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The 'One cow per poor family' programme: Current and potential fodder availability within smallholder farming systems in southwest Rwanda

C.J. Klapwijk [a,*], C. Bucagu [a,b], M.T. van Wijk [c], H.M.J. Udo [d], B. Vanlauwe [e], E. Munyanziza [f,1], K.E. Giller [a]

[a] Plant Production Systems Group, Wageningen University, P.O. Box 430, 6700 AK Wageningen, The Netherlands
[b] National University of Rwanda, Department of Crop Science, P.O. Box 117, Butare, Rwanda
[c] International Livestock Research Institute (ILRI), P.O. Box 30709, Nairobi, Kenya
[d] Animal Production Systems Group, Wageningen University, P.O. Box 338, 6700 AH Wageningen, The Netherlands
[e] International Institute of Tropical Agriculture (IITA) – Kenya, P.O. Box 30709, Nairobi, Kenya
[f] National University of Rwanda, Department of Soil and Environment Management, P.O. Box 117, Butare, Rwanda

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ABSTRACT

Livestock is an essential component of smallholder farming systems in the East African highlands. The 'One cow per poor family' programme was initiated in Rwanda as part of a poverty alleviation strategy, aiming to increase the livestock population. A four month-study was conducted in Umurera village (Simbi sector), southern Rwanda with the objectives to (1) quantify the on-farm fodder availability, (2) quantify the amount and quality of fodder on offer to livestock, (3) analyse potential fodder availability under five future scenarios and (4) evaluate the implications and feasibility of the programme. Farmers' surveys, measurements of field sizes, together with daily measurements of fodder on offer, milk production and fodder refusals were conducted. Feeds used were diverse, comprising grasses (53%), banana plant parts (25%), residues of several crops (9%) and other plants (10%). Herbs collected from valley-bottoms, uncultivated grasses and crop residues were predominant fodder types on poorer (Resource group 1 – RG1) farms while *Pennisetum* and *Calliandra* were predominant fodder types for moderate (RG2) and better resource endowed (RG3) farms. The amount of fodder on offer for cattle ranged from 20 to 179 kg fresh weight animal^{-1} day^{-1} (9–47 kg DM). The milk yield ranged between 1.3 and 4.6 L day^{-1}. The amount of *Pennisetum* and *Calliandra* fodder available decreased in the dry season with a concomitant increase in reliance on banana leaves and pseudo-stems. The poorest farmers (RG1) were not able to feed a local cow under all scenarios. RG2 farmers can sustain a local cow during both seasons when using all possible fodder resources, but can sustain a European cow under just two scenarios during the rainy season. RG3 farmers can feed a European cow during the rainy season under all scenarios and for four scenarios during the dry season. We conclude that the 'One cow per poor family' programme needs to be adjusted to increase its effectiveness. Our main recommendations are to shift to livestock that require less fodder, for example local cattle or small ruminants such as goats.

1. Introduction

Mixed crop-livestock farming is practiced on landholdings as small as 0.2–1 ha in the highlands of East Africa in which crop production and livestock play complementary roles (Tittonell et al., 2005a; MINAGRI, 2009). Livestock contributes to food security through provision of high value protein in the form of milk and meat, provision of additional income to the household and serves as a way to store capital and meet social obligations of the farmer (Powell and William, 1993). Cattle is a major livestock species in Rwanda with a population estimated at one million heads comprising 86% of local, 13% of crossbred and 1% of exotic breeds (MINAGRI, 2006, 2009). Crops together with cultivated grasses provide the bulk of feed for cattle, small ruminants (goats and sheep), pigs and to some extent rabbits, which return soil nutrients to the cycle through the supply of organic manure.

Cattle feeding is largely based on a zero-grazing system in which fodder is carried to the animal kept in confinement. Reasons for this practice are land-scarcity and limited forage resources, minimizing the risk of overgrazing and environmental degradation. Cattle grazing outside the farm is prohibited, though small

* Corresponding author. Current address: International Institute of Tropical Agriculture (IITA) – Kalambo, Bukavu, The Democratic Republic of Congo.
E-mail address: lotteklapwijk@gmail.com (C.J. Klapwijk).
[1] Professor Esron Munyanziza passed away suddenly in June 2012.

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ruminants (e.g. goats) may be tethered outside the farms to browse on roadside vegetation. Animal feeds are diverse, including grasses and legumes (both indigenous and exotic), crop residues and other organic household wastes (Mutimula and Everson, 2011). Crop residues commonly fed to livestock include sweet potato vines, foliage and damaged tubers, bean residues, banana pseudo-stems and leaves. Some agroforestry species such as *Calliandra calothyrsus* and *Sesbania sesban* are used to provide fodder and have shown good potential for biomass production (Roose and Ndayizigiye, 1997; Niang et al., 1998).

Livestock production in Rwanda occurs in a diverse biophysical and socio-economic context. Variation in annual rainfall and its irregular distribution are key factors determining seasonal fluctuations in fodder availability. Feed shortage is most acutely felt during the dry season when the fodder quantity is often insufficient for the number of cattle, leading to starvation of grazing animals, as well as poor productive and reproductive performance (Mapiye et al., 2006; Hall et al., 2008). Farmers shift from dependence on certain types of fodder to others depending on their relative availability. In Kenya, for instance, in both of the rainy seasons, the bulk of the fodder consists of fodder crops and weeds, while in the dry season these are supplemented by crop residues and banana pseudo-stems (Abate et al., 1992; Paterson et al., 1999). Moreover, feed shortage is often compensated through the use of poor quality fodder, which is inadequate to sustain lactating and/or reproducing cattle (Shem and Otsyia, 1997; Lanyasunya et al., 2006).

Besides climate variability, local conditions may determine fodder production such as the strong heterogeneity in soil fertility within smallholder farming systems caused by natural factors (type of parental material and topography) and farmer management practices (Tittonell et al., 2005b; Giller et al., 2006; Zingore et al., 2007). For instance, Napier grass (*Pennisetum purpureum*) is mostly established on field edges close to annually cultivated food crops and therefore receives nutrients through application of manure or mineral fertilizer. Other fodder types such as weeds or uncultivated grasses grow in fallowed plots or degraded fields.

In 2006 the Government of Rwanda initiated the 'One cow per poor family' programme, which aims to make cattle available for the most vulnerable households (MINAGRI, 2006). Farmers need to construct a cowshed, establish improved forages and have to agree to pass the first offspring to another farmer. The programme seeks to reduce malnutrition through an increase in milk consumption by the rural poor, to provide farmers with manure for soil fertility improvement, to promote social cohesion through a system where the first born calf is passed on to others in need, and to create opportunities to earn additional income. Currently, milk consumption is estimated to be only 13 L person^{-1} year^{-1} in Rwanda, far less than the 220 L person^{-1} year^{-1} recommended by FAO. Child malnutrition in Rwanda is estimated to average 43% (MINAGRI, 2006).

The community selects beneficiaries of the programme based on strict criteria such as the families owning no cattle and less than 0.75 ha of land. Some 668,763 families are expected to benefit from the programme nationwide (MINAGRI, 2006). The 'One cow per poor family' programme focuses on providing Holstein Friesian crossbred cows, motivated by their potentially higher milk production compared with local breeds. The larger live weight of crossbred cattle and their higher milk yields automatically result in a higher feed demand.

Despite the envisaged benefits of the 'One cow per poor family' programme there is scanty information on the availability of fodder resources on smallholder farms in Rwanda. Existing information is based largely on estimates by the farmers collected through surveys (Mutimula and Everson, 2011). Knowledge of on-farm availability of fodder resources and their quality is key in exploring opportunities to increase fodder production. We conducted this study to: (1) quantify fodder availability on different farm types in south-west Rwanda, (2) quantify the amount and quality of fodder offered to livestock by farmers who currently own cattle, (3) analyse potential fodder availability across seasons under different future scenarios and (4) analyse the implications of our results for the 'One cow per poor family' programme.

2. Materials and methods

2.1. Study site

The study was conducted in Umurera village (164 households, 1324 people) located 17 km from Butare, Southwestern Rwanda (2°30′28″ and 028°42′09″) with a population density of 520 inhabitants km^{-2}. The area is located in Simbi sector and shares biophysical and socio-economic features with the Central Plateau agro-ecological zone (AEZ) (Table 1). The topography of the zone is dominated by hills and valleys lying at an altitude around 1634 m above sea level. The average temperature is 20 °C (daily range: 10–30 °C). Rainfall ranges from 1050 to 1200 mm annually and has a bimodal distribution pattern, allowing two major cropping seasons, the short rainy season from September until December and the long rainy season from mid-February until June (Hagedorn et al., 1997).

The majority of soils in the area are acidic (pH 4.3 to 5.7), sandy loam or sandy clay loams with high variation among fields. Soil organic carbon (SOC) ranges from 1.3 to 4.0% and total N from 0.1 to 0.4%. The cropping system is dominated by basic food crops including beans (*Phaseolus vulgaris* L.) and sweet potato (*Ipomoea batatas* L.). Other important food crops are maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L) Moench), banana (*Musa* spp.) and White potatoes (*Solanum tuberosum* L.). Coffee (*Coffea arabica* L.) is the main cash crop. Cattle are the main livestock species alongside small ruminants (sheep and goats) as well as pigs and chickens.

Agroforestry is widely practiced with a large diversity of tree species on individual farms. Trees and shrubs, including timber, fruit and legume species, are planted in different niches. Fruit trees (avocado, *Persea americana* Mill., being the most visible on farm) are established near the homestead, legume tree species for stakes and fodder are established on field edges (e.g. *C. calothyrsus* Meissner, *S. sesban* (L.) Merr., *Leucaena leucocephala* (Lam.) de Wit) and timber tree species (e.g. *Eucalyptus* spp.) are established away from crop fields (Bucagu et al., 2013).

2.2. Farm selection

All rural households in Rwanda have been categorised according to a governmental typology named 'Ubudehe'. The Ubudehe (translated: local collective action) programme aims at targeting poverty alleviation and it stratified households according to their resource status (Reckling, 2011). In Simbi, households were found from three of the total of six categories. For this study we renamed them as three resource groups (RG): poor resource group (RG 1: representing 86.6% of the households), moderate resource group (RG 2: 8.5%) and wealthier resource group (RG 3: 4.9%). Initially twelve farms were selected; within each of the resource groups four farms were randomly selected. During the data analysis, one household was found to have mistakenly been categorised in RG 1, and was reclassified as RG 2. Data collection was interrupted for one RG 3 farm when the farmer was unavailable. Therefore, data analysis was completed for 11 farms, comprising 3 farms from RG 1 and RG 3 and five farms from RG 2. Interviews were conducted during the short rainy season (September to December 2010). The first interview was conducted to collect general data such as the number of household members, livestock and number and area of fields. A

Table 1
Major biophysical and socio-economic characteristics of Simbi compared with the Central Plateau Agro-ecological zone.

Variables	Units	Simbi	Central Plateau AEZ[b]
Altitude	m	1634[a]	1500–1700
Rainfall	mm	1050–1200[b]	1200
Population density	# inhab km^{-2}	520[b]	400–500
Dominant crops		Predominance of sweet potatoes, beans, maize, sorghum, Irish potatoes, cassava and bananas[a]	Sweet potatoes, cassava, beans, maize, bananas, colocasia and soybeans
Predominant tree and shrub species		Timber trees (*Eucalyptus* spp. and *Grevillea robusta*), fruit trees (*Persea americana*, Citrus spp.), legume shrubs (*Calliandra calothyrsus*, *Sesbania sesban*) [a]	*Eucalyptus* spp., Grevillea robusta, Markhamia, fruit trees (mostly *Persea americana*), indigenous (*Ficus thonningii*, *Dracaena afromontana* and *Euphorbia tirucalii*) around the rugo (home compound)
Dominant livestock		Cows (both local and cross-bred) kept under zero-grazing system, pigs, goats under semi-stabled[a]	Cows, pigs, goats and sheep, mostly intensive, semi-stabled
Dominant soils		Sandy-loam, sandy clay loam[*]	Clay sandy soils
Mean household size	# Family members household^{-1}	4–6[a]	5.1
Soil chemical parameters			
pH		4.3–5.7[a]	4.3
OC	%	1.3–4.0[a]	1.2–1.4
Total N	%	0.12–0.39[a]	0.15
Clay	%	11–27[a]	29

[a] Own observations or measurements.
[b] Obtained from literature (den Biggelaar, 1996; Yamoah et al., 1989; Verdoodt, 2003; Mugabo, 2003).

second interview was conducted during the last weeks of the study and focused specifically on sources of uncultivated fodder; locations and ways of as well as rules for collection.

2.3. Farming systems

Fodder collection and feeding strategies occur in an integrated system in which resources flow between fields, livestock, households and the market (external to the system) (Fig. 1). In the diagrams illustrating the types of farming systems, the farm boundaries are limited to the fields located uphill while the valley-bottom is considered an external niche since most farmers rent those fields on a contract basis. Most crop residues used as fodder are produced in mixed cropping systems with sometimes more than three crops within a single field. Beans (both climbing and bush types) is the predominant crop during both the short and long rainy season, occupying about 20% of cultivated land. Sweet potato is also an important staple crop of which vines and damaged roots are used as fodder. Napier grass is one of the most important sources of fodder, planted along the edges of most fields and is also a cash crop for RG 1 farmers who sell the fodder to cattle owners during periods of shortage. Banana plants are established both around the household and in crop fields. Pseudo-stems used for fodder are collected mainly from suckers on banana plants scattered in the crop fields, while plants near the household are used to produce fresh banana bunches or beer. Nutrient flows from fields to the livestock occur through the collection of crop residues, *Pennisetum*, uncultivated grass, banana pseudo-stems and several herbs (*Commelina benghalensis* and *Cyperus* spp.). In return, livestock provides manure to be used in the fields. Urine is not collected and flows into the soil, often next to the home compound. Collected fresh manure is usually stored in a compost pit or piled within the home compound together with crop residues and other organic materials (e.g. fodder refusals). The interactions between livestock and crops occur in different farms with the following patterns:

2.3.1. Resource Group 1: poor farmers without cattle, keeping small ruminants (1 or 2 goats/pigs)

Livestock is primarily fed with uncultivated grasses, herbs from the valley-bottom and banana plant parts, with *Pennisetum* mainly established to sell. The small amounts of manure collected from the animal pens together with crop residues and other materials are applied mainly to fields cropped with beans and sweet potato. No forage legumes are used as fodder, despite having *Calliandra* shrubs planted along field edges. Major livestock products are offspring of small ruminants sold to the market. Labour is used to transport fodder and manure between fields and the homestead.

2.3.2. Resource Group 2: moderate farmers keeping cattle (1/2 heads), goats and pigs

Livestock have several functions; cattle are kept mainly to produce milk and manure while goats and pigs are kept to generate cash. Main sources of fodder are uncultivated grasses, together with *Pennisetum* produced on field edges as well as banana plant parts. The contribution of herbs from the valley-bottom is smaller than in RG 1. Fodder legumes contribute to livestock feeding.

2.3.3. Resource Group 3: wealthier farmers keeping cattle (3 head), goats and pigs

Generally, cattle are kept in a roofed shed. Similar to RG 2, cattle are kept for milk and manure production while small ruminants are kept to generate cash. *Pennisetum* is the major fodder source, followed by uncultivated grasses and banana plant parts. Farm sizes are large, with many fields, allowing for a greater production area for *Pennisetum*. Labour demand is high due to the various cropping and livestock activities. In addition to family labour, a full-time labourer is often hired to take care of livestock fodder. Cash is generated from the sales of surplus milk and offspring of goats and pigs, either locally or to traders.

2.4. Socio-economic characteristics

The average number of family members in RG 2 and RG 3 was much larger (6.3 and 5.6 people family^{-1}) compared with the RG 1 farmers (4.0 people family^{-1}) (Table 2). However, the average was similar for RG 2 and RG 3 farmers. Land available for fodder production was located both uphill and in the valley-bottom. In the uphill areas, more land was available for RG 3 farms (1.26 ha) than for RG 2 and RG 1 farms (0.32 and 0.08 ha respectively). Similarly, available land for RG 3 farmers in the valley-bottoms

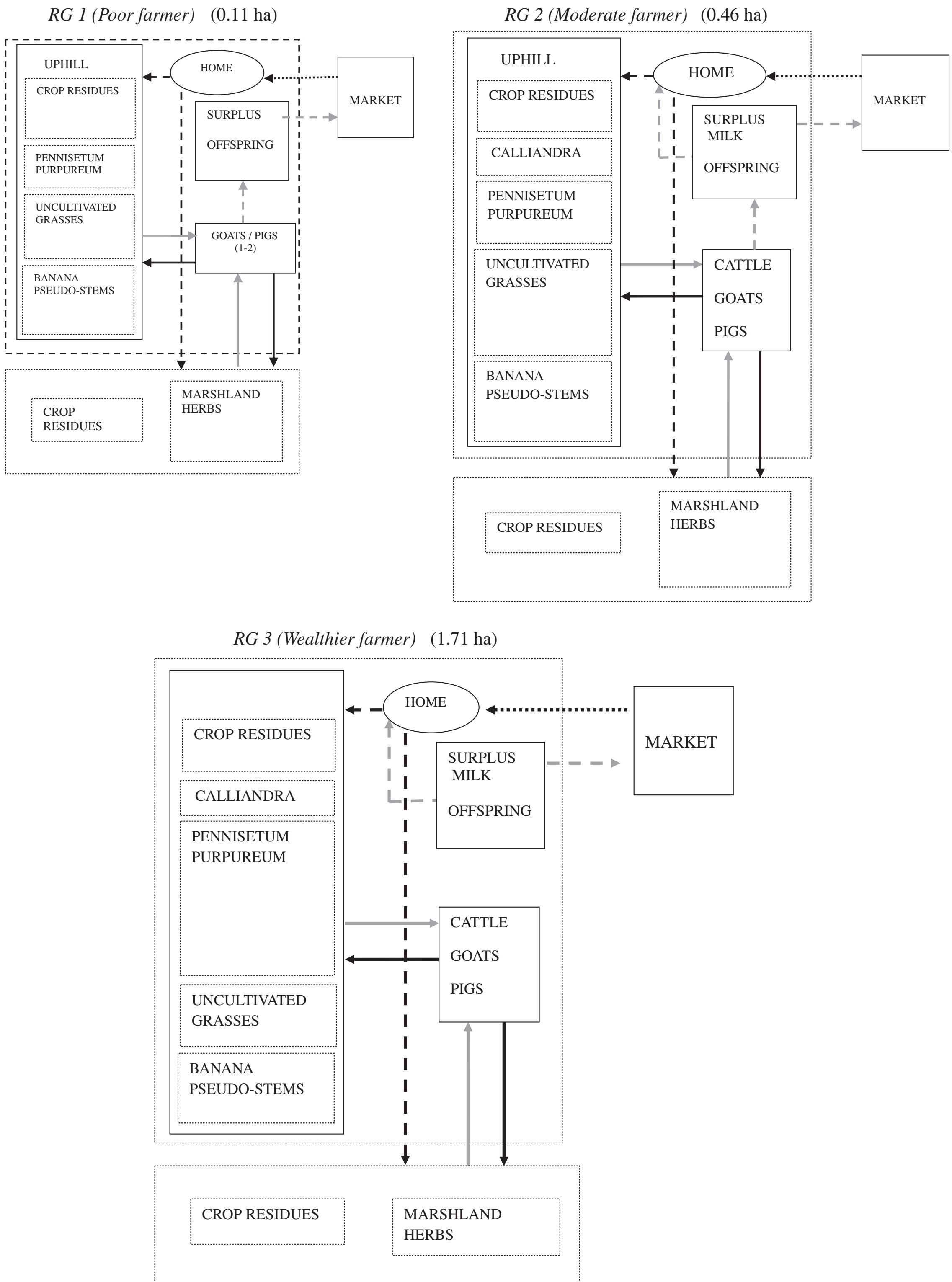

Fig. 1. Schematic representation of fodder sources and allocation patterns for the resource groups (RG 1-3). The sizes of the components and the systems boundaries indicate the relative importance (not to scale). Arrows indicate the types of flows between components. HOME: Household.

(0.45 ha) was also larger compared with RG 2 (0.13 ha) and RG 1 farmers (0.03 ha). More land available in both the valley-bottom and uphill resulted in RG 3 farmers having most total land available for fodder production (1.71 ha), compared with 0.46 and 0.11 ha in RG 2 and RG 1 farms respectively. RG 3 owned more livestock (3.0 cattle, 3.7 goat) than RG 1 (0.3 cattle, 1.7 goat), but a more or less similar number as RG 2 (2.4 cattle, 2.6 goat).

2.5. Fodder availability

Measurements of the length of field edges were done for all fields (both uphill and valley-bottom) of each farmer using a 50 m measuring tape. The surface of each field was calculated using the measurements of the edge-lengths. Measurements of the total edge-length available per farmer were required to

Table 2
Socio-economic characteristics of different farm resource groups (RG 1–3) selected for the study conducted from September to December 2010 in Simbi (means with ranges in parentheses).

Farm type	N	Family size	Land availability (ha)			Livestock			
			Uphill	Marshland	Total	Cattle	Goats	Pigs	Total
RG 1[a] (Umukene)	3	4.0 (4–4)	0.08 (0.06–0.1)	0.03 (0–0.06)	0.11 (0.10–0.13)	0.3 (0–1)	1.7 (1–2)	0.0 (0)	2.0 (1–3)
RG 2[a] (Umukene wifashije)	5	5.6 (5–6)	0.32 (0.21–0.32)	0.13 (0.02–0.23)	0.46 (0.44–0.48)	2.4 (1–3)	2.6 (1–4)	0.6 (0–1)	5.6 (3–7)
RG 3[a] (Umukungu)	3	6.3 (5–7)	1.26 (0.46–2.56)	0.45 (0.16–0.90)	1.71 (0.9–2.8)	3.0 (3)	3.7 (1–6)	0.7 (0–1)	7.3 (4–10)

[a] Corresponding farm categories in Ubudehe classification.

estimate possibilities for fodder production. The farmers measured the amount of fodder on offer for cattle on a daily basis. A 50 kg mechanical hanging scale with units of 0.5 kg was used to weigh different types of fodder at each feeding time (morning, midday and/or evening). Fresh weights were recorded and converted to dry matter (DM) using the average DM content of plant samples from Umurera (see Section 2.6). The average amount of daily fodder on offer (fresh weight) per week was derived using measurements from seven consecutive days. The daily milk production (L day^{-1}) was measured by five farmers who owned a lactating cow, during at least one week of the research period using a 500 ml cup. Refusals were measured during the last five weeks of the research. Fodder refused by cattle was weighed at the end of a day. All farmers put the refusals inside the cow shed at the end of each day to function as bedding. In general, the cow shed was emptied into a compost-pit once or twice a month. The fodder types offered to cattle were classified into Napier grass, uncultivated grass (mixed grass species with dominance of scutch grass, *Cynodon dactylon* (L.) Pers.), banana plant parts (*Musa* spp., pseudo-stems and leaves), crop residues (mainly sweet potatoes: *I. batatas* and beans: *P. vulgaris*), marshland herbs (*Cyperus* spp., *C. benghalensis* L.) and 'others' (comprising exceptions such as leaves of *Ficus thonningii* Blume and avocado, *Amaranthus* spp. and *Tithonia diversifolia* (Hemsley) A. Gray).

Farmers were asked to rank their top three fodder types, according to use, for both the dry and the rainy season. The most important fodder type was given three points, while the third type received one point. This information was translated into an 'expected' diet composition for each of the seasons.

2.6. Fodder quality

Twelve samples were taken from nine different fodder species; from three species two samples were taken. Included were banana leaves and pseudo-stems, as well as a sample from both a marshland and an uphill field for cultivated (Napier) and uncultivated grass. For each sample a plastic bag was filled with about 1 dm^3 of plant material that was cut into small pieces. All samples contained all aboveground biomass of the plants, with an exception for the two banana samples. The quality of fodder depends on its chemical composition (Mwangi et al., 2004). Therefore, the dry matter content and crude protein of the samples was estimated at the National University of Rwanda in Butare.

2.7. Future scenarios

Five scenarios were formulated in which the area under cultivation for three important fodder types (*P. purpureum*, *C. calothyrsus* and banana plant parts) was either increased, kept equal, or decreased. For the production of *Pennisetum* and *Calliandra*, the total edge-length (0.5 m width) of all uphill fields was taken as potential production area and increased to a maximum in each scenario. The edges of fields in the valley-bottom were excluded from the calculations, because it is unlikely that farmers will cultivate fodder on their most fertile fields. For the production of banana pseudo-stems, the percentage of total available land intercropped with banana was increased from 10% to 20% in Scenarios 3 and 4. *Calliandra* needs to be offered in a mixture, therefore the scenarios in which both *Pennisetum* and *Calliandra* are increased (Scenarios 2, 3 and 5), a ratio of 0.8:0.2 is used, derived from farmers' interviews. In Scenario 5, banana production was set to zero to see if farmers could maintain cattle when banana pseudo-stems are excluded from the diet. The three fodder types were chosen, because of their importance in the livestock diet and because production figures are available in the literature, allowing us to calculate the potential fodder production. The five scenarios can be summarised as follows:

Scenario[a]	*Pennisetum*	*Calliandra*	Banana
1	Increased to 100%	Kept equal	Kept equal (10%)
2	Increased to 80%	Increased to 20%	Kept equal (10%)
3	Increased to 80%	Increased to 20%	Increased to 20%
4	Increased to 100%	Kept equal	Increased to 20%
5	Increased to 80%	Increased to 20%	Decreased to 0%

[a] The second and third column relate to field edges, the last column relates to total available land.

The number of *Calliandra* shrubs and the edge-length currently cultivated with *Pennisetum* were estimated. Fodder production was calculated by multiplying the number of shrubs or the production area (m^2) by average yield figures obtained from several sources. Biomass yield of *Calliandra* cultivated on contours was estimated at 3.8 kg DM $shrub^{-1}$ $year^{-1}$ (Bucagu et al., 2013). The width of a *Pennisetum*-edge was assumed to be 0.5 m, a cultivated edge of 10 m therefore translated into an area of 5 m^2. We used an average *Pennisetum* yield of 2.13 kg per m^2 calculated from production measured in comparable environments in Rwanda and other East African countries (Niang et al., 1998; Mwangi et al., 2004; Tibayungwa et al., 2010). The potential production of banana plants was calculated using both literature and measurements. The number of banana fields for farmers in Umurera was estimated to be 10% of all fields. Using total farm size and an average planting density of 3000 plants per ha (Hauser and Van Asten, 2008), we estimated the total number of banana plants per farm. The average total DM content used to calculate the production of banana pseudo-stems was 3.84 kg $pseudo\text{-}stem^{-1}$ (Van Asten, 2011 pers. comm.).

The added amount of the three fodder types (*Pennisetum*, *Calliandra* and banana plant parts) was calculated and used to derive the daily total fodder production for each farm type. Potential fodder production during the dry season was calculated by either adding or subtracting the fraction of fodder types representing the change in fodder availability relatively to the rainy season. Daily fodder availability was then compared with the daily feed requirements for a local and a European cow. A local cow (250 kg, producing 3 kg of milk) requires 6.2 kg DM day^{-1}, while a European cow (350 kg, producing 6 kg of milk) requires 9.7 kg DM day^{-1} (Moran, 2005). The predicted daily and annual fodder production per RG were plotted against daily and annual feed requirements of a local and a European cow, assuming the amounts of fodder collected from the valley-bottom to be constant over time since water is not a limiting factor. Annual demands were derived by multiplying the daily available fodder amounts during the rainy season by 240 days (8 months) and the daily available fodder amounts during the dry season by 120 days (4 months).

3. Results and discussion

3.1. Fodder availability on different farm types

The availability of the most important shrubs and grasses was assessed in terms of available production area and weekly yield per farm (Table 3). *P. purpureum* was generally planted on field edges or contours of terraces. The available land area and biomass production for *Pennisetum* was much bigger on RG 3 farm (831 m^2, 885 kg farm^{-1} week^{-1}) than on RG 2 and RG 1 farms. Production was also larger on RG 2 (418 m^2) than on RG 1 farms (90 m^2). The wide range in land cultivated with *Pennisetum* (ranging from 52 to 153 m^2 on RG 1 farms) was due to the variation in the number of fields and therefore the number of field edges. The amounts of *Pennisetum* available were estimated at 885, 445 and 96 kg farm^{-1} week^{-1} on RG 3, RG 2 and RG 1 farms respectively. *Pennisetum* produced by RG 1 was mainly sold to cattle-owning farmers. The number of *Calliandra* shrubs was high on RG 3 and RG 2 farms (125 and 58 shrubs farm^{-1}) but low on RG 1 farms (19 shrubs farm^{-1}). Estimated *Calliandra* biomass collected per week was somehow comparable on RG 2 and RG 3 farms (532 and 249 kg farm^{-1} week^{-1} respectively) but much less on RG 1 farms (81 kg farm^{-1} week^{-1}). The average number of banana pseudo-stems and their fresh biomass was also larger on RG 3 (340 plants farm^{-1}; 1305 kg farm^{-1} week^{-1}) than on RG 2 (138 plant farm^{-1}; 531 kg farm^{-1} week^{-1}) and RG 1 farms (34 plants farm^{-1}; 131 kg farm^{-1} week^{-1}). Thus, the total amount of the major three fodder types was largest on RG 3 farms (4954 kg farm^{-1} week^{-1}). Similarly, the total amount of fodder per week was larger on RG 2 (2344 kg farm^{-1} week^{-1}) than on RG 1 farms (685 kg farm^{-1} week^{-1}).

Fodder sources were diverse across the different resource groups. Based on daily measurements (Fig. 2), the percentage of uncultivated grasses fed to livestock was 27% of the diet on RG 1 farms. Other fodder sources were supplied in comparable proportions (13–23% of the total feeds). The relatively small amounts of grasses used by RG 1 farmers were compensated by feeding larger quantities of marshland-herbs and banana plant parts, both representing 23% of the total amount of fodder. Differences in diet composition between RG 2 and RG 3 farms were reflected in the larger proportion of uncultivated grasses used on RG 2 (35%) compared with RG 3 farm (27%) and a greater amount of *Pennisetum* grass on RG 3 (30%) than on RG 2 farms (26%). Proportions of other fodder sources were comparable or even equal for the two RGs with banana plant parts representing 27% and crop residues representing 7% and 6% for RG 2 and RG 3 respectively. Of the banana plant parts that were used as fodder, the most important one was the pseudo-stem; only about 3% consisted of leaves while the remaining 97% was pseudo-stems.

3.2. Fodder on offer and refusals

Only the farmers of RG 2 were able to measure refusals of fodder on offer, for two local cows (LC1: 6 yrs. and LC2: 7–8 yrs., lactating) and a crossbred cow (IC: mature, lactating) (Fig. 3). The daily amount of fodder on offer for the two local cows ranged between 41 kg (LC2) and 70 kg (LC1), while for the crossbred cow, the average daily amount of fodder on offer was 144 kg (fresh weights). Large daily variation was observed with offered fodder ranging from 50–90 kg for LC1, 20–58 kg for LC2, and 120–178 kg for IC. The cows readily consumed almost all fodder on offer, so there were few refusals, ranging from 2.2–7.5 kg per day (fresh weight). The amount of refusals remaining from the crossbred cow was so small that it was impossible to quantify. On occasions when this animal refused feed (at 314 and 316th Julian days), an avocado tree had been cut down and leaves were offered as fodder. Surprisingly, refusals were recorded for cow LC 2 while the amounts of fodder on offer for this animal were extremely small. This can probably be explained by the poor quality of fodder. For example, 3–4% of the diet consisted of *Cyperus* spp., which was later explained by the farmer to be offered to livestock to increase the amount of compost.

Our results indicate a large diversity of animal feeds with a predominance of grasses; uncultivated as well as *P. purpureum*, consistent with other findings in the tropics (Lanyasunya et al., 2006; Mapiye et al., 2006). *Pennisetum* grown on field edges and small plots serves both as fodder source and as soil conservation measure. Surprisingly, maize stover was not an important source of fodder in Simbi, despite the large area cropped with maize in the valley-bottom and the proportion of farmers cultivating maize. In contrast to other countries in East Africa (Uganda, Kenya) where maize stover is a major source of livestock fodder (Paterson et al., 1999), farmers in Simbi prefer to use maize stover as stakes, firewood, or leave it in the fields for mulching. Although the amount of fodder on offer in Umurera was comparable to amounts fed to cattle in Kenya: *Pennisetum* intake of about 80 kg animal^{-1} day^{-1} (fresh weight), or the DM equivalent in terms of crop residues, weeds and parts of banana plants (Paterson et al., 1999), the diet in the Kenya case was supplemented with 2 kg of commercial dairy meal, resulting in higher feed quality than in Umurera (Rwanda). Ongadi et al. (2010) reported that farmers in Kenya provided an average amount of fodder ranging 35–65 kg animal^{-1} day^{-1} to stall-fed cattle.

3.3. Fodder quality

The dry matter (DM) content and the chemical composition of the *Pennisetum* samples indicate a clear difference quality between fodder collected in marshland and land uphill (Table 4). The samples from the marshland had a lower DM content combined with a higher N content, which can be explained by the relatively moist and fertile conditions of the marshlands. Niang et al. (1998) recorded a DM content of *Pennisetum* of 242 g/kg in southern Rwanda, with N of 11.5 g/kg, P of 1.8 g/kg and K of 1.3 g/kg (Niang et al., 1998). Rufino et al., 2009 used similar numbers for modelling livestock productivity with *Pennisetum* as one of the feeds on offer; a DM of 170 g/kg and N of 24 g/kg (Rufino et al., 2009). Juma et al. (2006) measured an average DM of 200 g/kg, with 12.2 g/kg N in a study conducted in Kenya. Drechsel and Reck (1998) studied smallholder farming systems in Butare, southern Rwanda. They measured an N concentration for *Calliandra* ranging between 25 and 34 g/kg, again confirming the results from our study in Umurera. Measurements by Niang et al. (1998) recorded a DM content of 378 and 381 g/kg and N of 35.7 and 37.4 g/kg. The high content of condensed tannins in *Calliandra* (Lascano et al., 2003; Paterson et al., 1998; Tiemann et al., 2010) reduces its digestibility, which normally ranges from 40–60% (Lascano et al., 2003; Paterson et al., 1998). For *Sesbania*, they found a DM content of 320 and 322 g/kg and N of 27.0 and 29.3 g/kg. Dry matter digestibility of *Sesbania* is reported to be about 70–75% (Heuzé et al., 2012). The percentages of crude

Table 3
Current availability and production of main fodder types (*Pennisetum purpureum*, *Calliandra calothyrsus* and banana pseudo-stems) for different farm types in Simbi.

Farm type	*N*	*Pennisetum purpureum*		*Calliandra calothyrsus*		Banana (*Musa* spp.)		Total fresh biomass	
		Land available (m^2)	Fresh biomass (kg $farm^{-1}$ $week^{-1}$)	Number of shrubs $farm^{-1}$	Fresh biomass (kg $farm^{-1}$$week^{-1}$)	Plants $farm^{-1}$	Fresh biomass (kg $farm^{-1}$$week^{-1}$)	3 Feed species (kg $farm^{-1}$ $week^{-1}$)	All feed species (kg $farm^{-1}$ $week^{-1}$)
RG 1	3	90 (52–153)	96.3 (55.5–163)	19.0 (5–34)	81 (21–145)	34 (30–39)	130.6 (115–150)	308 (241–435)	684.9 (435–941)
RG 2	5	418 (178–720)	445 (189–767)	58.0 (0–180)	249 (0–740)	138 (117–144)	530.8 (449–588)	1224 (723–1785)	2344.9 (1781–2781)
RG 3	2	831 (690–972)	885 (735–1035)	125.0 (100–150)	532 (426–639)	340 (270–411)	1305 (1037–1573)	2725 (2711–2739)	4954.4 (4925–4983)

protein in the diets of RG 1 to RG 3 were 9.7%, 9.8% and 10.3% respectively, sufficient for maintenance of the animals.

Literature covering the chemical composition of banana pseudo-stems or leaves is very scarce. The latter were studied recently by Nyombi et al. (2010) during two crop cycles in Uganda, at two sites. An N content of 25.4 and 17.0 g/kg was recorded at the first site; these numbers were 25.0 and 16.5 g/kg for the other site (Nyombi et al., 2010). Unpublished data collected in Uganda show an average DM content of 340 g/kg for banana leaves and 119 g/kg for banana pseudo-stems (Van Asten, 2011 pers. comm.). Digestibility of pseudo-stems is around 75% while the digestibility of banana leaves is 65% (Heuzé et al., 2013). As pseudo-stems contain mainly water (up to 95%) and very little protein (Heuzé et al., 2013), a proportion of banana plant parts higher than 15% of the diet DM results in decreased digestibilities (Heuzé et al., 2013). The species containing the highest amount of nitrogen (Table 4) are the three leguminous shrubs (*Leucaena*, *Sesbania* and *Calliandra*) which are able to fix atmospheric nitrogen (Mwangi et al., 2004). Fodder legumes also have a higher nutritive value than tropical grasses (Mwangi et al., 2004). Strikingly, the next three samples high in nitrogen all originate from the marshland, confirming its relatively high fertility. The sample of banana pseudo-stems contained a very low amount of nitrogen, while it is an important fodder species for the farmers in Umurera. A part of the livestock feed was of low quality, confirmed by the crude protein percentages of the diets, which can result in decreased production of cattle (Paterson et al., 1999).

3.4. Milk production

Daily milk yields (DMY) were recorded for five individual cows; E (6 yrs.), F (>3 yrs.), H (>7 yrs.), J (8 yrs.) and K (15 yrs.) (Fig. 4). Cow F was crossbred, while the other animals were 100% local breeds. The highest daily milk yield (4.6 L day^{-1}) was recorded for the crossbred cow F. The DMY of cows F, H and K (4.6, 1.9 and 3.2 L day^{-1} respectively) was fairly constant over time, while the production of cow J (2.2 L day^{-1}) decreased substantially. The owner stated that this cow was near the end of her lactation, which in Umurera is about 2–5 months.

Most reports on dairy production in Africa focus on *B. taurus* cattle, while there is little information on pure *B. indicus* breeds. The daily milk yield (DMY) of the only crossbred cow in Umurera (F: 4.6 L day^{-1}) is close to yields reported for dairy type animals in Kenya and Tanzania (Bee et al., 2006; Juma et al., 2006; Udo et al., 2011). There appears to be scope to improve daily milk yield in the Central African region. Inadequate nutrition is the main cause of low milk production by African cattle (Paterson et al., 1998; Teferedegne, 2000). Therefore, improving both feed quantity and quality should be the focus of attempts to reach the genetic potential of cattle. A high protein content of fodder (16–18%) is essential to meet the requirements of lactating cattle (Moran, 2005; Juma et al., 2006). The crude protein content of the diets in Umurera was low (9–10%), indicating marginal milk yields. A common way to increase the protein content of a livestock diet is the supplementation with commercial concentrates (Ongadi et al., 2010), but the majority of subsistence farmers are unable to invest in such additions (Mwangi et al., 2004). Despite its high tannin contents (Lascano et al., 2003; Paterson et al., 1998; Tiemann et al., 2010) supplementation with the protein-rich fodder *C. calothyrsus* is the most viable option for farmers in Umurera, as the shrub is well established in the area and currently grown by most farmers.

3.5. Fodder availability under five future scenarios

Our calculations of potential fodder production in five scenarios suggest that the poorest farmers (RG 1) are unable to maintain

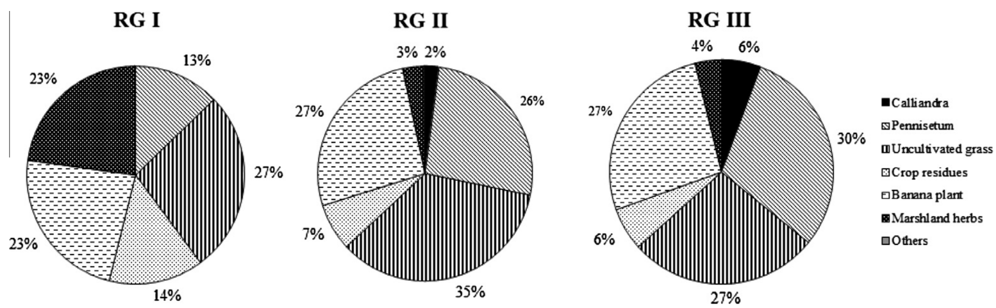

Fig. 2. Composition of fodder on offer (% of the total DM) for the three Resource Groups in Simbi (averages over seven weeks).

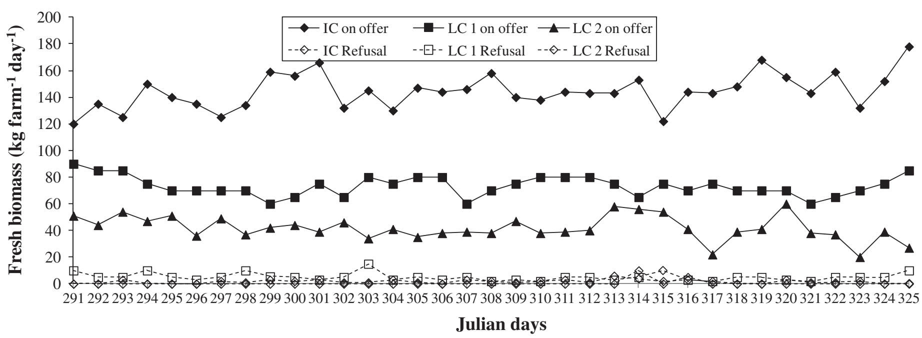

Fig. 3. Total amount of fodder on offer (plain lines) and refusals (dotted lines) in kg green weight/animal/day for local and crossbred cattle of RG 2. IC: crossbred cow (mature cow lactating), LC 1: local cow 1 (6 yrs.), LC 2: local cow 2 (mature cow, lactating >7–8 yr).

Table 4
Location, dry matter, nitrogen (g/kg) and crude protein content (%) of twelve plant samples from Umurera.

Name	Location	DM	N	% cp
Leucaena	Uphill	331.28	39.55	24.7
Sesbania	Uphill	239.49	38.20	23.9
Calliandra	Uphill	387.74	27.50	17.2
Pennisetum	Marshland	150.28	24.40	15.3
Cyperaceae	Marshland	216.47	21.80	13.6
Sw. potato plant	Marshland	122.90	19.10	11.9
Pennisetum	Uphill	214.51	18.20	11.4
Scutch grass	Uphill	297.03	16.10	10.1
Banana leaves	Uphill	253.51	15.15	9.5
Scutch grass	Marshland	308.50	13.35	8.3
Commelina	Marshland	241.61	12.70	7.9
Banana stem	Uphill	261.28	3.35	2.1

either a local or a European cow even during the rainy season (Fig. 5a). The largest fodder production was 3.9 kg DM farm^{-1} day^{-1} considering only the three main feeds and 4.2 kg DM farm^{-1} day^{-1} (Scenario 3) when all feeds are considered. This fodder availability is less than the requirements of a local (6.2 kg DM farm^{-1} day^{-1}) or European cow (9.7 kg DM farm^{-1} day^{-1}) (Moran, 2005). A RG 2 farmer (Fig. 5b) could meet the DM requirements of a local cow using all fodder resources for all scenarios (least fodder production of 8.6 kg DM farm^{-1} day^{-1}) and could maintain a European cow under 3 Scenarios. A RG 3 farmer (Fig. 5c) can meet the requirements of a local cow under all scenarios, also when using only the three major fodder types (the least production being 6.5 kg DM farm^{-1} day^{-1} under Scenario 5). However, to be able to maintain a European cow, (s)he would need to utilize other fodder sources. Under Scenario 5 (banana plant parts completely removed), the total amount of the major feeds (6.5 kg DM farm^{-1} day^{-1}) is barely sufficient to reach the requirements of a local cow (6.2 kg DM farm^{-1} day^{-1}), highlighting the importance of banana pseudo-stems within the livestock diet.

During the dry season, fodder production on farms was reduced resulting in critical fodder shortage (Fig. 5d,e). The largest expected fodder production on a RG 1 farm (3.7 kg farm^{-1} day^{-1}, all fodder types under Scenario 3) was only half of the 6.2 kg farm^{-1} day^{-1} required by a local cow. The RG 2 farmers (Fig. 5e) were able to meet the requirements of a local cow when using all fodder types under all scenarios in the rainy season. RG 2 farmers were unable to maintain a European cow under all scenarios (the largest production was 9.4 kg DM farm^{-1} day^{-1} under Scenario 3 < 9.7 kg DM farm^{-1} day^{-1}). For RG 3 farms (Fig. 5f), the farmers can potentially maintain a local cow using only the three main fodder types under Scenarios 1–4. Furthermore, a RG 3 farmer could keep a European cow when all fodder sources are used under Scenario 2–4 (production of 13.4 and 12.3 kg DM farm^{-1} day^{-1} respectively), while during the rainy season the same farmers could keep a European cow under all scenarios. These results indicate that during the dry season the reduction in the amount of *Pennisetum* and *Calliandra* substantially reduced the capacity of the RG 3 farmers to keep a European cow.

Our results confirm earlier findings on the importance of seasonality in fodder availability in Eastern Africa (Abate et al., 1992) and throughout sub-Saharan Africa (Renard, 1997) where both the quantity and quality of fodder offered to cattle are reported to be far below optimum requirements. There is a strong need to increase both the quantity and the quality of fodder during the dry season.

The estimated annual fodder production on farms of the different resource groups was plotted for the five scenarios to determine whether farmers would be able to keep animals year round (Fig. 6). A farmer of RG 1 (Fig. 6a) is unlikely able to produce sufficient fodder to maintain a local cow, let alone a European cow. A RG 2 farmer (Fig. 6b) would be able to keep a local cow if all possible fodder sources are used (the least production was 851 kg DM farm^{-1} day^{-1} under Scenario 1 > 2262 kg DM year^{-1} required) and would hardly be able to keep a European cow under

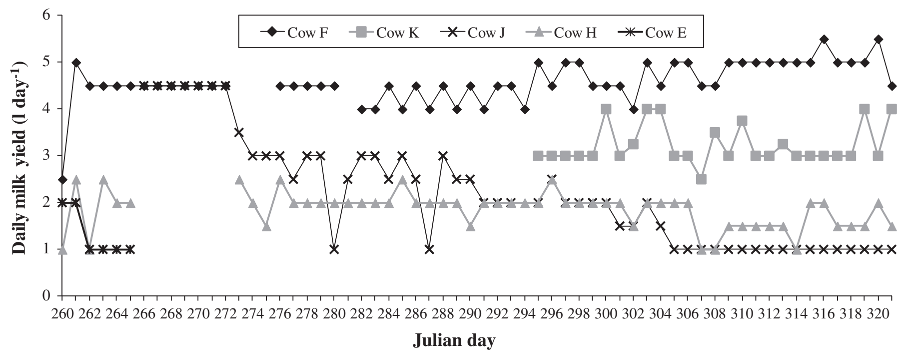

Fig. 4. Milk production per day for five individual cows; E (6 yr), F (>3 yr), H (>7 yr), J (8 yr) and K (15 yr). Cow F is crossbred, the other animals are local. Unrecorded data denote days when cows were not milked.

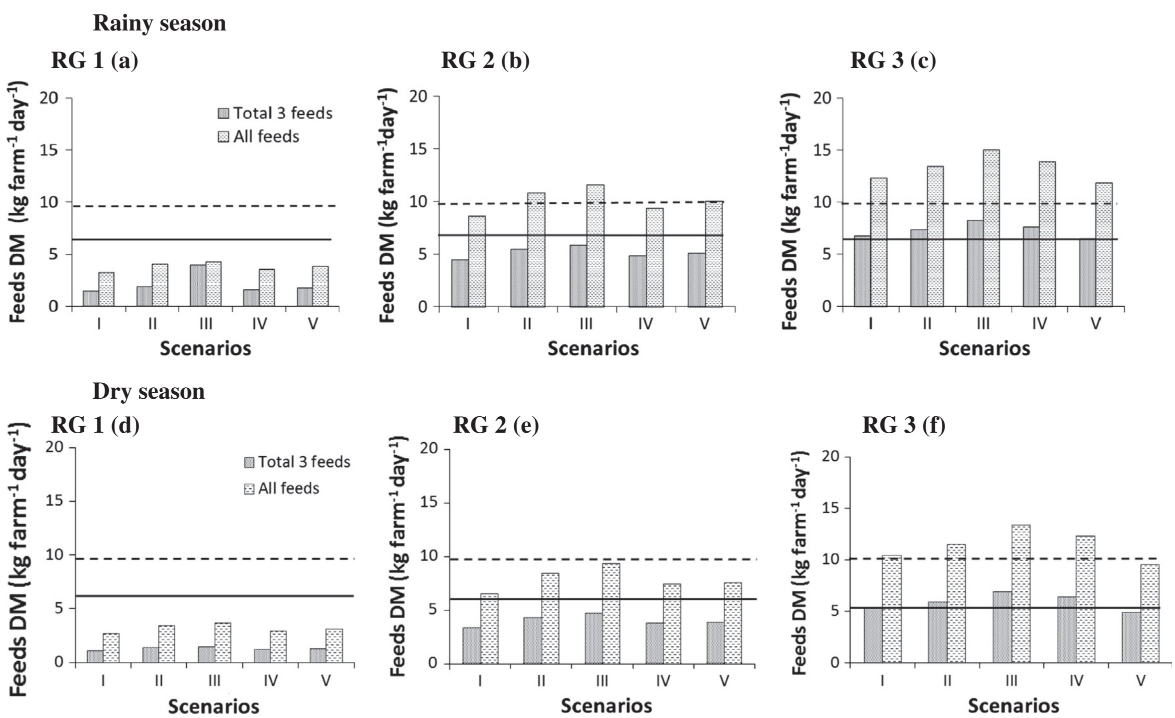

Fig. 5. Estimated amount (kg DM day^{-1}) for three major fodder types (*Pennisetum purpureum*, *Calliandra calothyrsus* and banana pseudostems) and all fodder available on RG 1 (a), RG 2 (b) and RG 3 (c) farms in Simbi during rain (a–c) and dry season (d–f) under different scenarios (1: 100% of upland edges with *Pennisetum*, *Calliandra* and banana production kept unchanged, 2: 80% with *Pennisetum* and 20% planted with *Calliandra*, banana production kept equal, 3: 80% of edges with *Pennisetum* and 20% planted with *Calliandra* and banana production doubled, 4: 100% of edge with *Pennisetum* and banana production doubled, *Calliandra* kept equal, 5: 80% of edges with *Pennisetum* and 20% of edges with *Calliandra* and banana production set at zero). Amounts were compared with feed requirements for a local cow (6.2 kg DM, solid line) and European cow (9.7 kg DM day^{-1}, dashed line).

only two of the scenarios. A RG 3 farmer (Fig. 6c) could keep a local cow under all scenarios, using only the three major fodder types. However, to keep a cow, (s)he would need to use all possible fodder sources in each scenario. For all farmers, collection of fodder (uncultivated grasses and weeds) from outside the farm is essential to feed their cattle. An increase in the number or quality of cattle in the village will result in an increased pressure on these off-farm resources.

The expected increased production under Scenario 3 is due to the importance of banana pseudo-stems in the diet of livestock in Rwanda. This is highlighted by a drastic reduction of the available fodder when banana pseudo-stems are excluded in Scenario 5. In Rwanda, bananas are found on every single farm, planted densely in fields close to the homestead and less densely in crop fields. Banana plant parts are reported to be of poor fodder quality due to their low protein content (<1%), leading to a relatively low dry matter intake (Ffoulkes and Preston, 1978; Table 4). The importance of banana pseudo-stems in livestock diets is probably partly responsible for the poor milk production in Simbi (Fig. 4).

Our results indicate that while RG 2 and RG 3 farmers would be able to maintain a local and even a European cow under specific scenarios, this is not feasible for RG 1 farmers. With the extremely small land area available (0.11 ha, Table 1) and nationwide land scarcity in Rwanda, the RG 1 farmers face a critical constraint and high risks when investing in cattle. In the scenario of maximised fodder production (Scenario 3) and under the favourable conditions of the rainy season, the total production of RG 1 farmers could reach a maximum of 4.2 kg DM day^{-1}, which is still lower than the 6.2 kg DM day^{-1} minimal requirements for maintenance and milk production of a local cow (250 kg). The situation is likely to worsen during the dry season when fodder production and quality are further reduced. Fodder collected during the dry season has a low crude protein (CP) content (<3%) and when CP is below 7–8%, animal growth is compromised (Evans, 1968).

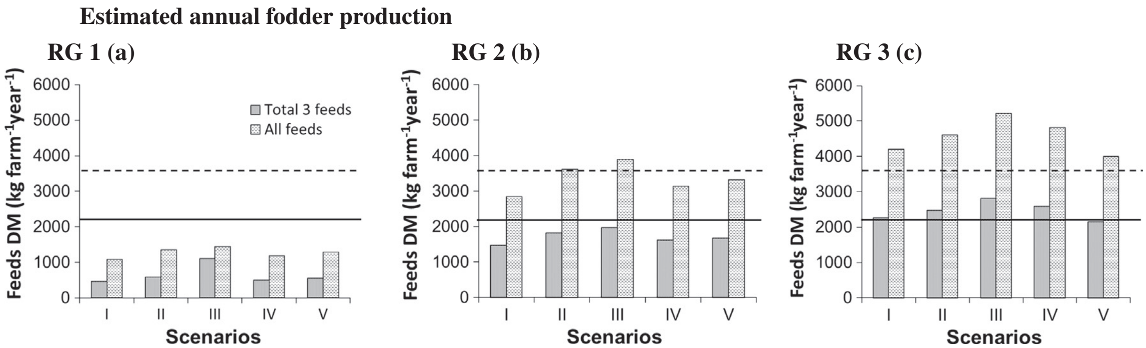

Fig. 6. Estimated amount (kg DM farm^{-1} year^{-1}) of the three major feeds (*P. purpureum*, *C. calothyrsus* and banana pseudostems) and all feeds available on RG 1 (a), RG 2 (b) and RG 3 (c) farms in Simbi under different scenarios (1: 100% of upland edges with *Pennisetum*, *Calliandra* and banana production kept unchanged, 2: 80% with *Pennisetum* and 20% planted with *Calliandra*, banana production kept equal, 3: 80% of edges with *Pennisetum* and 20% planted with *Calliandra* and banana production doubled, 4: 100% of edge with *Pennisetum* and banana production doubled, *Calliandra* kept equal, 5: 80% of edges with *Pennisetum* and 20% of edges with *Calliandra* and banana production set at zero). Amounts were compared with feed requirements for a local cow (2263 kg DM year^{-1}, solid line) and European cow (3541 DM year^{-1}, dashed lines).

A realistic possibility for smallholder farmers to increase fodder quality is to supplement with a protein-rich fodder such as *C. calothyrsus*. The majority of the farmers in Umurera already cultivate *Calliandra*, which has good potential for biomass production in Rwanda (Roose and Ndayizigiye, 1997). The downside of using *Calliandra* is the high tannin content of the leaves (Paterson et al., 1998; Tiemann et al., 2010) which decreases the digestibility of the diet and thereby its effect. According to Paterson et al. (1998), a farmer needs approximately 250 m of hedge annually to supplement one cow, which is a viable option for the RG 2 and RG 3 farmers. For the poorest farmers (RG 1), between 50% and 100% of their available field edges would have to be planted with *Calliandra*, resulting in high investments. Also, *Calliandra* can only be used for supplementation; the basal fodder of cattle still needs to come from other plants. A possible downside of cultivating all the edges with fodder plants could be of negative edge effects on crop production, which could be exacerbated on small fields.

At village scale, the increased number of cattle should be accompanied by effective integrated soil fertility management, otherwise nutrient mining would lead to a decline in production of feed producing areas. Implementation of such practices is not guaranteed, as farmers appear to prioritise manure for food production. Joint or collective ownership of livestock and/or crop-livestock intensification appear to be viable alternatives at village level. Farmers without cattle could specialize in fodder production, or farmers together could match the feed resources necessary for a jointly owned cow, thereby sharing the benefits of livestock.

Many constraints are expected to appear when cattle would be given to smallholder farmers, especially for the poorest. For the programme to be successful, all recipients must be able to access sufficient fodder (Budisatria and Udo, 2012), which will be a constraint in densely populated areas. Other necessary investments, such as the construction of a cowshed, might be impossible for the most resource-constrained farmers (Van den Berg, 2009). The majority of poor farmers (71%) do not possess sufficient land to qualify for participation in the programme (Uwimana, 2010). There might be scope for farmers to cooperate and share both the responsibilities for fodder production as well as benefits such as manure and milk, but this might be difficult to realise. Therefore, we suggest adjusting the programme and include the distribution of small animals, since these are more suitable for livestock programmes than large ruminants (Udo et al., 2011). Goats produce some income, can serve as capital saving (Budisatria and Udo, 2012) and provide manure and meat. Even though benefits of smaller livestock might be less, requirements and investments are also less.

4. Conclusion

Whilst smallholder farmers use a wide variety of fodder types, the availability of fodder limits opportunities for livestock keeping and milk production in southwest Rwanda. Fodder availability differed strongly among farmers due to differences in land availability and its productivity. The better-off farmers (RG 2 and RG 3) with larger land areas grew more *Pennisetum*. The poorest farmers (RG 1) compensated the limited availability of *Pennisetum* by feeding more crop residues and uncultivated grasses and herbs. Our results indicate that RG 2 and RG 3 farmers are probably able to maintain a local or even a European cow under specific scenarios, but for RG 1 farmers, who comprise 86% of the population, it seems impossible to keep either a local or European cow.

Legume species, such as *C. calothyrsus*, are currently underutilised as fodder probably due to the limited farmer's knowledge about the high fodder quality of this shrub. Legume shrubs such as *Calliandra* can supplement low quality fodder effectively and increase milk production (Paterson et al., 1999). *Calliandra* contains a relatively high content of tannins (Lascano et al., 2003; Paterson et al., 1998; Tiemann et al., 2010), which decreases its digestibility, but it nevertheless seems the most viable option for Umurera, as many farmers already own at least several such shrubs. The issue of fodder quantity and quality is also of importance in maintaining nutrient recycling through the livestock diet (Delve et al., 2001). In addition, *Calliandra* planted on field edges was reported to be effective in maintaining soil fertility through biological nitrogen fixation (Nyaata et al., 2000). Further efforts are needed to develop strategies for effective integration of legume shrubs and trees into the livestock diet of dairy cattle. Intercropping of *Pennisetum* with leguminous fodder trees or shrubs could boost both quantity and quality of fodder production, especially during the dry season. The feasibility of on-farm fodder conservation strategies (haymaking of grasses and legumes) could also be explored to make use of possible surpluses produced during the rainy season.

The 'One cow per poor family' programme is a strategic spear point of the Government of Rwanda and an attempt to empower the most disadvantaged households. The programme is part of strategies to fulfil a long-term vision seeking to substantially reduce poverty rates in rural areas and to improve people's nutrition (MINAGRI, 2009). In 2000, the average land-surface available per Rwandan household was only 0.71 ha, even less compared with land availability during the eighties, when households possessed an average of 1.20 ha (Ansoms et al., 2008). Combining this acute land-scarcity with the socio-economic conditions of the poorest smallholder farmers, our results suggest that the 'One cow per poor family' programme should be reviewed to increase its effectiveness. Under current conditions in Simbi, the poorest farmers, representing the majority of smallholders, are unable to produce a sufficient amount of fodder to maintain even a local cow. Land-scarcity makes the expansion of available land an unrealistic option and the land currently available is much needed for food production. We recommend the livestock promoted as part of the programme should be changed to goats or local cattle that require less feed.

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