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Towards an assessment of on-farm niches for improved forages in Sud-Kivu, DR Congo

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Abstract

Inadequate quantity and quality of livestock feed is a persistent constraint to productivity for mixed crop-livestock farming in eastern Democratic Republic of Congo. To assess on-farm niches of improved forages, demonstration trials and participatory on-farm research were conducted in four different sites. Forage legumes included *Canavalia brasiliensis* (CIAT 17009), *Stylosanthes guianensis* (CIAT 11995) and *Desmodium uncinatum* (cv. Silverleaf), while grasses were Guatemala grass (*Tripsacum andersonii*), Napier grass (*Pennisetum purpureum*) French Cameroon, and a local Napier line. Within the first six months, forage legumes adapted differently to the four sites with little differences among varieties, while forage grasses displayed higher variability in biomass production among varieties than among sites. Farmers' ranking largely corresponded to herbage yield from the first cut, preferring Canavalia, Silverleaf desmodium and Napier French Cameroon. Choice of forages and integration into farming systems depended on land availability, soil erosion prevalence and livestock husbandry system. In erosion prone sites, 55–60 % of farmers planted grasses on field edges and 16–30 % as hedgerows for erosion control. 43 % of farmers grew forages as intercrop with food crops such as maize and cassava, pointing to land scarcity. Only in the site with lower land pressure, 71 % of farmers grew legumes as pure stand. When land tenure was not secured and livestock freely roaming, 75 % of farmers preferred to grow annual forage legumes instead of perennial grasses. Future research should develop robust decision support for spatial and temporal integration of forage technologies into diverse smallholder cropping systems and agro-ecologies.

Keywords: mixed crop-livestock systems, tropical forages, Napier grass, farming system research, participatory research

1 Introduction

In the Sud-Kivu province of eastern Democratic Republic of Congo (DRC), farmers traditionally practice mixed crop-livestock production. Since 1996, cattle have become a target of war, so that mixed farming is threatened with complete breakdown, lacking manure to sustain crop cultivation (Cox, 2012). Especially due to the "quasi-disappearance of cattle" (Vlassenroot, 2005), overall livestock holdings have been severely reduced to 0.2–0.5 Tropical Livestock Units (TLU) per household, which is too low to satisfy subsistence or allow for

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regular sale (Maass *et al.*, 2012; Ouma & Birachi, 2012). Despite their low productivity, existing smallholder production systems can still provide a steady source of animal protein and manure for household consumption and sale. With a certain level of intensification, these systems could provide a pathway out of poverty (Maass *et al.*, 2013). In addition to a general lack of knowledge and skills in animal husbandry and poor access to veterinary services, farmers consider scarcity of (quality) livestock feed, especially in the dry season, as one of the main constraints for livestock production (Zozo *et al.*, 2010). Currently, grazing on natural pastures and collection of roadside grasses and herbs constitute the main source of feed, while 37 % of farmers cultivate forages on small plots contributing only 6 % to the livestock diet (Bacigale *et al.*, 2014).

Improved forages can play an important role in enhancing livestock production, while generating additional environmental co-benefits. Direct benefits for crop production include weed suppression, pest and disease reduction, and soil fertility improvement through N fixation, while environmental effects could be soil organic matter and carbon increase, reduced greenhouse gas emission intensities and soil erosion control. Increased feed production on agricultural land less suitable for cropping and recuperation of degraded land also contribute to increased land use efficiency (Peters *et al.*, 2013). However, despite the range of potential benefits, the cultivation of forages and especially forage legumes in sub-Sahara Africa remains low (Thomas & Sumberg, 1995; Muir *et al.*, 2014). One of the reasons for the low adoption of technologies is the high heterogeneity of farming systems and agro-ecologies in sub-Sahara Africa. Instead of trying to find silver bullets to development, provision of multiple technologies and targeting is key (Giller *et al.*, 2011). Sown forages are knowledge intensive technologies, and they can play various roles in farming systems, determined by market access, population density, and agro-ecological potential (from low to high): (1) as pasture in grazing systems, e.g. through over-sowing of natural grasslands; (2) a niche role in semi-intensive mixed crop-livestock systems which rely on a diverse feed basket, e.g., planted as live barriers on farm and field boundaries, under-story in plantation, or as cover crop, green manure or intercrop with food crops; (3) as pure stand on arable land in intensive mixed crop-livestock systems, e.g., grass in sole stand or forage legume rotations with grasses and food crops. Regarding these different roles of forage technologies, it is key to develop multiple forage options together with farmers, using participatory methods (Peters *et al.*, 2003).

This study is based on two approaches that have been underlined in targeting interventions to specific socio-economic and agro-ecological environments: (1) The concept of socio-ecological niches which was initially developed to match legume technologies with the heterogeneity of agro-ecologies and farming systems in terms of soil fertility, rainfall, socio-economic status and resource endowment (Ojiem *et al.*, 2007); (2) Participatory on-farm research which is essential to integrate farmers' priorities into technology development and dissemination. Evidence from participatory trials in Sud-Kivu shows that such research approaches can increase farmers' learning and technology uptake while contributing to the scientific evidence base for improving technologies (Paul *et al.*, 2014). For the present study, researcher-managed demonstration plots as well as farmer-managed on-farm niche trials with selected forage legumes and grasses were established in four sites with contrasting agro-ecological conditions in order to (i) locally confirm agro-ecological adaptation of improved forage grasses and legumes; (ii) appraise farmers' preferences for improved forage varieties; and (iii) evaluate on-farm niches for forage grasses and legumes integrated in the cropping systems.

2 Materials and methods

2.1 Study area

The research was conducted in four sites with different agro-ecological conditions representative of Sud-Kivu: Muhongoza (02°04′S, 028°54′E – Kalehe territoire), Nyacibimba (02°29′S, 028°47′E – Kabare Territoire), Tubimbi (02°44′S, 028°35′E – Walungu Territoire), and Kamanyola (02°44′S, 029°01′E – Walungu Territoire) (Figure 1). Territoire refers to the administrative unit used in Sud-Kivu province which are, from superior to inferior: 'Territoire', 'Collectivité', 'Groupement', 'Localité', 'Village'. Sites differ in altitude, average land sizes, soil fertility, and erosion potential (Table 1).

All sites are characterised by a long rainy season from September to December, a short rainy season from February to April, and a dry season from June to August. Figure 2 shows the monthly rainfall for Nyacibimba which was chosen as most central site. Total rainfall during 2011–2013 ranged between 1345 and 1597 mm year^{-1}, with 2014 being a drier year (922 mm year^{-1}) (Figure 2).

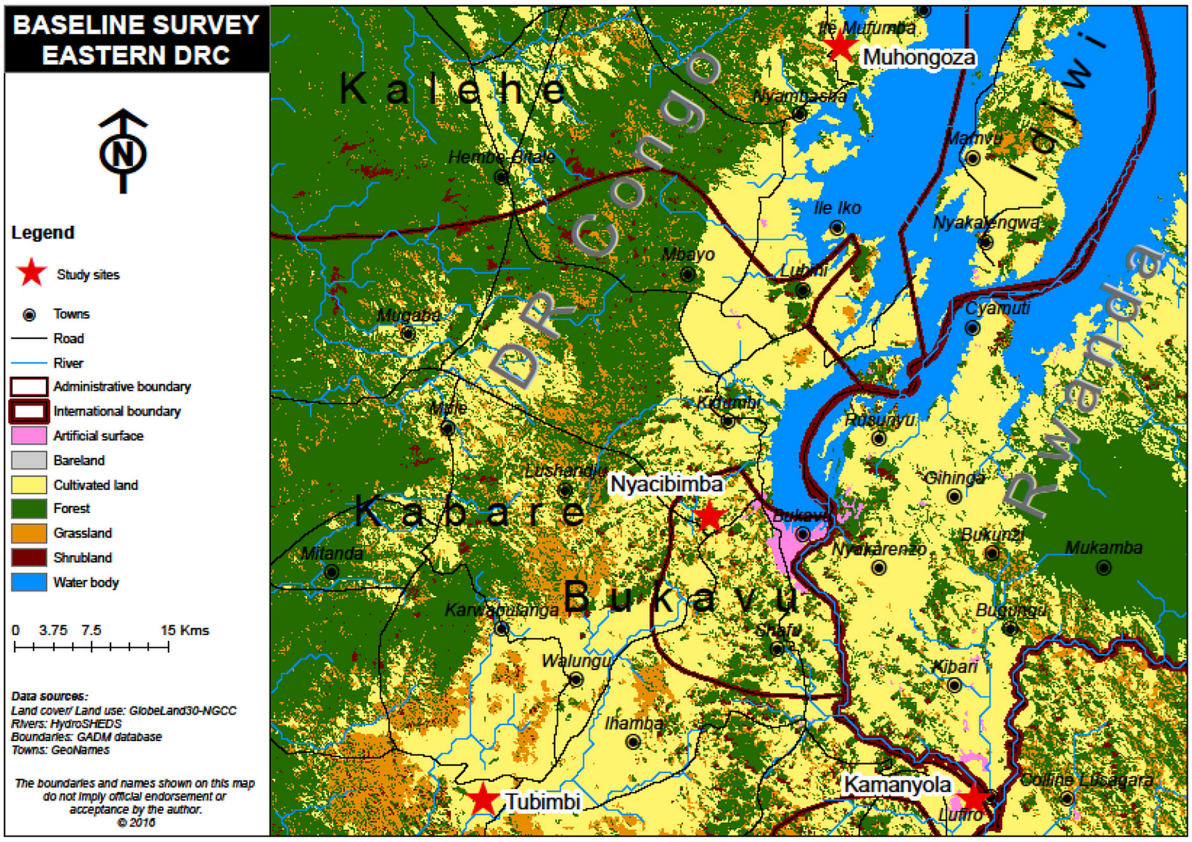

Fig. 1: *Map of study sites*

Table 1: *Study site characteristics. Land size is divided into small (<0.5 ha), medium (0.5–1 ha) and large (>1 ha). Soil fertility was scored in general terms, taking into account pH, organic matter content and nutrient availability. Soil erosion was classified as none, medium, or strong, depending on topography and rainfall.*

Site	*Territoire* *	*Altitude* (m asl) †	*Land size*	*Soil fertility*	*Slope (%)*	*Soil erosion*
Muhongoza	Kalehe	1548	Medium	Medium	5–10	Medium
Nyacibimba	Kabare	1955	Medium	Low	>10	Strong
Kamanyola	Walungu	940	Small	High	<5	None
Tubimbi	Walungu	1100	Medium	Low	<5	None

* In Sud-Kivu province, administrative units used are, from superior to inferior, ‘Territoire’, ‘Collectivité’, ‘Groupement’, ‘Localité’, and ‘Village’; † asl, above sea level.

Table 2: *Physical and chemical soil quality in study sites.*

Site	*Clay* (%)	*Sand* (%)	*Silt* (%)	*pH* (water)	*K* (%)	*Olsen P* (ppm)	*Total N* (%)	*Total C* (%)
Muhongoza	58.41	27.25	14.33	4.03	0.09	13.16	0.25	3.61
Nyacibimba	40.52	39.12	20.36	4.45	0.33	16.32	0.30	2.97
Kamanyola	34.51	29.15	36.35	5.41	0.20	7.86	0.25	3.26
Tubimbi	34.50	33.16	32.34	3.89	0.10	28.71	0.22	2.77

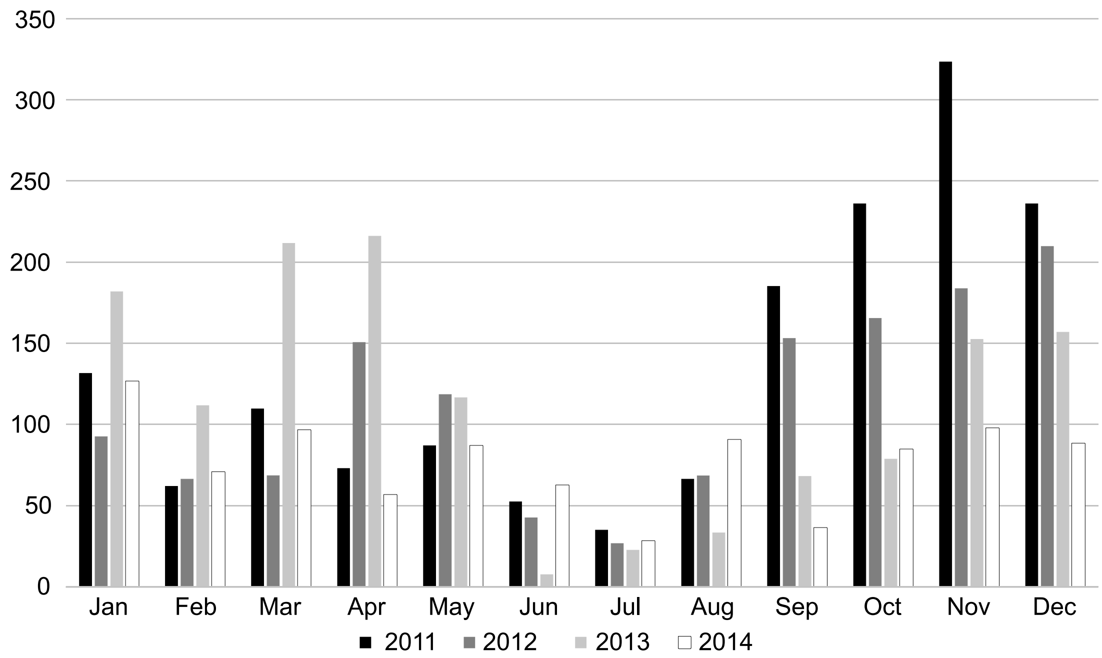

Fig. 2: *Monthly rainfall (mm) in Nyacibimba, DR Congo. Data retrieved from NASA for 01/01/2011–31/12/2014.*

Soil fertility was determined through soil sampling in August 2014 and analysed for texture, pH, and soil nutrients at the CIAT (International Center for Tropical Agriculture) soil laboratory in Nairobi, Kenya. Fertility differs among sites, mainly restricted by the low pH limiting nutrient availability and increasing Al toxicity. Only in Kamanyola, pH was close to the critical level of 5.5 for plant production (Table 2). Farmers in all four sites were organised in Innovation Platforms (IP) since end of August 2012 that were established according to the principles of Integrated Agricultural Research for Development (IAR4D) (Chiuri *et al.*, 2013) in order to improve the cavy (*Cavia porcellus*) value chain. Each IP appointed four different technical committees and held regular monthly meetings to plan common activities which included forage experimentation to improve livestock feeding.

2.2 *Trial establishment, management and agronomic measurements*

Two demonstration trials were established in each of the four study sites. The demonstration plots were planted, managed and harvested by the IP farmers themselves, however, directed by a researcher from UEA (Université Evangélique en Afrique) who also used the field events for training both farmers and agronomy students from the university. The first trial tested the forage legumes *Canavalia brasiliensis* CIAT 17009 (Canavalia), *Stylosanthes guianensis* CIAT 11995 (Stylo) and *Desmodium uncinatum* cv. Silverleaf (Silverleaf desmodium). These legumes had previously performed well in the study area (Katunga *et al.*, 2014). Seeds were obtained from Karama Research station of RAB (Rwanda Agriculture Board) in Eastern Rwanda. Silverleaf desmodium is already naturalised in the study area and was used in this trial as local control. The second trial tested the forage grasses Napier grass (*Pennisetum purpureum*) cv. French Cameroon, a local Napier variety as well as Guatemala grass (*Tripsacum andersonii*). Cuttings of cv. French Cameroon and Guatemala were acquired from INERA (Institut National pour l'Etude et la Recherche Agronomiques) Mulungu, while those of local Napier grass were obtained in the respective sites and used as local control. The two trials were established in a completely randomized block design with three replications and lasted six months from October 2012 to April 2013. Planting dates were 2, 4, 6 and 19 October in Tubimbi, Muhongoza, Nyacibimba and Kamanyola, respectively. In the legume trial, each plot measured 3 m × 1.5 m with sowing spacing of 50 cm × 25 cm, while in the grass trial, plots measured 4 m × 3 m with planting spacing of 1 m × 1 m. Blocks and plots were separated by 1 m. Neither chemical fertilisers nor pesticides were applied, but two hands of cow manure per hole were applied in both trials before planting. Fresh biomass was harvested only once after six months between 26 March and 4 April 2013. For the legume trial, biomass was assessed from an area of 1 m^2 by cutting any green material 15 or 10 cm above soil surface (for Canavalia or Stylo/Silverleaf desmodium, respectively); whereas for the grasses, fresh biomass was cut inside an area of 6 m^2 and 50 cm above soil surface in order to allow plants to regenerate. A homogeneous sample of at least 100 g fresh matter was collected from each of the three replications for all forage varieties. Samples were oven-dried at INERA in Mulungu at 75°C during 48 hours to obtain dry matter (DM) content. Percentage (%) soil cover was estimated before biomass harvest. This helped to evaluate the potential to reduce soil erosion and suppress weed growth. Average plant height was taken on five plants in each plot from the plant bottom up to top of the highest leaf. Analysis of variance (ANOVA) was carried out with R Studio Version 0.97.449 (R Core Team, 2013). Grass and legume trials were analysed separately for DM yield, plant height and soil cover, with site, variety and block as treatment factors. Local Napier in Kamanyola was disregarded from the statistical analysis since there was no yield from any replicate. Means are presented with standard errors. A P-value ≤ 0.05 was considered significant.

2.3 Participatory evaluation

A participatory evaluation was carried out in each site before forage biomass was harvested. Across all sites, a total of 63 farmers (43 women) were involved in the forage appraisal. After explaining the methodology, farmers were arranged in two groups by gender. In every site, one field replication was randomly chosen for the exercise. From each group, participants went individually to appraise the three plots within the forage grass and legume trials, together with a scientist who took note of their ranking. Farmers ranked forages from 1 (most preferred) to 3 (least preferred) according to their own selection criteria; data in this paper are presented as percentages. Farmers were also individually asked which of the criteria were most important for ranking the different forage varieties.

2.4 On-farm niche planting and data collection

An on-farm study was carried out from October to December 2013 to assess niches for forages. A total of 79 farmers of which 73 % women volunteered to test improved forages in their own fields. Before sowing, farmers were trained on importance and management of forages: planting, maintenance, harvesting biomass and seed, feeding animals as well as about the potential spatial niches on their farms. Two packages were availed to each farmer to be planted during the wet season: a package of forage legume seeds (Canavalia, Stylo, *Lablab purpureus* CIAT 22759 and Silverleaf desmodium) of about 60–100 g for each variety and a pack of at least 40 cuttings per variety of grasses including Guatemala and Napier grass (French Cameroon and the local variety). Farmers were free to choose where and how to integrate these forages in their farming systems. After successful establishment, farmers were also encouraged to share any planting material or seeds produced in the future with other IP members or neighbours. The IP technical committees recorded all farmers who had planted forages and shared these data in December 2013. A second assessment of on-farm niches was carried out in September and October 2014 using the same methodology.

3 Results

3.1 Demonstration trials

Agro-ecological conditions of the different sites significantly influenced DM yields of the legumes ($P < 0.001$), with DM yields ranging from 6.1–6.9 t ha $^{-1}$ in fertile soils (Kamanyola), 2.6–4.1 t ha $^{-1}$ in medium soils (Muhongoza) and 0.3–2.1 t ha $^{-1}$ in poor soils (Nyacibimba and Tubimbi) with the exception of Silverleaf desmodium which performed well (5.4 t ha $^{-1}$) in Nyacibimba (Table 3). There were no significant differences among the legume varieties across all sites ($P = 0.63$), but a significant interaction effect between site and variety ($P = 0.002$) (Table 3). Plant height was closely related to DM biomass production. Soil cover depended both on site conditions ($P < 0.001$) and the legume varieties ($P < 0.001$) tested. Stylo covered consistently less soil than Silverleaf desmodium and Canavalia (Table 3).

The three forage grass varieties performed differently in each site with regard to DM yield ($P = 0.006$), but the effect was weaker than in legumes. The effect of site on plant height ($P = 0.13$) and soil cover ($P = 0.08$) was not significant, in contrary to legumes (Table 4). Differences between the grass varieties were strong in terms of DM yield ($P < 0.001$), plant height ($P < 0.001$) and soil cover ($P < 0.001$). French Cameroon DM yields ranged from 3.5–10.1 t ha $^{-1}$, being the highest yielding variety in Kamanyola and Tubimbi, and the second highest in Nyacibimba and Muhongoza. Guatemala grass DM yields varied between 1.3–2.6 t ha $^{-1}$ and were the lowest in all sites except Kamanyola where local Napier did not yield any biomass at all. This was probably due to the fact that local Napier grass in Kamanyola originated from swampy lowland areas and it was not adapted to the drier conditions of the site where the demonstration plot was established.

Table 3: *Dry matter (DM) yield (t ha^{-1}), plant height (cm) and estimated soil cover (%) of three forage legume varieties tested at four sites in Sud-Kivu, DRC.* †

	Variety	Site			
		Muhongoza	*Nyacibimba*	*Kamanyola*	*Tubimbi*
DM yield (t ha^{-1})	Canavalia	3.2 (0.3)	2.2 (0.5)	6.9 (1.0)	1.5 (0.2)
	Silverleaf desmodium	2.6 (0.2)	5.4 (0.5)	6.1 (0.6)	0.3 (0.1)
	Stylo	4.2 (0.5)	1.6 (0.6)	6.7 (0.7)	2.1 (1.0)
ANOVA	Variety	$P = 0.63^{ns}$			
	Site	$P < 0.001^{***}$			
	Variety∗Site	$P = 0.002^{**}$			
Plant height (cm)	Canavalia	48.4 (4.1)	36.9 (2.1)	45.7 (4.4)	40.3 (1.1)
	Silverleaf desmodium	27.6 (5.6)	61.7 (6.2)	53.3 (4.0)	15.1 (2.3)
	Stylo	42.3 (2.3)	30.9 (1.6)	53.1 (2.5)	41.5 (3.7)
ANOVA	Variety	$P = 0.32^{ns}$			
	Site	$P < 0.001^{***}$			
	Variety∗Site	$P < 0.001^{***}$			
Soil cover (%)	Canavalia	86.7 (0.1)	66.7 (0.3)	96.7 (1.0)	68.3 (0.2)
	Silverleaf desmodium	66.7 (0.5)	100.0 (0.2)	68.3 (0.6)	16.7 (0.1)
	Stylo	65.0 (0.6)	37.5 (0.5)	73.3 (0.7)	63.3 (1.0)
ANOVA	Variety	$P < 0.001^{***}$			
	Site	$P < 0.001^{***}$			
	Variety∗Site	$P < 0.001^{***}$			

† Values are means with standard error (N=3). Levels of significance: * < 0.05, ** < 0.01, *** < 0.001, ^{ns} not significant

Table 4: *Dry matter (DM) yield (t ha^{-1}), plant height (cm) and estimated soil cover (%) of three forage grass varieties tested at the study sites in Sud-Kivu.* †

	Variety	Site			
		Muhongoza	*Nyacibimba*	*Kamanyola*	*Tubimbi*
DM yield (t ha^{-1})	French Cameroon	3.5 (0.6)	5.6 (1.5)	10.1 (1.7)	3.6 (1.7)
	Local Napier	6.2 (1.0)	7.5 (1.8)	NA	1.9 (1.0)
	Guatemala	2.4 (0.4)	1.3 (0.1)	2.6 (0.8)	2.4 (0.5)
ANOVA	Variety	$P < 0.001^{***}$			
	Site	$P = 0.006^{**}$			
	Variety∗Site	$P = 0.02^{*}$			
Plant height (cm)	French Cameroon	239.1 (1.7)	228.9 (12.0)	280.8 (24.8)	238.1 (24.1)
	Local Napier	278.8 (6.3)	270.1 (22.4)	NA	183.3 (35.7)
	Guatemala	116.9 (5.8)	143.9 (7.3)	149.4 (10.7)	156.1 (4.9)
ANOVA	Variety	$P < 0.001^{***}$			
	Site	$P = 0.13^{ns}$			
	Variety∗Site	$P = 0.01^{*}$			
Soil cover (%)	French Cameroon	64.0 (1.5)	80.0 (0.6)	83.3 (1.7)	73.3 (1.7)
	Local Napier	70.0 (1.8)	66.7 (1.0)	NA	40.0 (1.0)
	Guatemala	78.3 (0.1)	66.7 (0.4)	86.7 (0.8)	86.7 (0.5)
ANOVA	Variety	$P < 0.001^{***}$			
	Site	$P = 0.08^{ns}$			
	Variety∗Site	$P < 0.001^{***}$			

† Values are means with standard error (N=3). Levels of significance: * < 0.05, ** < 0.01, *** < 0.001, ^{ns} not significant

3.2 Participatory evaluation

Generally, farmers' preferences for forages were guided by the following criteria in decreasing order of importance: biomass production, leaf size, animal preference, recovery and drought tolerance (legumes); biomass production, animal preference, adaptation, use in erosion control, tillering capacity, and novelty in the area (for grasses only). Women and men expressed the same preference criteria. For legumes, the overall highest priority in high altitude (Muhongoza and Nyacibimba) was given to Silverleaf desmodium (40 % and 70 %), while second choice was Canavalia (47 % and 55 % respectively). In mid altitude (Tubimbi) and low altitude (Kamanyola), first choice was Canavalia (61 % and 70 %, respectively) and second Stylo (56 %) for Tubimbi and Silverleaf desmodium (50 %) for Kamanyola (Table 5). For the grasses, cv. French Cameroon clearly was the first choice across all sites (87 % in Muhongoza, 70 % in Nyacibimba and 61 % in Tubimbi) except in Kamanyola, where it was ranked second (60 %) after Guatemala grass (Table 5). Gender had no influence on the choice of forages (data not presented).

3.3 On-farm planting

Interest of farmers varied across sites, and in 2013 participating farmers ranged from 32 in Muhongoza to 8 in Kamanyola. Overall, women were more active in on-farm experimentation of improved forages across all the sites, with 58 out of 79 participating farmers, corresponding to 73 % (Figure 3a). In Muhongoza, Nyacibimba and Tubimbi 54 % of farmers decided to plant grasses together with legumes, 45 % grasses alone and 1 % legumes alone; while in Kamanyola 25 % of farmers planted grasses and legumes together, 0 % grasses alone and 75 % legumes alone (Figure 3a). Compared to 2013, the overall number of farmers who planted forages was the same in 2014; however, percentage of women decreased to 47 %. While in Muhongoza more farmers planted forages in 2014 than in 2013 (+40 %, with all additional farmers being men), in Nyacibimba, they almost halved (−45 %, with all dropping out farmers being women). In Nyacibimba the farmers growing grasses decreased to 9 %, while in Kamanyola 43 % of farmers started growing grasses (Figure 3b).

Farmers' integration of forages into their farming system also varied according to site as well as forage type. In 2013, forage legumes were intercropped with other crops such as maize and cassava across all sites by 43 % of the farmers, while 40 % grew them as pure stand. Especially in Tubimbi, more farmers grew legumes as pure stand (71 %) in small plots around the homesteads and later mixed for feeding with natural forages (Figure 4a). Across sites, grasses were mainly planted on field edges (56 % of farmers), followed by pure stands hedges for erosion control (19 %) and pure stand (10 %). In the high altitude sites of Muhongoza and Nyacibimba, more farmers planted grasses on field edges (55 % and 60 %, respectively) and in hedgerows for erosion control (16 % and 30 %). Only in Tubimbi, 47 % of farmers initially planted grasses as pure stand (Fig. 4c). In 2014, there was more niche diversity for grasses in Tubimbi in 2014, where farmers experimented with planting forages in banana plantations, under trees as well as on field edges and for erosion control (Figure 4d). Overall, the integration of both forage legumes and grasses into farming systems in 2014 was similar to 2013 (Figure 4).

Table 5: *Farmers' choice (%) among three forage grasses and three forage legumes according to site in Sud-Kivu, DRC.*

Site	*Grass variety*	*Choice* (%)			*Legume variety*	*Choice* (%)		
		1st	*2nd*	*3rd*		*1st*	*2nd*	*3rd*
Muhongoza (N=15)	French Cameroon	86.7	6.7	6.7	Canavalia	33.3	46.7	20.0
	Local Napier	6.7	66.7	26.7	Silverleaf desmodium	40.0	13.3	46.7
	Guatemala	6.7	26.7	66.7	Stylo	26.7	40.0	33.3
Nyacibimba (N=20)	French Cameroon	70.0	15.0	15.0	Canavalia	30.0	55.0	15.0
	Local Napier	15.0	40.0	45.0	Silverleaf desmodium	70.0	30.0	0.0
	Guatemala	15.0	45.0	40.0	Stylo	0.0	15.0	85.0
Kamanyola (N=10)	French Cameroon	20.0	60.0	20.0	Canavalia	70.0	10.0	20.0
	Local Napier	10.0	10.0	80.0	Silverleaf desmodium	0.0	50.0	50.0
	Guatemala	70.0	30.0	0.0	Stylo	30.0	40.0	30.0
Tubimbi (N=18)	French Cameroon	61.1	38.9	0.0	Canavalia	61.1	27.8	11.1
	Local Napier	0.0	5.6	94.4	Silverleaf desmodium	11.1	16.7	72.2
	Guatemala	38.9	55.6	5.6	Stylo	27.8	55.6	16.7

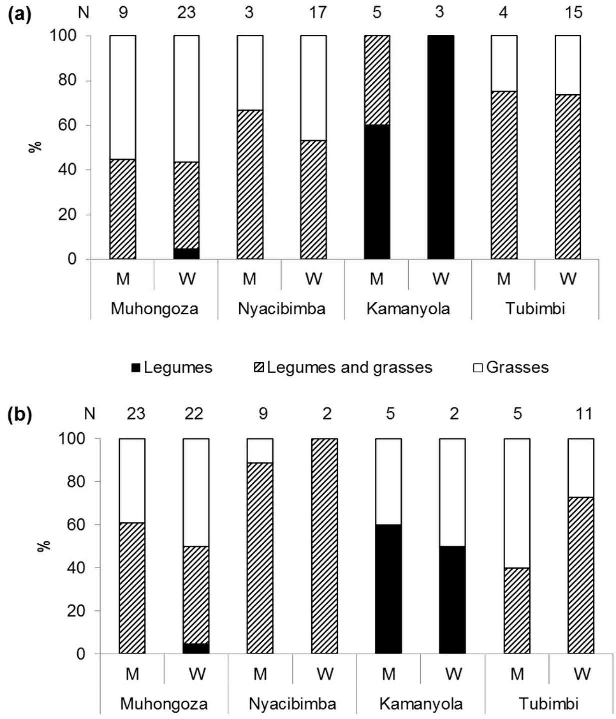

Fig. 3: *Forage types cultivated by farmers on their own farms in four different sites of Sud-Kivu, DRC in (a) December 2013 and (b) September/October 2014. M refers to men, W to women. All sites are described in Tables 1 and 2.*

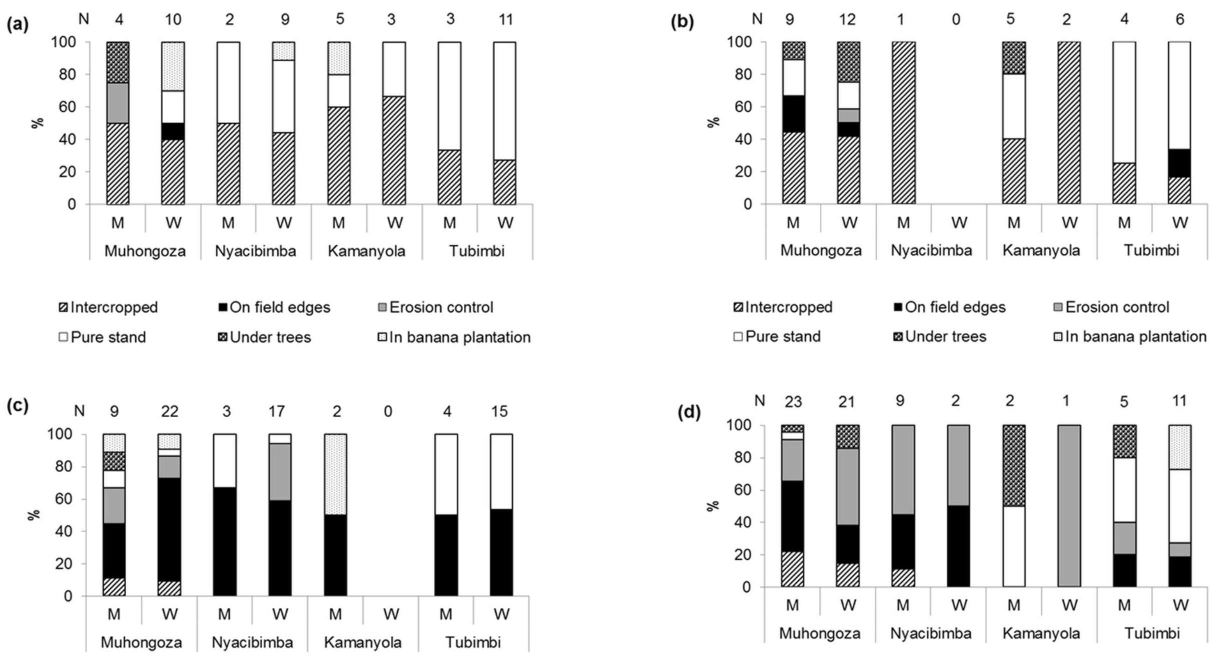

Fig. 4: *Integration of (a, b) forage legumes and (c, d) grasses into farming systems by farmers on their own land in four different sites of Sud-Kivu, DRC in (a, c) December 2013 and (b, d) September/October 2014. M refers to men, W to women. All sites are described in Tables 1 and 2.*

4 Discussion

4.1 Improved forage legume and grass options across different agro-ecologies

Herbage yield of the first cut of both legumes and grasses was dependent on agro-ecological conditions. Biomass production was highest in Kamanyola, which has the least acidic soils of all sites. Tubimbi showed lowest and most variable biomass production, which is probably due to most acidic soils (pH 3.9) limiting P availability and increasing Al toxicity as well as plant susceptibility for diseases and pests. Forage legumes adapted differently to the four sites with no differences among varieties, confirming that forage legumes are highly site specific. Stylo appeared less suitable for soil protection due to relatively low above-ground soil cover, although roots also contribute to reduction of soil erosion. Forage grasses displayed higher variability in biomass production among varieties than among sites, underlining their broader adaptability. French Cameroon showed consistently higher biomass yield than Guatemala grass, as did local Napier except for its failure in Kamanyola.

However, it is important to note that the agronomic data from the demonstration trials presented in this study can only be considered as indicative for agro-ecological adaptation. The main reason is that only one herbage cut was done, and it was carried out later than normally (six months after planting). This does not only limit comparability with other agronomic forage trials, but also rather gives insights into the establishment of the forages tested, not their performance over several seasons. For example, farmers in Nyacibimba abandoned French Cameroon in the second year (2014) as it was susceptible to pests (small flies) in most farms that caused drying of the leaves (F. L. Muhimuzi, unpublished observation). Nevertheless, the trials confirmed performance of the best bet forages evaluated in a previous agronomic study in the same sites (Katunga *et al.*, 2014). The study season (October 2012 – April 2013) fell into a normal rainfall season when comparing with previous and following seasons (Figure 2). Thus the results can still be interpreted as indicative for establishment and agro-ecological adaptation.

Farmers in the region have very minor tradition of cultivating improved forages (Maass *et al.*, 2012; Bacigale *et al.*, 2014), and if so, they are rather familiar with grasses (Napier, Guatemala) and fodder shrubs. Particularly, the offered annual legumes were new to most farmers so that they had to choose new selection criteria during focus group discussions. Farmers prioritized biomass production and animal preference, which resulted in highest rankings for herbage yield. The same priorities had been previously observed for forage legumes (Katunga *et al.*, 2014) and cassava-legume intercropping in the same area (Pypers *et al.*, 2011). However, visual assessment of biomass production corresponded to apparent and not necessarily real biomass production, which may have resulted in farmers favouring Canavalia with its large leaves. Two additionally important criteria for grasses were novelty in the area and capacity for erosion control, which made French Cameroon the most popular choice especially in new research sites (Muhongoza and Nyacibimba), where farmers have not previously been in contact with this variety. It is known that Guatemala grass is well adapted to the higher areas of Sud-Kivu (Compere, 1960), although it is not prevalent in the region. In this study, farmers of most sites selected Guatemala second after French Cameroon. As Guatemala grass is fairly drought-tolerant, Guatemala can still offer digestible forage during the dry season when Napier grass is losing its forage quality.

4.2 On-farm niches for forages in Sud-Kivu

Farmers' interest to participate in forage research and planting varied among sites, also reflecting livestock husbandry systems and traditions. In Kamanyola, the relatively lower interest can be partly explained by the predominant free livestock roaming system, which is the most common practice once crops have been harvested. In such areas, there is no tradition of planting forages for livestock feeding, which has been confirmed by a previous feed assessment showing the low percentage of farmers currently growing fodder (Bacigale *et al.*, 2014).

Initially, women were more interested in forage cultivation than men across research sites. This might have two reasons: Firstly, women are often in charge of livestock feeding (Maass *et al.*, 2012), and planting forages close to the homestead can considerably reduce time and effort for collecting forages from far. In South-East Asia, the labour saving effect for women was an important entry point for forage technology adoption (Phengsavanh & Stür, 2006). Women are likely to favour forage crops, especially when they have multiple uses such as food crop, soil erosion and weed control, as well as soil fertility maintenance and/or farm or field boundary demarcation. Secondly, the IPs through which the experimentation was conducted focussed on cavies that are predominantly tended by women and boys (Zozo *et al.*, 2010; Maass *et al.*, 2012). One year later, men also became interested in planting forages to feed goats, resulting into almost equal participation of men and women.

The choice of forage type as well as their integration into cropping systems depended on various factors, mostly land availability, land tenure, soil erosion prevalence and livestock husbandry system. While in most sites, farmers chose to cultivate both legumes and grasses, Kamanyola was the only site with a majority of farmers initially choosing to grow (annual) legumes only. The high percentage of rented land and free livestock roaming in the dry season on fields does not favour cultivation of perennial grass varieties that remain when the annual food crops have been harvested. Farmers in high altitude and sloping sites of Muhongoza and Nyacibimba had the highest preference for grass varieties planted as hedgerows due to the erosion control benefits. In general, farmers preferred cropping system integration over monocropping, especially for legumes. This can be explained with low land availability in Sud-Kivu, where average farm sizes are as low as 0.4 ha (Ouma & Birachi, 2012), although livestock farmers were shown to have larger land sizes of 1.5 ha (Maass *et al.*, 2012). Only in Tubimbi, more forage grasses and legumes are grown as sole stand due to the comparably larger average land sizes and lower pressure on land. Furthermore, men work in nearby artisanal mines. Thus women can more easily decide to allocate more land to forage cultivation since normally their access to land is limited by their ability to negotiate with the male household head (Zozo *et al.*, 2010).

4.3 Future opportunities and further research needs

These results underline the importance of targeting forages well to specific agro-ecological conditions, but also to conduct adaptive research to fine-tune matching forages to the farmers' interests, needs and production systems. It has been suggested before to provide farmers with a basket of forage options to choose from (Stür *et al.*, 2002). A well-functioning, robust and convincing forage innovation is most critical to adoption (Stür *et al.*, 2013). As shown in this study, forage crops' adaptability can be highly site-specific and integration into cropping systems depends on various factors, especially in heterogeneous smallholder farming systems. Rigorous, long-term multi-locational system agronomy trials are needed to test spatial and temporal integration of annual and perennial forage crops with other food and forage crops. Good examples are provided by the work of Naudin *et al.* (2011), who have experimented with integrating different forages (*Vigna unguiculata*, *Vicia villosa*, *Lablab purpureus*, *Stylosanthes guianensis*) into maize, cassava and rice systems in Madagascar for feed, soil fertility, and protection purposes.

Our study underlines the usefulness of the concept of on-farm niches for better understanding why and how farmers choose to grow forage crops. However, the socio-ecological niche approach needs more systematic operationalisation in order to be useful for targeting of technologies to agro-ecologies and farming systems for maximum impact on farmers' livelihoods and environmental quality. Formalising previous research and expert knowledge into simple decision support tools could help to match contexts (e.g. constraints in terms of land, labour, capital, input availability, knowledge and markets) and farmers' objectives and needs (e.g. in terms of food, feed, soil protection, income) with suitable forage technologies. These are needed to assist scientists, development and extension workers in recommending and promoting most suitable technologies with maximum potential impact.

Moreover, better understanding of forage technology uptake and adoption is needed for sub-Sahara Africa. Although the principle of IAR4D proved useful in linking farmers to a value chain, further research from the area is needed on economic and labour benefits of forage cultivation and their (potential) contribution to smallholders' incomes and livelihoods. Developed value chains and functioning extension services can provide crucial market pulls and expertise stimulating behavioural change towards farm-grown fodder and stall feeding, such as recently shown in Vietnam (Stür *et al.*, 2013).

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