure 3.2). The total area of the district is 1303 km^2 and the population in 2007 was approximately 292,380 (MINALOC 2008). The average population density of the district is 205 persons per km^2 ranging from 91 persons per km^2 in Rweru sector to 396 persons per km^2 in Ruhuha sector (JICA 2007).



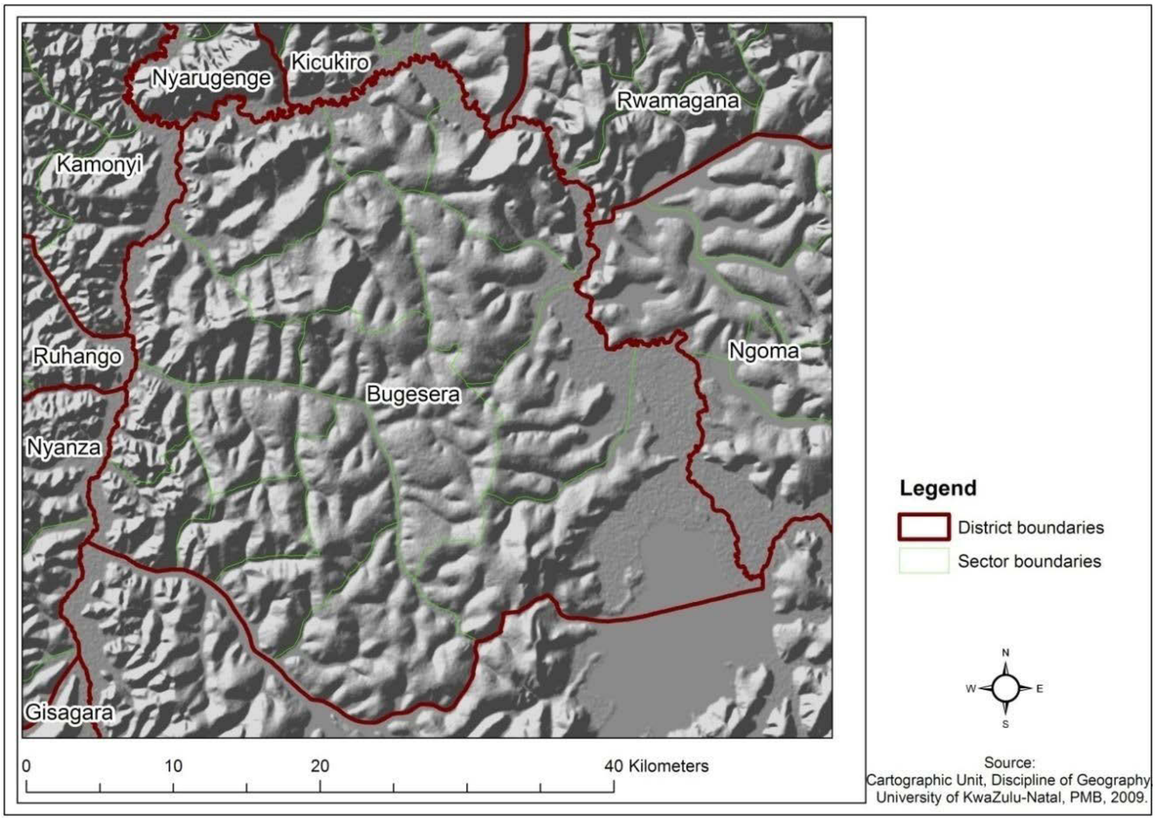
Source:
Cartographic Unit, Discipline of Geography, University of KwaZulu-Natal, PMB, 2009.

Figure 3. 1 The locality of the districts (Bugesera and Nyamagabe) in Rwanda.

3.1.2 Soil and Topography

Bugesera is located in a new eastern province of Rwanda at an altitude varying between 1350 and 1600 m a.s.l. It is in the savanna agro-ecological zone of Rwanda (Kalinganire 1996). Its soils are sandy apart from around lakeshores and in the valley where the soils are characterized by clay and low content of organic elements and materials respectively (JICA 2008). Although there is humus in the soils of Bugesera, its colour is red in the whole district (Mutabazi 1984). The soils were formed from quartz-schist, schist-quartz, mica-schist, granite, gneiss, and intrusion of basic rocks and from colluviums, alluvium (found in marchlands and valleys) coming from the above elements

(Balasubramanian and Egli 1988). These authors describe the topography of Bugesera as undulating at altitudes varying between 1350 m and 1600 m about sea level with a moderate slope less than 15 % (Figure 3.2). Although the slopes are gentles, JICA (2007) said that some places in Bugesera might face problems of soil erosion. Observations confirm that the erosion problem occurs when the land slope is steeper than 5%. For this reason, crops cultivated on slopes suffer from erosion and farmers spend a lot of time trying to control it by planting some grasses like vetiver grass (*Chrysopogon zizanioides*) on contour bunds (JICA 2007).



Source:
Cartographic Unit, Discipline of Geography
University of KwaZulu-Natal, PMB, 2009.

Figure 3. 2 Map of the Bugesera district.

3.1.3 Climate and vegetation

The climate of Bugesera is characterised by an average temperature of the coldest month lower than 18°C and a long dry season (Munyemana 2001). This dry season is an acute season, which lasts for 4–5 months (Jun–October) of the year. Annual rainfall is highly variable, ranging from 761–1192 mm at Ruhuha station, 671–1524 mm at Nyamata, and 671–1082 mm at Karama in the Gashora sector. The average rainfall in the whole district is 750 mm per annum. While heavy rain causes serious damage on farmlands in the wet season, the drought causes serious problems in upland agriculture in the dry season (Rwicaninyoni 1987). The latter author said that the daily temperature generally varies between 15°C and 28°C with an average of 21.5°C. The average relative sunshine calculated over 18 years is 51.5%, the relative humidity of the air is around 73.5% and the mean velocity of the wind is 3.68 km h^{-1}.

In the Bugesera district, the main vegetation type is savanna woodlands (Pinners and Balasubramanian 1991) characterised by xerophilous thickets. These thickets contain a large diversity of species with *Carissa* spp., *Haplocoelum* spp., *Olea* spp. dominating, whereas the small lawns are mainly gramineous, especially *Brachiaria humidicola* and *Brachiria decumbens,* which grow between the thickets. These thickets characterize the local pastures (Munyemana 2001) and the natural vegetation of the Bugesera district (Mutabazi 1984).

3.1.4 Farming system

In the Bugesera district, many people face a shortage of land. Currently, about 30% of households have no land while 40% own less than a half-hectare (JICA 2007). To address the issue, 19% of the population rent land (pay some money to someone for the use of land in a given period). There is 3% borrowed land (borrowing a piece of land from someone without paying money for a given period, sometimes one cropping season). In the district, as in many areas of Rwanda, farming is based on crop production for subsistence (home consumption) (NISR 2007). On average, only 18% of households in Bugesera produce for the market. More market-oriented households are found in Ntarama, Musenyi and Mayange sectors, where 40, 35 and 33% of households produce for the market, respectively (JICA 2007).

Because of land shortage, the traditional farming system based on a fallowing system is no longer practised, because there are no cultivated lands currently reserved for fallow longer than two years. Relatively well-off farmers purchase land from poor immigrant farmers. Consequently, many poor farmers lost their land and have to rent from neighbours (JICA 2007). The main crops cultivated in the district are maize, cassava, sweet potatoes, sorghum, beans, soybeans, and peanuts. Other cultivated crops include rice, irish potatoes, taro, green peas, and vegetables (e.g. cabbage, tomato, eggplants) (JICA 2007). The main domestic animals raised in Bugesera are cattle, goats, sheep, poultry, pigs, and rabbits. Typically, better-off farmers own at least five local (Ankole) cows and a few goats; the middle class own one to three cows and five to eight goats, while the poor possess only a few goats and the very poor only a few rabbits (JICA 2007). In addition to agricultural crops, cattle are well distributed in the Bugesera district. About 20,950 cattle were recorded in the district in 2007, with high numbers in Nyamata and Kamabuye and less in Shyara and Nyarugenge sectors (JICA 2007). Poverty alleviation is the principal goal in rural and agricultural development of Bugesera. Livestock production is expected to improve livelihoods of the poor. However, policy interventions do not practically support these entire complex systems. The constraints of the farming system in the district, according to Musahara (2001) are: long dry season, lack of fertilizers, lack of property rights which is a disincentive for perennial crops, lack of water in the dry season especially in the southern and northern parts of the district though there is abundant water in lakes and the Akagera river. In the southwest part of Bugesera farmers face similar constraints but these are compounded by scarcity of land and almost complete absence of grazing land. The latter issue has led the livestock owners to adopt a zero grazing system where animals are kept and solely fed in a shed.

3.2. Nyamagabe District

3.2.1 Location and population

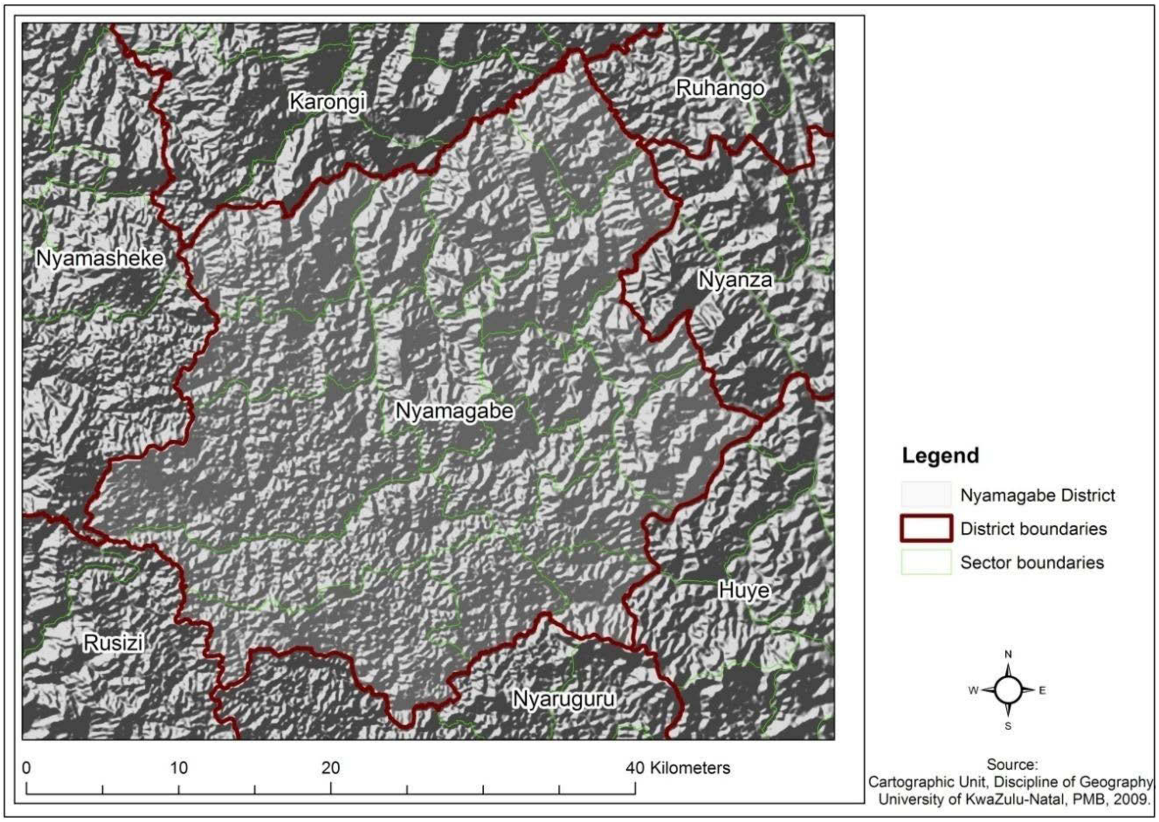
Nyamagabe district is located in the southern province of Rwanda. It is a new district which resulted from the merging of the former districts of Nyamagabe, Kinyamakara and Karaba in 2006. It lies between $29^{o}56$‘‘ east and $24^{o}47$‘‘ south. It has 17 sectors and is bounded in the south by the district of Nyaruguru, in the north by the district of Karongi, in the east by the districts of Ruhango, Nyanza and Huye and in the west by the districts of Nyamasheke and Rusizi (Figure 3.3). The total area of the district is 1091 km^2 and the population in 2007 was approximately 333,587 (MINALOC 2008).

3.2.2 Soil and Topography

Nyamagabe is a highland area with very steep slopes. Its altitude ranges from 1500–2500 m a.s.l with an average of 1800 m a.s.l (Olson 1994a). The altitudes increase from east to west and half of the area has a slope ranging between 40-50% (FAO 1989). The steep slopes (Figure 3.3) and the demographic pressure on this uneven land of Nyamagabe, has led to severe erosion in the area (Olson 1994b). The soil of Nyamagabe is classified as hygro kaolisols humiferes (humic ferrasols) (PIA 1986). It is in the ruzian system constituted by the complex rocks (metamorphic) of the precambrian age: with diverse schist, granite, gneiss, quartzite and basic rocks (amphibolites and pyroxemites) (PIA 1986).

Different areas of the Nyamagabe district are characterized by severe soil acidity and aluminium toxicity. In the high altitude areas (more than 2000 m) of the district, peat predominates over mineral soils. The soils in swamps are clay and kaolin with high soluble alumina (Al^{3+}= 4 meq 100 g^{-1} of soil) and pH ranging between 4.3 and 4.9 (Nzamurambaho 1996). The low pH combines with high levels of aluminium obstructing biological activities (PIA 1986).

The agricultural potential is low to average and the altitude limits the variety of crops. Physical properties are good and the risk of acute dryness is limited by the climate (Kanyarukiga and Ngarambe 2003). In the Nyamagabe district, some components of the ecosystem especially the vegetation is under stress because of the acidic soil, which leads to low food production (Musahara 2006).



Source:
Cartographic Unit, Discipline of Geography
University of KwaZulu-Natal, PMB, 2009.

Figure 3. 3 Map of the Nyamagabe district.

3.2.3 Climate and vegetation

The Nyamagabe district has two rainy seasons. The short rainy season is from September to November and long rainy season is from March to June. In the lowland, the average temperature is 18^{o}C, the rainfall is 1472 mm year^{-1}, and this is the characteristic of humid climate (Ndikumana and Leeuw 1996). In the highland (2000–2500 m a.s.l), the average temperature is 15.5^{o}C and the rainfall is 1800 mm. For the whole district the average annual rainfall is about 1636 mm and the annual temperature ranges from 11.5^{o}C to 20.5^{o}C with an average of 16.5^{o}C (Nzamurambaho 1996).

In the Nyamagabe district, vegetation was composed by grassland, which was created by pastoralists and managed through burning, ensuring younger grass for their grazing animals (Schoenbrun 1993). Due to high population and problem of erosion, grasslands have disappeared. However, some grasses are found under planted trees for erosion control. These are dominated by *Brachiaria* spp. and other species grown in the acidic soils like *Eragrostis* spp., *Hyparrhenia* spp., and *Digitaria* spp. (Nzamurambaho 1996). The remaining natural vegetation in the Nyamagabe district is the Nyungwe forest, which is mountain forest (PIA 1986). As grasslands have disappeared and that there is severe soil depletion, keeping animals in a shed has become an important activity to provide milk for home consumption, cash and manure for crop fertilisation. For this reason, growing grasses and tree legumes is a part of the crop-livestock production system in the Nyamagabe district (Olson 1994a).

3.2.4 Farming system

The Nyamagabe district is part of the highlands in the country and has a diverse farming system that follows the altitude (Table 3.1). The farming system depends on the climate and the topography. Increased population pressure has resulted in continuous cultivation on the same plots. This has led to low soil fertility particularly on steeper slopes resulting in decreased agricultural production (Niyongabo 2004). The latter author reported that the average farm size in Nyamagabe has declined dramatically in the last three decades (11% increases in households with less than one hectare land).

Table 3. 1 Farming system in the Nyamagabe district

Occupation and use of land	**Farming system**
Edge of Nyungwe forest (> 2000 m of altitude)	1) Irish potato 2) Maize 3) Tea 4) Peas
Central plateau (1600–1800 m of altitude)	1) Soybean 2) Sweet potato 3) Beans 4) Cassava 5) Colocase
Intermediary zone (1900 m of altitude)	1) Sylviculture (planted forest) 2) Livestock

Source: Adapted from Nzamurambaho (1996)

The traditional farming system in Nyamagabe is related to land tenure where land is either inherited (land given/left to children by parents) or purchased (getting land from someone by giving money or other worthy things). Farming is based on traditional tools (e.g. hoes) used in land cultivation. Farmers use ordinary seeds bought from local market or from neighbours and crops are mixed in the small plot with no fertilizer application (NISR 2007). This traditional farming system has led to low crop production and soil depletion. However, near the homestead, the soil is fertile due to organic manure from stalled animals which is spread on the nearest crops and/or planted pastures (PIA 1986).

3.3 Summary of the two sites

The two districts have a contrasting environment in terms of soil, climate, topography, vegetation and farming systems. Characteristics of the two sites (Table 3.2) show their distinctions.

Table 3. 2 Environmental comparison of the study sites

Environment characteristics	Nyamagabe district	Bugesera district
1. Location and population	Southern province of Rwanda, lying between 29^{o} 56" east and 24^{o} 47" south. Elevation ranges from 1500 to 2500 m a.s.l. The area is 1090 km^2 with a population of 333587 approximately	Eastern province of Rwanda, lying 30^{o}–30° 25" east and 2° 05"–2° 30" south. Elevation is ranging from 1350 and 1600 m a.s.l. The area is 1303 km^2 with a population of 292380 approximately
2. Soil and topography	Clay and kaolin. Soil is acidic (pH 4.3–4.9) with Al^{3+} = 4 meq (milliequivalent) 100 g^{-1}. The district is in highland with steep slope ranging between 40% and 50%	Clay, sandy, low content of OEM. The pH of soil is > 5.5. Undulated topography with slope > 15%
3. Climate	Average rainfall per year 1636 mm and average temperature is 16.5^{o}C.	Four to five dry months per annum, average rainfall of 600–900 mm per year with annual temperature of 21^{o}C.
4. Vegetation	Dominance is *Eragrostis* spp., *Hyparrhenia* spp., *Digitaria* spp. and *Brachiaria* spp.	It is savanna woodland with xerophilous thickets.
5. Farming system	Subsistence farming depends on altitude but the main crops are irish potatoes, maize, tea and peas which are integrate with livestock composed of pigs, cattle, goats, chickens and rabbits.	Subsistence farming. Main crops are maize, cassava, sweet potatoes, sorghum and beans integrated with livestock especially cattle, goats, sheep, chicken, pigs and rabbits

The Nyamagabe district is more populated (0.33 ha of land per person) than Bugesera (0.44 ha of land) (MINALOC 2008). In Nyamagabe, soil acidity, high human population and heavy rain on the steep slopes have had a negative impact on crop and livestock production. In Bugesera, dryness and high human population are the major constraints to farm production.

The vegetation differs according to topography and climate. In the study area, it varies from woodland and rainforest for Nyamagabe and to savanna for Bugesera. Common constraints across the two sites are land shortage due to the high population (IFAD 2007). Even though some crops and livestock are the same, some crops are specific to each site. For example, tea is found on the highland area of Nyamagabe and is one of the cash crops in the area, while irrigated rice is one of the cash crops in the Bugesera district. Livestock farmers in both districts own the same type of animals but Bugesera has a larger number of cattle and goats than Nyamagabe. Traditionally, the Bugesera district has been a pastoralist area and its population has increased in recent decades. In Nyamagabe land shortage due to high population pressure has been reported for several decades (Musahara and Huggins 2005) and has led to a decrease in animal numbers, especially cattle (FAO 2006a). According to IFAD (2007), the distribution of livestock in the Nyamagabe district depends on the wealth of people where the better off can buy cattle and/or pigs. In the Bugesera district many farmers raise cattle and goats that they inherit from their parents. The number of ruminants in both districts showed that in 2002 the Kigali-Ngari province (with current Bugesera district) had 89359 head of cattle and 107045 heads of goats. This number was higher than that of Gikongoro province (with current Nyamagabe district) which was 50701 heads of cattle and 15344 heads of goats. However, sheep were higher in Gikongoro province (40202 heads) than in Kigali-Ngari province (4171 heads) (HPI 2005). While some farmers are constrained to keep animals in a shed due to the decrease of grazing land in the Bugesera district, in Nyamagabe farmers has adopted that system and collect manure for crop fertilization. This system of keeping animals in sheds will also need quantity and good quality of forage adapted to these two contrasting environments.

Some studies carried out in the southern province of Rwanda (where the Nyamagabe district is located) have reported crop failure for bush beans because of soil acidity and aluminium toxicity (FAO 2006b). To address this issue, the Rwanda Agricultural Research Institute (ISAR) and the International Centre for Tropical Agriculture (CIAT) carried out research trials and were able to recommend climbing beans, which could resist this stress. However, less attention has been given to the poor quantity and quality forage for livestock.

3.4 Description of grasses used as controls

Grasses used as control in this study were *Brachiaria decumbens* and *Cenchrus ciliaris*. While *B. decumbens* grows naturally in Rwanda, including the Bugesera and Nyamagabe districts, *C. ciliaris* was naturalised and used as forage in both district.

3.4.1 Brachiaria decumbens

Brachiaria decumbens is native to Africa particularly in central and east Africa from 500–2300 m a.s.l., including Burundi, Kenya, Rwanda, Tanzania, Uganda and Democratic Republic of Congo (Whiteman 1980, Schultze-Kraft and Teitzel 1992). In Rwanda, forage researchers collected accessions of *Brachiaria decumbens* from almost the whole country including the Bugesera and Nyamagabe districts (Keller-Grein *et al.* 1996). It is now widely distributed in many places of tropical America, southeast Asia and the Pacific.

Brachiaria decumbens grows on a wide range of soil types including those of low fertility, low pH (as low as pH= 3.5) and high aluminium saturation (Rao *et al.* 1996). Many areas of the tropics are extensively planted to *B. decumbens* by broadcasting seed (Fisher and Kerridge 1996). *Brachiaria decumbens* can also be planted easily from vegetative sets (leaf with rhizomes) although it may not spread and cover new land very quickly.

Brachiaria decumbens has a moderate to high nutritive value similar to other tropical grasses, but it is greatly dependent on the fertility of the soil and/or the quantity of the fertilizer applied (Ndikumana and Leeuw 1996). It gives a high quality of forage resulting in high yield of beef and milk (Rivas and Holmann 2005). However, animal production (especially body weight and milk production) declines after a few years on acidic soils planted to *B. decumbens* unless fertiliser is applied every two to three years (Abdalla *et al.* 1999).

3.4.2 Cenchrus ciliaris

Cenchrus ciliaris originated from tropical and sub-tropical Africa and southern Asia. It has been naturalised and expanded in northern and western Queensland in Australia (Cameron 2004) and in Texas and Mexico (Mandy 2002). It is well adapted to well drained soil, especially on sandy loam soils, but its growth is inhibited by tight clay soil or waterlogging, salinity and deep sandy soils (Wayne 1988). *Cenchrus ciliaris* grows best in the tropics and subtropics with rainfall ranging from 300–1200 mm year^{-1} (Cameron 2004). *Cenchrus ciliaris* can be established using a seeding rate of 3 to 4 kg ha^{-1} or by tillers and is used to re-seed denuded arid lands (Whiteman 1980, Ndabikunze 2004). When stolons are used to establish it, it requires enough rainfall for rhizomes to sprout (Mandy 2002).

The DM production of 4–5 t ha^{-1} has been obtained in Australia with fertilizer application. With application of N (20 kg ha^{-1}), the annual DM production increased from 942 to 1785 kg ha^{-1} over ten years in arid zones of India (Rao *et al.* 1996). Increases of 300 kg ha^{-1} DM of *C. ciliaris* were obtained when applied fertiliser was combined with mulching in Ethiopia (Gebremeskel and Pieterse 2008).

Cenchrus ciliaris is an aggressive grass that grows in disturbed, mesic conditions and can compete with other grasses. According to Marais *et al.* (2006), when conducting a trial of irrigation on perennial grasses in South Africa, they suggested that *C. ciliaris* should not be used as control grass under irrigation trials because it is known as drought tolerant grass.

CHAPTER FOUR–ASSESSMENT OF LIVESTOCK FEED RESOURCE-USE PATTERNS IN THE BUGESERA AND NYAMAGABE DISTRICTS OF RWANDA

Abstract

Livestock rearing in Rwanda, including the Bugesera and Nyamagabe districts is practised under stalling. This is due to the high human population which results in a land shortage. More land is devoted to cropping than to livestock production. In the Bugesera district, animal feed is constrained by low rainfall whereas in the Nyamagabe district, it is constrained by acidic soil with aluminium toxicity. As feeds for animals have become labour-intensive, within a community, men and women may have different interests in livestock production. In addition, wealth status of farmers may influence the development of livestock production under the problem of land shortage and different abiotic and biotic stress conditions. The objectives of this study were (i) To determine feed resources and the availability of each feed resource that was used by farmers each month and (ii) To analyse the role of gender and wealth categories in livestock activities in target areas. Focus group discussions were held by 20 farmer representatives from each district. Farmers were divided into two groups of males and females and each group drew up livestock activities related to gender. In each district, 20 farmers identified criteria to rank the identified feed resources. Individual farmers gave scores to each identified feed resource according to farmers‟ criteria and the scores were considered as quantities measured. It was found that in both districts, livestock activities were shared between genders, but certain activities (e.g. milking cows, animal shed construction) were intended for males due to the culture beliefs. In both districts, wealth ranking showed that land, number of cattle and the type of cattle owned by farmers were the important characteristics of categorising the community. In the low rainfall district (Bugesera), four exotic, three indigenous fodder species and six crop residues were identified with preference scores ranging from zero to ten. *Pennisetum purpureum* (Napier grass) was given the highest score which ranged between six and eight because of its availability all year round. The indigenous grass received a median score of five for its availability year

round. In acidic soil area district (Nyamagabe), five exotic fodder species, five indigenous fodder species and 11 crop residues were identified. Napier grass and *Commelina benghalensis* were scored high with a median score of eight. *Panicum maximum* (indigenous grass species), maize stovers (crop residue) and *Albizia amygdalina* (indigenous tree species) were important forage because they were given a median score of seven. The preference ranking confirmed that overall Napier grass was the major fodder crop used throughout the two districts followed by some indigenous species and crop residues. The scores for availability, quality and quantity of feeds showed a shortage of livestock feed resources in both districts indicating a need for suitable forage species adapted to these areas of low rainfall and acidic soils.

4.1 Introduction

Forage production in Rwanda has become more labour-intensive because of the scarcity or complete loss of rangelands. Crop residues, cut grass and browse are gathered to feed livestock kept in confinement (Hoffman *et al.* 2001, Kebreab *et al.* 2005). Poor animal nutrition is one of many constraints faced by smallholder farmers since they rely on naturally growing grass on limited plots of land for feeding dairy cattle (Malima 2005, Nkya *et al.* 2007). Grasslands are an important feed for livestock production especially for low resource smallholder farmers (Wanyama *et al.* 2003). However, grasslands mature rapidly, become very fibrous, and of low quality especially during the dry season (Bennett *et al.* 2007). Furthermore, grazing lands are rapidly shrinking as more land is devoted to crop cultivation to satisfy the needs of the increasing human population. Crop residues are another important feed source but their quality is often too low to sustain ruminant production. Feed resources are classified into four main categories for use in smallholder crop-livestock farming systems. These are grass and legumes (indigenous and improved grasses, herbaceous legumes and multi-purpose trees), crop by-products, agro-industrial by-products (e.g. rice bran, molasses, maize bran) and non-conventional feed resources (e.g. brewers grain) (Devendra and Sevilla 2002, Mekasha *et al.* 2003).

Livestock and cropping have always been complementary in Rwanda, where more than 90% of the population depends on these activities for food and income generation. In

Rwanda, traditionally most livestock owners used a continuous grazing system. However, the growth of the population has led to increased settlements resulting in a decrease in grasslands. This has led to the adoption of a zero grazing system (animals are kept and solely fed in a shed) as the dominant system in Rwanda including the Bugesera and Nyamagabe districts. In the Bugesera district, grasslands have disappeared due to the long dry season, increased density of human population and mismanagement of communal grazing land. According to Niang *et al.* (1998), the area of native pasture has decreased by 22% in 1990 and by a further 14% in 2002. In the Nyamagabe district, the decrease of the grasslands is the result of a combination of many factors such as human density, continuous erosion due to the steep slopes in the area and high aluminium concentration and low pH in the soils. To address the above constraints, the zero grazing is the most appropriate crop-livestock production system. In some countries like Swaziland, farmers do not grow fodder crops but use the maize stover remaining after grain harvesting for livestock fodder. As a result, they have to purchase hay and other fodder types to supplement animals in the dry season and these are not only scarce but also expensive (Malima 2005). Contrary to this, in Rwanda small-scale farmers grow fodder crops especially grasses. Sometimes they are constrained by lack of improved and adapted forage species. The most important factor that controls both the composition and productivity of the plant community is rain. Not only the amount of rain but also the distribution is important (Butterworth 1985, Zambatis 2003).

According to Chinwe *et al.* (2008), apart from the amount of rain in a given area, other factors like labour scarcity and lack of appropriate agricultural policy contribute to poverty within households. When conducting an on-farm research study, Asten *et al.* (2009) and Roba and Oba (2009) suggested the use of farmer participatory research (FPR) as an important factor, which incorporates indigenous knowledge in the process of technology development.

The farmer participatory research has been used in many studies and it requires knowing some characteristics of farmers within community, such as gender analysis and wealth ranking of the community. Poats (1991) describes gender analysis as the social attributes and roles of men and women in a community. The author continues in saying that physical and biological aspects are different between men and women. Gender is an important socio-economic variable in analysing roles, responsibilities, constraints, opportunities, and incentives of the females and males involved in agriculture (Poats 1991). Gender analysis is an important aspect influencing livestock management in working communities. Within a community, men and women may have different interests in the livestock production. On the other hand, wealth ranking is also an important parameter to analyse in order to establish the link between wealth categories and capturing the interest of the farmers in a new technology. According to Alumira (2002), stratifying members of a community in wealth and role of gender can help researchers to direct the best developed technologies to the development pathway of that community. The aim of this chapter was to identify animal feed resources used by the farmers in the Bugesera and Nyamagabe districts of Rwanda. The objectives were (i) to assess the feed resources used under low rainfall, acidity and Al-toxic stress conditions, (ii) to analyse the role of gender and wealth categories in livestock activities in target areas (iii) to assess the quality in the wet and dry seasons in terms of type of feed resource. The results of this study will be used to identify the main constraints faced by farmers in each district so that forage researchers can develop suitable forage technologies to overcome these constraints.

4.2 Materials and methods

4.2.1 Site selection

The study was conducted in the Bugesera and Nyamagabe districts of Rwanda. The criteria for selection were exposure to low rainfall and acidic soils; the criteria were selected because they represent different constraints experienced by farmers. The other aspects were that crop and livestock production should be the major economic activities in the areas. Three sectors (government administrative division under a district) of the Bugesera district that were selected were Nyamata, Mareba and Musenyi. They were selected based on their crop-livestock integration systems and the facilities (roads and transport) to access the area. Selected sectors in the Bugesera district were highly populated with limited space for cattle grazing. Due to the high population (292,380 on

1303 km^2 of land) and the large number of cattle (89,359), large areas in the Bugesera district were overgrazed (HPI 2005). Although the number of cattle has been reduced to 20,950 in the whole Bugesera district (JICA 2007) feeding is still constrained by the long dry season.

In the Nyamagabe district one sector, Gasaka was selected. It was a sector which had a large number of dairy cattle owners and had serious animal feed scarcity. This was due to the land shortage (the total area of the district is 1,090 km^2 and the population in 2007 was approximately 333,587 (MINALOC 2008). with acidic soil. To represent the whole sector, three cells (government administrative division under a sector) Murambi, Ngiryi and Kigeme were selected. The selection of these cells was based on the integration of crop-livestock production system, easy access to the area and acidic soil (pH 4.3–4.9) (Nzamurambaho 1996).

4.2.2 Selection of communities

One of the policies of the government of Rwanda in terms of poverty alleviation is to provide a dairy cow to poor farmers in order to help them to get manure and milk. For this reason, some NGOs such as the Heifer International Project (HPI) and Send a Cow Rwanda (SCR) were participating in this policy by providing dairy cows to farmers. These livestock providers were operating in the study area by supporting the ministry of agriculture (MINAGRI) at the district and sector level, they assisted in identification of potential farmers for the study.

Farmer groups were chosen in both districts. Farmers who practised zero grazing system were recorded at a sector level. From this record, in each district, twenty farmer representatives were randomly selected and later we contacted them in their respective cells for the participatory diagnosis. The targeted farmers were mixed crop-livestock producers or they were cattle (especially crossbred cattle for milk production) owners. Among selected farmers were those who have been in the area for many years and practised farming. According to Ojiako *et al.* (2009), these farmers can help in categorizing the community in terms of wealth because they were well known in the community for a long period. A conceptual model for on-farm agronomic research (Figure 4.1) was adapted to identify and prioritize constraints and opportunities in livestock feeding.

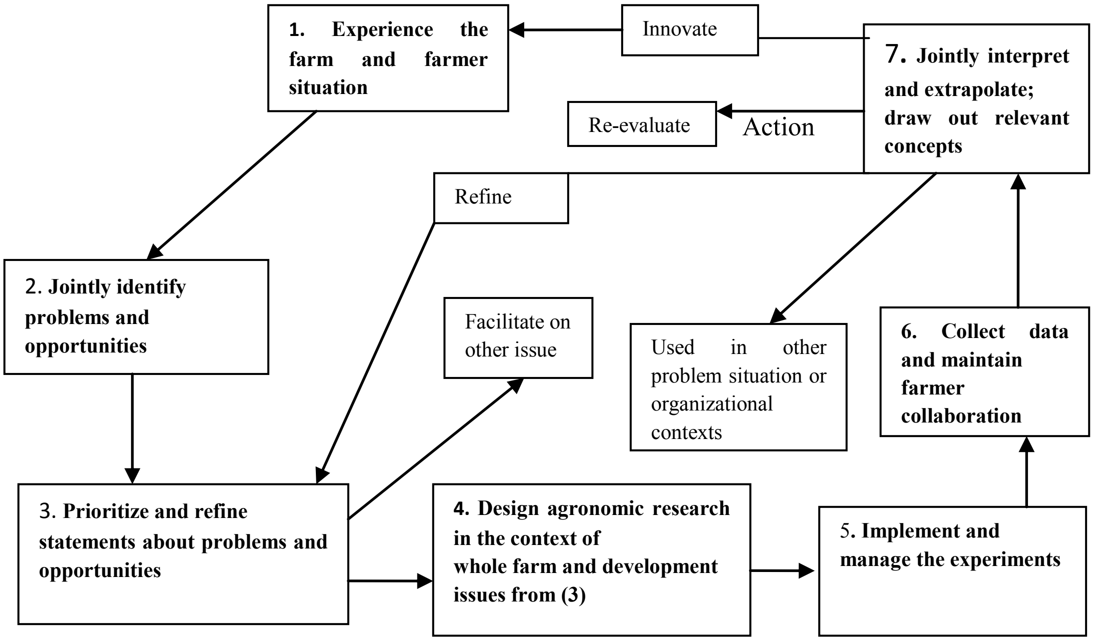


Figure 4. 1 Conceptual model adapted for on-farm agronomic research (proposed by Ison and Ampt 1992).

4.2.3 Participatory Rural Appraisal

Participatory rural appraisal (PRA) techniques used in this research included gender analysis, wealth ranking and feed calendar development. Preparatory meetings were held with the livestock owners who volunteered to participate in the study in each district. In the Bugesera district, meetings were held at the Nyamata sector which was the most convenient place for all farmers from the three sectors. In the Nyamagabe district, these meetings were held at the Ngiryi cell in the Gasaka sector as this was central for all selected farmers within the sector. The aim of these meetings was to explain the objectives of the research study, the expected outputs, as well as the use of participatory rural appraisal (PRA) tools. Prior arrangements were made before undertaking the PRA exercise in each district by talking to agriculture and livestock providers in each district and visiting selected farmers at their homes. Livestock providers during that time were the representatives of the MINAGRI, HPI and SCR at sector level. The two latter organisations provide dairy cows to the farmers in collaboration with the MINAGRI. The meetings were held during the dry season (month of August 2007) when farmers were almost available because it was not a cropping season.

During these discussions, the following questions were addressed: (1) what role do livestock play in the livelihoods of crop-livestock farmers in the Bugesera and Nyamagabe districts? (2) How does the forage flow in the farming system? (3) What are the main constraints in keeping livestock?

The first question was addressed through discussions in a group of twenty farmers and with service providers (representative of Ministry of Agriculture at sector level, HPI and SCR) in each selected area. These service providers were not present in the farmers" meetings but had given their responses during previous meetings. The second and third questions were addressed through participatory elaboration of a feeding calendar. Farmers were grouped into the same categories in terms of wealth and gender. In each group, criteria for feed resources rating were defined, followed by a ranking exercise based on individual scores for each feed resource. This allowed participation of all farmers, avoiding bias or domination by some farmers in the exercise. Wealth ranking and gender analysis were done in group discussions. The specific objectives of this exercise were: (i) to assess the distribution of livestock farming activities differentiated by gender and (ii) to determine the distribution of wealth within the community based on assets owned and income generation.

The results were used to determine the link between livestock ownership (critical herd sizes) and wealth. At the same time, the relation between wealth standard by social category and farmers" motivation to invest in forages for dairy farming was investigated. This was contrasted with the assessment of current feed options in terms of proportion and availability throughout the year.

4.2.3.1 Gender analysis

An exercise to determine the effect of gender on livestock ownership and control was done with women (did not differentiate single or married) and men forming separate groups. Each group of ten males and ten females did an independent exercise in which they stated their activities in livestock farming and the role of boys and girls as the members of family involved in these activities. After independent work, all groups came together and presented their activities. This allowed each gender category to express its thoughts about livestock farming activities. Through an activity profile, farmers arranged seasonal constraints and opportunities throughout the year. It is in this context that the role of gender in livestock rearing was determined. The objective of this exercise was to assess the role of gender in livestock farming activities in the contrasting low rainfall and acidic soil districts.

4.2.3.2 Wealth ranking

Wealth raking is a method where community members meet and categorize farm households based on the wealth possessed by each household in a selected area (Phiri *et al.* 2004). For this study, farmers themselves identified criteria to determine the different categories of wealth in the community. This exercise was done by using the list of households who owned livestock in the areas of the study; this was done in a group of twenty farmers (ten females and ten males). The group used characteristics that the community used to determine the household‟ wealth and each household from the list in the area was categorized by wealth. The objective was to determine the distribution of wealth within the community based on assets owned and income. This will enable links to be determined between livestock ownership (critical herd sizes) and well-being of farmers. The results will be used to establish the link between wealth standards by social category and farmers‟ interests and motivation to invest in forage for dairy farming. It also helps to know where the intervention is needed for improving farmers‟ livelihoods (Barbara 1988).

4.2.3.3 Feed calendar development

Among the Participatory Rural Appraisal (PRA) techniques, feed calendar development was used in the two districts of the study area to determine the availability and use of animal feed, differentiated by wet and dry seasons. A feed calendar was drawn up by community members, in which the feed types used by farmers each month of the year were identified. A group of twenty farmers in each district listed all feed resources that they use during the year. Separately each individual farmer was asked to score each identified feed (from zero= not available to 10= highly available) according to their criteria.

A seasonal feed calendar was also developed. A matrix of feed resources (columns) corresponding to the months of the year (rows) was drawn on a paper. The group of farmers was given ten beans that were allocated between feed resources for each month according to their importance. A feed resource could receive a score of 0 to 10 based on its importance in a particular month. The importance of this exercise was to know the different types of feeds use at different periods of the year. It indicated the shortages and availability in a given month and then throughout the year. This exercise was followed by a matrix scoring where farmers indicated the availability of each feed resource in percentage according to the wet and dry seasons.

4.2.4 Statistical analysis

According to Kuntashula and Mafongoya (2005) and Mekoya *et al*. (2008), the scores for the feed resources can be considered as quantities measured. These data can be analysed by descriptive statistics (Sheskin 2007). In this case, Microsoft Office Excel was used to generate boxplots for the comparison of median scores of different feed resources according to farmers‟ criteria. The use of median is an appropriate measure as the samples were not normally distribution (Frigge *et al*. 1989, Massart *et al*. 2005).

4.3 Results

4.3.1 Gender analysis

The results on the role of gender in livestock activities in the Bugesera and Nyamagabe districts (Table 4.1) have shown that different genders have different activities. In the Bugesera district apart from cattle, farmers owned small ruminants (i.e. goats) and small stock (rabbits and chickens). Animal husbandry and activities related to it varied by gender. Both women and men carried out cattle herding, donation of cattle and cattle selling, raising of goats, rabbits and chickens were restricted to women, girls and boys. Planting forage, construction of animal sheds, seeking grazing land and animal disease treatment were men‟s activities whereas milking cows was reserved for men and boy‟s activities.

Table 4. 1 The role of gender in livestock farming activities in selected districts

	Gender balance in livestock rearing							
	Bugesera district				Nyamagabe district			
Activities	**Women**	**Men**	**Girls**	**Boys**	**Women**	**Men**	**Girls**	**Boys**
Pigs herding	○	○	○	○	x	-	-	x
Cattle herding	x	x	-	-	x	x	-	x
Goats herding	x	-	x	x	x	-	x	x
Rabbits rearing	x	-	x	x	-	-	x	x
Chickens rearing	x	-	x	x	-	-	x	x
Planting Forage	-	x	-	-	x	x	-	-
Animal sheds construction	-	x	-	-	-	x	-	x
Fetching water for cattle	x	x	x	x	x	-	x	x
Seeking grazing land	-	x	-	-	○	○	○	○
Feeding cattle	x	x	x	x	x	x	x	x
Animal disease treatment	-	x	-	-	-	x	-	-
Cleaning shed	x	-	x	-	x	x	x	x
Donation of cattle	x	x	-	-	x	x	-	-
Selling	x	x	-	-	x	x	-	-
Cow milking	-	x	-	x	-	x	-	x

x: applicable to; -: not applicable to;

○ = activity not found in the district

The only activities in animal rearing which were common to both male and female adults and children was fetching water for cattle and feeding cattle in the shed. Women and girls were responsible for the cleaning of animal sheds. Physical hard labour was done by men while less physical tasks were done by women and children. During group discussions farmers stated that when women and children are household heads, they take care of all activities. Men do not consider small stock (chickens, goats, and rabbits) as worthy animals. Women and children, who spend much of their time at home, exclusively rear these animals. Selling of small stock was done by women in consultation with their husbands whereas selling a cow was done by men after reaching a common understanding with their wives. During gender group discussions, it was stated that under no circumstance could children sell or give animals (as a gift) unless their parents died.

In the Nyamagabe district, the results from the gender analysis of animal rearing (Table 4.1) were dissimilar to those of the Bugesera district. Cattle rearing was done by men, women and boys whereas goat keeping was done by women, girls and boys. Rabbits and chickens were managed by both girls and boys, whereas pigs were only kept by women and boys. The activities of planting forage, selling and donation of animals were reserved for men and women. The construction of animal sheds, treating ticks on cattle and milking cows were carried out by men and boys. Fetching water for cattle was the activity for women, girls and boys in the Nyamagabe district whereas the activity common across gender and age groups was cleaning animal sheds and cattle feeding. The only activity reserved for men alone was the treatment of animal diseases.

In the contrasting districts, common and variable gender roles differentiated by location were identified. Fetching water for the animals was a common activity for men and children in the Bugesera district whereas in the Nyamagabe district men do not fetch water for animals. Cattle feeding was the only activity executed by men, women, girls and boys in both districts. This is a crucial activity as both districts practise a zero grazing system. Participants mentioned that cattle feeding takes time for farmers to get enough feed and that is why all categories of age and gender were involved in this activity. However, treatment of animal diseases remained men‟s activity in both Bugesera and Nyamagabe districts. Although many activities in livestock rearing were shared between males and females, others were still related to only male or female. In the Bugesera district cleaning of animal sheds was reserved for only females (women and girls) whereas milking cows and animal shed construction were confined to males (both men and boys) in the Bugesera and Nyamagabe districts. In households headed by either women and/or children, all the activities could be carried out by women except milking a cow where Rwandan culture does not allow a woman to milk a cow. In this situation, she should look for assistance from a male from her neighbours. In both areas because of the zero grazing system established in both districts, most livestock activities were shared between genders but there was evidence of cultural beliefs in terms of cattle rearing in the Bugesera and Nyamagabe districts. These beliefs were based on the Rwandan traditional culture which considers cattle as a sacred animal and women could not milk a cow but could handle milk.

4.3.2 Wealth categories

The objective of the exercise for ranking of wealth category in the Bugesera and Nyamagabe districts was to categorize farmers in terms of wealth and relate the results to cattle ownership. Farmers first developed categories of wealth for the community. After giving all categories, they discussed the wealth of each individual farmer from the list of livestock owners availed at the sector level including the participants. After a general discussion about characteristics of each category, they allocated these to each farmer. The wealth categories defined by farmers in the Bugesera and Nyamagabe districts were: the „very rich", the „rich", the „moderately poor", the „poor" and „very poor" (Table 4.2 and Table 4.3). In the Bugesera district, the number of livestock owned by farmers was one of the major criteria used by farmers in categorizing community members in terms of being socially better off. The majority of people (75%) in the selected cells of the Bugesera district were in the category of „moderately poor". Many of them owned land of less than 0.5 ha and reared one indigenous cattle. Even though some farmers had a dairy exotic cow provided by the government of Rwanda or NGO, ownership was used as a selection criteria for differentiation.

Table 4. 2 Wealth category ranking in the Bugesera district

Wealth category	Characteristics
Very rich (UMUKIRE)	Owns: a car; a motorcycle; houses; possesses money at least 10000 US$ or much more; owns 3 exotic dairy cows or 30 indigenous cattle; owns property; has a plot of planted trees for timber and fuel; has 3 cell phones
Rich (UMUKUNGU)	Owns: many properties; houses; 5 indigenous cows; 10 goats; 10 chickens, a bicycle; cell phone; 1 motorcycle; possesses at least 1000 US$ to 2000 US$; gains at least 7.5 US$ per day; has a forest
Moderately poor (UMUKENE)	Possesses forest of <1 ha; owns 1 bicycle; 1 dairy cow; 2 goats; 3 chickens; 4 rabbits; 1 pig; possesses a house; owns a cell phone; can pay medical insurance; can send children to school (able to pay school fees)
Poor (UMUTINDI)	Owns a grass house; hires land for cropping; owns: 1 goat; 2 chickens, can"t pay his/her medical insurance; unable to pay school fees for his or her children
Very poor (UMUTINDI NYAKUJYA)	Owns a grass house; begs for food; has no means; lives badly; wears dirty clothes

The categories of the „very rich" and the „rich" were distinguished by the amount of money they possess and daily cash income (Table 4.2). However, the „moderately poor" and „poor" are differentiated by the availability of food. The last wealth category is the „very poor" (UMUTINDI NYAKUJYA). In this category, one does not own animals or land, and lives by begging and he or she has no esteem within the community.

In the Nyamagabe district, although results on wealth ranking also showed five categories of farmers, the characteristics identified by farmers within each category were different (Table 4.3).

Table 4. 3 Wealth category in the Nyamagabe district

Wealth category	Characteristics
Very rich (UMUKIRE)	Owns: more than one car; houses for business; possesses at least 20,000 US$; owns at least ten exotic dairy cows; owns many properties; has multiple cell phones
Rich (UMUKUNGU)	Owns: at least 5 ha of land; ten indigenous cows; 15 goats; 100 chickens; two pigs; 2000 coffee trees; 1 ha of forest; a bicycle; a telephone; a motorcycle; possesses 400 to 2000US$; gains at least 2 US$ per day;
Moderately poor (UMUKENE)	Owns: 0.5 ha of land; 500 coffee trees; one pig; one indigenous cow; one goat, eight chicken, three rabbits; possesses a house of 5 x 4 m with roofing tiles; owns a cell phone; can pay medical insurance; children can attend only primary school; has sufficient food
Poor (UMUTINDI)	Owns: a grass thatched house; a small piece of land for cropping or hires it; one goat; one pig; one rabbit; cannot pay medical insurance; unable to pay children"s school fees and has insufficient food
Very poor (UMUTINDI NYAKUJYA)	Has no house; begs for food; has no means; lives in poverty and wears donated clothes.

In contrast to the Bugesera district, in the Nyamagabe district, the „very rich" refers to cash income and possession (Table 4.3). The „rich" category was characterized by access to properties and food. The number of livestock and breeding type of cows owned by farmers were one of the major criteria used by farmers in categorizing the community in terms of social welfare in the Nyamagabe district. The „very rich" category owns exotic dairy cows whereas in other categories only the number of cows is important to be categorized into „rich" or „moderately poor". In the selected cells of the Nyamagabe district, 50% of the farmers were in the category of „moderately poor‟ whereas 18.75% were in the category of „rich‟.

Wealth ranking in the Bugesera and Nyamagabe districts showed that even though farmers are located in different areas of Rwanda, similar criteria were used to categorize the community in terms of social livelihood. However, having the same categories for wealth ranking in the community does not mean that characteristics are the same within each category. In the Nyamagabe district, farmers mentioned a particular characteristic within the categories of the „rich‟ and the „moderately poor‟ that was the number of coffee trees. In the Bugesera district, the „very rich‟ and „rich‟ were differentiated by the number of properties owned whereas in the Nyamagabe district the „very rich‟ and „the rich‟ were defined by access to cash.

4.3.3 Animal feed resources and farmers' preference ranking

During workshops with farmers, the availability and utilisation of feeds throughout the year was defined using feed calendars. In the Bugesera district, farmers identified thirteen feed resources whereas in the Nyamagabe district twenty-one feed resources were identified. Farmers‟ criteria for feed resources ranking were the availability, palatability, stomach fill, ease to cut, increased milk yield, adaptation to acidic soil and drought tolerance, ease of storage and speed of regrowth. The boxplots from the two districts showed differences according to the identified criteria (Figures 4.2 and 4.3). In both districts, some of the feeds used by farmers were indigenous (e.g. indigenous grasses dominated by *Brachiaria* spp., trees like *Ficus* spp., *Albizia amygdalina*.). Others were crop residues (e.g. leaves of cabbage, maize stovers). Furthermore, there were exotic grasses (e.g. Napier grass, *Setaria* spp., *Tripsacum* spp.), legumes (e.g. *Mucuna pruriens*) and tree legumes (e.g. *Calliandra* spp. and *Leucaena* spp.).

4.3.3.1 Availability

In the Bugesera district, Napier grass (*Pennisetum purpureum)* was scored highest in terms of availability (Figure 4.2a). The scores given by farmers to the Napier grass ranged between six and eight with a median score of seven. It was followed by *Tripsacum* and *Setaria* which were scored between five and seven with a median score of six. Natural grass and banana stems were scored between four and seven with a median score of five. The lowest median score (zero) for the criterion of availability in the Bugesera district was given to leaves of cabbage and *Mucuna pruriens* (Figure 4.2a).

In the Nyamagabe district many farmers highly scored Napier grass and *Commelina benghalensis* with a median score of eight (Figure 4.3a). They were followed by *Panicum*, maize stover and *Albizia amygdalina* that received a median score of seven. Natural grass and banana stems had a median score of six. The lowest median score (zero) was obtained by bean peelings and banana beer residues (Figure 4.3a).

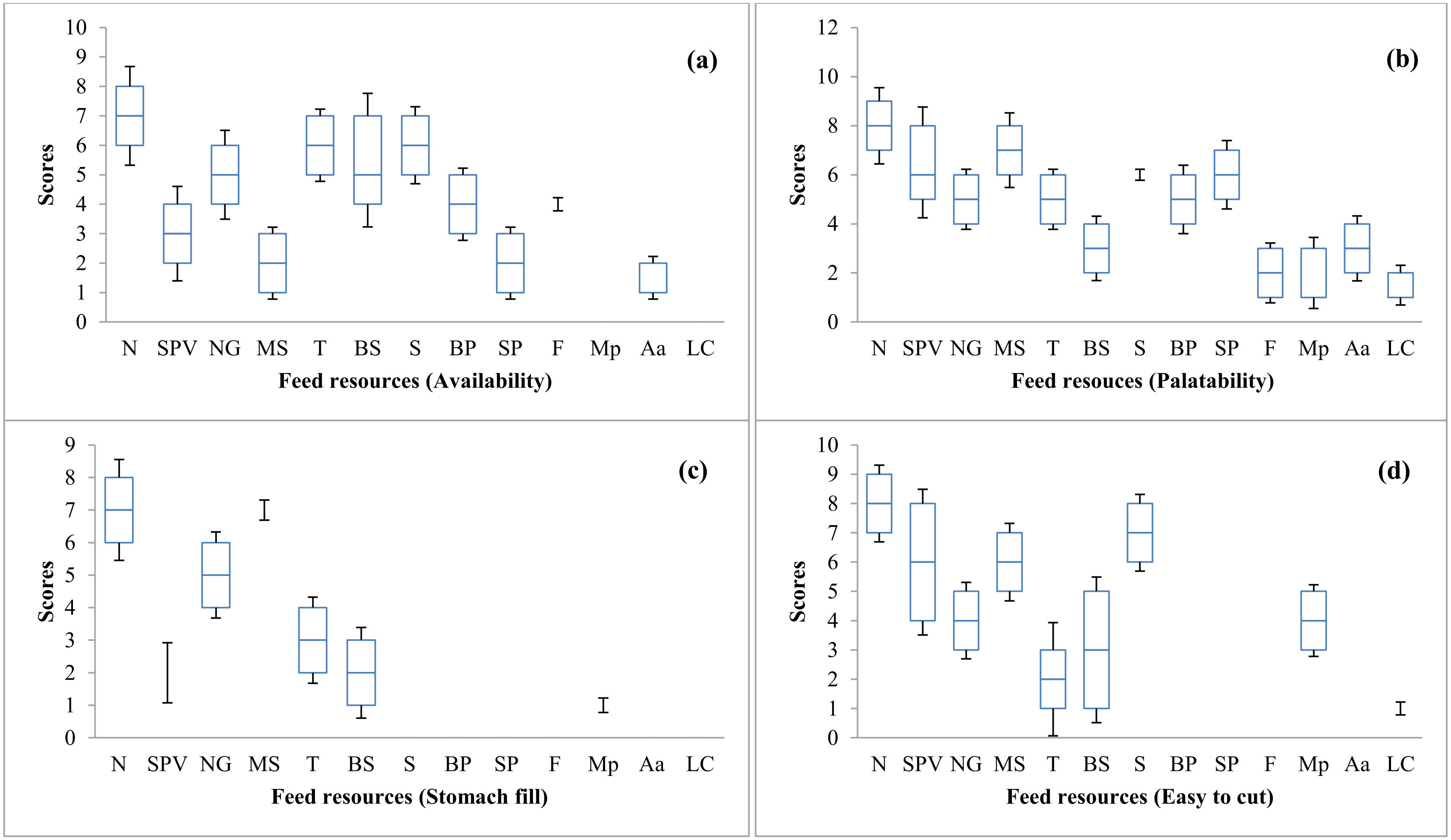
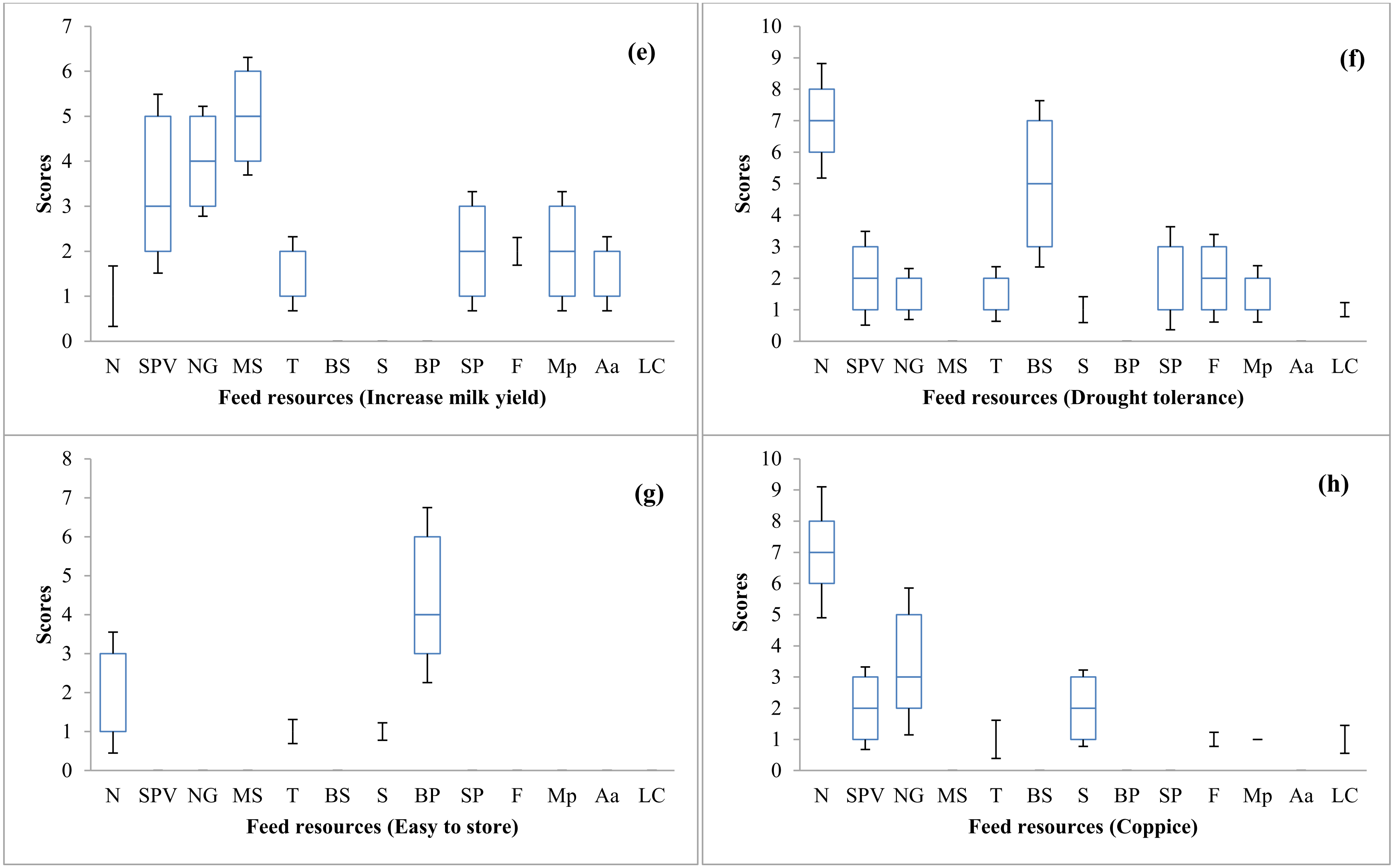


Figure 4. 2 Boxplot of feed resources from farmers' preference ranking in the Bugesera district according to criteria. (a)= Availability; (b) = Palatability; (c) = Stomach fill; (d) = Easy to cut; (e) = Increase milk yield; (f) = Drought tolerance; (g) = Easy to store; (h) = Coppice.



Key for feed resources in the Bugesera district:

N= Napier grass; SPV= Sweet potato vines; NG= Natural grass; MS= Maize stover; T= *Tripsacum*; BS= Banana stems; S= *Setaria*; BP= Bean peelings; SP= Sweet potatoes; F= *Ficus*; Mp= *Mucuna pruriens*; Aa= *Albizia amygdalina;* LC= Leaves of cabbage.

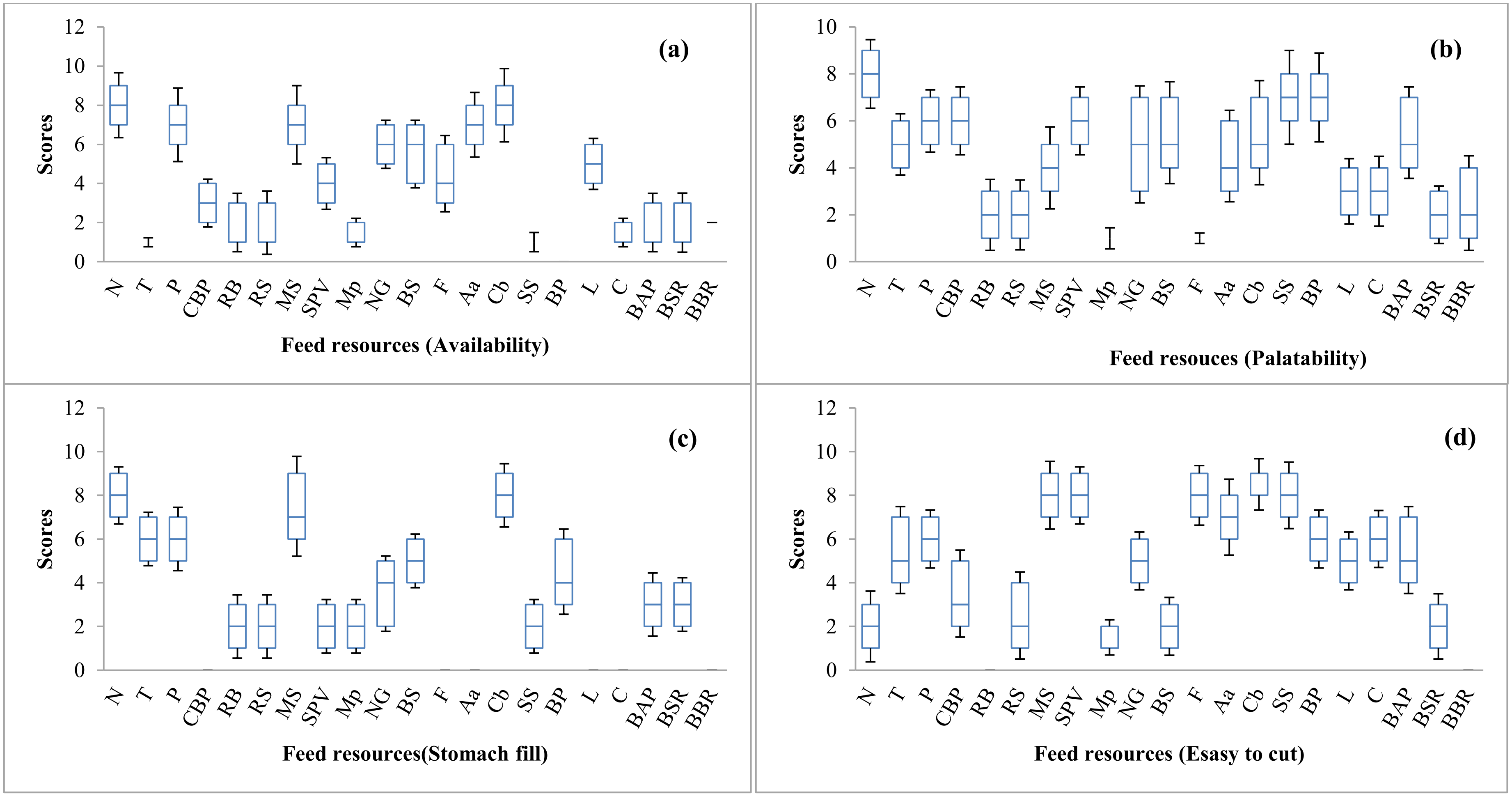
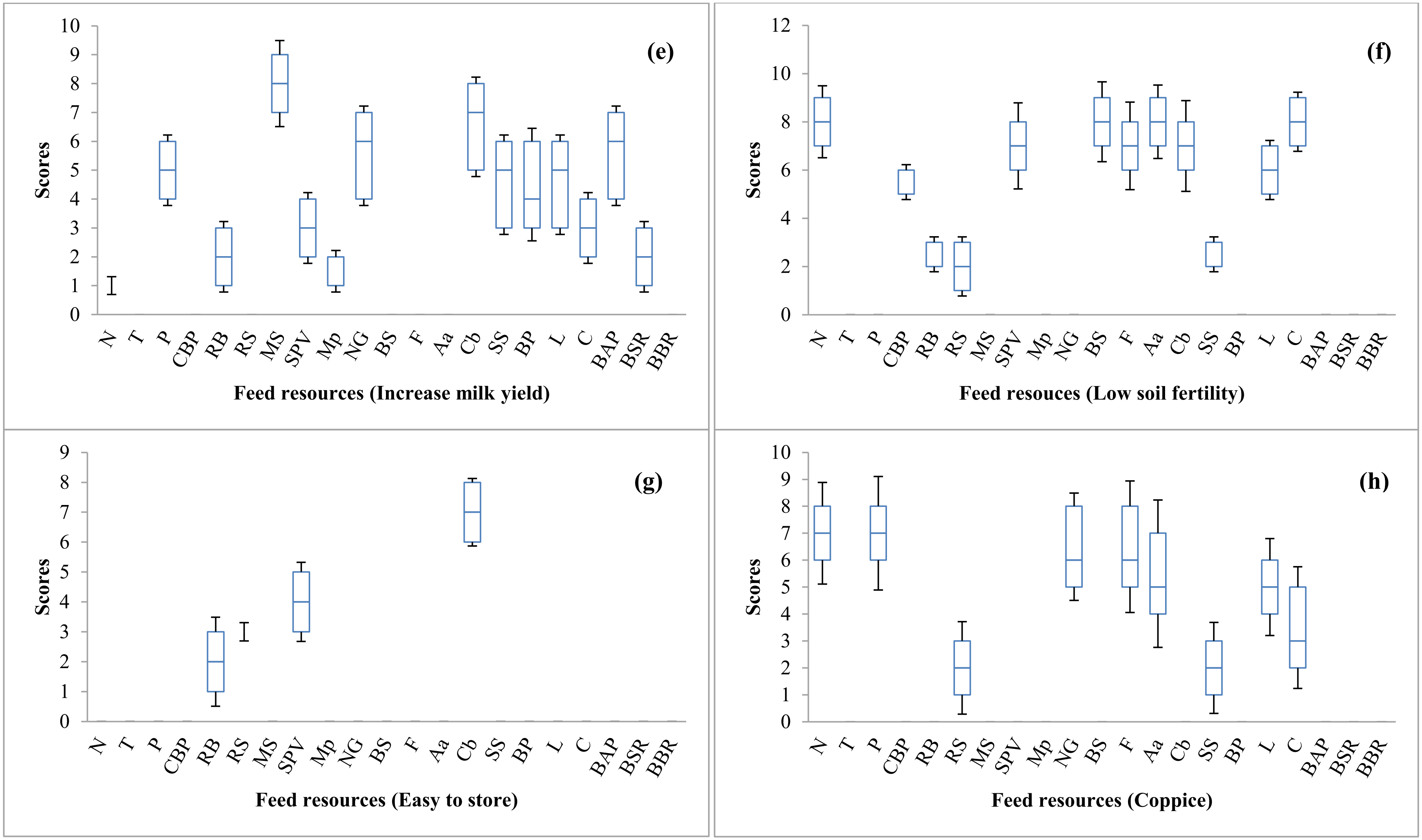


Figure 4. 3 Boxplot of feed resources from farmers' preference ranking in the Nyamagabe district according to criteria. (a)= Availability; (b) = Palatability; (c) = Stomach fill; (d) = Easy to cut; (e) = Increase milk yield; (f) = Low soil fertility tolerance; (g) = Easy to store; (h) = Coppice.



Key for feed resources in the Nyamagabe district:
N= Napier grass; T= *Tripsacum*; P= *Panicum*; CBP= Cooked banana peelings; RB= Rice bran; RS= Rice straw; MS= Maize stover; SPV= Sweet potato vines; Mp= *Mucuna pruriens*; NG= Natural grass; BS= Banana stems; F= *Ficus* spp.; Aa= *Albizia amygdalina;* Cb= *Commelina benghalensis;* SS= Suckers of Sorghum ; BP= Bean peelings ; L= *Leucaena* spp.; C= *Calliandra* spp.; BAP= Banana peelings; BSR= Beer sorghum residues ; BBR= Banana beer residues.

4.3.3.2 Palatability

The comparison of different feed resources in the Bugesera district showed differences between Napier grass and other feed options in terms of palatability (Figure 4.2b). The scores given to the Napier grass varied between seven and nine with a median score of eight. This was the highest score for the criterion of palatability. Napier grass was followed by maize stover that received a median score of seven. Sweet potato vines, *Setaria* spp. and sweet potato each had a median score of six. The median score of the native grass, *Tripsacum* and bean peelings was the same (five) for their palatability in the Bugesera district (Figure 4.2b). The lowest scores that varied between zero and two with a median score of one was given to leaves of cabbage for their low palatability in the Bugesera district.

In the Nyamagabe district, Napier grass also had a median score of eight. It was followed by suckers of sorghum and bean peelings which each had a median score of seven. These were followed by *Panicum* spp., cooked banana peeling and sweet potato vines with a median score of six (Figure 4.3b). The native grass received a median score of five whereas *Ficus* spp. and *Mucuna pruriens* were the lowest scored with a median score of one for their palatability in the Nyamagabe district.

4.3.3.3 Fill stomach

The criterion of „stomach fill‟ was used by farmers for preference ranking of feed resources in the Bugesera and Nyamagabe districts. The boxplots showed that the Napier grass and maize stovers were highly scored with a median score of seven in the Bugesera district (Figure 4.2c). They were followed by native grass that received a median score of five. The lowest feed resources scored by farmers were leaves of cabbages, *Setaria* spp., *Ficus* spp., *Albizia amygdalina*, bean peelings and sweet potatoes. Their median score was zero (Figure 4.2c) and these feed resources were the least in farmers‟ preference ranking for the criterion of quick stomach fill in the Bugesera district.

In the Nyamagabe district, *Commelina benghalensis* and Napier grass were the feed resources, which were highly rated with a median score of eight for their quick stomach fill (Figure 4.3c). They were followed by maize stover which received scores ranging between six and nine with a median score of seven. *Panicum* spp. and *Tripsacum* spp. received a mean score of six whereas banana stems obtained a median score of five. The scores of native grass ranged between two and five with a median of four for the criterion of stomach fill. In this criterion, the lowest median score (zero) was obtained by cooked banana peelings, *Ficus* spp., *Calliandra* spp., *Leucaena* spp., banana beer residues and *Albizia amygdalina* (Figure 4.3c).

4.3.3.4 Easy to cut

In the Bugesera district, farmers mentioned that the Napier grass was the easiest forage to cut. This was scored higher (eight) than other feeds resources in the area. It was followed by *Setaria* spp. with a median score of seven. Sweet potato vines received scores ranging between four and eight with a median score six (Figure 4.2d). The maize stover was also given a median score of six with variation of scores between five and seven. The lowest median score (zero) was given to *Albizia amygdalina*, *Ficus* spp., sweet potatoes and bean peelings.

In contrast to the Bugesera district, *Commelina benghalensis* received the higher score in the Nyamagabe district where scores varied between eight and nine. It was followed by *Ficus* spp., suckers of sorghum, sweet potato vines and maize stover that scores each with a median score of eight (Figure 4.3d). *Albizia amygdalina* was among the feed resources that was scored high by farmers for the criterion of „easy to cut" because it had a median score of seven. The Napier grass had scores between one and three with a median score of two. In this exercise, the lowest median score (zero) was given to rice bran and banana beer residues (Figure 4.3d). Even though crop residues (e.g. bean peelings, banana peelings, rice bran, banana beer residues) were scored low, the time spent by farmers for getting these crop residues was considered as „easy to cut".

4.3.3.5 Increase milk yield

Feed resources in the Bugesera district identified for the criterion of increase of „milk yield‟ were generally low (Figure 4.2e). Maize stover was scored higher than the rest of feed resources with a mean score of five. It was followed by the natural grass (a median score of four) and sweet potato vines (a median score of three). The Napier scored very low (a median score of one) for this criterion. The lowest median score (zero) was given to banana stems, *Setaria*, leaves of cabbage and bean peelings.

Likewise, in the Nyamagabe district maize stover obtained the highest median score (eight). It was followed by *Commelina benghalensis* that received scores between five and eight with a median score of seven. Native grass and banana peelings each had a median score of six (Figure 4.3e). The Napier grass had a median score of one for the criterion of „increasing milk yield‟. The lowest median score (zero) was given to *Tripsacum* spp., rice straw, banana stem, cooked banana peelings, *Ficus* spp., *Albizia amygdalina* and banana beer residues.

4.3.3.6 Low soil fertility and drought tolerance

In the Bugesera district, farmers identified „drought tolerance‟ as a criterion (Figure 4.2f) whereas in the Nyamagabe district farmers mentioned „low soil fertility tolerance‟ (Figure 4.3f). Farmers‟ preference for feed resources based on identified drought tolerance in the Bugesera district showed that Napier grass had highest scores (a median of seven). It was followed by banana stems with a median score of five. Sweet potato vines and *Ficus* spp. received scores varied between one and three with a median score of two for this criterion of „drought tolerance‟ (Figure 4.2f). The lowest median score (zero) was given to maize stovers and bean peelings for their tolerance to drought in the Bugesera district. These crop residues were scored low based on their crop origins (maize and bean). Furthermore, *Albizia amygdalina* was not given any score because farmers did not know if it could tolerate drought or not.

In the Nyamagabe district, some feed resources (maize stover, *Mucuna pruriens*, bean peelings, sorghum beer residues and banana beer residues) were not scored for the criterion of „low soil fertility tolerance". The comparison of median scores of the rest of the feed resources showed a difference among them (Figure 4.3f). Napier grass, banana stems, *Albizia amygdalina* and *Calliandra* spp. were highly scored (between seven and nine) with a median score of eight as forage options that were tolerant of low soil fertility in the Nyamagabe district. They were followed by sweet potato vines, *Ficus* spp. and *Commelina benghalensis* with a median score of seven. The lowest median score (zero) with upper quartile of one was given to *Tripsacum* spp. and *Panicum* spp. (Figure 4.3f). According to farmers these grass species do not tolerate low soil fertility and must be grown using fertilizer (either organic or chemical) otherwise they will not yield high biomass. The criterion of low soil fertility tolerance for preference ranking was important because it is the main constraint in the Nyamagabe district and farmers found it difficult and expensive to buy fertilizers each cropping season.

4.3.3.7 Easy to store

Feed storage in both districts concerns the storage of cut and carried forage (e.g. Napier grass, *Setaria*, native grass) and stored in the house where it can be kept for one or two weeks. Crop residues (e.g. rice bran, rice straw and bean peelings) are already dried and can be stored by farmers for a month or more.

In the Bugesera district, only four feed resources (Napier grass, *Tripsacum* spp., *Setaria* spp. and bean peelings) were identified for the criterion of „easy to store" because farmers did not know how other feed resources were stored. Their indigenous knowledge on feed storage was limited to bean peelings, Napier grass, *Tripsacum* spp. and *Setaria* spp. (among the thirteen identified feed resources). Although there was a difference among the four feed options, bean peelings was the highest scored (median score of four) by farmers as a feed that is easy to store followed by Napier grass, *Tripsacum* spp. and *Setaria* spp. (Figure 4.2g) . The three latter grasses were mentioned by farmers as forage to be stored (conserved) easily because in the Bugesera district, some farmers knew how to use these species and to make silage on a small-scale.

In the Nyamagabe district, the criterion of „easy to store" was only applied to four of the twenty-one feed resources (Figure 4.3g). The rest of feed resources (e.g. Napier grass, *Tripsacum*, *Mucuna pruriens*) were not scored because farmers did not know how to store them and they have never tried to store these feed resources. The median scores of the four forage options showed differences among them. The *Commelina benghalensis* and sweet potato vines were scored highest with a median score of seven and four respectively in the Nyamagabe district (Figure 4.3g). This is because *Commelina benghalensis* and sweet potato vines can be harvested and kept in the house for two weeks without losing their smoothness and animals like these feeds when they are withered.

Of all the criteria that were identified by farmers for preference ranking in both districts we found that during the individual scoring, in addition to the criterion of drought and low soil fertility tolerance the criterion of „easy to store" was another major criterion of importance for scoring feed resources. Farmers mentioned that many feeds (especially crop residues) were wasted due to lack of knowledge on feed storage and/or conservation.

4.3.3.8 Quick re-growth

This criterion was applicable to seven feed resources among the thirteen identified in the Bugesera district (Figure 4.2h). The median score showed a difference among these seven resources scored by farmers. The Napier grass was highly scored with a median score of seven followed by native grass, as both have quick re-growth after cutting. *Setaria* spp. and sweet potato vines were scored (a median score of two) in addition to *Tripsacum* spp., leaves of cabbage and *Ficus* spp. which had the lowest median score (one).

In the Nyamagabe district, only nine of the twenty-one feed resources were scored by the farmers for „quick regrowth". Napier grass and *Panicum* spp. were most highly scored (median score of seven). They were followed by *Ficus* spp. and native grass that had a median score of six. *Albizia amygdalina* and *Leucaena* spp. had obtained a median score of five among the rest of scored feed resources. The lowest median score (zero) was given to *Tripsacum* spp. and *Commelina benghalensis* in this exercise of preference ranking in the Nyamagabe district. Farmers mentioned that even if *Commelina benghalensis* is tolerant of the low soil fertility it does not re-grow quickly after cutting.

4.3.4 Feed calendar development

During the group discussion, farmers participated in feed calendar development. Preferences of farmers for different forages in the Bugesera district were differentiated according to season. In the wet season Napier grass, native grass (road side grasses), sweet potato vines, *Tripsacum* spp. and bean peelings were the feed resources mostly used, while in the dry season banana stems, Napier, leaves of cabbage and branches of trees like *Ficus* spp. and *Albizia amygdalina* were used (Table 4.4). Other forage types such as *Setaria* spp. and *Mucuna pruriens* var. Utilis were only used by large-scale dairy farmers because of their higher requirements in agronomic management and their seeds were not available to smallholder farmers.

The crop residues, which were used to feed animals in the area, their availability and quantity, depended on harvest period and the climatic conditions during the cropping season. Maize stover and bean peelings were examples of crop residues that were available from December to January and in June. In the Bugesera district, there were two cropping seasons per year. Quantity of crop residues was related to rainfall quantity and distribution in the previous wet months (September, October and November). The percentage of feed supplies in the Bugesera district show that during the rainy season a wide range of forage options is available, with emphasis on Napier grass, sweet potato vines and road side grasses. However, in the dry season feed resources became scarce sometimes leading to death of cattle. Forage options used by farmers in the Bugesera district (Table 4.5) indicate that in the wet season, all farmers used Napier grass and roadside grass whereas the use of these is reduced up to seventy percent and sixty percent respectively during the dry season. *Albizia amygdalina* and banana stems are not available during the rainy season but become important (eighty percent of use) during the dry season. Farmers lack the knowledge on how to store forage in the form of silage or hay. However, in addition to the above major forage options, many other feed resources options were used in the Bugesera district (Table 4.5).

Table 4. 4 Seasonal feed calendar in the Bugesera district

		Forage resources													feed availability
Season	**Month**	A	B	C	D	E	F	G	H	I	J	K	L	M	
Dry	**Jan**	5	1	2					1	1					x
Dry	**Feb**	4	1	1	1	1	1							1	x
Wet	**Mar**	5		3	1	1									xxx
Wet	**Apr**	6		3	1										xxx
Wet	**May**	6		2	1	1									xxx
Dry	**June**	5	1	1	1	1			1						x
Dry	**July**	2	2				1	1			1			3	x
Dry	**Aug**	1	2				1	1			1	1		3	x
Dry	**Sept**	1	1				2	1			1	1		3	x
Wet	**Oct**	5		2	1	1							1		xxx
Wet	**Nov**	6		2	1	1									xxx
Wet	**Dec**	6		2					1	1					xxx

Legends:

A = Napier grass; B = sweet potato vines; C = Road side grasses; D= *Setaria* spp.; E= *Tripsacum* spp.; F= *Ficus* spp.; G= *Albizia amygdalina*; H=Maize stover; I=Bean peelings; J= Cabbage leaves; K= Sweet potatoes; L= *Mucuna pruriens;* M=Banana stems
Numbers 1 to 10 in rows refer to the relative contribution of forage resource to the animal diet.
xxx= means feed resources are available and fed ad *libitum*; x= means feed resources are limited.

Table 4. 5 Matrix scoring of feed availability by farmers in the Bugesera district

Feeding system	Wet season (%)	Dry season (%)
Napier grass	100	70
Sweet potato vines	85	40
Native grass	100	60
Setaria	35	5
Tripsacum	30	10
Ficus spp.	5	45
Albizia amygdalina	0	35
Maize stover	35	0
Bean peelings	70	0
Leaves of cabbage	5	5
Sweet potatoes	20	15
Mucuna pruriens cv. Utilis	15	15
Banana stems	0	80

The feed calendar development also showed the use of a wide range of feedstuffs in the Nyamagabe district (Table 4.6) due to lower availability of feed. Twenty-one forage options were identified compared to thirteen in Bugesera. Contrary to Bugesera, in the Nyamagabe district *Commelina benghalensis* was the feed resource available throughout the year, indicating the scarcity of grasses for ruminants in the area. Napier grass, maize stover, *Panicum* spp., *Albizia amygdalina* and sweet potato were the other main feed resources used by farmers in combination with crop by-products. In addition, because of steep slopes in the area many trees and shrubs were planted on contour bunds of terraces to reduce the speed of water runoff and to protect soil from erosion. These trees also contributed to the diet of the animals especially ruminants.

The seasonal utilisation of the wide range of forage species in the Nyamagabe district (Table 4.7) indicated that in contrast to Bugesera, there was no particular forage option, which was used by all farmers. During the wet season Napier grass, *Tripsacum*, *Panicum*, cooked banana peelings, roadside grasses (native grass), banana stems, *Ficus* spp.*, Albizia amygdalina*, *Calliandra* spp. and *Commelina benghalensis* was each utilised at 50% by farmers. Among these, some were used in the dry season at the same rate as in the wet season (e.g. cooked banana peelings, *Calliandra calothyrsus*, *Commelina benghalensis*, banana stems and *Ficus* spp.) whereas bean peelings were mostly used in the dry season.

Table 4. 6 Seasonal feed calendar in the Nyamagabe district

		Forage resources																					feed availability
Season	**Month**	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	
Dry	**Jan**	2		2	1					1			1		1		1			1			x
Dry	**Feb**	2		2	1			2	1	1					1								x
Wet	**Mar**	4	1	2	1						1				1								xxx
Wet	**Apr**	4	1	2	1						1				1								xxx
Wet	**May**	3	1	2	1						2				1								xxx
Dry	**June**	2		1	1			1			1			1	1		1	1					x
Dry	**July**	1		1	1	1	1					1		1	1			1			1		x
Dry	**Aug**	1		1	1	1	1					1		1	1			1				1	x
Wet	**Sept**	1		1	1						1	1		1	2	1		1					x
Wet	**Oct**	2	1	2	1						1	1			1				1				xxx
Wet	**Nov**	3	1	2	1						1				1				1				xxx
Wet	**Dec**	3	1	2	1			1			1				1								xxx

Legends:

A = Napier grass; B = *Tripsacum* spp.; C = *Panicum* spp.; D= Cooked banana peelings; E= Rice bran; F= Rice straw; G= Maize stover; H= Sweet potato vines; I= *Mucuna pruriens*; J= Road side grasses; K= Banana stems; L= *Ficus* spp.; M= *Albizia amygdalina*; N= *Commelina benghalensis*; O= Suckers of sorghum; P= Bean peelings; Q= *Leucaena* spp.; R= *Calliandra* spp.; S= Banana peelings; T= Sorghum beer residues; U= Banana beer residues
Numbers 1 to 10 in rows refer to the relative contribution of forage resource to the animal diet. xxx= means feed resources are available and fed ad *libitum*; x= means feed resources are limited.

Table 4. 7 Typical matrix scoring of feed sources by farmer in the Nyamagabe district

Feeding system	Wet season (%)	Dry season (%)
Napier grass	50	25
Tripsacum	50	0
Panicum	50	15
Cooked banana peelings	50	50
Rice bran	15	15
Rice straw	15	15
Maize stover	15	25
Sweet potato vines	20	35
Mucuna pruriens	10	0
Native grass	50	0
Banana stems	50	50
Ficus spp.	50	50
Albizia amygdalina	50	45
Commelina benghalensis	50	50
Suckers of sorghum	0	25
Bean peelings	0	50
Leucaena spp.	35	35
Calliandra spp.	50	50
Banana peelings	25	25
Sorghum beer residues	20	20
Banana beer residues	15	15

In contrast to Bugesera, in the low soil fertility environment of Nyamagabe a wider range of forage was used in the wet season while crop residues and some fodder trees were used throughout the year.

4.4 Discussion

4.4.1 Gender analysis

In the Rwandan traditional culture, livestock farming, especially cattle rearing, was confined to men and boys. Cattle rearing was practised in the extensive farming system when communal grazing land was used by farmers. Currently, due to the land shortage in Rwanda, animals are kept in sheds and fed by the cut and carry of forage. In this situation, an analysis was done on how males and females shared livestock activities in the study areas.

Gender analysis for livestock farming activities in the Bugesera and Nyamagabe districts of Rwanda showed a variable distribution of activities according to gender. In both districts, livestock farming was part of intensive mixed crop-livestock farming systems. Small stock were overseen by women and children whereas cattle were mostly reserved for men. These results support those found in Togo and Uganda by Dolan (2002) who stated that women raised small stock and were involved in processing activities while men were responsible for large animals and marketing. The small stock were cared for women and children because they are mostly carrying out home activities and can feed small stock with kitchen residues. This was supported by Valdivia (2001) who mentioned that livestock rearing was shared by women and children in the poor rural households in Kenya, Indonesia, Bolivia and Peru where small ruminants were left to the responsibility of women either for their management or for their sale. Other reasons why women were responsible for small stock were that, the latter are easier to keep and are an investment strategy enabling women either to increase the existing income earnings or to invest in a new income generation activity and food security. In both districts, there were particular male activities for livestock according to Rwandan culture. These were milking of cows and animal shed construction. This result was found also by Njiro (2002) who stated that there are inequities in gender in rural African mountain communities of Soutpansberg Mountains in South Africa, where boys and men alone are engaged in livestock activities and even if it happens that females control livestock, they are restricted to chickens. The same idea was expressed by IFAD (1994) in their study on women‟s role in livestock production in developing countries, which stated that because of cultural differences found in the Great Lakes region of central Africa there were some prohibitions towards women from having any activities to do with livestock. In contrast, in the Bugesera and Nyamagabe districts apart from married female and widows who cannot milk a cow, the rest of the activities related to livestock could be done by a female. However, as both districts practise the zero grazing system both female and male participate in their activities but as stated by IFAD (1994) the larger part of activities are carried out by women and children who stay at home during the day doing household activities and can care for homestead animals. Looking at these livestock activity divisions by gender in both districts, it is likely that new technology especially, forage options can be followed by both females and males.

4.4.2 Wealth categories

The objective of this exercise was to determine household wealth categories in the communities in the study area. This helps to find out relevant development projects for a given category of wealth within the community (Grosvenor-Alsop 1989). In both districts, household livestock owners were classified into five categories by twenty farmer representatives chosen to participate in the exercise. The five categories were „very rich‟, „rich‟, „moderately poor‟, „poor‟ and „very poor‟. These categories are almost similar to those defined by GoR (2002) during the assessment of poverty reduction (as reported by Howe and Mckay 2007). The wealth category of „the resourceful poor‟ could not be distinguished during this study in the Nyamagabe and Bugesera districts. It may be similar to the household category of „poor‟ in our study. Wealth categories vary from one country to another and from culture to culture, thus they need to be seen in a specific context. An example is given by Bahamondes (2003) who found that in Chile wealth categories could be classified into four categories (high, medium, medium poor and poor) and their characteristics are different from what we found in our study areas. While livestock were not an important characteristic in differentiating household wealth in Chile, livestock played a considerable role in wealth ranking in the Bugesera and Nyamagabe districts. The number of cattle and other stock were mentioned as key criteria used to differentiate categories of farmers. The „very rich" and the „rich" were more likely to own exotic cattle breeds and the animal herds increased with wealth status. This is in agreement with findings by Sieff (1999) among the Datoga pastoralists of Tanzania and for Zimbabwe (Alumira 2002) where the wealthy households were able to increase their cattle and small ruminants herds whereas in poor households the rate of livestock off-take was high reducing livestock numbers. In the Nyamagabe and Bugesera districts livestock, especially cattle, was a key characteristic of wealthy households because cattle ownership requires a high investment, which is not affordable by poor households. Another characteristic of wealth categories was landholding in which its size increased with welfare of households. The bigger land size is more likely to increase the number of agricultural commodities and forage plots for livestock and the use of casual labour in all crop-livestock production activities. However, some households may own a piece of land but are unable to produce crops because of a low number of family members. Even if the land is not used, within the community this household will be classified into the category of „*Umutindi'* (the poor). In South Africa, this category of the „poor" is characterised by a life of begging in order to survive (Hargreaves *et al.* 2007), whereas in the Bugesera and Nyamagabe districts this characteristic was for the „very poor" category. From the „poor" to „very rich" wealth categories found in both districts, land and livestock farming activities were able to support the income of households by selling animals and crops. This was also found by Thornton (2009) where in Peddie, a former homeland town in South Africa, livestock rearing was an important activity for improving livelihoods of peri-urban low-income households.

4.4.3 Livestock feed resources and feed calendar development

The assessment of feed resources showed a diverse range of feedstuffs used in the Bugesera and Nyamagabe districts. However, in the Bugesera district where the dry season is more pronounced, the number of feed resources (thirteen) was smaller than in the Nyamagabe district (twenty-one). Even though the latter had a large range of feed resources, the issue of soil acidity in the area made many of these feed options scarce. For example, for six months of the year *Tripsacum* spp. and roadside grasses were not available. The use of a high number of feed resources was found by Mapiye *et al*. (2006a) who reported that in Zimbabwe this high number of feed resources was an indication of animal production. In South Africa, although feed resources are not scarce the use of crop residues is limited by their low crude protein (Kadzere 1995).

Results indicated that in Bugesera the Napier grass was the most preferred feed, followed by sweet potato vines, indigenous or naturalized grasses and maize stover. The feed calendar confirmed the perception that Napier grass is a major fodder crop used throughout Rwanda. This supports Nyaata *et al.* (2000) who stated that in central Kenya many smallholder dairy farmers fed Napier grass to their cattle during the dry season. The criteria for farmers" choice of Napier include its forage availability throughout the year, palatability, low soil fertility and drought adaptation, stomach fill, easy handling for cutting and good regrowth. Many farmers were not sure which forage option resulted in higher milk yields. However, some acknowledged that forage resources like banana stems were low quality feeds for animals. They were not usually fed to animals but during the dry season, they were utilised to help cattle to cope during this period. Similar results were found by Ffoulkes and Preston (1978) who reported that the low digestibility of banana stems is due to its low protein content (<1%) and this led to reduced dry matter intake. In the Bugesera district, farmers mentioned Napier grass as the main planted fodder used in the zero grazing system. This result supports that of JICA (2007) on their baseline survey for agricultural development of Bugesera and stated that Napier grass (*Pennisetum purpureum)* is widely planted in farmlands as a fodder crop in order to feed cattle by the cut and carry method. Napier grass is reported by many authors (e.g. Manaye *et al*. 2009, Juma *et al.* 2006) as a basal diet that can be improved by fodder legumes or if it is well managed can improve its quality (Wayne and Terres-Cardona 2001). In this study farmers preferred Napier grass for fodder as a basal diet because it is adapted to a wide range of local climatic conditions, it can be used for other purposes like house construction and as stakes for climbing beans, and it can be used for erosion control on steep slopes (Nyaata *et al.* 2000).

In Nyamagabe *Commelina benghalensis,* Napier grass, *Panicum, Albizia amygdalina* and maize stover were scored high. The preference of *Commelina benghalensis* by farmers supports results found by Lanyasunya *et al.* (2008), who reported it as good supplementary forage for ruminants. Mixed with grasses it can improve feed intake and hence is a good feed supplement for livestock. When comparing districts, maize stover was the only resource feed to be highly scored by farmers for the criterion of „increase milk yield‟. This is because maize is harvested at a fresh stage for home consumption and fresh stovers are fed to animals. Ajmal *et al.* (2009) have reported that if maize is not available for animals, it can be replaced by *Panicum* which is similar for milk production. However, even though maize stover was preferred by farmers, this crop residue has low nutritive value (Chinh and Viet 2001). In many countries, high quantities of stovers are produced but only a small amount is used for ruminant diets. If they have to be solely used, they must be chemically treated (e.g. urea) to improve their quality (Muñoz *et al.* 1996). However, in both districts maize stover was used as a complementary feed resource without any chemical treatment.

Other feed resources stated by farmers to be important varied according to location and season. Normally during the dry season and short rainy season especially in semi-arid areas, the chemical composition of forage declines to a critical level (Nyamukanza *et al.* 2008, Yayneshet *et al.* 2009). While in Nigeria *Panicum* spp., sweet potato vines and dried brewers of beer mixed with *Panicum* were better at increasing the live weight of pre-weaning calves (Etela *et al.* 2008), crop residues like straws and stubbles were very low in quality (Salem and Smith 2008) and their use should be chemically treated (Ahmed *et al.* (2001). Other crop by-products used in the Bugesera and Nyamagabe districts were sweet potato vines. Farmers reported that they increased milk and were easy to store. These observations were in line with Larbi *et al.* (2007), Etela *et al.* (2009) who stated that in poor farming systems sweet potato foliage could be used to feed livestock. Some crop residues and local agro-industrial by-products have high nutritive value. Examples are brewer‟s grains that have high protein content and high digestibility and legume tree leaves that are high in proteins (more than 18% of crude protein) and moderately high in digestibility (Jayasuriya 2002). The brewer residues in Nyamagabe were used by farmers to supplement grass like Napier or roadside grasses.

Some improved forage legumes like *Mucuna pruriens* were identified by farmers as a forage option, but were not ranked highly as important forage. This is because *Mucuna pruriens* is not yet disseminated in many areas of Rwanda and farmers do not know much about it. However, the importance of *Mucuna pruriens* has been reported by Peters *et al.* (2001) who stated that it is adapted to various ranges of climatic conditions (e.g. humid and wet-sub humid tropics, central America and west Africa), it is a good forage and can improve soil fertility. Its seeds (beans) can be used as human food and it provides a high level of resources for poor smallholder farmers. Juma *et al.* (2006) stated that *Mucuna* spp. could increase daily milk up to 32% from Jersey cows in the period of lactation, when it was mixed with Napier grass. The biases of farmers on *Mucuna* sp. (lowest score for increase milk yield) (Table 4.5) can be attributed to the lack of extension services. The new fodder options (*Mucuna* and other fodder legumes) were brought to farmers, but there was inadequate technology transfer and evaluation together with the farmers. The low rating of these fodder species may be because the perception of issues is often different between farmers and scientists. In many areas of semi-arid Africa, drought is perceived by farmers as the major constraint reducing their farm production, whereas for scientists, soil depletion is identified as the main constraint (Slegers 2008). However, in our case, the two factors (low rainfall and soil depletion) were identified in the Bugesera and Nyamagabe districts respectively as the major factors affecting the availability of livestock feeds. Forage species adapted to these factors which limit animal feed availability are highly recommended in the low rainfall and acidic soil areas of the study.

4.5 Conclusion

All parameters used (gender analysis, wealth ranking and feed resources) in this study, have revealed problems in terms of livestock production that farmers face in the Bugesera and Nyamagabe districts. Gender analysis carried out in these two districts showed the common and diverse activities related to livestock rearing between men and women. Because of zero grazing found in the two districts, both genders shared livestock activities. However, due to the Rwandan culture, activities like milking cows, construction of cattle sheds and treatment of animal diseases are confined to men and boys. This could potentially block the development of livestock production in stalling because a household that does not have a boy or husband may not raise cows for milk production.

In addition, wealth ranking has an impact on livestock management. For example, of the five wealth categories the top two (the „very rich‟ and the „rich‟) were characterized by the possession of cows and land. These two characteristics are important in the areas where there are dense populations like in the Bugesera and Nyamagabe districts. This is because where small plots are over-exploited agricultural production can only be increased if there is addition of manure. Thus, „very poor‟ to „moderately poor‟ households will have plots prone to low production.

Furthermore, animal feed resources identified in the Bugesera and Nyamagabe districts showed that they were scarce. Although farmers identified thirteen feed resources in the Bugesera district and twenty-one in the Nyamagabe district, their availability during the year was limited. For example, in the Nyamagabe district low quality feed such as *Commelina benghalensis* and banana stems were fed to animals by up to 50% of the farmers during the rainy and dry seasons. In the Bugesera district, low quality banana stems were used by 80% of farmers for forage for cows during the dry season. The grasses like Napier grass that should constitute most of the ruminant diet were used at 25% in the diet during the dry season in the Nyamagabe district. In addition, the use of low nutritive value feeds (e.g. banana stems, leaves of trees like *Albizia* spp., *Ficus* spp.) confirmed the need for intervention in the forage options in the study areas. Fodder crops that are of good quality and can adapt to the particular climate constraints found in each district will be important. For example, in the Bugesera district the fodder crops could be tolerant to the long dry period whereas in the Nyamagabe district, they might be tolerant to the combination of soil acidity and aluminium toxicity.

CHAPTER FIVE–ON-FARM EVALUATION OF IMPROVED *BRACHIARIA* GRASSES IN LOW RAINFALL AND ALUMINIUM TOXICITY PRONE AREAS OF RWANDA

Abstract

One of the major limitations of livestock production in Rwanda, in particular in the areas constrained by low rainfall and acidic soils is the scarcity of quality forage year round. The International Centre for Tropical Agriculture (CIAT) initiated a breeding programme to develop high quality forage species to overcome these limitations. The aim of this study was to determine the production of improved *Brachiaria* grass in comparison with indigenous *Brachiaria* under low rainfall and aluminium toxicity areas of Rwanda. The specific objectives were (i) to assess the on-farm production of improved *Brachiaria* grasses (varieties and hybrids) and (ii) to determine the criteria by which farmers selected the new *Brachiaria* species in the study areas. Three varieties and five hybrids of *Brachiaria* grass from CIAT and two local grasses (control) were used for on-farm participatory trials without fertiliser application. Twelve farmers were selected in each study area and on each farm ten grasses were established in 2 m x 3 m plots. Biomass was harvested six times during the year at two monthly intervals. For each cut, dry matter (DM) was measured. The crude protein (CP), calcium (Ca) and phosphorus (P) were also measured once in the wet season and once in the dry season. In the low rainfall area, *Brachiaria brizantha* cv. Toledo and *Brachiaria decumbens* (local) had the highest DM yields (5.71and 5.61 t ha^{-1} respectively), while DM of the rest of the grasses ranged from 1.2 to 5.13 t ha^{-1}. In the acidic soil area, *Brachiaria* hybrid Bro2/1485 had higher DM (5.95 t ha^{-1}) than the rest of the grasses (1–4.47 t ha^{-1}). The highest quality grass was *Brachiaria* hybrid Bro2/1485 which obtained a CP value of 12.15% in the low rainfall area, whereas in the acidic soil area hybrid cv. Mulato II obtained the highest CP value of 11.6%. In the low rainfall area the *Brachiaria* hybrid cv. Mulato obtained a high mean Ca value of 2.15% while in the acidic soil area, cv. Marandu obtained a high Ca value of 2.41% during the wet and dry seasons. The cv. Toledo had high P (0.28%) compared to the other grasses (0.07–0.11%) in the low rainfall area. In the acidic soil area, the

Brachiaria hybrid Bro2/1485 had high P of 0.53% compared to other grasses in which P varied between 0.16 and 0.47%. Local control grasses had lower nutrients than the improved *Brachiaria* grass in the low rainfall and acidic soil area. Although *Brachiaria* hybrid cv. Mulato II was not the most productive grass, it was selected by farmers as the preferred cultivar at both sites because of its adaptability to low rainfall and acidic soil stress, and its production of green forage year round without any input of fertilizer.

5.1 Introduction

Most farmers in Rwanda practise a mixed crop-livestock production system aiming to produce at the same time crops for humans and forages for animals. Animals are kept in sheds and their manure is used for production of food crops and fodder crops on a small plot. Most farmers possess only 2 to 5 cows. Some families are supported by the government policy of providing one cow per household. Different NGOs in the study area provide improved livestock and artificial insemination (AI) to improve the genetic base of the local animals for higher milk production. However, one of the major limitations of milk and livestock production is the lack of suitable fodder crops that can produce green forage year round. This situation becomes severe in the areas constrained by low rainfall and acidic soils (Leeuw *et al*. 1992). In Rwanda, low rainfall occurs in the eastern region and in particular in the Bugesera district (Butterworth 1985) while the acidic soils are the major constraints in the Nyamagabe district located in the southwestern part of the country. In these areas, soils are highly deficient in plant nutrients (Beinroth 2001) and when combined with fluctuations of rainfall, crop-livestock production decreases (Verdoodt and Van Ranst 2006). During the dry season, farmers from these contrasting districts rely on non-conventional feeds of low nutritive value to their cattle. For example, farmers collect indigenous grasses including *Brachiaria* grass from the roadsides to feed their cattle in these areas. *Brachiaria* is a graminaceous plant which grows naturally in Rwanda but its production is limited by long dry periods and acidic soil combined with aluminium toxicity.

In other areas like Latin America, *Brachiaria* spp. are planted on large areas in order to increase the production of beef cows as well as dairy cows (Utsunomiya *et al.* 2005).

Miles *et al.* (1996) estimated that more than 70 million hectares are sown to *Brachiaria* spp. in Brazil and that the savanna of the poor and acidic soils in Brazil is covered by this species (Utsunomiya *et al.* 2005). The importance of the genus *Brachiaria* was discovered 40 years ago in Australia where it was sown for fodder for grazing cattle (Miles *et al.* 1996). Currently the genus *Brachiaria* is widespread in many tropical areas where there are more than 100 species in the tropical countries of Africa (Renvoize *et al.* 1996). The introduction of *Brachiaria* in Latin America was done accidentally during the colonial time when the species *Brachiaria decumbens* was used as bedding for slaves in the ships that transported them to Latin America (FAO 1971, Keller-Grein *et al.* 1996). Its adaptation and its importance in livestock production encouraged forage breeders to create high quality cultivars, which were adapted to the various abiotic stresses of a given area (Pascotto *et al.* 2006).

In the last 10 years, studies of selection, classification, genetic improvement and biotechnology of *Brachiaria* were undertaken by CIAT (Miles *et al.* 1996). However, Barbosa *et al.* (2002) reported that this genetic improvement was constrained by the introduction of new species from the tropical countries of Africa. These new introduced species from Africa were confusing because of the resemblance found among *Brachiaria* species (Maass 1996). Currently, more than 20 cultivars are used in livestock production in tropical America and all of them originated from seven species of tropical Africa (e.g. *B. brizantha*, *B. decumbens*, *B. ruziziens*) (Keller-Grein *et al.* 1996). In Latin America and southeast Asia improved forage grasses and legumes have been highly effective for intensifying small-scale livestock production, whilst protecting soil from erosion and other natural resources (Peters and Lascano 2003, Roothaert *et al*. 2003). In Africa, many studies on forage focused on on-station evaluation especially on grasses like *Pennisetum purpureum* (Napier grass), *Panicum* spp., *Adropogon gayanus* and legumes like *Stylosanthes* spp., *Lablab* spp., *Mucuna pruriens* among others (Gray 1984, Leeuw *et al*. 1992, Agbenin and Adeniyi 2005, Tedonkeng *et al*. 2007). However, few studies were on-farm with farmer participation (Nyaata *et al*. 2000, Mekoya *et al.* 2008). In Rwanda, forage studies focused on on-station evaluation of grasses and legumes (e.g. Napier grass, *Cenchrus ciliaris*, *Chloris gayana*, *Mucuna pruriens*) (Myambi 2006). However, when successful species were presented to farmers to promote sustainability of forage production they failed because of farm prevailing conditions. Some of the reasons were the inability of new forages to adapt to on-farm drought and acidic soils with aluminium toxicity. Improved *Brachiaria* grass (e.g. cv. Mulato, cv. Mulato II, cv. Toledo) were therefore developed to adapt to the low rainfall and acidic soil to help farmers tackle the issue of forage shortage under these conditions. These *Brachiaria* grasses have also shown good agronomic characteristics. For example, in 2004, cv. Mulato II produced more than 15 t DM ha^{-1} in a sandy clay soil with pH of 4.6 in Panama, whereas cv. Mulato produced 3.9 t ha^{-1} per harvest time in Mexico (Pedro *et al.* 2007).

Considering the production of improved *Brachiaria* grass (e.g. 16.3 t of DM ha^{-1} for *B. brizantha* cv. Marandu, Fisher and Kerridge 1996) and its adaptation to the various geographical areas, improved *Brachiaria* grass may be able to address the lack of fodder in the areas of low rainfall and acidic soils. This will also allow the farmers to select the best varieties adapted to their respective areas while helping to increase profit from cattle production (Rivas and Holmann 2005, Doole and Pannell 2008). This study tested the following hypotheses: (i) drought and aluminium toxicity tolerant varieties and hybrids of *Brachiaria* grass will produce a greater yield of dry matter and nutrients than indigenous *Brachiaria* and naturalised grasses used as forage by farmers in the low rainfall and acidic soils areas and (ii) the new *Brachiaria* grasses which were bred for higher quantity and quality under drought and aluminium toxicity will be favoured over common forages by farmers under these conditions. It is predicted that these drought and Al-toxic resistant grasses will produce more forage for cattle than the commonly used forages and will be preferred by farmers in the study area The objectives of this study were (1) to determine the production and quality of improved *Brachiaria* grasses (varieties and hybrids) through on-farm trials in the low rainfall, acidity and aluminium toxicity stress conditions and (2) to determine the criteria of selection of new *Brachiaria* grass by farmers in the area of the study.

5.2 Materials and methods

5.2.1 Site selection

Two districts with different constraints in farming systems were selected for the participatory evaluation of forages. The main biophysical aspects in the selected sites are represented below (Table 5.1).

Table 5. 1 Biophysical characteristics of selected sites

Site	**Altitude (m a.s.l)**	**Average rainfall (mm year^{-1})**	**Average temperature year^{-1}**	**Geographical coordinates**	**Topography**	**Main soil types**
Bugesera district	1425	750	21.5°C	Long.30°25“E Lat. 2° 30“ S	Undulating	Sandy and clay soils
Nyamagabe district	1800	1800	16.5°C	Long. 29°56“E Lat. 24° 47“ S	Steep slopes	Clay and kaolin soils

Adapted from Nzamurambaho 1996 and Munyemana 2001

The Bugesera district

The Bugesera district was selected for its low rainfall (750 mm year^{-1}). Some farmers in the district have adopted an intensive integrated crop-livestock farming system where animals are fed in sheds and their manure is used to fertilise crops.

The Nyamagabe district

This district was selected for its aluminium toxicity and acidic soils (pH < 5.5), medium–high altitude (1800–2500 m a.s.l) and the intensive integrated crop-livestock farming system where a cut and carry forage system is practised.

5.2.2 Farmer selection

Three cells (the lowest local government administrative division) were selected per district. Four farmers per cell were selected and 12 farmers per district were selected. In the Bugesera district, five female farmers were selected while in the Nyamagabe there were two. The selection of farmers was done in conjunction with local extension personnel, by targeting farmers that were seeking new forage options for an integrated crop-forage management system. That is why the number of female and male farmers was not the same across the two districts.

5.2.3 Experimental forage

The experimental forages were selected varieties and hybrids of *Brachiaria*, which were bred for tolerance to infertile, acidic soil and drought conditions. Some of the hybrids and varieties are resistant to spittlebugs. Varieties and hybrids of *Brachiaria* which were used in our experiment were *Brachiaria decumbens* cv. Basilisk (CIAT 606), *Brachiaria brizantha* cv. Toledo (CIAT 26110), *Brachiaria brizantha* cv. Marandu (CIAT 6294), *Brachiaria* hybrid cv. Mulato (CIAT 36061), *Brachiaria* hybrid cv. Mulato II (CIAT 36087), *Brachiaria* hybrid Bro2/0465, *Brachiaria* hybrid Bro2/1452 and *Brachiaria* hybrid Bro2/1485.

Cultivar Mulato (CIAT 36061) (*Brachiaria brizantha* x *Brachiaria ruziziensis*) is a perennial grass which is semi-erect. It can be spread by root cuttings from lower culm nodes. Its leaf has a sharp edge and is linear-triangular in shape. The leaf is broad, dark green colour on both abaxial and adaxial surfaces and is solidly covered with long hairs. The leaf sheath is densely pubescent. Its inflorescence is a panicle of 12 cm long, with 4–8 racemes about 6 cm long, and spikelets arranged in two rows on each raceme (Pedro *et al.* 2007).

Cultivar Mulato II (CIAT 36087) (*B. ruziziensis* x *B. decumbens* x *B. brizantha*) is very similar to cv. Mulato in appearance, but it has shorter and less hairs on the leaf, and has white stigmas (Pedro *et al*. 2005).

The *Brachiaria* hybrids (cv. Mulato and cv. Mulato II) are adapted to well-drained soils of good fertility (Pedro *et al.* 2007). However, they can grow in poor and acidic soils containing high aluminium concentration (Hoyos *et al.* 2007). Cultivar Mulato and cv.

Mulato II are adapted to an annual rainfall of 1000–3500 mm with good production during the dry season. They can also resist heavy grazing and high stoking rates, however, they need some period of rest for regrowth (Miles *et al.* 2004, Pedro *et al.* 2005, Pedro *et al*. 2007). Cultivar Mulato and cv. Mulato II can give a high forage yield (more than 19 t ha^{-1} $year^{-1}$ of DM) with good quality (crude protein up to 16%) when nitrogen is applied on deficient soils (Pedro *et al*. 2007).

Brachiaria hybrid Bro2/0465*, Brachiaria* hybrid Bro2/1452 and *Brachiaria* hybrid Bro2/1485 are also found in CIAT"s breeding programme. These hybrids have shown a higher production than other hybrids in terms of green forage (leaf + stem) yield in the rainy and dry season after establishment with low initial fertilizer application and this adaptation seems to be closely associated with lower amounts of stem nitrogen (N) content (Ricaurte *et al*. 2008b).

Brachiaria brizantha has many common names according to regions, but the most used is the Palisade grass (Senanayake 1994). *Brachiaria brizantha* is a perennial grass, which has an erect growth habit but is sometimes creeping. The height of *B. brizantha* varies from 60–150 cm but in some cases, it can grow up 200 cm (Clayton and Renvoize 1982). This species has a crescentic rachis that is wider than 1 mm and it has longer leaf blades than other *Brachiaria* species. Its spikelets are naturally in a single row (Renvoize *et al.* 1996). The main difference between *B. brizantha* and *B. decumbens* is the growth habit. *B. brizantha* is more erect than *B. decumbens*. These species differ in the arrangement of their rachis and the form of their spikelets (Renvoize *et al.* 1996).

The productivity of *B. brizantha* generally requires high soil fertility. Its forage quality depends on the level of soil fertility more than other *Brachiaria* species (Miles *et al.* 2004). Its crude protein ranges for 7–16% and digestibility of leaves from 40–70% have been recorded (Lapointe and Miles 1992). Its dry matter (DM) production is very high and can support high stocking rates with good persistence under continuous or rotational grazing (CIAT 2007b). The DM yields range from 8–20 t ha^{-1} $year^{-1}$ and this allows cattle live weight gains of 400–500 kg ha^{-1} $year^{-1}$ at stocking rates of 2.5 steer ha^{-1} in the wet season and 1.5 in the dry season. However, it has some toxicity that can cause severe photosensitization in sheep, goats and young cattle (Miles *et al*. 2004).

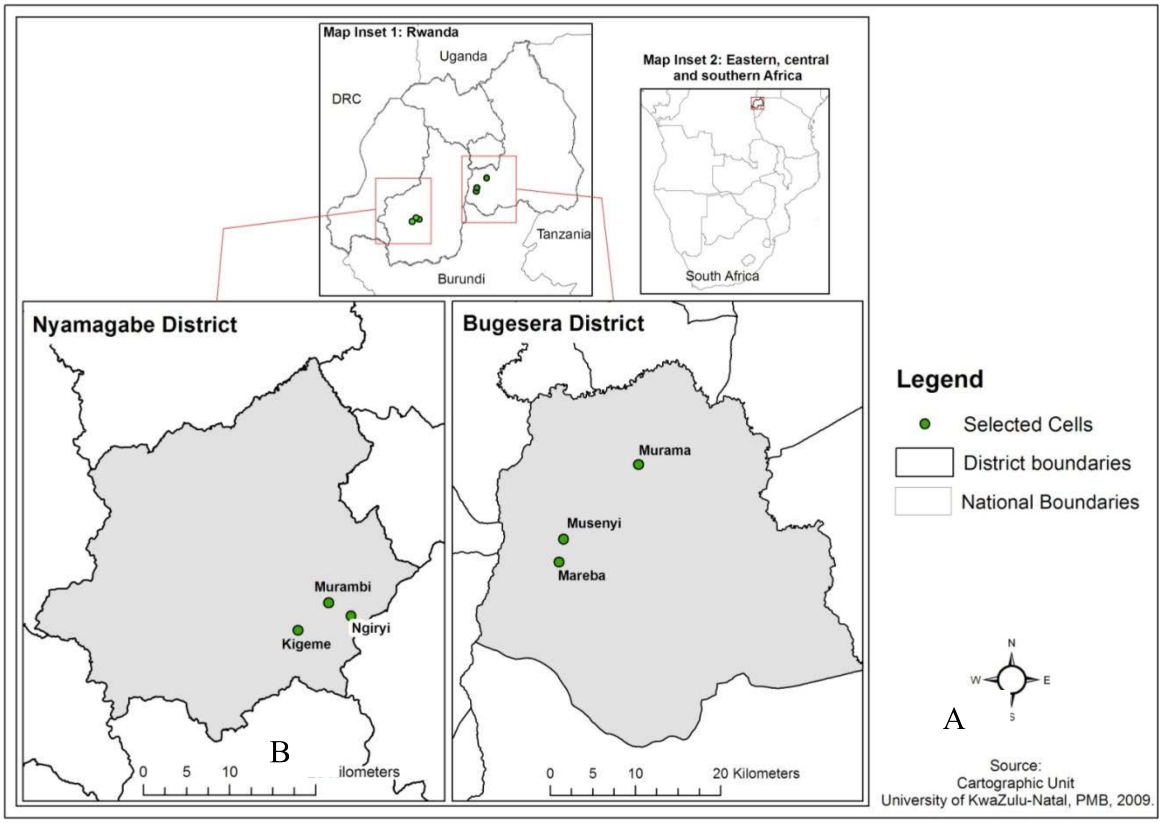
5.2.4 On-farm establishment of Brachiaria grasses

Improved *Brachiaria* grass seeds were supplied by CIAT after receiving an importation permit from the Rwandan Ministry of Agriculture and Animal Resources (MINAGRI). The different species of *Brachiaria* were multiplied by seed in the nursery at Karama Research Station of Rwandan Agricultural Research Institute (ISAR). From the plants, established vegetative material was taken to the different sites. Apart from these grass species, *Brachiaria decumbens* (native grass) and *Cenchrus ciliaris* (Buffel grass) were used as control species in the on-farm trials in both Bugesera and Nyamagabe districts. *Cenchrus ciliaris* (Buffel grass) has been tested under different agro-ecological zones of Rwanda and showed good adaptation in the Bugesera district (Myambi 2006). Currently, buffel grass is naturalised and used by farmers as forage in different areas of Rwanda.

The on-farm trial was carried out on three cells in the low rainfall (Bugesera district) and three in the aluminium toxicity acidic soil (Nyamagabe district). The distances between the three cells in each district are shown (Figure 5.1). In each cell, four farmers were selected and hence 12 farmers for each district. The distances were calculated using the global positioning system (GPS) waypoint option. The Bugesera district is a lowland area where selected farmers were close to one another (<2,894 m) whereas in the Nyamagabe district this was not always possible due to the steep slopes in the area (<6,575 m). The distance between the two districts by road is about 223 km from southeast to southwest of the country. Within a cell the distance from one farmer to another varied according to the district (Table 5.2) and the distance between cells within the district varied according to target farmers (Figure 5.1A and 5.1B).

Table 5. 2 The distance between selected farmers within a cell per district

	Cells	Distance between farmers within a cell
The Bugesera district	Murama	Varying from 50 m to 200 m
	Musenyi	2894 m
	Mareba	2154 m
The Nyamagabe district	Ngiryi	Varying from 3459 m to 4505 m
	Kigeme	Varying from 2376 m to 6575 m
	Murambi	Varying from 2681 m to 4073 m



Source:
Cartographic Unit
University of KwaZulu-Natal, PMB, 2009.

Figure 5. 1 Location of study sites in Rwanda

During on-farm establishment, a total of three *Brachiaria* varieties and five hybrids with two local control grasses were established at the Karama research station of ISAR. These were used for vegetative material for on-farm participatory trials. The experimental design (Figure 5.2) comprised 10 plots (2 m x 3 m) which included five hybrids of *Brachiaria*, three cultivars of *Brachiaria* and two local forage controls *Brachiaria* *decumbens* (indigenous grass) and naturalized *Cenchrus ciliaris*. Although many farmers use Napier grass (*Pennisetum purpureum*) as fodder, it was not used as a control grass because of its tall growth habit and different cutting height from *Brachiaria* grass. The indigenous *Brachiaria* and the naturalised buffel grass (*Cenchrus ciliaris*) were considered as suitable controls in this trial since farmers, even those who use Napier grass, rely on the „cut-and carry‟ of indigenous *Brachiaria* from the roadside. The distribution of treatments (forage grasses) within plots was different from one farm to another.

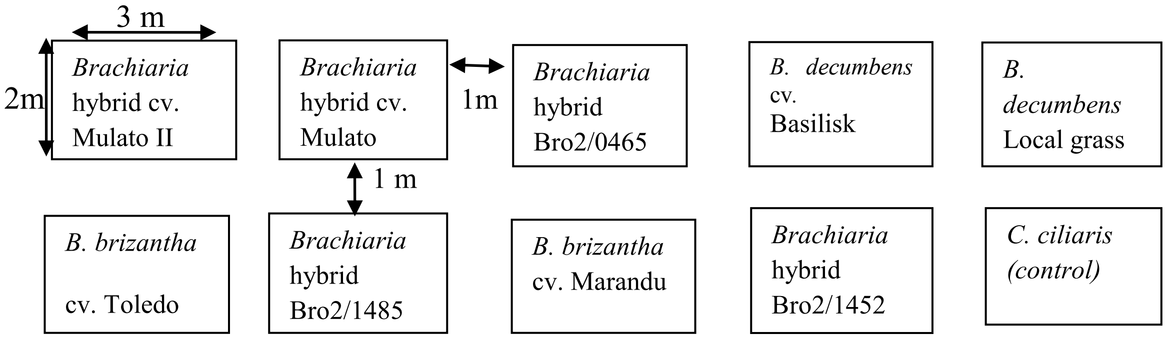


Figure 5. 2 Experimental design of on-farm trial

Before trial establishment, soil samples from four selected farms within each cell in the Bugesera and Nyamagabe districts were analyzed for pH, Al^{3+} and available phosphorus following the recommendations of Anderson and Ingram (1993) for tropical soils standard methods of analysis. The plot size was 2 m x 3 m and the spacing between plots was 1 m. All grasses were established without fertilizer application.

5. 2.5 Evaluation of forage

5.2.5.1 Quantity and quality

- Forage yield evaluation took place six times a year at approximately two monthly intervals with cutting at 10 cm height. For the creeping species, especially *Brachiaria decumbens* and *Cenchrus ciliaris*, cutting at 10 cm height was recommended by Tudsri *et al.* (2002). For erect species, cutting at 10 cm height increases the yield (Tarawali *et* *al.* 1995). Biomass was harvested in a 1 m^2 quadrat randomly placed within each 2 m x 3 m plot at each of the following harvest time:

- during peak of first rainy season (November 2007)
- during beginning of first dry season (January 2008)
- during the second rainy season (March 2008)
- during the end of second rainy season (May 2008)
- during the dry season (July 2008)
- during the rainy season (September 2008)

After collecting samples from 1 m^2 quadrat, the whole plot was cut to allow the homogenous regrowth for the next cut.

Biomass subsamples from 1 m^2 quadrat were oven dried at 105°C to constant mass to give dry matter production estimates during the study period (Griggs *et al.* 2007, Ibáñez and Alomar 2008). The dry matter was calculated as indicated by Tarawali *et al.* (1995), Pieper (1978) cited by Kidunda (1996):

- Dry matter (DM) yield kg ha^{-1}= (Tot FW x (DW ss/FW ss)) x 10

where:

Tot FW= Total fresh weight from 1 m^2 quadrat in grams
DW ss= Dry weight of the subsample in grams
FW ss= Fresh weight of the subsample in grams

All samples were taken to the laboratory of animal feed analysis at Rubona Research Station of the Rwandan Agriculture Research Institute (ISAR) and at High Institute of Agriculture and Animal Husbandry of Busogo (ISAE Busogo) for nutritive value analysis. Samples taken from dried grasses were chemically analysed according to the recommendations of AOAC (1990) (once in the wet season and once in the dry season) for crude protein, phosphorus and calcium.

5.2.5.2 Participatory variety selection

Participatory variety selection (PVS) is used in many on-farm research trials to allow the farmers to judge and select the best crop varieties and/or hybrids established on their farms (Walker 2007, Misiko *et al.* 2008, Vial *et al*. 2008). The PVS approach fosters adoption and dissemination of new technologies in suitable niches for high production of the new options (Joshi *et al*. 1997, Gowda *et al*. 2000). It also helps to empower farmers with knowledge of the new technology (Pandit *et al*. 2007a, Jun *et al*. 2009). At the end of the trial, a PVS was done in order to know which varieties and/or hybrids of *Brachiaria* were selected and preferred by farmers according to their criteria. All farmers that had *Brachiaria* grass on their farm participated in this variety selection. Farmers met on one plot of grass treatments in each area. Based on identified criteria, they gave negative and positive feedback on each variety and hybrid used in the experiment. From the criteria given, the farmers ranked all the forage plants. Forage that possessed many positive criteria were likely to get a high rank.

5.2.6 Statistical Analysis

The soil samples taken in the two districts were compared using one-way analysis of variance (ANOVA). This was calculated by using general linear model procedures of Genstat–version 9 (2006) at 5% confidence level.

For the statistical analysis of on-farm grass trials, a farm was taken to be block/ replicate and plot to be the experimental unit. Although the farms were selected, they were considered as random factors as they were randomly located in each district. Farms were nested within a specific site (district). Species were randomised within each farm so that each farm had all ten species, and was treated as a block relative to species. It was assumed that there was homogeneity within farms. The number of cuts of grass over time was considered as repeated measures. The residual or restricted maximum likelihood (REML) multivariate model was used to assess the relationship among the variables (dry matter, crude protein, calcium and phosphorus).

In general, the equation and format for the residual or restricted maximum likelihood (REML) for comparison of different varieties and hybrids of *Brachiaria* within sites was as follows:

Fixed model = constant + Site + Site.Treatments (Brachiaria grasses) + Site.Treatments.Harvest time.

Where:

Site.Treatments is the effect of site on treatments

Site.Treatments.Harvest time is the effect of harvest time on treatments within site

However, the REML analysis does not give an F-statistic but gives a Wald statistic. The Wald test uses Chi-square (χ^2) probability in comparison to F-probability. According to Virk and Witcombe (2008), the two models give the same results and the significance levels increase as the sample size increases.

5.3 Results

5.3.1 Soil analysis

Results from the analysis of variance (ANOVA) showed a significant difference ($p<0.05$) between parameters (Table 5.3). The comparison of pH between two sites shows that pH in the Bugesera district was higher (5.75) than in the Nyamagabe district (5.09). This shows that soils of Bugesera are not acid whereas in Nyamagabe, they are acid.

Table 5. 3 Soil analysis in the Bugesera and Nyamagabe districts

Parameters	Bugesera Mean ± SE	Nyamagabe Mean ± SE	F-ratio	P. value	$LSD_{0.05}$
pH	5.75±0.06	5.09±0.10	6.25	0.002**	0.23
Al^{3+}(meq 100 g^{-1})	0.24±0.09	1.47±0.13	12.53	0.001**	0.31
Avail. P (meq 100 g^{-1})	6.88±1.04	4.30±0.66	1.23	0.037*	2.41

**= P (<0.001), *= (p<0.05); SE = Standard Error; Avail. P= Available Phosphorus; Al^{3+}= Aluminium; meq 100 g^{-1} = Milliequivalent per 100 grams of soil; $LSD_{0.05}$= Least Significant Difference at level of 5%.

The aluminium concentration in the soil was found to be higher in the Nyamagabe district than in the Bugesera district (Table 5.3). As the soil pH decreased, Al increased for the Nyamagabe and Bugesera respectively. The level of Al that causes toxicity to the plants is 2 meq 100 g^{-1} of soil. The results showed that Al concentration in selected cells of the Nyamagabe district was more likely to reach the level of toxicity (Al^{3+} =1.4 meq 100 g^{-1} of soil) than in the selected cells of the Bugesera district (Al^{3+} = 0.24 meq 100 g^{-1} of soil). Therefore, the acidic soils and high Al will inhibit crop and fodder production in the Nyamagabe district. Furthermore, the available phosphorus (P) analysis indicated that there was a significant difference ($p<0.05$) between the two sites. Available phosphorus was more variable between cells in the low rainfall area (the Bugesera district) than in the acidic soil area (the Nyamagabe district); and the low rainfall area had a higher available P (6.88 meq 100 g^{-1}) than in the acidic soil area (4.30 meq 100 g^{-1}). The low soil pH, high concentration of Al and the low available phosphorus were the major constraints faced by farmers in the Nyamagabe district.

5.3.2 Quantity and quality of experimental grasses

5.3.2.1 Dry matter analysis

The dry matter yield analysis (Table 5.4) showed that grass varieties and hybrids between sites were significantly different ($p<0.01$). The effect of treatments within sites also showed a significant difference ($p<0.01$). In addition, there was a significant difference ($p<0.01$) of effect of harvesting time on treatments within sites.

Table 5. 4 Wald tests for fixed effects for the dry matter analysis of the treatments

Fixed term for the effects	**Wald statistic**	**d.f.**	**Wald/d.f.**	**chi pr**
Site	8.42	1	8.42	0.004**
Site .Treatments	127.66	18^{a}	7.09	<0.001**
Site .Treatments.Harvest time	429.11	100^{b}	4.29	<0.001**

** = Significant at $p<0.01$; d.f. = degree of freedom; Site.Treatments = effect of site on treatments; Site .Treatments.Harvest time = effect of harvest time on treatments within sites; ^{a} = Site (2) multiply by Treatments minus one (10-1); ^{b} = Site (2) multiply by harvest time minus one (6-1) multiply by treatments (10).

The mean total DM yield in the low rainfall area was significantly different ($p<0.05$) between grasses (Table 5.5). The highest mean annual dry matter yield was achieved by *B. brizantha* cv. Toledo (5.71 t ha^{-1}) and *B. decumbens* (local) (5.61 t ha^{-1}). They were followed by cv. Mulato II (5.13 t ha^{-1}), cv. Mulato (5.03 t ha^{-1}), cv. Basilisk (4.79 t ha^{-1}), hybrid Bro2/1485 (4.67 t ha^{-1}) and cv. Marandu (4.58 t ha^{-1}) (Table 5.5). The lowest mean annual DM yield was obtained by *C. ciliaris* (1.19 t ha^{-1}).

At the first cut during the wet season in the low rainfall area, the *Brachiaria* hybrid cv. Mulato had highest DM (8.29 t ha^{-1}) (Table 5.5). It was followed by *B. brizantha* cv. Marandu (7.46 t ha^{-1}) and *Brachiaria* hybrid cv. Mulato II (7.07 t ha^{-1}). The lowest DM for the same harvest time was obtained by *Brachiaria* hybrid Bro2/0465 (2.14 t ha^{-1}) and *Cenchrus ciliaris* (2.24 t ha^{-1}). However, in the second and third harvest in the same area, *B. decumbens* (local) had a DM of 11.89 and 11.10 t ha^{-1} respectively. It was followed by *B. brizantha* cv. Toledo that had a DM of 11.18 and 11.05 t ha^{-1} for the second and third cutting respectively. At the fourth harvest during the dry season, the mean DM yields of almost all tested grasses were not different and varied from 2.6 to 4.15 t ha^{-1}. However, hybrid Bro2/0465 and the control *C. ciliaris* yielded the lowest DM during this period in the same low rainfall area (Table 5.5). At fifth harvest during the dry season the mean DM of cv. Toledo, cv. Marandu, hybrid Bro2/1452 and cv. Mulato II were not different and ranged from 1.77 to 2.42 t ha^{-1}. At this harvest time, the control *C. ciliaris* yielded the lowest DM (0.54 t ha^{-1}).

Table 5. 5 Means of DM yield (t ha^{-1}) of treatments for each harvest time in the low rainfall area (Bugesera district)

	Harvest time (two month intervals)						
Season	**Wet**	**Dry**	**Wet**	**Dry**	**Dry**	**Wet**	
Treatments	**Nov**	**Jan**	**Mar**	**May**	**Jul**	**Sep**	$\overline{X}$
B. brizantha cv. Marandu	7.46^{bc}	6.71^{abc}	6.87^{abc}	3.29^{bc}	1.90^{bc}	1.25^{bc}	4.58^{bcd}
B. brizantha cv. Toledo	4.09^{ab}	11.18^{bc}	11.05^{bc}	3.77^{bc}	2.42^{c}	1.72^{c}	5.71^{d}
B. decumbens cv. Basilisk	5.16^{abc}	8.09^{abc}	8.49^{bc}	4.00^{bc}	1.46^{b}	1.53^{bc}	4.79^{bcd}
B. decumbens cv. Local	4.70^{abc}	11.89^{c}	11.10^{c}	3.22^{bc}	1.45^{b}	1.31^{bc}	5.61^{d}
Brachiaria hybrid Bro2/0465	2.14^{a}	4.31^{ab}	4.39^{abc}	2.44^{ab}	1.46^{b}	1.04^{b}	2.63^{ab}
Brachiaria hybrid Bro2/1452	3.51^{ab}	4.27^{ab}	4.19^{ab}	2.60^{bc}	1.77^{bc}	1.47^{bc}	2.97^{abc}
Brachiaria hybrid Bro2/1485	3.76^{ab}	9.86^{bc}	9.50^{bc}	2.63^{bc}	1.34^{ab}	0.95^{b}	4.67^{bcd}
Cenchrus ciliaris	2.42^{a}	1.55^{a}	1.34^{a}	0.98^{a}	0.54^{a}	0.30^{a}	1.19^{a}
Brachiaria hybrid cv. Mulato	8.29^{c}	9.47^{bc}	7.51^{abc}	2.63^{bc}	1.24^{ab}	1.02^{b}	5.03^{cd}
Brachiaria hybrid cv. Mulato II	7.07^{bc}	8.00^{abc}	8.27^{bc}	4.15^{c}	1.88^{bc}	1.39^{bc}	5.13^{cd}
LSD (α=0.05)	**4.06**	**7.43**	**6.88**	**1.60**	**0.86**	**0.62**	**2.01**

Means in the column followed by the same superscript letter are not significantly different ($p > 0.05$); LSD: Least Significant Difference at level of 5%; $\overline{X}$= Overall mean.

At sixth harvest time the mean DM of cv. Marandu, cv. Toledo, cv. Basilisk, *B. decumbens* (Local), hybrid Bro2/1452 and cv. Mulato II were not different and ranged from 1.31 to 1.72 t ha^{-1}. The lowest DM yields (0.3–1.04 t ha^{-1}) were obtained by hybrids Bro2/0465, Bro2/1485, cv. Mulato and control grass *C. ciliaris*. Although the sixth harvest was done during the rainy season, the DM decreased because it followed two previous harvests done during the dry season and was possibly due to soil depletion, as fertiliser was not used in this study.

In the acidic soil area, the mean total DM yields of the grasses were significantly different ($p<0.05$). The highest mean annual dry matter yield was achieved by *Brachiaria* hybrid Bro2/1485 (5.95 t ha^{-1}), cv. Basilisk (4.57 t ha^{-1}) and cv. Marandu (4.47 t ha^{-1}). They were followed by cv. Toledo (4.18 t ha^{-1}), cv. Mulato II (4.18 t ha^{-1}), Local (3.72 t ha^{-1}) and cv. Mulato (3.48 t ha^{-1}) (Table 5.6). The lowest mean annual DM yield was obtained by the control *C. ciliaris* (1 t ha^{-1}).

The DM of the first harvest time was higher than that of the later harvest times (Table 5.6). This first DM yield in the acidic soil was also higher than that of yields found in the Bugesera district. This is because in that period, it was the first rainy season, which was insufficient for the plant growth in the Bugesera district, but was enough in the Nyamagabe district. This first harvesting time was the cutting two months following grass establishment. Some of the hybrids established quickly and produced high yields within two months of planting (e.g. hybrid Bro2/1485 yielded 14.96 t ha^{-1}). However, some hybrids had poor establishment and low yields at this time (e.g. hybrid Bro2/0465 yielded 1.66 t ha^{-1}). In the acidic soil area (the Nyamagabe district), initial high yields of some grasses decreased significantly by the second cutting time. For example, the hybrid Bro2/1485 yielded 6.2 t $ha^{-1}$and cv. Basilisk obtained 5.09 t ha^{-1}. For the all harvests in the acidic soil area, the DM yield showed that cv. Marandu, cv. Toledo, cv. Basilisk, local *Brachiaria* (control), *Brachiaria* hybrid Bro2/1485, cv. Mulato and cv. Mulato II performed better than the two hybrids (*Brachiaria* hybrid Bro2/0465 and *Brachiaria* hybrid Bro2/1452) and control *C. ciliaris* under this condition (Table 5.6).

The differences between treatments within each site per harvest time showed that the Bugesera district had higher DM yield than the Nyamagabe district for all cutting times (Tables 5.5 and 5.6). However, *Brachiaria* hybrid Bro2/1485 obtained a higher DM in the Nyamagabe district than that observed in the low rainfall area (Tables 5.5 and 5.6). The significant difference ($p<0.05$) between the two sites in terms of grass DM yield may be due to difference in stress conditions encountered in each area.

Table 5. 6 Means of DM yield (t ha^{-1}) of different treatments for each harvest time in the acidic soil area (Nyamagabe district)

	Harvest time (two month intervals)						
Season	**wet**	**dry**	**wet**	**dry**	**dry**	**wet**	
Treatments	**Nov**	**Jan**	**Mar**	**May**	**Jul**	**Sep**	$\overline{X}$
B. brizantha cv. Marandu	8.44^{cd}	4.97^{bc}	4.82^{bc}	2.22^{c}	4.23^{c}	2.12^{d}	4.47^{cd}
B. brizantha cv. Toledo	8.64^{cd}	4.46^{bc}	4.57^{bc}	2.16^{c}	3.61^{bc}	1.64^{bcd}	4.18^{c}
B. decumbens cv. Basilisk	11.26^{de}	5.09^{bc}	5.13^{bc}	1.66^{bc}	3.10^{bc}	1.20^{bcd}	4.57^{cd}
B. decumbens cv. Local	7.49^{abcd}	4.90^{bc}	4.90^{bc}	1.19^{abc}	2.82^{bc}	1.01^{abc}	3.72^{c}
Brachiaria hybrid Bro2/0465	1.66^{a}	2.73^{ab}	2.97^{ab}	1.61^{bc}	1.82^{ab}	1.26^{bcd}	2.01^{ab}
Brachiaria hybrid Bro2/1452	2.04^{ab}	1.40^{a}	1.04^{a}	0.91^{ab}	1.79^{ab}	0.72^{ab}	1.32^{a}
Brachiaria hybrid Bro2/1485	14.96^{e}	6.20^{c}	6.20^{c}	2.17^{c}	4.18^{c}	1.97^{cd}	5.95^{d}
Cenchrus ciliaris	3.20^{abc}	0.93^{a}	1.23^{a}	0.21^{a}	0.28^{a}	0.13^{a}	1.00^{a}
Brachiaria hybrid cv. Mulato	8.19^{bcd}	3.78^{abc}	3.78^{abc}	1.64^{bc}	2.12^{ab}	1.35^{bcd}	3.48^{bc}
Brachiaria hybrid cv. Mulato II	6.80^{abcd}	5.26^{bc}	5.64^{bc}	2.14^{c}	3.64^{bc}	1.60^{bcd}	4.18^{c}
LSD (α=0.05)	**6.19**	**3.05**	**3.00**	**1.15**	**1.96**	**1.00**	**1.48**

Means in the column followed by the same superscript letter are not significantly different; LSD: Least Significant Difference at level of 5%; $\overline{X}$= Overall mean.

In both sites DM yield of tested grasses were evaluated during the rainy and dry seasons. It was found that during the rainy season (harvest times November, March and September) there was no significant difference ($p>0.05$) between sites in terms of dry matter yield for all treatments. However, there was a significant difference ($p<0.01$) of site effect on treatments and effect of harvest time on treatments within sites (Table 5.7). During the dry season there was a significant difference ($p<0.01$) between sites, effect of site on treatments and the effect of harvest time on treatments within sites.

Table 5. 7 Dry matter analysis of treatments for the wet and dry seasons

		Wet season		Dry season	
Fixed term of effects	**d.f.**	**Wald statistic**	**chi pr**	**Wald statistic**	**chi pr**
Site	1	2.03	0.154NS	17.47	<0.001**
Site.Treatments	18[a]	59.95	<0.001**	41.42	<0.001**
Site.Treatments.Harvest time	40[b]	274.50	<0.001**	357.68	<0.001**

Site.Treatments= effect of site on treatments; Site.Treatments.Harvest time = effect of harvest time on treatments within sites; d.f. = degree of freedom; NS: no significant difference ($p>0.05$); ** =significant difference at $p<0.01$; [a] = site (2) multiply by treatments minus one (10 - 1); [b] = site (2) multiply by harvest time minus one (3-1) multiply by treatments (10).; chi pr = Chi-square (χ^2) probability.

In the low rainfall area, in the third rainy season (September) when treatments were on their sixth harvest time the DM of cv. Marandu, cv. Toledo, cv. Basilisk, *B. decumbens* (control), *Brachiaria* hybrid Bro2/1452 and cv. Mulato II (1.25–1.72 t ha^{-1}) were not significantly different ($p>0.05$) (Table 5.5). During the first dry (January) season at the second harvest time cv. Toledo and *B. decumbens* (local) produced the highest dry matter recorded during the study (11.89 t ha^{-1} and 11.18 t ha^{-1} respectively). The lowest DM yield was produced by the control grass *Cenchrus ciliaris* (1.55 t ha^{-1}). By the second dry season (May) at the fourth harvest the DM of all treatments decreased and only cv. Mulato II and cv. Basilisk were able to produce 4.15 and 4.0 t ha^{-1} of DM respectively (Table 5.5). The yield of the control, (*B. decumbens*) (3.22 t ha^{-1}) was not significantly different from the top producers, but the control *Cenchrus ciliaris* had the lowest yield (0.98 t ha^{-1}). By the third dry season (July) at fifth harvest, the yield decreased further with the top producers cv. Toledo, cv. Marandu, cv. Mulato II and hybrid Bro2/1452 only yielding 1.7–2.42 ha^{-1}. The decrease of DM during this harvest time was evident as it was the peak of the dry season and the reason might be the moisture in the soil that was likely to be too low for growth of the plants in the low rainfall area.

In the acidic soil area (the Nyamagabe district), the trend of mean DM of treatments showed that the DM of the first cut in the rainy season produced higher dry matter but declined with increasing number of harvests (Table 5.6). All harvest times in the wet season showed that *Brachiaria* hybrid Bro2/1485 produced higher DM than the other treatments except for the third cut in the wet season where cv. Marandu produced 2.12 t ha^{-1} of DM versus 1.97 t ha^{-1} of DM for *Brachiaria* hybrid Bro2/1485 (Table 5.6). The lowest dry matter production from the wet and dry seasons in acidic soil area was found in *C. ciliaris* and followed by *Brachiaria* hybrid Bro2/1452.

The DM of the dry and wet seasons in the low rainfall area showed that the wet season yielded slightly higher DM than the dry season for each treatment. The DM obtained by cv. Marandu in the wet and dry seasons was not significantly different from that of cv. Toledo, cv. Basilisk, *B. decumbens* (control), hybrid Bro2/1485, cv. Mulato and cv. Mulato II in the low rainfall area (Figure 5.3B). However, the DM of these treatments was higher than that of the hybrids Bro2/1452, Bro2/0465 and control *C. ciliaris*.

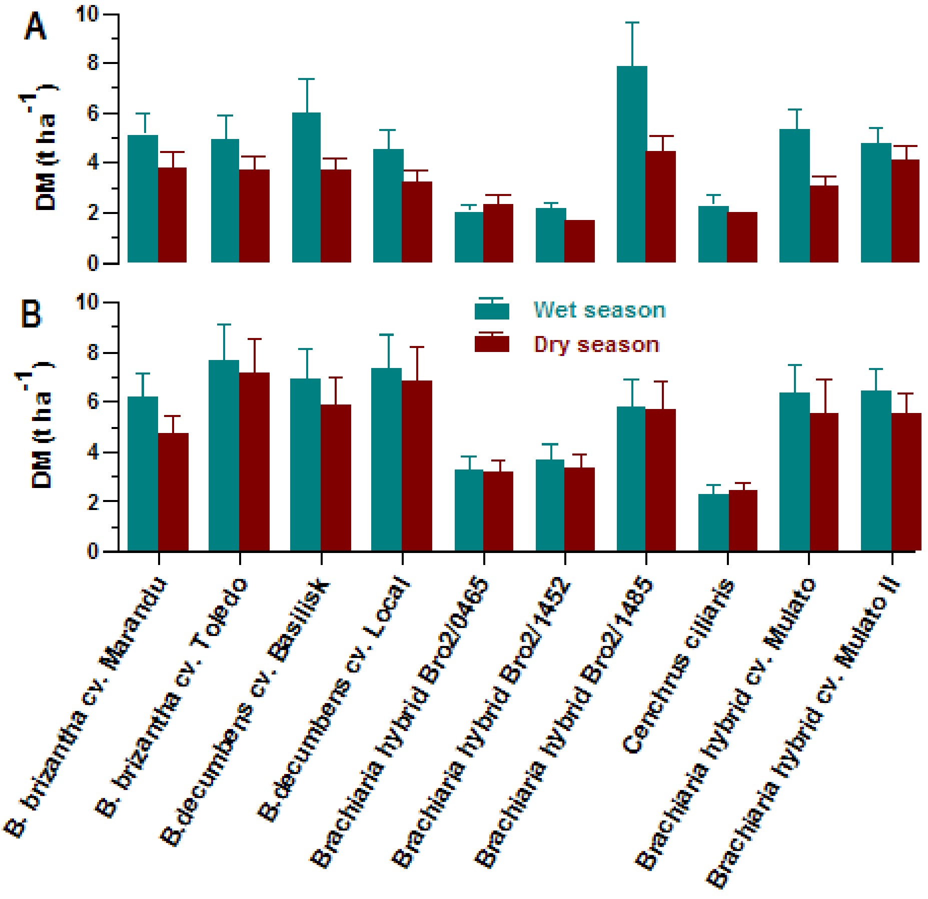


Figure 5. 3 Mean DM (t ha^{-1}) yield from the wet and dry seasons in the acidic soil area (A) and low rainfall area (B).

Under acidic soil stress, the comparison of mean total DM of grasses harvested in the dry season and rainy season in the acidic soil area showed that each tested grass yielded higher DM in the wet season (Figure 5.3A). The trends of DM from the two seasons in the acidic soil area showed that *Brachiaria* hybrid Bro2/1485 had higher DM yield (7.85 and 4.44 t ha^{-1}) than the rest of tested grasses. Even though the DM in the wet season was greater than that of the dry season, some varieties and hybrids had very low yields in the wet season. These were *Brachiaria* hybrids Bro2/0465, Bro2/1452 and control *C. ciliaris* (Figure 5.3A). Although the low rainfall area had a longer dry season compared to the acidic soil area, tested grasses obtained higher DM during the dry season in the low rainfall area than the acidic soil area. This may be caused by the combination of Al-toxic and dry soils encountered in the acidic soil area at this period.

The means of dry matter production in each treatment from all harvest times were compared in both study sites. It was found that DM production of each grass in the low rainfall area was greater than in the acidic soil area except for *Brachiaria* hybrid Bro2/1485 (Figure 5.4). However, when comparing the DM production per site and per harvest time, (Figure 5.5) the first harvest time the DM of all treatments was greater in the acidic soil area than in the low rainfall area. The establishment of the grasses in the two sites was done in the short rainy season, which is always less effective on sandy soil of the low rainfall area than on clay soil of the acidic soil area and therefore likely to promote better establishment of grasses in the Nyamagabe district than in the Bugesera district.

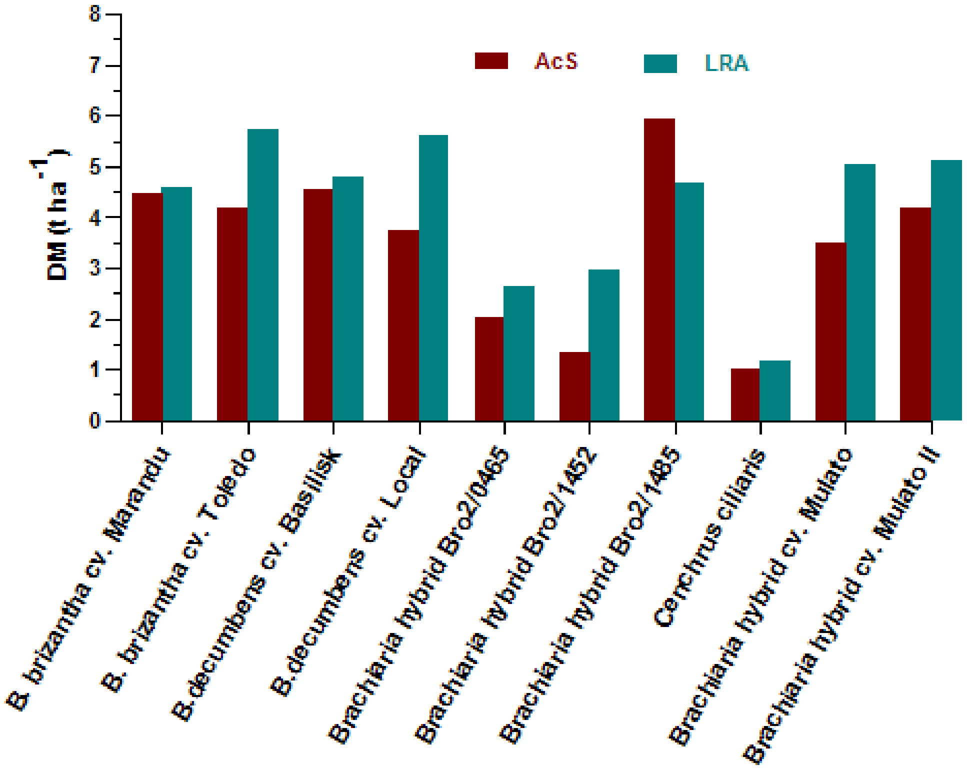


Figure 5. 4 Total dry matter yield of grasses under low rainfall area (LRA) and acidic soil area (AcS) stress conditions.

Following this first harvest, the seasonal trend of DM was higher in the low rainfall area (the Bugesera district) except for the harvest time in July (Figure 5.5). The July harvest time was done during the peak of the dry season. At this time all grasses in the Bugesera district were dry while grasses in the Nyamagabe district had some green leaves indicating some moisture was retained in the soil.

The combined seasonal dry matter yield of tested grasses in the low rainfall area was not significantly different ($p>0.05$) for all entries in the wet season except *C. ciliaris* which yielded the lowest DM (Table 5.8). Furthermore, the combined mean DM yield from each treatment in the low rainfall area during the dry season showed that there was no significant difference ($p>0.05$) between cv. Marandu, cv. Toledo, cv. Basilisk, control *Brachiaria*, *Brachiaria* hybrid Bro2/1485, cv. Mulato and cv. Mulato II (3.97–5.79 t ha^{-1}) (Table 5.8). The only species that had a significantly lower yield was *Cenchrus ciliaris* (1.0 t ha^{-1}).

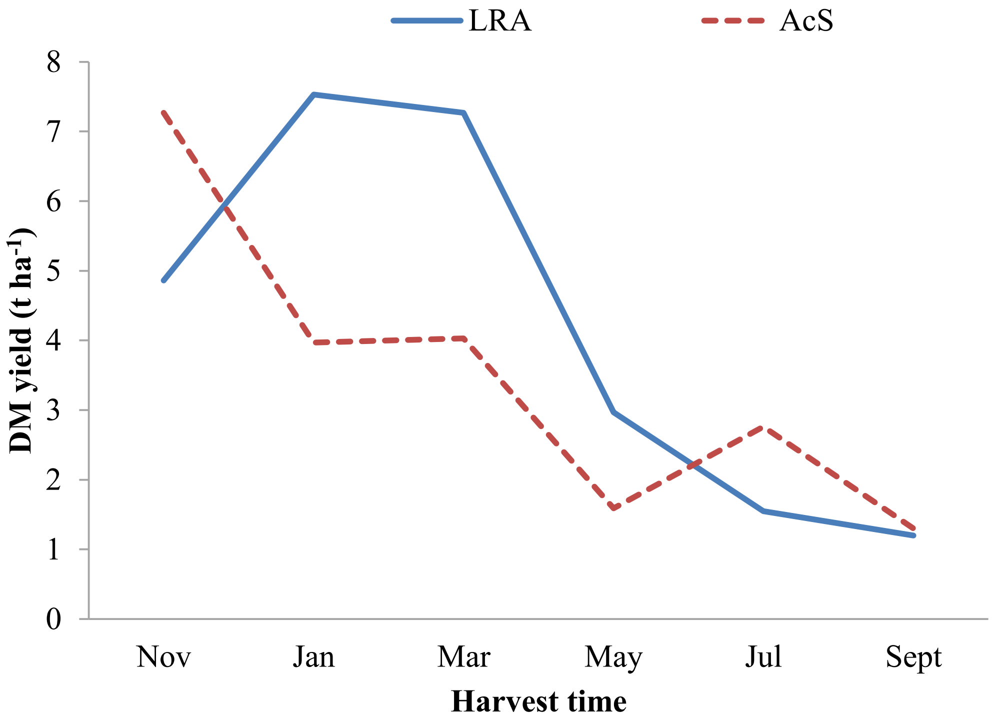


Figure 5. 5 Seasonal trends of all treatments in the contrasting LRA and AcS environments.

However, in the acidic soil area, the mean total DM yield of grasses during the wet season was significantly different ($p<0.05$) and Hybrid Bro2/1485 yielded higher (7.7 t ha^{-1}) than the rest of grasses. It was followed by cv. Mulato II (4.68 t ha^{-1}) and the lowest was the hybrid Bro2/1452 (1.27 t ha^{-1}) and control *C. ciliaris* (Table 5.8).

It was also found that the combined dry matter yields of cv. Marandu, cv. Toledo, cv. Basilisk, Local *Brachiaria,* hybrid Bro2/1485 and cv. Mulato II (2.97–4.18 t ha^{-1}) during the dry season in the acidic soil area were not significantly different ($p>0.05$). The lowest mean total yield was recorded for *C. ciliaris* (0.47 t ha^{-1}) in the dry of the acidic soil area.

Table 5. 8 Mean DM yield (t ha^{-1}) of treatments in the dry and wet seasons in the two study sites

	Low rainfall area (the Bugesera district)		**Acidic soil area (the Nyamagabe district)**	
Treatments	**Wet**	**Dry**	**Wet**	**Dry**
B. brizantha cv. Marandu	5.2^{b}	3.97^{bc}	5.13^{cd}	3.81^{de}
B. brizantha cv. Toledo	5.72^{b}	5.79^{c}	4.95^{cd}	3.41^{de}
B. decumbens cv. Basilisk	5.06^{b}	4.52^{bc}	5.86^{cd}	3.28^{cde}
B. decumbens cv. Local	5.6^{b}	5.52^{bc}	4.47^{bc}	2.97^{bde}
Brachiaria hybrid Bro2/0465	2.52^{ab}	2.74^{ab}	1.96^{ab}	2.05^{bc}
Brachiaria hybrid Bro2/1452	3.06^{ab}	2.88^{ab}	1.27^{ab}	1.37^{ab}
Brachiaria hybrid Bro2/1485	4.78^{b}	4.61^{bc}	7.7^{d}	4.18^{e}
Cenchrus ciliaris	1.35^{a}	1.02^{a}	1.52^{ab}	0.47^{ab}
Brachiaria hybrid cv. Mulato	5.61^{b}	4.44^{bc}	4.44^{bc}	2.51b^{cd}
Brachiaria hybrid cv. Mulato II	5.58^{b}	4.68^{bc}	4.68^{c}	3.68^{de}
LSD$_{0.05}$	**2.91**	**2.81**	**2.62**	**1.33**

Means in the column followed by the same superscript letter are not significantly different; LSD$_{0.05}$: Least Significant Difference at level of 5%.

Likewise, the mean DM of tested grasses in the dry season from both sites showed that cv. Marandu, cv. Toledo, cv. Basilisk, Local *Brachiaria*, hybrid Bro2/1485, cv. Mulato and cv. Mulato II were the grasses, which showed high DM yield in both environments. The DM yield of the control grass *Brachiaria decumbens* (indigenous) was not significantly different ($p>0.05$) from the DM of the hybrids and varieties of the commercial *Brachiaria* especially in the low rainfall area. However, *Cenchrus ciliaris* yielded the lowest DM of all the grasses (Table 5.8).

5.3.2.2 Crude protein, calcium and phosphorus analysis

There was a significant difference ($p<0.01$) in phosphorus (P) between sites but no significant difference ($p>0.05$) for crude protein and calcium (Table 5.9). However, treatments (grasses) within sites were significantly different ($p<0.01$) for crude protein (CP), calcium (Ca) and phosphorus (P). The effect of harvest time on treatments within sites showed that there was only a significant difference ($p<0.01$) for crude protein (Table 5.9), whereas there was no significant difference ($p>0.05$) for calcium and phosphorus for the same effect.

Table 5. 9 REML analysis for crude protein, calcium and phosphorus in the two contrasting environments

		Wald statistic		
Fixed term	**df**	**CP**	**Ca**	**P**
Site	1	0.08NS	0.82NS	49.16**
Site.Treatments	18[a]	54.04**	51.95**	40.78**
Site.Treatments.Harvest time	20[b]	68.40**	3.02NS	2.33NS

Site.Treatments= effect of site on treatments; Site .Treatments.Harvest time = effect of harvest time on treatments within sites; d.f. = degree of freedom; NS= no significant difference ($p>0.05$); **= significant difference at $p<0.01$; [a] = site (2) multiply by treatments minus one (10-1); [b =] site (2) multiply by harvest time minus one (2-1) multiply by treatments (10).

The highest quality grass in the low rainfall area (the Bugesera district) in terms of crude protein (CP) during the wet season was *Brachiaria* hybrid Bro2/1485 (15.69%). There was, however, no significant difference ($p> 0.05$) in the wet season between cv. Marandu, *Brachiaria* hybrid Bro2/1452, cv. Mulato and cv. Mulato II (9.83–12.29%) (Table 5.10). The control grasses had a low CP content during the wet season in the low rainfall area (5.07–6.68%). During the dry season, the CP content decreased for all tested grasses except for *C. ciliaris*, which had slightly higher CP in the dry season than in the wet season in the low rainfall area (5.82% versus 5.07%) (Table 5.10). In this area during the dry season, cv. Mulato II had the highest CP content (9.85%). It was followed by cv. Marandu and hybrid Bro2/1485 which had 8.29 and 8.62 % of CP respectively. The lowest CP content during the dry period in the low rainfall area was found in the two local control grasses *B. decumbens* (indigenous) and *C. ciliaris*, which obtained 6.43 and 5.82% respectively.

Table 5. 10 Mean values of crude protein of tested grasses during the wet and dry seasons of both areas

	Bugesera district		**Nyamagabe district**	
	Crude protein (%)		**Crude protein (%)**	
Treatments	**Wet**	**Dry**	**Wet**	**Dry**
B. brizantha cv. Marandu	9.83^{abc}	8.29^{bcd}	10.91^{abc}	6.69^{cd}
B. brizantha cv. Toledo	7.58^{ab}	7.32^{abc}	12.38^{bc}	7.74^{cde}
B. decumbens cv. Basilisk	6.71^{ab}	7.49^{cbc}	9.43^{ab}	6.41^{bcd}
B. decumbens cv. Local	6.68^{ab}	6.43^{ab}	9.48^{ab}	4.92^{ab}
Brachiaria hybrid Bro2/0465	8.20^{ab}	6.73^{abc}	9.21^{ab}	5.77^{abc}
Brachiaria hybrid Bro2/1452	10.91^{abc}	6.95^{abc}	8.90^{ab}	4.34^{a}
Brachiaria hybrid Bro2/1485	15.69^{c}	8.62^{cd}	12.69^{bc}	7.25^{cde}
Cenchrus ciliaris	5.07^{a}	5.82^{a}	7.88^{a}	5.55^{abc}
Brachiaria hybrid cv. Mulato	11.94^{bc}	7.81^{bc}	11.56^{abc}	7.07^{cd}
Brachiaria hybrid cv. Mulato II	12.29^{bc}	9.85^{d}	14.29^{c}	8.91^{e}
$LSD_{0.05}$	**6.67**	**1.91**	**4.40**	**1.70**

Means in the column followed by the same superscript letter are not significantly different; $LSD_{0.05}$: Least Significant Difference at level of 5%.

In the acidic soil area (the Nyamagabe district), during the wet season the highest quality grasses in terms of CP were cv. Marandu, cv. Toledo, Local *Brachiaria*, hybrid Bro2/1485, cv. Mulato and cv. Mulato II (10.91–14.29%). The lowest CP (7.88%) was found in *C. ciliaris* (control) in this area during the wet season (Table 5.10). During the dry season in the acidic soil area, the decrease of CP was more marked. The CP content in all tested grasses declined significantly during this season (Table 5.10). The lowest CP content was found in *Brachiaria decumbens* (local), *Brachiaria* hybrid Bro2/0465, *Brachiaria* hybrid Bro2/1452 and *Cenchrus ciliaris* which obtained 4.92; 5.77; 4.34 and 5.55% respectively (Table 5.10). The most marked decrease in quality was recorded for *B. decumbens* which decreased from 9.48% CP in the wet season to 4.92% in the dry season.

In the low rainfall area, during the wet season the calcium content was not significantly different ($p>0.05$) for the tested grasses (Table 5.11).

Table 5. 11 Mean values of calcium of tested grasses during the wet and dry seasons of both areas

	Bugesera district		**Nyamagabe district**	
	Calcium (%)		**Calcium (%)**	
Treatments	**Wet**	**Dry**	**Wet**	**Dry**
B. brizantha cv. Marandu	1.54^{ab}	1.43^{ab}	2.47^{d}	2.35^{d}
B. brizantha cv. Toledo	1.91^{b}	1.96^{bc}	1.89^{abcd}	1.89^{abcd}
B. decumbens cv. Basilisk	1.73^{b}	1.56^{abc}	1.51^{ab}	1.51^{a}
B. decumbens cv. Local	1.98^{b}	1.97^{bc}	2.20^{cd}	2.20^{cd}
Brachiaria hybrid Bro2/0465	2.16^{b}	2.04^{bc}	1.82^{abc}	1.76^{abc}
Brachiaria hybrid Bro2/1452	1.72^{b}	1.97^{bc}	2.03^{bcd}	2.11^{bcd}
Brachiaria hybrid Bro2/1485	1.81^{b}	1.87^{bc}	2.05^{bcd}	1.99^{abcd}
Cenchrus ciliaris	0.89^{ab}	1.10^{a}	1.30^{a}	1.57^{ab}
Brachiaria hybrid cv. Mulato	2.13^{b}	2.17^{c}	2.31^{cd}	2.13^{bcd}
Brachiaria hybrid cv. Mulato II	1.87^{b}	1.73^{abc}	2.36^{cd}	2.14^{bcd}
$LSD_{0.05}$	**0.74**	**0.69**	**0.60**	**0.58**

Means in the column followed by the same superscript letter are not significantly different; $LSD_{0.05}$: Least Significant Different at level of 5%.

Calcium values ranged from 0.89% for *C. ciliaris* to 2.16% for *Brachiaria* hybrid Bro2/0465. However, during the dry season the concentration of calcium differed between treatments. It was found that mean values of Ca in cv. Toledo, cv. Basilisk, *Brachiaria decumbens* (local), *Brachiaria* hybrid Bro2/0465, *Brachiaria* hybrid Bro2/1452, *Brachiaria* hybrid Bro2/1485, cv. Mulato and cv. Mulato II were not significantly different (1.56–2.17%). The lowest Ca content was recorded for *C. ciliaris* (1.10%) (Table 5.11).

In contrast to the low rainfall area, the calcium content in treatments from the acidic soil area during the wet season showed that cv. Marandu had the highest concentration of calcium (2.47%) which was significantly different ($p<0.05$) from cv. Basilisk, *Brachiaria* hybrid Bro2/0465 and *C. ciliaris* (1.3–1.82%) (Table 5.11). Similarly, during the dry season in the acidic soil area, the mean values of calcium content in cv. Marandu were significantly higher (2.35%) than that found in cv. Basilisk, *Brachiaria* hybrid Bro2/0465 and *C. ciliaris* (1.51–1.76%). The remaining treatments were not different from cv. Marandu in calcium content (1.89–2.14%) The comparison of the two sites showed that at both sites there was no significant difference in the calcium content between the wet and dry season (Table 5.11).

The phosphorus (P) content in the treatments during the wet season in the low rainfall area was significantly higher for cv. Toledo (0.28%) than *Brachiaria* hybrid Bro2/1452 (0.11%) and *C. ciliaris* (0.05%). The mean values of P content of the remaining treatments were not significantly different from P content in cv. Toledo (Table 5.12). In the low rainfall area during the dry season, the only difference in P content was again observed between cv. Toledo, and *Brachiaria* hybrid Bro2/1452 and *C. ciliaris* (which obtained the P content of 0.28; 0.10 and 0.10% respectively) and other treatments (Table 5.12).

In the acidic soil area, similar values of P content in treatments were measured. It was observed that during the wet season P in grasses was significantly higher in *Brachiaria* hybrid Bro2/1485 (0.54%) than in cv. Toledo (0.29%) and *C. ciliaris* (0.21%). The mean values of P content in the rest of the treatments were not significantly different (Table 5.12). However, during the dry season in the acidic soil area, the difference of mean values of P content in treatments was only observed between *C. ciliaris* and the rest of treatments. *Cenchrus ciliaris* (control) obtained 0.11% of P, which was the lowest mean value of P recorded in all treatments (Table 5.12).

Table 5. 12 Mean values of phosphorus in the treatments during the wet and dry seasons of both sites

	Bugesera district		**Nyamagabe district**	
	Phosphorus (%)		**Phosphorus (%)**	
Treatments	**Wet**	**Dry**	**Wet**	**Dry**
B. brizantha cv. Marandu	0.16^{abc}	0.17^{ab}	0.41^{abc}	0.42^{b}
B. brizantha cv. Toledo	0.28^{c}	0.29^{b}	0.29^{ab}	0.29^{ab}
B. decumbens cv. Basilisk	0.18^{abc}	0.20^{ab}	0.39^{abc}	0.39^{b}
B. decumbens cv. Local	0.25^{bc}	0.25^{ab}	0.47^{bc}	0.47^{b}
Brachiaria hybrid Bro2/0465	0.21^{abc}	0.21^{ab}	0.41^{abc}	0.35^{ab}
Brachiaria hybrid Bro2/1452	0.11^{ab}	0.12^{a}	0.40^{abc}	0.40^{b}
Brachiaria hybrid Bro2/1485	0.23^{bc}	0.23^{ab}	0.54^{c}	0.53^{b}
Cenchrus ciliaris	0.05^{a}	0.10^{a}	0.21^{a}	0.11^{a}
Brachiaria hybrid cv. Mulato	0.17^{abc}	0.26^{ab}	0.39^{abc}	0.39^{b}
Brachiaria hybrid cv. Mulato II	0.23^{bc}	0.23^{ab}	0.43^{abc}	0.43^{b}
$LSD_{0.05}$	**0.17**	**0.18**	**0.24**	**0.24**

Means in the column followed by the same superscript letter are not significantly different; $LSD_{0.05}$: Least Significant Difference at level of 5%.

The quality of tested grasses (CP, Ca and P) in general was higher in the acidic soil area during the wet and dry season compared to the low rainfall area. This might be possible because for most of the harvests in the acidic soil area grasses were still young resulting in high concentration of nutrients.

5.3.3 Participatory variety selection

At the end of the on-farm trial, a participatory variety selection (PVS) was done in the study sites. The farmers who had the treatments on their plots participated in the evaluation. The PVS showed the selection and rank of *Brachiaria* varieties and hybrids according to the farmers‟ criteria in the Bugesera and Nyamagabe districts (Table 5.13). In this exercise, drought tolerance, biomass production and palatability were the major criteria mentioned by farmers in the Bugesera district. In the Nyamagabe district, the farmers‟ major criteria were palatability, acidic soil tolerance, biomass and erosion control. Although the criteria for selection were almost the same in both sites, the sites differed in species chosen. The top four ranked grasses in the Bugesera district were cv. Marandu, cv. Basilisk, cv. Mulato and cv. Mulato II. In the Nyamagabe district, the highest ranks were given to Hybrid Bro2/1485, cv. Basilisk, cv. Mulato II and indigenous *Brachiaria,* with three grasses sharing the same highest rank (Table 5.13). The highest ranked *Brachiaria* across the two sites was the *B*. hybrid cv. Mulato II. In both districts, the farmers mentioned that the highest rank given to cv. Mulato II was due to its palatability and its ability to remain green year round. The most highly ranked grasses by farmers in the Bugesera and Nyamagabe districts had high values of crude protein, calcium and phosphorus. Indeed, farmers‟ curiosity on the new forages was understandable as it was the first time they had seen the other *Brachiaria* grasses, unlike the indigenous *Brachiaria*, which is a popular grass and the most used in the cut and carry system from roadsides. The farmers‟ high rank of improved *Brachiaria* grass in the low rainfall area (the Bugesera district) was also related to the growth habit. Farmers selected the tall *Brachiaria* because of its ease to cut and carry. While Hybrid Bro2/1485 was ranked lowest in the low rainfall, it was ranked highest in the acidic soil area because of its adaptability to acidic soil and its ability to produce high biomass (Figure 5.3A and Table 5.13). The indigenous grass (*B. decumbens*) used as control was among the highest ranked in the Nyamagabe district, but in the Bugesera, neither *Cenchrus ciliaris* nor *B. decumbens* (indigenous) received a high rank (Table 5.13).

Table 5. 13 Farmer participatory variety selection and ranking of *Brachiaria* grass in the Bugesera and Nyamagabe districts

Grass	The Bugesera district			The Nyamagabe district		
	Negative aspects	Positive aspects	Rank	Negative aspects	Positive aspects	Rank
Brachiaria hybrid Bro 2/0465	Does not resist to cutting, does not grow tall, and low biomass, not tolerant to drought	Roots can control erosion, highly palatability	8	Low biomass, not tolerant to poor soil fertility, difficult to cut because it is a short grass ,	Erosion control, palatable	10
Brachiaria hybrid cv. Mulato II	No negative aspect	High biomass, palatable, less hair, drought tolerance, quick regrowth, perennial, easy to cut and carry	1	No negative aspects	Medium biomass, palatable, less hair, drought tolerance, medium regrowth, perennial, easy to cut and carry, acidic soil tolerance, disease tolerance	1
B. brizantha cv. Marandu	Dry up when drought persists, difficult to cut	High biomass, palatable, quick regrowth, perennial	2	Difficult to cut	Medium biomass, medium acidic soil tolerance, palatable, disease tolerance, medium regrowth	6
Brachiaria hybrid Bro 2/1485	Less palatability, difficult to cut, less biomass, less regrowth after cut	Drought tolerance, perennial	10	No negative aspects	Palatable, drought tolerance, Medium regrowth, perennial, easy to cut and carry, acidic soil tolerance, medium disease tolerance, high biomass, medium soil erosion control	1
Brachiaria hybrid cv. Mulato	Less biomass, less regrowth after cut	Palatable, smoothness, easy to cut and drought tolerance	3	Low biomass, poor acidic soil tolerance, poor drought tolerance and poor disease tolerance	Medium palatability, medium easy to cut, medium regrowth and medium erosion control	7
B. brizantha cv. Toledo	Strong stem which makes it less palatability and difficult to cut	Drought tolerance, high biomass, erosion control, quick regrowth, perennial	5	Difficult to cut	High biomass, medium palatability, acidic soil tolerance, medium disease tolerance, erosion control, medium drought tolerance, medium regrowth	5
Cenchrus ciliaris	Less palatability, difficult to cut, less biomass	Drought tolerance, quick regrowth, perennial,	7	Low biomass, low palatability, poor acidic	Medium regrowth, easy to cut, medium disease tolerance	9

				soil tolerance, poor drought tolerance		
B. decumbens cv. Local	Difficult to cut, less regrowth, not able to control erosion	Palatable, drought tolerance, perennial, high biomass	6	No negative aspects	Medium biomass, palatable, easy to cut, medium acidic soil tolerance, disease tolerance, erosion control, drought tolerance and medium regrowth	1
Brachiaria hybrid Bro 2/1452	Low palatability, low biomass, difficult to cut and less regrowth	Drought tolerance, perennial, erosion control	9	Low biomass, low palatability, poor acidic soil tolerance, poor drought tolerance, poor erosion control, low regrowth	Disease tolerance	8
B. decumbens cv. Basilisk	Does not resist to multiple cuts	Drought tolerance, easy to cut, erosion control, high biomass, quick regrowth, palatable	4	No negative aspects	High biomass, medium palatability, easy to cut, acidic soil tolerance, disease tolerance, medium erosion control, medium drought tolerance and medium regrowth	4

5.4 Discussion

5.4.1 Soil quality in the study sites

In the Nyamagabe district, the pH was lower than in the Bugesera district. According to Hovsepyan and Bonzongo (2009) the soil becomes acid when the pH value is below 5.5 and the pH value in the Nyamagabe district was 5.09, thus an acidic soil area. The acidity of soil in the Nyamagabe district has also been reported by PIA (1986), Nzamurambaho (1996) and Kimirembe (2007). The Al content of the soil was also higher (1.47 meq) in the Nyamagabe than in the Bugesera district (0.24 meq). Previous studies have reported that aluminium concentration in the soil of the Nyamagabe was higher (4 meq 100 g^{-1} of soil) than the level of toxicity (2 meq 100 g^{-1} of soil) and this was due to high leaching of organic matter (Nzamurambaho 1996). Furthermore, when pH of the soil is below 5.5 (Vitorello *et al.* 2005), the presence of Al^{3+} becomes toxic and can inhibit the growth of roots which reduces access to water and results in poor growth and death of the plant (Kinraide 1991). The death occurs when roots of a plant are exposed to the dryness and there is no uptake of water and nutrients (Kari 2006). The results from this study support the findings of Kinraide (1991) who reported that the low soil pH can be the source of aluminium toxicity as its presence was significant in the soil of the Nyamagabe district. By contrast, the higher pH (5.7) of the selected sites of the Bugesera district had low Al (0.2 meq 100 g^{-1} of soil) which is unlikely to cause toxicity. As stated by Wenzl *et al.* (2003) and Mimmo *et al.* (2009), soils in the tropics are highly weathered and deficient in nutrients, which allow the presence of Al to become toxic and to inhibit the uptake of phosphorus by the plant. This could be the cause of toxicity in the Nyamagabe district as the heavy rain (average of 1800 mm $year^{-1}$) on high steep slopes (50%) causes soil erosion in the area (Olson 1994b).

The available phosphorus in the soil varies according to the soil types and depends on crop type. According to Valkama *et al.* (2009), the P is low in clay soil when it is below six milliequivalent (meq) 100 g^{-1} of soil. Furthermore, in the tropical countries, according to the Olsen method, the P is low when it is below ten (PIA 1986). The available phosphorus which was significantly different ($p<0.05$) between the two districts showed that the Bugesera had higher available P (6.88 meq) than the Nyamagabe district (4.30 meq). However, as both the P values were below 10 (according to the Olsen method) and these sites are in a tropical country, they are considered to be critically low.

The results on fertility status of the soil in the study areas indicated that low pH and high concentration of aluminium found in the Nyamagabe district would inhibit the growth of plants and lead to low production of a given crop. According to Edem and Ndaeyo (2009) when the soil is low in pH and high in aluminium, the application of lime, organic and inorganic fertilizers are necessary for better sustainable crop production. Although the application of fertilizers on these types of soil is recommended, the use of crops tolerant to Al-toxicity stresses is also important (Blevins and Barker 2007). For example, varieties and hybrids of *Brachiaria* grasses have been bred for drought and acidic soil tolerance to overcome the problem of lack of forage for animals in Latin America (Pedro *et al* 2007). Not only improved forage boosts animal production under acidic and drought areas but also can be used to rehabilitate degraded soil. According to Karlen *et al*. (2007), forage increases soil quality by adding organic matter into the soil, allowing water infiltration, reducing raindrop intensity and controlling erosion through its deep roots in the soil. Under low rainfall and acidic soil of the Bugesera and Nyamagabe districts respectively, the use of improved *Brachiaria* grasses can address the problems of animal nutrition as well as acidic soils.

5.4.2 Dry matter yield of tested grasses

The dry matter content in the diet of animal is important because its increase leads to the increase of energy. According to Meissner (2000), the deficit of energy in the animals‟ diet leads to low production of livestock. The grasses that have high DM content are likely to boost energy in forage for cattle. The mean dry matter of tested grasses in the low rainfall area showed that cv. Mulato yielded higher DM (8.29 t ha^{-1}) than the rest of grasses for the first harvest time. The DM of cv. Mulato was slightly less than that found by Jimenez *et al.* (2008) who recorded that cv. Mulato yielded 9.7 t of DM ha^{-1} in the rainy season and 1.41 t of DM ha^{-1} in the dry season. At the second harvest time DM obtained by indigenous *Brachiaria* (the local control grass.) in the dry season was higher

(11.89 t ha^{-1}) than that found by Romero and Gonzalez (2004) in Costa Rica, where *B. decumbens* produced 2.3 t ha^{-1} per cut. However, cv. Toledo yielded a similar DM in the wet season (11.05 t ha^{-1}) as that found by Jimenez *et al.* (2008) in Mexico where cv. Toledo yielded 11.17 t ha^{-1}. In the dry season, our results on DM of cv. Toledo (Table 5.8) were greater (5.59 t ha^{-1}) than what these authors found over three annual seasons (2.40 t ha^{-1}). The increase in DM of cv. Toledo from the first to the second cut may be due to increasing number of tillers per plant. Tudsri *et al.* (2002) stated that the dry matter of *Pennisetum purpureum* (Napier grass) from the first to the second cutting in Thailand increased because of increasing shoots from different points of the grass. The high DM production of cv. Toledo and the local *Brachiaria* in the low rainfall area could also be explained by the fact that these entries have strong roots that enable them to access moisture at deeper soil depths especially during the dry season. In addition, Serrao and Simao (1975) reported that *B. decumbens* (local) is well adapted to a wide range of tropical climate conditions and can produce high forage under varying soil conditions. The high DM found in cv. Toledo was due to its tolerance of sandy soil and its ability to remain green year round in the dry season (Pedro *et al.* 2004). The DM yield in the low rainfall area for cv. Mulato II (5.13 t ha^{-1}) was higher than that recorded by CIAT (2004a) who reported 2.3 t ha^{-1} for cv. Mulato II cut every six weeks over two years, on medium soil fertility in Costa Rica. Although the Bugesera district is characterised by a long dry season, its sandy clay soil allows plants to grow quickly when a little rainfall comes. When the soil is permeable and the oxygen is absorbed in the soil then uptake of nutrients by the plant is facilitated (Roy 1972). The mean DM of all treatments in the two contrasting environments were significantly different ($p<0.05$) among treatments. This indicates that grasses were more tolerant of the dry stress conditions, while others could tolerate acidic soil stress conditions. For example, cv. Marandu, cv. Toledo, cv. Basilisk, local *Brachiaria*, hybrid Bro2/1485, cv. Mulato, and cv. Mulato II produced high DM (4.58–5.71 t ha^{-1}) in the low rainfall area (Table 5.5). This may be due to the high stubbles they possess which maintain the reserves in the stem during the dry season and when the rain occurs, grasses use these reserves for quick regrowth (Tudsri *et al.* 2002). However, the DM produced by cv. Toledo, cv. Mulato and cv. Mulato II at fourth harvest at the beginning of dry season (end of May) decreased to 3.77; 2.63 and 4.15 t ha^{-1}

respectively (Table 5.5). These DM yields were slightly less than those found in cv. Toledo and cv. Mulato (4.7 and 3.1 t ha^{-1} respectively) but slightly higher than those reported for cv. Mulato II (2.8 t of DM ha^{-1}) by CIAT (2007c) in Las Segovias, Latin America. By the fifth harvest, at the end of dry season the yields of DM for cv. Toledo, cv. Mulato and cv. Mulato II had decreased further to 2.42; 1.24 and 1.88 t ha^{-1} respectively. These were similar to those reported for cv. Mulato and cv. Mulato II (1.2 and 1.9 t ha^{-1} respectively) but slightly higher than that reported for in cv. Toledo (1.8 t ha^{-1}) by CIAT (2007c) in Las Segovias in the same dry season. Furthermore, the DM of cv. Toledo in the second rainy season was greater (11.03 t ha^{-1}) than that reported by Pedro *et al.* (2004) who reported that cv. Toledo yielded 3.8 t DM ha^{-1} every two months in the dry season and 5.1 t DM ha^{-1} in the rainy season from 11 contrasting sites in Colombia. When we compare DM yields of grasses during the wet and dry season in the low rainfall area, we found that the DM yield was higher in the wet season than the dry season. The DM obtained in cv. Toledo (5.71 t ha^{-1}) was significantly higher than that found in cv. Marandu by Rao *et al.* (1998), who reported that cv. Marandu yielded greatest higher DM in the wet and dry seasons than the hybrids, cv. Basilisk, *B. Brizantha* cv. La Libertad and *Brachiaria ruziziensis* in a field of Colombia with some fertiliser application. The DM yield of *Brachiaria decumbens* in the dry season was greater than that found by Stür *et al.* (1996) who reported that in northeast Thailand the mean DM during the dry season was 3.1 t ha^{-1}. The DM yielded by cv. Marandu, cv. Toledo, cv. Basilisk and cv. Mulato during the dry season was 3.97; 5.79; 4.52 and 4.44 t ha^{-1} respectively in the low rainfall area. These yields are higher than those found by Pedro (2006) in Costa Rica, during the dry season for the same cultivars (Marandu, Toledo, Basilisk and Mulato) which yielded 2.75; 2.37; 3.20 and 2.25 t ha^{-1} of DM respectively. The tested grasses that obtained high DM content during the wet and dry season, have shown their adaptation and therefore will increase livestock production in the low rainfall area.

It was found that in the acidic soil area DM yield decreased with increasing number of harvest times. According to Harris (1978) and Mapiye *et al.* (2006a), the successions of cutting reduce enormously the DM yield because of exhaustion of nutrients in the soil. With the exception of *Brachiaria* hybrid Bro2/0465 all grasses at the first harvest time yielded higher DM than the rest of cutting times. Although the area is constrained by acidic soil, this harvest time took place at the end of the rainy season when grasses were well established. This supports Tudsri *et al.* (2002) who stated that cutting done at the end of the rainy season, gives high forage production. The *Brachiaria decumbens* cv. Basilisk and hybrid Bro2/1485 obtained significantly higher DM (11.26 and 14.96 t ha^{-1} respectively) in the acidic soil area for the first cut than the other treatments. The high DM yield of cv. Basilisk was significantly higher than values reported by Ndikumana and Leeuw (1996) who recorded that cv. Basilisk yielded a DM of 3.8 t ha^{-1} in the dry season and 8.6 t ha^{-1} in the wet season across eight sites in infertile soils of western and central Africa over 12 weeks. Furthermore, the DM of *Brachiaria* hybrid Bro2/1485 was significantly higher than that of Ricaurte *et al.* (2008b) in Matazul, Colombia; they found that hybrid Bro2/0465 had higher DM than hybrid Bro2/1485 but cv. Toledo and cv. Mulato II produced higher DM than the three hybrids (Bro2/0465, Bro2/1452 and Bro2/1485). The mean values of DM found in the acidic soil area were slightly less than those found by Pedro *et al.* (2007). They found that *B. brizantha* cv. Toledo, *Brachiaria* hybrid cv. Mulato and cv. Mulato II yielded 2.2; 2.1 and 2.3 t ha^{-1} of DM respectively over two years on inceptisols medium fertility soil (pH=5.4) of Costa Rica with high moisture tropical conditions. Nevertheless, the mean DM of *Brachiaria decumbens* (indigenous) found in the year in the acidic soil condition was 3.72 t ha^{-1}of DM (Table 5.6), slightly higher than 2.11 t of DM ha^{-1}of *Brachiaria decumbens* found by Enoh *et al.* (2005) in Ngaondere, Cameroon for the period of a year.

During the dry seasons, the DM of treatments decreased gradually from the first dry season to the second, but increased slightly in the third dry season. This increase of DM in the third dry season could be explained by the fact that the low percentage of water in the grasses increases the percentage of DM. Mandret (1990) found that the percentage of DM increased quickly during the dry period by up to 80–90%. With a low production of biomass of *Brachiaria* in the acidic soil, the DM of the third dry season increased slightly due to low content of water in the grasses.

As in the wet season, *Brachiaria* hybrid Bro2/1485 yielded highest DM in the dry period (4.18 t ha^{-1}, Table 5.8). The high DM production of hybrid Bro2/1485 in acidic soil was also reported by Ricaurte *et al.* (2008a). These authors reported that hybrid Bro2/1485 is able to persist in acidic soil in combination with a toxic level of Al. According to Richards (2008), grass can produce high yield in abiotic stress (e.g. acidic soils, drought) by developing a vigorous root system which enables it to access water and nutrients. The DM yield of *Brachiaria* hybrid Bro2/0465 in the wet season was 2.15 t ha^{-1} and was slightly less than that its yield (2.34 t ha^{-1}) during the dry season. In the acidic soil area, cv. Marandu, cv. Toledo, cv. Basilisk, indigenous *Brachiaria* (control), hybrid Bro2/1485, cv. Mulato and cv. Mulato II yielded a higher DM than the other treatments (Figure 5.4). Although these treatments showed their adaptation by producing high DM, Rao *et al.* (1998) stated that the rapid establishment of cv. Marandu and its high DM production are due to rapid uptake of nutrient, but this can lead to low persistence especially in the acidic soil stress conditions if fertiliser is not applied.

5.4.3 The comparison of DM yield in the two sites

The higher DM yield in the low rainfall area may be due to the characteristics of soil in the area. Sandy soils in low rainfall areas allow the absorption of oxygen and enable the uptake of nutrients by the plant (Roy 1972). The establishment of cv. Mulato in the low rainfall area may be due to the well-drained soil of that area while its low production in the acidic soil area may be due to the poorly drained soil and acidic soil. The higher DM during the dry season supports Tadesse *et al.* (2004) who reported that dwarf Napier grass produced high DM during the dry season in Thailand. This is also in agreement with Meissner (2000), how said that the low DM occurs during the summer (wet season) because of low DM content of green forage. In addition, cv. Mulato II sometimes produced higher DM in the dry than in wet seasons in Colombia (CIAT 2007b). Higher DM yield found in the low rainfall area than in the aluminium toxicity area may be due to high temperature (> 20^{o}C) found in the low rainfall which influenced the increase of DM yield of the grasses (Eriksen and Whitney 1981).

The high DM yield of cv. Toledo and cv. Mulato II during the dry season of low rainfall area and acidic soil area supports Pedro *et al.* (2007) who recorded that these grasses persisted and produced forage during the dry season for a period of four months in

Colombia. In the current study the mean yield of all harvests for hybrid Bro2/1485 in the low rainfall area and acidic soil area (4.67 and 5.95 t ha^{-1}) (Tables 5.5 and 5.6) was higher than that found by Hoyos *et al.* (2007) on this hybrid. These authors reported that cv. Marandu cv. Basilisk, hybrid Bro2/0465 and cv. Mulato were likely to produce more green forage under drought stress conditions than hybrid Bro2/1485. In the low rainfall and acidic soil sites, the indigenous *Brachiaria* had comparable yields to the most improved *Brachiaria* indicating adaptation to these conditions. Higgs and James (1969) found that *B. decumbens* (local) had features which allow it to adapt and produce under particular stress conditions. The adaptation of these species to the drier area could be due to the fact that they originated in tropical Africa (east and central). Keller-Grein *et al.* (1996) reported that *B. decumbens* and *B. brizantha* were collected from Rwanda. The areas that they were collected in Rwanda included the low rainfall and acidic areas. This shows that they are adapted to the types of soil and dry climatic characteristics of the area. By contrast, *C. ciliaris* had low DM compared to the rest grasses tested under low rainfall and aluminium toxicity areas.

5.4.4 Quality of tested grasses

Quality of forage refers to its nutrient content. The nutrients are intended to increase livestock production (Meissner *et al.* 2000). The authors said that the major nutrients for animals are crude protein, calcium and phosphorus. For example, a late stage pregnant cow requires 11% of CP, 0.37% of Ca and 0.26% of P daily (Meissner *et al*. 2000). These nutrients in forage vary according to many factors such as forage species and climate (Baron and Belanger 2007). In the low rainfall area the CP value for cv. Mulato during the wet season was slightly lower (11.94%) than that reported by Plazas (1998), who found that CP of cv. Mulato in 90 days regrowth in Colombia was 13.1%. During the dry season, CP for all treatments decreased and this decrease of CP during the dry season was found by Tedonkeng *et al.* (2007). Although CP decreases during the dry season, Vega *et al*. (2006) stated that other factors like maturity of the grass can be the source of declining CP. As the harvest time was planned for two monthly intervals during this study, the decrease of CP in grasses may be caused by the dry season. Looking at the CP value of improved grasses tested in the low rainfall area, cv. Mulato II (12.29%) and cv. Mulato (11.94%) will meet the CP requirements of a pregnant cow, unlike the control grasses in the low rainfall area. In addition, during the wet season in the low rainfall area, the hybrid Bro2/1485 produced a CP of 15.67% that is able to meet the CP requirement of 15% per day recommended by Meissner *et al*. (2000) for a dairy cow in lactation which produces more than 29 litres of milk per day.

In both seasons, *C. ciliaris* (control) obtained the lowest CP in the low rainfall area. The seasonal decrease of CP in *C. ciliaris* has been reported by many authors. For example, according to Yayneshet *et al.* (2009), in the short rainy season CP content in *C. ciliaris* was 5.12% in semi-arid region of northern Ethiopia. In India CP content in *C. ciliaris* declined from 10.2% in the heavy rainy season to 6.4 and 4.4% in winter and summer respectively which were characterised by low rainfall (Shinde *et al.*1998). The grasses used as the control in this study yielded the lowest CP in the low rainfall area (5.44% for *C. ciliaris* and 6.56% for indigenous *Brachiaria*). This CP of indigenous *Brachiaria* was similar to the results found by Enoh *et al.* (2005) who reported that CP level in *B. decumbens* after twelve weeks (three months) of harvest was of 5.8% in Adamawa plateau of Cameroon. Nevertheless, our results on CP of the indigenous *Brachiria* were lower than that found by Evitayani *et al.* (2005). They stated that in the tropical region of Indonesia, *Brachiaria decumbens* collected in the natural grassland of Sumatra during the wet and dry seasons, CP was 12.8 and 8.7% respectively.

Calcium (Ca) and phosphorus (P) are important minerals in the diet of animals because are involved in the growth of bones (Miles and Manson 2000). These authors confirmed that Ca and P are high in milk and a cow will need sufficient of these minerals in its daily diet. For example, a dairy cow which produces between 21 and 29 litres of milk per day requires 0.54% of Ca and 0.38% of P per day (Meissner *et al*. 2000). For this reason, it is important to provide forage of high mineral content to dairy cows. Tested grasses in the low rainfall area showed that there was no significant difference ($p>0.05$) between Ca in grasses during the wet season, nor between the wet and dry season. However, a significant difference was found between Ca of grasses during the dry season with cv. Mulato having a higher Ca content (2.17%) than the control grass *C. ciliaris*. During the wet and dry seasons in low rainfall area cv. Marandu obtained slightly higher Ca contents (1.54 and 1.43% respectively) than that found by Itamar *et al.* (2009), who reported that cv. Marandu obtained 1.3% in Brazil. The Ca in all tested grasses during the wet season showed that they can meet the Ca requirement of 0.6% per day recommended by Meissner *et al*. (2000) for a dairy cow able to produce more than 29 litres of milk per day.

Furthermore, P content analysed in tested grasses showed that cv. Toledo had 0.28% in the wet season and 0.29% in the dry season in the low rainfall area. These values were not significantly different from local *Brachiaria* (0.25%). However, the P of cv. Toledo can meet the P requirement of 0.26% per day for a late stage pregnant cow, while neither P of local *Brachiaria* nor of *C. ciliaris* can meet this requirement. The P of local *Brachiaria* (control) in both seasons was less than that of Prezotto *et al.* (2005) who recorded P value of 0.91% in *Brachiaria decumbens* during the second cut. However, it was similar to that of Evitayani *et al.* (2005) who recorded (0.19 and 0.21%) during the dry and wet seasons respectively in Indonesia. In the wet season, the P content in cv. Basilisk (0.18%) was similar to that of Rao *et al.* (1996), who reported P value was 0.10% in the low rainfall area.

The availability of the crude protein in the diet of livestock is crucial. This is because low CP in a cow‟s daily diet reduces its fertility (fecundity) and weight loss (Meissner 2000). It is recommended that cattle owners should look for a good quality grass for forage especially a high CP content. The tested grass in the acidic soil area showed that cv. Mulato II had the highest CP value (14.29%) during the wet season. In this period, cv. Mulato II can meet the CP requirement of 14% daily for a lactating cow which produces between 14 and 21 litres per day (Meissner *et al*. 2000). The control grasses (local *Brachiaria* and *C. ciliaris*) yielded low CP in both season in fact that they could not even meet the CP requirement of 13% per day for a cow producing less than 14 litres of milk per day in the acidic soil area. In this area, The CP found in cv. Mulato was less (11.56%) than that reported by Vendramini *et al.* (2008) who recorded a CP of 14% in this hybrid in Florida. The mean CP recorded for cv. Mulato in this study (11.56%) falls within the range (9–16%) reported by Pedro *et al* (2005). During the wet season, the CP content in the indigenous *Brachiaria decumbens* (9.48%) was low compared to the CP of

11.4% reported by Romero and Gonzalez (2004). In the dry season, the CP of *B. decumbens* (indigenous) decreased from 9.48% to 4.92%. This decrease supports Holmann and Peck (2002) who found that during the wet season the CP content was 10.3% in *B. decumbens* (local) and declined to 3% during the dry season. The other control grass, *Cenchrus ciliaris* had a low CP of 5.55% in both seasons. The low concentration of CP in *C. ciliaris* was also reported by Sanderson *et al.* (1999) in Texas, who found that the CP content in *C. ciliaris* was 5.83% during the warm season. A similar decrease in quality of forage, especially CP during the dry period was also found by Mislevy and Everett (1981) and Yayneshet *et al.* (2009). The decrease of CP during the dry season affected also the top producer (cv. Mulato II) in the area which decreased to 8.91%. It was followed by cv. Toledo and hybrid Bro2/1485 which obtained a CP of 7.74 and 7.25% respectively. The CP obtained by cv. Toledo (10.06%) in the acidic soil during the wet and dry season was higher than that found by Jimenez *et al.* (2008) in Mexico who reported that *B. brizantha* yielded CP of 8.03% for 6 months (January–June).

It was found that in both seasons Ca ranged between 1.43 and 2.41%. The mean value of Ca found in cv. Mulato, cv. Mulato II, *Brachiaria decumbens* cv. Basilisk and *B. brizantha* was higher than that found by Pedro *et al*. (2007) for the same hybrids and varieties. At the first and second harvesting time the results found in *B. decumbens* for Ca was 2.19% content. These results are higher than that found by Prezotto *et al.* (2005) who recorded that the Ca level found in *B. decumbens* (local) for two harvest periods was 0.42%. In terms of the Ca content in the tested grasses, it was apparent that although differences occurred they would be able to meet the Ca requirement of any physiological stage of cattle in the acidic soil area.

Furthermore, during the wet and dry seasons, *Brachiaria* hybrid Bro2/1485 yielded high P followed by *B. decumbens* (control). The P content for *B. decumbens* was slightly higher than that of Prezotto *et al.* (2005), who reported that P of 0.22% in *B. decumbens* was obtained in Brazil. In the acidic soil area, during both seasons most grasses showed that they can meet cattle requirements in P. However, *C. ciliaris* (control) had low P (0.11 –0.21%) indicating that it cannot meet the lowest P requirement (0.26% per day for the growth of a heifer, Meissner *et al.* 2000).

The level of nutrient content (CP, Ca and P) found in grasses tested under the acidic soil area was higher than that of the low rainfall area. This may be explained by the climatic conditions found in the low rainfall area that allows grasses to mature rapidly and leads to low mineral content (Eriksen and Whitney 1981). In general, the Ca found in the treatments (*Brachiaria* grasses) was similar to that found in some forage legumes (*Stylosanthes* spp., *Arachis* spp.) reported by Lascano (1994), Rao *et al*. (1996) and Mutimura *et al*. (2009). The Ca content in the tested grasses was high for graminaceous plants, and was similar to the results of Collins and Fritz (2003) who reported that the Ca content in Orchard grass *(Dactylis glomerata L)* was 2.3%. In addition, some researchers on tropical grasses also found that Ca content in the grasses was sufficient to meet cattle and sheep"s requirement for the Ca mineral (Youssef and Braithwaite 1987). These authors confirm the Ca content in tested grasses in meeting the Ca requirements for cattle. However, according to McDowell and Valle (2000), some forage grasses and legumes collected from different regions of Latin America and Africa showed low concentrations of Ca (< 0.3%). This shows that our results on Ca were higher than those found by these authors. It is likely that the grasses tested will be able to meet the CP, Ca and P requirements of the most ruminants in the low rainfall and acidic soil areas.

5.4.5 Variety selection in the study sites

The selection of grasses tested by the farmers in the study area was done at the end of the experiment after they had been established on their farms for a period of one year. The inclusion of farmers in the variety selection enabled them to select the best variety and/or hybrid of the new forage according to their experiences. Farmers were able to select varieties which performed well in their local environments. According to Abebe *et al*. (2005), Nkongolo *et al*. (2008), participatory variety selection (PVS) helps the farmers to select better technologies by comparison to the indigenous forage used by farmers. The criteria chosen by farmers in both districts to select the *Brachiaria* grasses were similar and the most important were „palatability", „high biomass production", „drought tolerance", „easy to cut", „acidic soil tolerance" and „regrowth capacity". These criteria were also similar to those identified by farmers in Malitbog, Philippines (palatability, regrowth capacity and drought tolerance) when they were selecting new forage options (Nacalaban *et al.* 1998). In Nicaragua, cv. Mulato and cv. Toledo were the varieties most preferred by farmers (CIAT 2004b). In the current study, the farmers also selected these grasses together with *Brachiaria* hybrid cv. Mulato II, *B. brizantha* cv. Marandu and hybrid Bro2/1485 over *B. decumbens* cv. Basilisk. Pandit *et al*. (2007b) reported that the interest of farmers on the new forage depended upon their needs especially quality, production and adaptation of the forage to their local climate conditions. The most highly selected *Brachiaria* grass was also the grass which had the highest DM and nutrient concentration. For example, the hybrid Bro2/1485 which yielded high DM in the acidic soil area was ranked high in the same area. The hybrid cv. Mulato II had high CP in both areas and it was selected by farmers in both contrasting environments. This relationship between farmers‟ indigenous knowledge on selecting new forages and their chemical composition supports Mekoya *et al*. (2008) who found that nutritive values of fodder from laboratory analyses in two districts of Ethiopia corresponded with the ranks of those feeds given by farmers. The participatory evaluation by farmers in the trial is important for the adoption of new forage technology and its expansion to other smallholder farmers. Most farmers from both sites stated that they would like to extend cv. Mulato II to a larger plot for the cut and carry system of forage for their livestock.

5.5 Conclusion

The soil analyses confirmed that the main constraints to forage production in the Nyamagabe district were low pH (5.09) and aluminium toxicity (1.47 meq). Low rainfall (750 mm year^{-1}) was the main constraint in the Bugesera district. On-farm trials were established to enable farmers to evaluate different varieties and hybrids of improved *Brachiaria* to increase fodder production under these conditions.

The most preferred variety of *Brachiaria* which was selected by farmers across the two sites was cv. Mulato II. It was selected by the farmers because of its adaptation to the two contrasting sites and its production of green forage (leaves and stems) during every season of the year.

The chemical analyses of each grass used in this study, indicated that the hybrid Bro2/1485 and cv. Mulato II had the highest nutrient content (CP >11 %) in both sites. The control entries had the lowest CP contents which were 5.44 and 6.56% for *C. ciliaris* and local *Brachiaria* grass, respectively. The mineral content varied according to species and sites. In the low rainfall site, cv. Mulato had the highest Ca (2.15%) whereas cv. Toledo obtained the highest P (0.28%). In the acidic soil site, the highest Ca content was obtained by cv. Marandu (2.41%) while the hybrid Bro2/1485 obtained the highest P (0.53%). The control grass (*C. ciliaris*) had the lowest minerals (Ca <1.4% and P<0.16%) compared to the rest of treatments in both sites. Since the minimum nutrient requirements for a late stage pregnant cow are 11% CP, 0.37% Ca and 0.26% P, the results of this study indicate that control grass *C. ciliaris* does not meet these requirements. Control grass *B. decumbens* (local) cannot also meet the requirement of CP, which is a crucial nutrient in animal nutrition. However, cv. Mulato II, selected by the farmers can provide adequate nutrients.

The most productive grass in terms of DM in the low rainfall area was cv. Toledo (5.71 t ha^{-1}) and in the acidic site the hybrid Bro2/1485 (5.95 t ha^{-1}). The highest DM producer in the low rainfall was not significantly different ($p>0.05$) from the local *Brachiaria* which had 5.6 t ha^{-1}. In the acidic soil area, the two control grasses (local *Brachiaria* and *C. ciliaris*) had low DM yields (3.72 and 1 t ha^{-1}, respectively) compared to the top producer in this site. The high nutrient content of the improved *Brachiaria* grasses is likely to increase milk yield which will encourage farmers to multiply these grasses to a large scale.

CHAPTER SIX–GENERAL DISCUSSION AND CONCLUSION

In the evaluation of new forage plants, it is important to look for adaptation and production of plants to given abiotic and/or biotic stress conditions. However, collecting data on chemical composition or yields of plants is not enough as they may vary from one season to another or with other environmental factors (Thorne *et al.* 1999). Furthermore, some forage research outputs that were directly presented to farmers without considering their judgment on the new technology had low adoption (Stür *et al*. 2002). The participatory evaluation approach for evaluation of different genotypes for specific environments has been used successfully in many on-farm studies (Inthapanya *et al*. 2000, Kuchinda *et al*. 2003, Khan *et al*. 2008). Although farmers may not know about the agronomic characteristics of a given forage option, through years of experience they can judge a new technology. The participation of farmers in all procedures of on-farm evaluation and selection of the best forage crop enables them to make decisions based on their specific constraints. Therefore, this participation allows forage scientists to recommend the most suitable technology for dissemination at a larger scale.

In the study on assessment of livestock feed resources in low rainfall and aluminium toxicity areas of Rwanda, the farmers gave many important reasons for this study. In the Bugesera district where the abiotic stresses are characterised by a long dry season, the main problem was that availability of forage becomes critical in that period. In the Nyamagabe district, however, although the rainfall is sufficient for cropping, the acidic soil combined with aluminium toxicity in the area limited the abundance of fodder crops. In addition to these abiotic stresses, the high human population in Rwanda has resulted in shortage of land. The land holding is limited to 0.5 ha per household. Understanding these problems with farmers was crucial in order to look for alternative forage plants adapted to these abiotic stress conditions. The farmer participatory diagnosis was an imperative aspect for knowing their own solutions to address the issue of shortage of livestock feeds.

The mixed crop-livestock production system found in the low rainfall and acidic soil areas of Rwanda will require the adoption of planted forages. *Brachiaria* grasses which were bred for these abiotic stresses and high quality forage may be able to boost the nutrition of livestock (Chakeredza *et al.* 2007). Stür and Horne (2001) reported that it is important to offer farmers a set of different forage species and varieties so that they may select those suited to their local environmental conditions. Farmers of the areas of the study will need to plant forage for cut and carry purposes. It will help them, not only to increase livestock production but also to save time (which was spent in collecting fodder for cattle) for other daily activities. For example, farmers in southeast Asia use the near home planted forage for the cut and carry system to save time for other income generating activities (Horne *et al.* 2007). It is, however, crucial that farmers fully participate in all processes of on-farm forage evaluation to increase farmers‟‟ skills for the new technology and promote dissemination and sustainability of the new forage options (Thrupp 2003). These skills help farmers to continue to evaluate technology. This has been observed in southeast Asia where new forage technologies were adopted and disseminated by farmers (Horne and Stür 1997). The aim of this study was to determine which varieties and hybrids of *Brachiaria* grass produce the highest yield and are selected by farmers in the low rainfall and aluminium toxicity areas of Rwanda. The objectives were : (i) To assess the feed resources used under low rainfall, acidity and aluminium toxicity stress conditions; (ii) To analyse the role of gender and wealth categories in livestock activities in target areas; (iii) To assess the production of improved and indigenous *Brachiaria* grasses on smallholder farms under low rainfall, acidity and aluminium toxicity stress conditions; (iv) To assess the quality (dry matter, crude protein, calcium and phosphorus) of improved and indigenous *Brachiaria* grasses and (v) To assess the farmers‟‟ perception on the new fodder crop and criteria for selecting new *Brachiaria* grass.

The diagnosis of livestock feed resources used in both areas was the key information for the second phase which concerned the on-farm evaluation of improved *Brachiaria* grass in the low rainfall and acidic soil stress conditions. In the low rainfall area, during the feed calendar development, farmers identified thirteen feed resources. Among them, four were exotic forages, three were indigenous plants and six were crop residues. The ranking of these feed resources showed that the naturalised exotic forage (Napier grass) was given the highest score by farmers. This Napier grass (*Pennisetum purpureum*) was the forage used year round but when the dry season occurred, it dries up and farmers begin to use crop residues (e.g. banana stem, rice straw, banana peeling) with low quality. Among feed resources, banana stems were scored third but were used 80% of the time during the dry season in the low rainfall area. In the acidic soil area, farmers identified twenty-one feed resources. Among the feed resources five were exotic fodder crops, five were indigenous plants and eleven were crop residues. The first scored *Commelina benghalensis* (Commelina) was an indigenous plant that is not a gramineae plant. The gramineae plants (grasses) generally constitute more than seventy percent of ruminants‟ diet (Penning *et al.* 1997). In this case, the high biomass of *Commelina* was not enough for animals but it was used as a supplement to grass forage (e.g. Napier grass).

The major grasses used by farmers were Napier grass, *Panicum* grass and *Brachiaria,* a roadside grass. The main crop residues used in the acidic soil area were cooked banana peelings and banana stems. The availability of feed resources in terms of quantity and quality showed that there was a gap in animal feed and feeding when the use of low quality crop residues was high in both districts. The problem of low quality feed was also found in South Africa where farmers of Okhombe sector used low quality maize stover to feed their cattle during the winter period when grasses were not available (Tau 2005). Availability of high quality feed was low in the Bugesera district during the dry season (July–September) where the use of banana stems and *Ficus* spp. was high. In the Nyamagabe district, because of lack of available feed, a wide range of feed resources were used over the whole year. An indication of forage scarcity in the study area was the high number of different low quality feeds (e.g. banana stems, rice straw) used by the farmers. In addition, seasonal gaps in feed availability due to dryness and acidic soils were major constraints faced by the farmers. The particular abiotic constraints, which characterise each area, were the reason for lack of appropriate livestock feeds. Note that livestock farming was found to be an important activity for cash income within the community in both study areas.

The activities related to cattle rearing were found to be shared between genders. This allowed members of a household to intervene in the matter of feeding animals as they are kept and totally fed in a shed. The division of labour between genders within the integrated crop-livestock has been found to be based on traditional beliefs, religion and socio-economy (Tangka and Jabbar 2005). In the study areas, labour division between genders was related to traditional beliefs. For example, milking cows, animal shed construction and animal disease treatment were activities reserved for males in both districts whereas cleaning a shed was reserved for females in the Bugesera district. The rest of livestock activities (e.g. cut and carry of forage, cattle feeding) were shared. This supports the results of Tangka and Jabbar (2005) who reported that in some countries (Kenya, India and Nepal) cut and carry of forage, feeding and milk sales were done by both men and women, but selling cattle was for men. Milk processing was reserved for women. This labour division between genders in both districts is likely to lead to the adoption of the selected *Brachiaria* grasses. This is because both genders were active in obtaining good forage for feeding their cattle which were kept in sheds.

Several studies have shown a relationship between wealth and adoption. For example, studies on adoption carried out in Zambia have shown that the better off were found to use improved technologies (Franzel and Scherr 2002, Phiri *et al*. 2004, Langyintuo and Mungoma 2008). Since wealth category can influence the adoption of the new technologies, it was important to determine the categories of farmers within the communities in the study sites in terms of wealth. The wealth ranking showed different categories in which households were classified in the low rainfall and acidic soil areas. In the low rainfall area, 75% of selected farmers were in the category of „rich‟‟ and 25% were in the category of „moderately poor‟‟. In the acidic soil area, 16.67% were „very rich‟‟, 25% were „rich‟‟ and 58.33% were „moderately poor‟‟. These wealth categories were able to get money to invest in farming activities and therefore likely to adopt the new *Brachiaria* grasses. Wanyama *et al*. (2003), reported that in the western Kenya, better off farmers were able to obtain off-farm income and finance faming activities which led to the adoption of forage technology. The development of livestock production was found among the wealth category of the „very rich‟‟ and „rich‟‟ because they could easily afford feeds for their animals. In both areas, the better-off categories were characterised by high cash income (400 to 2000 US$), large land size holding (five hectares) and one hectare of planted forest (planted trees in a particular area for sale as timber, fuel or for other use like house construction). The number of livestock and breeding type of cows owned by farmers were major criteria used by farmers in categorizing wealth of community members in both districts. In addition, other factors that influence the adoption of the new technologies by farmers are farming experience, response of improved technology on livestock productivity and participation of farmers in technology development (Mwangi and Wambugu 2003, Gebremedhin *et al*. 2003). In both districts, farmers experienced the shortage of forage. For this reason, improved *Brachiaria* grasses which showed a higher nutrient content to meet cattle requirements than the indigenous grasses, it is likely that farmers will adopt and continue to spread the new *Brachiaria* grasses.

The ranking by preference of feed resources by farmers enable the identification of suitable drought and aluminium tolerant *Brachiaria* grasses. According to El-Karbotly *et al.* (2003), it is important to evaluate and use the adapted forage species especially in the area constrained by abiotic stresses (e.g. drought, acidic, salty soils) where feed for livestock is scarce. Before grass establishment, soil samples taken from both sites confirmed the presence of acidic soil with aluminium toxicity (1.47 meq 100 g^{-1} of soil) in the Nyamagabe district. While in the Bugesera district, the characteristic of the dry period (4–5 months) was the main problem faced by the farmers. It is important for forage researchers to seek forage technology suited to prevailing farm conditions in the low rainfall and Al-toxic soil areas. The quantity of DM produced by each treatment in each area is an indicator of its adaptation to that environment.

To determine and evaluate the production of the improved *Brachiaria* grass in comparison to the indigenous *Brachiaria decumbens* and naturalised *Cenchrus ciliaris* (buffel grass), these grasses were established on famers‟ plots in both the low rainfall and acidic soil areas. The evaluation of dry matter yield at the sixth harvest showed that there were differences in production between grasses within and across the sites. In the low rainfall area, *Brachiaria brizantha* cv. Toledo (5.71 t ha^{-1}) and the indigenous *Brachiaria decumbens* (5.6 t ha^{-1}) had the highest mean dry matter (DM). The dry matter obtained by *B. decumbens* (local) in the low rainfall area also supports Hare *et al.* (1999) who stated that it grows well on drier areas and can yield high DM (10 t ha^{-1}) in the dry season. This yield is similar to our results (11 t ha^{-1}) at the second harvest time (dry season) in the low rainfall area. However, even though it is adapted to drier areas, Kretschmer and

Pitman (2001) argued that its quality was lower than that of *B. brizantha* in Brazilian ranches. Although *B. decumbens* and cv. Toledo grasses were ranked first in terms of DM yield, statistically it was not different from DM obtained by *Brachiaria* hybrid cv. Mulato II (CIAT 36087), *Brachiaria* hybrid cv. Mulato (CIAT 36061), *Brachiaria brizantha* cv. Marandu (CIAT 6294) and *Brachiaria* hybrid Bro2/1485.

In the acidic soil stress conditions, the hybrid Bro2/1485 had the highest DM production for all harvest times. In the acidic soil area, during the experiment, some grasses like *Brachiaria* hybrid Bro2/1485, cv. Basilisk, cv. Marandu and cv. Mulato II succeeded to regrow quickly after establishment and cutting. While in the low rainfall area, the varieties were cv. Toledo, local *Brachiaria*, cv. Mulato and cv. Mulato II. The perennial nature of a forage is a key factor for the livestock production. The tested *Brachiaria* grasses (e.g. cv. Toledo, cv. Mulato II, cv. Basilisk, local *Brachiaria*, hybrid Bro2/1485) had a high yield over six harvest times and will be able to support the forage for livestock in the area. The ability of quick regrowth after cut was one of the criteria famers used to choose cv. Mulato II and hybrid Bro2/1485 as the first forage in the acidic soil area. The tolerance of *Brachiaria* grasses to the low rainfall and acidic soils in Rwanda has also led to farmers choosing these grasses. According to Valério *et al*. (1996), in Latin America, due to adaption of *Brachiaria* grass to multiple environment conditions, beef cattle producers have planted *Brachiaria* on large areas. According to Humphreys (1991), the edaphic and climatic conditions found in a given area have led to a typical abiotic environment that some plants are able to tolerate. In general, all tested grasses yielded higher DM in the drier area of Bugesera than in the acidic soil of the Nyamagabe district. As these grasses originated from tropical areas, Hacker (1999) said that they need high annual temperature (>16^{o}C) for better growth and biomass production. This might be the reason for high DM in the low rainfall area as its average annual temperature was 21.5^{o}C. The dry matter found in the tested grasses needs a further study on its digestibility especially in vitro dry matter digestibility (IVDMD) which will also be an indicator of its quality for animal production.

Although the DM of the new hybrids was not significantly higher than the local *Brachiaria*, the nutrients (crude protein, calcium and phosphorus) measured during the wet season and the dry season in each site confirmed the high quality of the improved *Brachiaria*. The crude protein (CP) was higher (15.67%) in the *Brachiaria* hybrid Bro2/1485 than in the other grasses during the wet season in the low rainfall area. This CP content was roughly three times the CP of the control grasses during the wet season in the low rainfall area confirming the importance of improved grasses in meeting the protein requirements of livestock (15% for a lactating dairy cow). During the dry season, the *Brachiaria* hybrid cv. Mulato II (CIAT 36087) obtained higher CP concentration than the other grasses in the low rainfall area. This cultivar also obtained the highest CP in the acidic soil area during the wet and dry seasons. In both areas, the control grasses (indigenous *Brachiaria decumbens* and *C. ciliaris*) obtained the lowest CP content in both seasons of measurement indicating a critical deficiency in animal protein requirements. In addition, crude protein (CP) in grasses can be an indicator of environmental adaptation (Jonak *et al.* 1996). Although we did not calculate CP in terms of DM yield, we found that treatments with low DM were low in CP. This supports Annor *et al.* (2008) who found that in Ghana, CP content in *Panicum maximum* decreased as the DM decreased. *Cenchrus ciliaris* had a low DM yield (1.19 t ha^{-1}) and low CP (5.44%) in the low rainfall area. Low CP content in the grasses *Cenchrus ciliaris* and *Brachiaria decumbens* resulted in low livestock productivity especially during the dry season in central Africa (Kretshmer and Pitman 2001, Tedonkeng *et al.* 2007). Many factors affect the variation of CP in grasses. Although the study was not based on physiological stages of grasses, according to Trlica (1999) mature grass produces lower CP than young grass because young grass reserves CP for its growth whereas mature grass stores energy. The structural constituents of a plant (e.g. cell wall and fibre) can also affect plant quality. The higher these components are the less digestibility the plants (Mertens 2007). The measurement of the digestibility of the grasses used in this study is needed for on-farm conditions especially in the low rainfall and acidic soil stress conditions to insure the nutritional quality of these forage grasses.

The Ca content in tested grasses was highest in *Brachiaria* hybrid Bro2/0465 (2.16%) during the wet season while in the dry season it was high in the *Brachiaria* hybrid cv. Mulato (CIAT 36061) (2.17%) in the low rainfall area. The calcium content in grass tested in the acidic soil area was high in *B. brizantha* cv. Marandu (CIAT 6294) during the wet and dry seasons. Although in both areas, the Ca of improved *Brachiaria* (e.g. cv. Marandu) was higher than that of control grasses, but considering the Ca requirements (0.6% per day) for a high milk producer (> 29 litres per day) in lactation all tested grasses are likely to meet the Ca requirements.

According to Miessner *et al.* (2000), the P requirement of a late stage pregnant cow is 0.26% per day. The P recorded in cv. Toledo (0.28%) is likely to meet these requirements whereas the rest of tested grasses cannot meet that requirement in the low rainfall area. However, although in the acidic soil area P of hybrid Bro2/1485 (0.53%) was higher than that of control grasses, hybrid Bro2/1485 and *B. decumbens* (control) are likely to meet the P requirements of 0.4% per day recommended by Miessner *et al.* (2000) for a high milk producer in a period of lactation (> 29 litres per day).

The importance of forage is to increase livestock productivity. The results of this study indicate that grasses such as *Brachiaria* hybrid Bro2/1485 and hybrid cv. Mulato II that contained high CP (15.56 and 14.29% respectively) could address the issues of low quality of indigenous grasses used by farmers in both areas of study. Although some agronomic characteristics (DM, CP, Ca and P) of these grasses were covered in this study, further studies are necessary to determine the effect of using different levels of locally available fertilisers on their production. In addition, since soil degradation is a major problem in Rwanda, the ability of improved *Brachiaria* grasses to rehabilitate eroded soils especially in the acidic soil of the Nyamagabe district will be an important aspect to complement this study.

Although the on-farm trial indicated that cv. Mulato II was not the most productive grass, farmers highly ranked it in the low rainfall and acidic soil areas due to its adaptability and its green forage production year round without fertiliser application. Other grasses selected by farmers were cv. Marandu in the low rainfall area and *Brachiaria* hybrid Bro2/1485 in the acidic soil area. The main criteria used by farmers to select the new *Brachiaria* grasses were the palatability, high biomass production, drought tolerance, easy to cut, acidic soil tolerance, soil erosion control, quick regrowth and perennially.

These criteria were almost common in both sites where we found that the new forage option should meet these criteria if they are established by farmers in the areas of the study. While farmers from the Bugesera district wished to expand their plots under cv. Mulato II and cv. Marandu, in the Nyamagabe district, *B.* hybrid Bro2/1485 and cv. Mulato II were the grasses preferred by farmers.

The on-farm trials in this study have drawn the attention of farmers in Rwanda to new forage options. The most rewarding aspect was the commitment of farmers in the participation of the on-farm research. Their interest in establishing the new *Brachiaria* grasses tested on their farms was one of the encouraging aspects in this research. The results from the gender and wealth studies indicated that adoption of the new forage is likely because cattle owners were interested in looking for forage that can meet and increase their cattle production. Continued development of on-farm forage technology is recommended to promote the dissemination and sustainability of new forage options.

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