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Sustainable intensification of agricultural systems in the Central African Highlands: The need for institutional innovation

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ABSTRACT

This study identifies entry points for innovation for sustainable intensification of agricultural systems. An agricultural innovation systems approach is used to provide a holistic image of (relations between) constraints faced by different stakeholder groups, the dimensions and causes of these constraints, and intervention levels, timeframes and types of innovations needed. Our data shows that constraints for sustainable intensification of agricultural systems are mainly of economic and institutional nature. Constraints are caused by the absence, or poor functioning of institutions such as policies and markets, limited capabilities and financial resources, and ineffective interaction and collaboration between stakeholders. Addressing these constraints would mainly require short- and middle-term productivity and institutional innovations, combined with middle- to long-term NRM innovations across farm and national levels. Institutional innovation (e.g. better access to credit, services, inputs and markets) is required to address 69% of the constraints for sustainable intensification in the Central Africa Highlands. This needs to go hand in hand with productivity innovation (e.g. improved knowhow of agricultural production techniques, and effective use of inputs) and NRM innovation (e.g. targeted nutrient applications, climate smart agriculture). Constraint network analysis shows that institutional innovation to address government constraints at national level related to poor interaction and collaboration will have a positive impact on constraints faced by other stakeholder groups. We conclude that much of the R4D investments and innovation in the Central Africa Highlands remain targeting household productivity at farm level. Reasons for that include (1) a narrow focus on sustainable intensification, (2) institutional mandates and pre-analytical choices based project objectives and disciplinary bias, (3) short project cycles that impede work on middle- and long-term NRM and institutional innovation, (4) the likelihood that institutional experimentation can become political, and (5) complexity in terms of expanded systems boundaries and measuring impact.

1. Introduction

Growths in human population and food consumption are expected to increase global food demand of between 70% and 100% by 2050 (Royal Society of London, 2009). Sustainable intensification of agricultural systems in developing countries is perceived essential to meet this growing global food demand (Tilman et al., 2011). Especially in regions where pressure on agricultural land is high, and soil fertility and yields are low, sustainable intensification can enhance food security and economic development (Drechsel et al., 2001; Vanlauwe et al., 2014). The literature on intensification of agricultural systems in developing countries – be it sustainable or ecological[1] – generally

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[1] We acknowledge the similarities and differences between sustainable and ecological intensification, but feel that discussing their semantics and practices is beyond the scope and objective of this paper. Therefore we consistently refer to 'sustainable intensification'.

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focuses on generating more produce or income from existing agricultural land. To achieve that objective, sustainable intensification requires (1) productivity innovation (e.g. improved varieties, fertilizer, new crop management practices), (2) Natural Resource Management (NRM) innovation (e.g. reforestation and erosion control), and (3) institutional innovation (e.g. social infrastructure, policy, partnerships, access to finance, services, inputs and markets) (Pretty et al., 2011; Tittonell, 2014; Vanlauwe et al., 2014). These different types of innovations need to emerge in an integrated way, making smart use of available agro-ecological, human and financial resources across different systems levels in a specific context (Robinson et al., 2015). But this seems easier said than done. Review of sustainable intensification literature reveals a strong focus on productivity innovation, for instance the use of new varieties or fertilizers to increase crop yield (e.g. Folberth et al., 2014; Ojiem et al., 2014), and NRM innovation, such as water harvesting and agro-forestry (e.g. Carsan et al., 2014; Dile et al., 2013; Laurance et al., 2014). The importance of institutional innovation to support sustainable intensification is acknowledged in the literature, mainly in relation to access to credit, inputs, extension services and markets (e.g. Robinson et al., 2015; Vanlauwe et al., 2014). However, evidence from experimentation with, and investment in, institutional innovation to provide an enabling environment for sustainable intensification is limited. We wonder whether this is justified and why this is the case?

Perhaps the answer to the above question is rooted in different ideas about what sustainable intensification actually implies. A narrow approach to sustainable intensification would focus on understanding and alleviating biophysical and technological constraints for improved yields and revenues at plot or farm level. A broader systems approach to sustainable intensification seeks to understand the complex interrelations between biophysical, technological, social–cultural, economic, institutional and political problem dimensions across farm, village, district, regional and national levels, and how these are shaped through interaction and negotiation between different stakeholders and organisations. The title of this paper – referring to “sustainable intensification of agricultural systems” – reveals that we use a systems approach as our starting point.

Among the more advanced systems approaches to agricultural innovation is the Agricultural Innovation Systems (AIS) approach (Foran et al., 2014; Klerkx et al., 2012a). The AIS approach provides a framework for the integrated analysis of dimensions, levels and stakeholder perceptions related to a specific agricultural problem, and the functioning of the more generic innovation system in which the problem is embedded (Klerkx et al., 2010; Spielman et al., 2008). The active engagement of different stakeholder groups from different levels in identifying, prioritising and alleviating constraints is an important feature of the AIS approach (Foran et al., 2014). That this also applies to sustainable intensification is emphasised by Tittonell (2014) and Struik et al. (2014c) who underline that ‘sustainable intensification’ is likely to have different meaning for different groups of stakeholders. Stakeholder engagement is important for three reasons. First, different stakeholder groups can provide important insights about the different dimensions of constraints for sustainable intensification across different levels (Schut et al., 2016). Second, it can facilitate negotiation about what combination of sustainable intensification innovations would best align with specific constraints, as well as with the motivation, needs and interests of different stakeholder groups (Struik and Kuyper, 2014). Third, stakeholder engagement provides a basis for collective ex-ante design of AIS research, policy and development agendas for sustainable intensification (Foran et al., 2014).

This study provides AIS analysis of constraints and opportunities for sustainable intensification in the Central African Highlands. The region is in many ways representative for agricultural systems that require sustainable intensification: (a) population is expected to increase 2–3 fold in the next 35 years (United Nations, 2015), (b) yield gaps are among the largest in the world (Tittonell and Giller, 2013), (c) fallow land is virtually absent and the hilly landscape is prone to erosion which causes soil fertility challenges (Drechsel et al., 2001), (d) years of conflict have weakened agricultural extension systems and input and service supply, resulting in significantly output losses (FAO, 2000), and (e) similar to other tropical regions in the world, climate change and variability are threatening already vulnerable smallholder livelihoods (Morton, 2007). The study has three specific objectives. First, we identify and analyse constraints for sustainable intensification as experienced by different stakeholder groups. Second, we explore similarities, differences and linkages between the constraints identified across the stakeholder groups and study sites. Third, based on constraint network analysis and stakeholder prioritisation, we identify entry points for innovation for sustainable intensification of agricultural systems in the Central African Highlands.

2. Conceptual and methodological framework

2.1. Key-concepts

Stakeholders are those actors or actor groups with a stake in a specific problem or in the innovations that can lead to their resolution (McNie, 2007). In this study we distinguish between farmers, civil society and non-governmental organisations (NGOs), private sector, government officials, and researchers and trainers (Ortiz et al., 2013; Schut et al., 2015b). To address complex problems (such as sustainable intensification according to Struik et al., 2014c) interaction, negotiation and collaboration between stakeholders in describing, explaining and prioritising problems, and exploring, designing and testing solutions has been proposed (Douthwaite et al., 2009; Giller et al., 2008; Neef and Neubert, 2011). Innovation is defined as a co-evolving process of technological (e.g. seeds, breeds, fertilizer, agronomic practices) and socio-organisational (e.g. policy, markets, partnerships) change (Hall and Clark, 2010; Hounkonnou et al., 2012; Leeuwis, 2004). Many productivity, NRM and institutional innovations have both technological and socio-organisational dimensions. Innovations occur across different levels, and are shaped by interactions between stakeholders and organisations inside and outside the agricultural system (Kilelu et al., 2013; Klerkx et al., 2010). We use Spedding's (1988) definition of the agricultural system as the operational units of agriculture including all actors and organisations involved in agricultural production, processing and commercialization activities. In line with the objectives of this study, the delineation of the agricultural system's boundaries – a key challenge when doing (innovation) systems research (Klerkx et al., 2012b) – is done in a participatory way, by stakeholders. Sustainable intensification of agricultural systems is conceptualised as increasing the output of agricultural production, processing and commercialization activities, while at the same time increasing the efficiency of natural, physical, financial and human resource investments and reducing negative environmental and social impacts (Pretty et al., 2011). An entry theme is a broad topic or objective that applies across a region (e.g. intensification of crop–livestock systems). Entry points are the more specific productivity, NRM and institutional innovations, that combined can contribute to achieving the entry theme (Humidtropics, 2014).

2.2. Study site selection and characteristics

Data for this study were collected in the highlands of Burundi, Rwanda and eastern Democratic Republic of Congo (DR Congo). The region is part of one of the ‘action areas’ of the CGIAR Research Program on Integrated Systems for the Humid Tropics (Humidtropics). Humidtropics has adopted sustainable intensification of agricultural systems as its main approach to achieving development impacts. Within Humidtropics, multi-stakeholder approaches form the core of the programme's strategy to jointly identify, prioritise, design and implement research for development (R4D) activities.

Between July and September 2013, one-day multi-stakeholder workshops were organised in each of the three countries to select and prioritise study sites. Site selection was based on both 'hard' and 'soft' criteria. Hard selection criteria included: (1) population density, (2) potential for poverty reduction, (3) potential for reducing land degradation, and (4) potential for trade and market chains. Soft selection criteria included: (1) past engagements, (2) strength of partnerships, (3) monitoring and evaluation/impact assessment considerations (e.g. existence of baseline information), (4) possibility for joint stakeholder learning and action, and (5) national policies, priorities and interests in collaboration (Humidtropics, 2013). Based on a facilitated debate among the different stakeholders, study sites were identified and prioritised for Burundi (1 site), Rwanda (2 sites) and DR Congo (1 site) (Fig. 1 and Table 1).

2.3. Data collection

Data were collected between July 2013 and March 2014, and occurred in two phases. The first phase included the identification of one or more 'entry themes' for sustainable intensification in each of the four study sites. This happened between July and September 2013, during the same multi-stakeholder workshops in which site selection took place (Section 2.2). Workshop participants representing different stakeholder groups were purposefully selected based on their expertise and availability (Table 2). A facilitated discussion between the different stakeholder groups led to agreement on the entry theme(s) for sustainable intensification. Field visits were organised to validate the entry themes with farmers and other local stakeholders in the four study sites. During the second phase, a conceptual and methodological framework for the Rapid Appraisal of Agricultural Innovation Systems (RAAIS) was followed (Schut et al., 2015b). RAAIS is a diagnostic tool that aims to provide a coherent set of 'entry points' for innovation to address complex agricultural problems, and to enhance the functioning of the agricultural innovation system. One-day multi-stakeholder workshops were held in each of the four study sites in February and March 2014. Starting point of the workshops was for each individual participant to identify five constraints related to the entry theme identified during the first phase. A subsequent step was to develop a stakeholder group top 5. This top 5 was used throughout the rest of the workshop sessions in which the groups categorised their top 5 along constraint dimensions, causes, and levels, timeframe and innovation type. Furthermore, participants explored connections between their group's

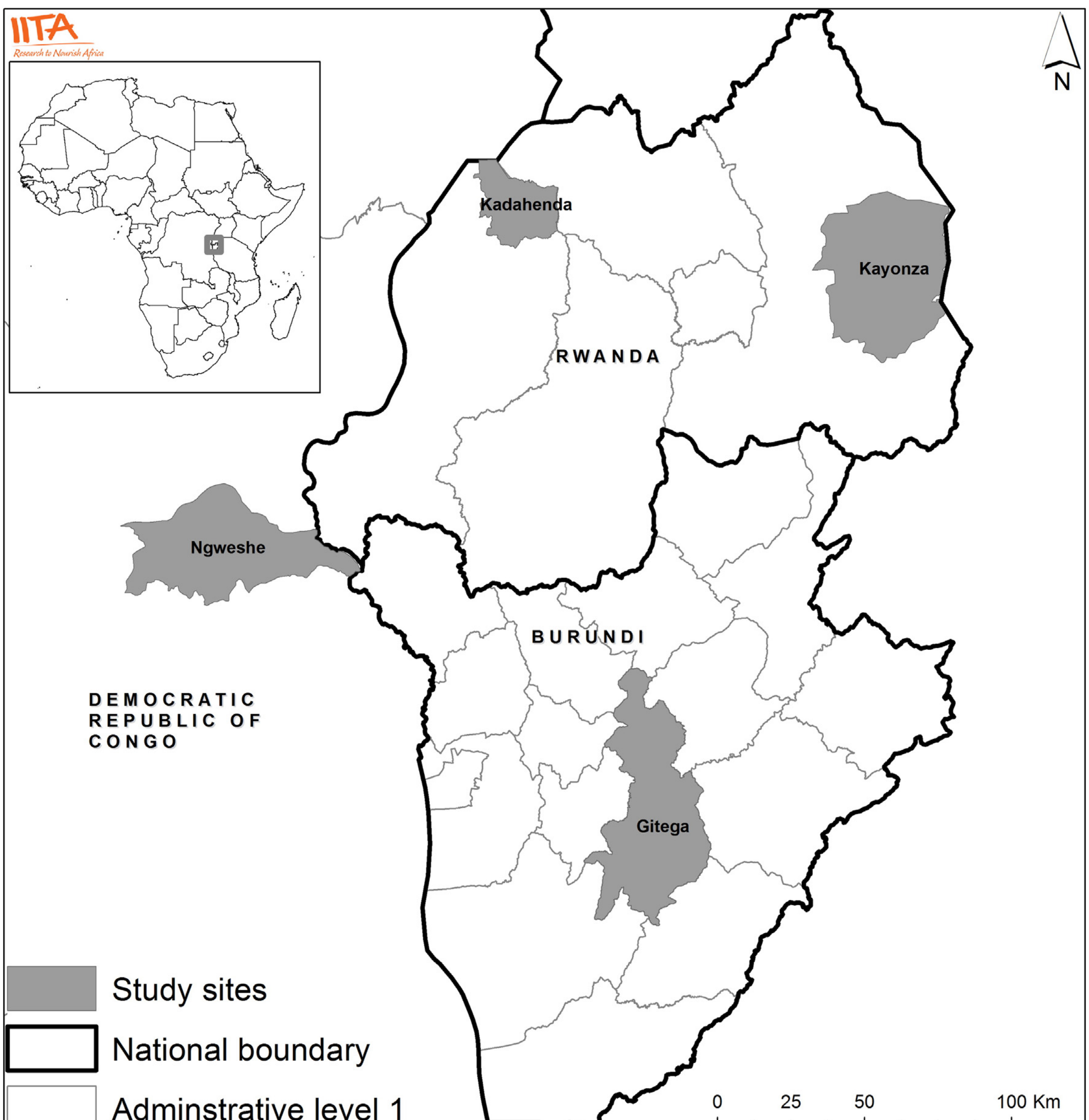

Fig. 1. Map of study sites in Burundi, Rwanda and eastern DR Congo.

Table 1
Key characteristics of agricultural systems in the study sites in Burundi, Rwanda and DR Congo (CIALCA, 2006; Hijmans et al., 2005; IITA, 2015; Jarvis et al., 2008; Linard et al., 2012).[a]

Country	Burundi	Rwanda		DR Congo
Study site	Gitega	Kadahenda	Kayonza	Ngweshe
Mean elevation (mtr. above sea level)	1.698	2.220	1.428	1.604
Population density (people per km2)	482	555	191	291
Mean annual rainfall (mm)	1.198	1.486	919	1.587
Average farm size (ha)	0.76	0.98	0.69	0.85
Main staple crops	Cooking banana Maize Semi-climbing beans	Potato Beans Maize	Cooking banana Beans Maize	Bush beans Bitter cassava Beer banana
Main cause of food insecurity	Poor crop yields Poor health/laziness	Climate Poor crop yields Diseases	Climate Poor crop yields Lack of capital	Lack of capital Poor crop yields Infertile soils
Use of chemical fertilizer among farmers (%)	24	21	13	2
Farmers using credit (%)	4	4	5	1
Farmer access to government extension services (%)	6	24	21	2
Farmer access to NGO extension services (%)	6	7	5	17
Farmer access to private extension services (%)	5	13	8	14

[a] Data derived from overlapping or nearby sites in CIALCA (2006).

constraints and those faced by other groups, and negotiated and prioritised entry points for innovation for each of the sites. For more detailed information on RAAIS' conceptual and methodological underpinnings and the workshop sessions, we refer to Schut et al. (2015b). Similar to the first workshop, participants were sampled purposefully to represent the different stakeholder groups, and based on study site expertise and their availability. Each workshop could accommodate a maximum of 25 participants, which determined the total sample size (Table 2). A facilitation and note taking protocol guided consistent execution and recording of the RAAIS workshops, which were all facilitated by the same person. The facilitator was an independent consultant who had previous experiences with leading multi-stakeholder RAAIS workshops. Both the set up of the workshops (stakeholders identify individual constraints, rank them in homogeneous groups, and negotiate over innovation priorities in heterogeneous groups), as well as the facilitation protocol (stressing the importance of providing space for different stakeholder, gender and age groups) sought to create an environment in which workshop participants could raise and discuss their ideas freely. However, many studies have shown that participatory or collaborative approaches are affected by power-asymmetries, political strive and that outcomes are shaped by unequal capacities and opportunities to take part, debate and exert influence (Foran et al., 2014; Giller et al., 2008). For example, despite our efforts to have a gender-balanced representation of different stakeholder groups in the two events, only 25% and 16% were female during the entry theme and entry points workshops respectively. Leeuwis (2000, 2004) has argued that power and politics are not necessarily negative, but that stakeholder negotiation is also needed to arrive at innovations that are economically and institutionally feasible, and social-culturally and politically acceptable.

2.4. Data analysis

Our dataset contains seven analysis categories: (1) study sites, (2) stakeholder groups, (3) dimensions of constraints for sustainable intensification (Schut et al., 2014), (4) causes for constraints using structural conditions for innovation (Klein Woolthuis et al., 2005), (5) levels where interventions to address the constraints are required (Douthwaite et al., 2003), (6) whether addressing these constraints requires short-, middle- or long-term timeframe, and (7) what type of innovation would be principally required to address the constraints (Pretty et al., 2011) (Table 3).

Data was analysed in four steps. During each of the steps different analysis methods and tools were used (Table 4).

3. Results and analysis

During the workshops conducted during the first phase, different entry themes were identified across the study sites (Table 5). Livestock integration was mentioned in each of the sites, and formed the core of the themes in the Rwanda and DR Congo sites. Agroforestry integration was identified in both Gitega and Kadahenda. The Gitega themes were formulated more broadly as compared to the themes for the other study sites.

These entry themes formed the start of the entry point identification workshops of which results are presented and analysed in the below

Table 2
Overview of stakeholder groups that involved in the identification of entry themes (phase 1) and entry points (phase 2), and the number of representatives across the different stakeholder groups and study sites.

Study site and country	Event	Location and date	Stakeholder groups targeted (number of representatives)					
			Farmers	NGO/civil society	Private sector	Government	Research and training	Total
Gitega, Burundi	Entry theme identification	Gitega, September 2013	6	18	2	9	11	46
	Entry point identification	Gitega, February 2014	4	5	4	5	6	24
Kadahenda and Kayonza, Rwanda	Entry theme identification	Kigali, July 2013	7	12	4	10	13	46
	Entry point identification Kadahenda	Kadahenda, March 2014	3	3	1	5	7	19
	Entry point identification Kayonza	Rwamagana, March 2014	6	2	3	2	5	18
Ngweshe, DR Congo	Entry theme identification	Bukavu, August 2013	3	6	3	5	7	25
	Entry point identification	Kalambo, February 2014	4	6	3	3	6	22
Total			33	52	20	40	55	200
%			17	26	10	20	28	100

Table 3
Analysis categories and subcategories.

Categories	Subcategories
1. Study sites	Gitega, Burundi; Kadahenda, Rwanda; Kayonza, Rwanda; Ngweshe, DR Congo
2. Stakeholder groups	Farmers; civil society/NGO; private sector; government; research and training
3. Constraint dimensions	Biophysical (e.g. soil types, water availability), technological (e.g. inputs and management techniques), social–cultural (e.g. cropping practices, beliefs), economic (e.g. human and financial resources, off-farm income), institutional (e.g. policies and rules) and political (e.g. power dynamics)
4. Constraint causes	Infrastructure and assets (e.g. physical and knowledge); institutions (e.g. policies and regulatory frameworks); interaction and collaboration (e.g. between stakeholders); capabilities and resources (e.g. entrepreneurship, human and financial resources)
5. Levels	International; national; regional/departmental/provincial; district/commune; ward/arrondisement/secteur; village/locality; farm[a]
6. Timeframe	Short term (<1 year); middle term (1–5 years); long term (5–10 year)
7. Type of innovation	Productivity; natural resource management (NRM); institutional

[a] Based on administrative system across the three countries, descriptions of levels were modified.

sections. A detailed overview of all data and results are provided as Supplementary Material to the paper.

3.1. Step 1: analysis within the analysis categories

Constraints for sustainable intensification were mainly of economic and institutional nature (24% and 22% resp.). Examples of economic constraints include “lack of finance to ensure quality and quantity of agricultural production” and “low technology adoption due to low financial capacity of farmers”. Several institutional constraints were specifically related to the entry themes, such as “insufficient capacity building on agro-livestock and agroforestry integration” (Kadahenda), whereas other institutional constraints were more generic such as constraints related to the “weak extension service”. Constraints were least categorised as having a strong biophysical or political dimension (both 11%). The main causes of constraints for sustainable intensification are due to the absence or poorly functioning of institutions such as policies (32%). Across the sites, the presence and quality of physical and knowledge infrastructure and assets was least often identified as cause of constraints related to the entry themes (14%). Addressing the vast majority of constraints requires interventions at national level (61%) and short- and middle-term timeframes (43% and 44% resp.). Institutional innovation would be needed to

Table 5
Entry themes identified in the study sites during phase one of the study.

Study sites and country	Entry theme(s)
Gitega, Burundi	▪ Introduction, evaluation and dissemination of improved varieties (e.g. high yield, nutritious, pest and disease resistant, etc.) adapted to farmer production systems and improving their market value ▪ Integrating agroforestry and livestock into farming systems for SI and improving agro-ecological integrity ▪ Improving NRM and soil fertility through the introduction, evaluation and dissemination of innovative technologies ▪ Providing innovative solutions for farmers' access to financial services and credits to intensify production and increase market opportunities
Kadahenda, Rwanda	▪ Improved crop (potato)–tree–livestock integration
Kayonza, Rwanda	▪ Improved maize–legume–livestock integration ▪ Improved banana–legumes–livestock integration
Ngweshe, DR Congo	▪ Improved banana–beans systems through livestock integration ▪ Improved of cassava–legume systems through livestock integration

addressing 69% of the constraints for sustainable intensification of agricultural systems, followed by productivity (20%) and NRM innovations (10%).

3.2. Step 2: analysis across the analysis categories

When looking at dimensions of constraints for sustainable intensification faced by different stakeholder groups, it appears that farmers experience more technological constraints (40%, e.g. limited knowhow of cultivation techniques). Private sector, civil society and government experience relatively more economic constraints (37%, 30% and 25% resp., e.g. insufficient finance to supply inputs to farmers). Compared to other stakeholder groups, government stakeholders experience more political constraints (20%, e.g. limited collaboration between stakeholders in agricultural sector), and research and training stakeholders experience more institutional constraints (30%, e.g. insufficient courses on integrated crop–tree–livestock at Universities) (Fig. 2).

The structural conditions that can cause constraints for innovation show diversity across different sites and stakeholder groups. In Burundi and DR Congo, the largest proportion of constraints is related to the absence or poorly functioning of institutions (main cause of 44% and 32% of the constraints resp.). Examples include “access to land” and “land security” (Gitega) and “no continuation of government projects leading to poor diffusion of innovation” (Ngweshe). The causes of constraints identified in Rwanda are more related to absence of capabilities and resources in Kadahenda (40%, e.g. “insufficient knowledge on agro-livestock production”), and related to lack of interaction and collaboration between stakeholders in Kayonza (36%, e.g. including “weak collaboration between research institutions”).

Table 4
Overview of four analysis steps, analysis approach and analysis methods and tools.

Analysis step	Analysis approach	Analysis methods and tools used
1. Analysis within the analysis categories	Descriptive statistics for categories 3–7[a]	Calculation of means and relative frequencies using SPSS v.23 for 5 categories.
2. Analysis across the analysis categories	Descriptive statistics for relations across categories 1–7	Calculation of cross frequencies and correlations between two variables using SPSS v.23 for 7 categories.
3. Constraint linkage analysis	Constraint network mapping	Network mapping of constraints using Fruchterman Reingold algorithm and analysis using analysis sub-categories as attribute values in Gephi v.0.9.1. (Bastian et al., 2009) as well as mean degree of constraint network.
4. Analysis of entry points for innovation	Participatory prioritisation of constraints and opportunities for innovation by stakeholders	Qualitative analysis of similarities and differences in entry points for productivity, NRM and institutional innovation across the study sites. Descriptive statistics of groups of important constraints, using relative frequency of sub-categories in a category

[a] Data for categories 1–2 (study sites and stakeholder groups) do not show heterogeneity.

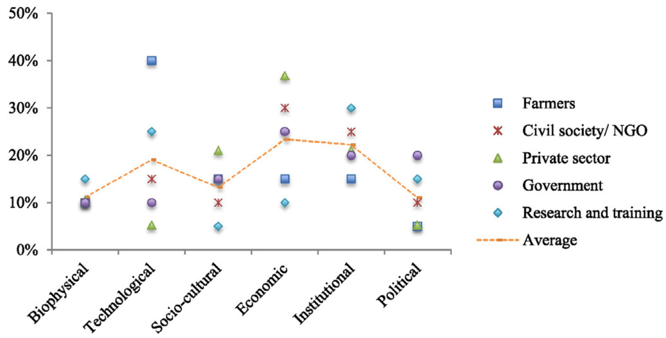

Fig. 2. Relative importance (y-axis) of different dimensions of constraints (x-axis) faced by different stakeholder groups.

Interventions to address stakeholder constraints would mainly be needed at national level (61%), followed by interventions at farm and regional level (12% and 11% resp.). The need for interventions at the international level (7%) can be explained by the climate change challenges that were identified and prioritised by four different stakeholder groups in Kayonza (all except for NGO/civil society). Also banana and bean diseases were categorised as requiring interventions at international level. Between stakeholder groups, more diversity can be observed. Of constraints faced by both government and research and training stakeholders, 80% require interventions at national level. For farmers, NGO/civil society and private sector this proportion is much smaller. For these groups, interventions at national level need to be complemented by approaches that target regional, district and farm level where the remaining constraints need to be tackled (45% for farmers, 40% for NGO/civil society and 50% for private sector).

Productivity innovation would mainly address constraints of technological nature (50%), caused by lack or poor quality of infrastructure and assets (50%). The limited access to and affordability of high quality inputs (seed, fertilizer, pesticides) for crop and/or livestock production appeared as a key production across the four study sites. Productivity innovation mainly requires interventions at national level (65%) and farm level (15%) on the short- and middle term (both 50%) (Fig. 3). NRM innovation mainly addresses constraints that are principally of biophysical nature (70%), caused by lack or poor quality of interaction and collaboration between stakeholders in the agricultural system (50%). Among the NRM constraints, limited land availability and related soil fertility constraints were prioritised across the Burundi and Rwanda sites. Limited farm size was specifically mentioned as a key constraint for integrated agriculture in Kayonza. Addressing NRM constraints would require interventions at international and national level (both 40%) on the middle- and long term (40 and 50% resp.). NRM constraints that cut across the Burundi and Rwanda sites include land scarcity, where pressure on land is more problematic as compared to the DR Congo site. Institutional innovations will mainly tackle constraints that are of institutional (32%) and economic (26%) nature, and that are caused by insufficient or absence of capabilities and resources (38%) (Fig. 3). Across the study sites, poor access to markets and credit form a key constraint leading to lack of financial resources for different stakeholder groups. Furthermore, limited adoption and impacts of agricultural innovations due to poor functioning of the agricultural extension system (Gitega and Ngweshe), farmer resistance to change (Kadahenda), and low knowledge and engagement levels due to insufficient capacity development (Kayonza) were identified as needing institutional innovation. Institutional innovations require interventions at the national level (64%) on short- and middle term (46% and 42% resp.) (Fig. 3). In DR Congo, institutional innovations would require additional action at regional/provincial level (32%), which has mainly to do with the decentralised mode in which the country is operating. Overall, in DR Congo, a higher proportion of constraints are perceived to require short-term action (64%).

3.3. Step 3: constraint linkage analysis

Fig. 4a shows how stakeholder constraints for sustainable intensification are related to each other. Constraint networks for both sites in Rwanda consist of two clusters (2a/b and 3a/b). Cluster 3a

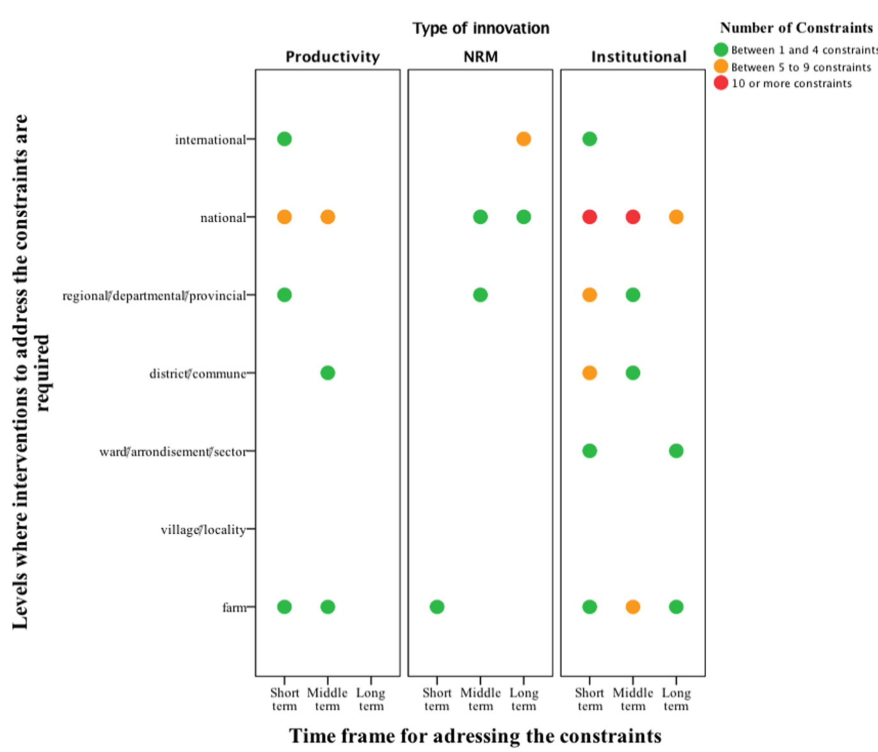

Fig. 3. Different types of innovations needed to address stakeholder constraints and the levels (y-axis) and the timeframe (x-axis) at which interventions are needed.

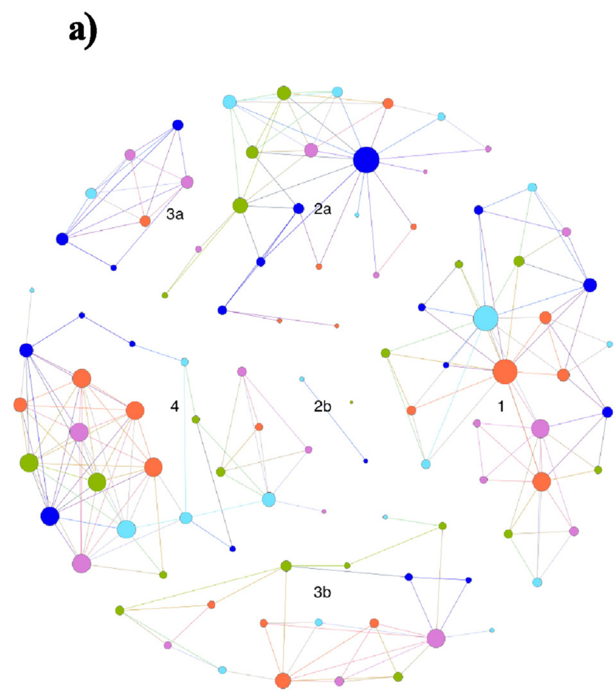

Fig. 4a. All constraint networks indicating different study sites, clusters and stakeholder groups. Nod sizes indicate the relative connectivity of the constraint.

shows interrelated climate change constraints experienced by different groups of stakeholders in Kayonza. The biggest clusters of constraints for each stakeholder group are those connected to government constraints (29% of farmer, civil society and private sector, and 32% for research and training). Examples include "poor collaboration between research, government and other institutions" and "low research budgets". With a mean degree of 5.9, the constraints network in DR Congo is most dense, implying that stakeholder constraints are more interrelated as compared to the other study sites such as those in Rwanda (3.8 and 4.0 for Kadahenda and Kayonza resp.) (Table 6).

Especially in Burundi and DRC, constraints faced by government show a high mean degree of connectivity (Table 6). Examples of highly connected government constraints include "insufficient finance" (related to 56% of other constraints identified in Burundi), and "no continuation of government projects leading to poor diffusion of innovation" and "limited alignment of projects with government priorities" (both related to 56% of other constraints identified in DR Congo). Fig. 4b shows just those constraints that have a higher degree of connectivity as compared to the mean degree of connectivity for the study site in which they were identified (henceforth referred to as 'important' constraints). In line with the above, government stakeholders face more important constraints (28%) as compared to the other stakeholder groups (farmers, 18%; civil society/NGO, 15%; private sector, 18% and research and training, 23%). Important constraints are of technological, economic and institutional nature (all 25%). Tackling 43% of the important constraints requires improved interaction and collaboration between stakeholders across international, national, regional and district levels. Institutional innovation would be needed to address 73% of the important constraints.

When clustering the important constraints, and zooming in on the top 3 for each of the study sites, we find similarities and differences (Table 7). Several clusters of constraints (those related to finance, agricultural information and knowledge, capacity development, climate change and pest and diseases) are study site specific. It does not mean that similar constraints were not identified across other sites, but merely that they were not labelled important or central in the constraint network analysis. Other clusters of constraints (e.g. those related to farmer competencies and governance, coordination and communication) cut across different study sites.

3.4. Step 4: analysis of entry points for innovation

Based on the prioritisation of constraints (Table 8), workshop participants identified entry points for productivity, NRM and institutional innovation for each of the study sites. Some of these innovations were specifically related to the entry theme (e.g. crop–tree–livestock integration), whereas others were more general.

Cross-cutting entry points for productivity innovation include (1) improved access to agricultural inputs (all sites), (2) capacity development to improve farming practices (Gitega, Kadahenda and Kayonza), and (3) pest and disease control (Gitega and Kayonza). Access to high quality agricultural inputs (seeds, breeds, fertilizer, etc.) is problematic in the region, which is reflected in the low proportion of

Table 6
Nodes, ties and mean degree of constraint connectivity per study sites and for stakeholder groups.

Study site and country	Nodes	Ties	Mean degree	Mean degree of constraint linkages per stakeholder groups				
				Farmers	NGO/civil society	Private sector	Government	Researchers and trainers
Gitega, Burundi	25	132	5.3	4.8	3.8	5.6	8.0	4.2
Kadahenda, Rwanda	25	94	3.8	2.8	4.6	3.4	2.2	5.8
Kayonza, Rwanda	25	100	4.0	5.6	3.6	2.6	4.6	3.6
Ngweshe, DR Congo	25	148	5.9	5.6	6.0	5.4	8.0	4.6
Total:	100	474	4.7	4.7	4.5	4.3	5.5	4.6

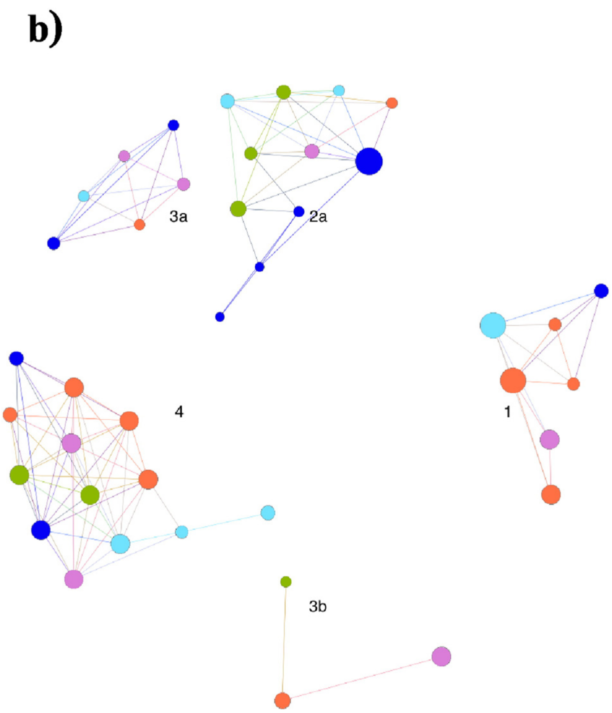

Fig. 4b. Important constraint network indicating different study sites, clusters and stakeholder groups. Nod sizes indicate the relative connectivity of the constraint. Figure legend: numbers: 1 = Gitega, Burundi; 2 = Kadahenda, Rwanda; 3 = Kayonza, Rwanda; 4 = Ngweshe, DRC. Colours: purple = farmers; green = civil society/NGO; light blue = private sector; orange = government; dark blue = research and training. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

households using chemical fertilizer is between 24% in Gitega, 21% in Kadahenda, 13% in Kayonza and 2% in Ngweshe (Table 1). Stakeholders identified local, large-scale production of high quality seed as an opportunity for Gitega, Kayonza and Ngweshe. Capacity development through farmer field schools, the identification and adaptation of technologies (varieties, breeds and production techniques) together with farmers, and improved agricultural extension were mentioned as potential innovations. To deal with pests and diseases issues in Gitega and Kayonza, (especially Banana Xanthomonas Wilt (BXW) and Cassava Mosaic Virus), the local production of organic pests and diseases products was seen as an entry point for innovation.

Entry points for NRM innovation identified include Integrated Soil Fertility Management (ISFM for Gitega, Kadahenda and Kayonza), and the testing of improved composting, organic manure and bio-fertilizer techniques (Gitega and Kadahenda). Capacity development on more efficient land use management (including land and soil conservation) was identified as a key entry point in Kadahenda. In addition, land extensive ways of producing high-value crops (e.g. mushrooms or off-ground crop production in bags) were mentioned. Related to the climate change constraints in Kayonza,[3] weather forecasting and warning systems, irrigation and soil conservation were mentioned to mitigate the effects of climate change.

Entry points for institutional innovation identified across the sites include the institutionalisation of mechanisms that can enhance multi-stakeholder collaboration (e.g. through multi-stakeholder platforms) to harmonize agricultural R4D agendas, approaches and activities. This responds to constraints related to limited interaction and coordination between stakeholders in the agricultural system that were considered important obstacles for sustainable intensification in Kadahenda and Ngweshe. Subsidy and credit policies, stronger farmer cooperatives, and farmer self-help groups were identified as opportunities for innovation to address constraints related to poor access to credit and market. Access to formal sources of credit (e.g. banks or microfinance institutes) is extremely low in the region (0% in Ngweshe, 4% in Gitega and Kayonza, and 5% in Kadahenda) (Table 1).

Table 7
Clusters of important constraints and their relative weight for the different study sites. Relative weight is calculated as the function of the # constraint ties divided by the total # of important constraint ties for each study site.

Clusters of important constraints	Gitega, Burundi	Kadahenda, Rwanda	Kayonza, Rwanda	Ngweshe, DR Congo
Finance	47%			
Agricultural information and knowledge	15%			
Governance, coordination and communication	15%			47%
Technology adoption		19%		16%
Farmers' competencies		29%	18%	13%
Capacity development/extension		22%		
Climate change			22%	
Pest and diseases			36%	
Other	23%	29%	24%	24%

4. Discussion

At the beginning of this paper, we wondered whether the limited experimentation with, and investment in institutional innovation to provide an enabling environment for sustainable intensification was justified and why this is the case? Based on our study we reflect on these questions, and provided guidance for further research, policy and development investments in sustainable intensification.

4.1. Is limited experimentation with, and investment in, institutional innovation for sustainable intensification of agricultural systems justified?

The results and analysis demonstrate that addressing constraints for sustainable intensification of agricultural systems would principally need institutional innovation (69%), followed by productivity

[3] Analysis of long time series of climatic data shows a significant increase in frequency of extreme climate effects such as prolonged dry spells that cause crop failure in rain-fed agriculture systems in Eastern Region of Rwanda (REMA, 2009).

Table 8
Prioritised constraints for productivity, NRM and institutional innovation identified for the study sites.[a]

Study sites and country	Prioritised constraints under the different categories of innovation required		
	Productivity	NRM	Institutional
Gitega, Burundi	1. Little knowhow of agricultural production techniques 2. High pressure of diseases and pests (for crops and livestock) 3. Insufficient improved varieties/breeds in the crop–livestock system	1. Poor soil fertility 2. Acidity and shortness of agricultural land	1. Lack of material and financial resources 2. Lack of adequate sensitization of the population for the adoption of innovation practices 3. Absence of agricultural credit policies that can motivate the private sector to invest
Kadahenda, Rwanda	1. Limited knowledge on Integrated Soil Fertility Management (ISFM) practices and their economic profitability and benefit 2. Lack of agricultural inputs (seeds, trees, animals) 3. Lack of diversification of tree-fodder species and resistant potato varieties	1. Lack of knowledge on biophysical options (crop, tree, livestock, landscape, land, climate, water quality) 2. Limited farm size for integrated agriculture	1. Insufficient capacity development leading to low knowledge and engagement levels 2. Weak farmers' organisations 3. Low collaboration between researchers and other stakeholders in the agricultural sector
Kayonza, Rwanda	1. Inappropriate Integrated Soil Fertility Management (ISFM) and Integrated Pest Management (IPM) to address Crop Intensification Programme (CIP) constraints (disease, nutrient depletion) 2. No access to agricultural inputs (seed, fertilizer, pesticides, etc.) 3. Extreme diseases (banana and beans)	1. Climate change 2. Limited land	1. Farmers are resistant to innovations that may aggregate their produce 2. Shortcomings in production techniques due to ineffective extension system 3. Lack of market for agricultural produce
Ngweshe, DR Congo	1. No access to the high quality inputs for crops and livestock due to low household income 2. Insufficient germoplasm and inputs (for crops and livestock) 3. Seed quality	1. No respect of farming calendar	1. Poor collaboration between actors, organisations and projects in the agricultural sector 2. Limited impact of agricultural innovations 3. No access to agricultural credit

[a] Light editing was performed by the authors to enhance readability.

innovation (20%) and NRM innovation (10%). Data show a similar trend across the study sites and stakeholder groups. Similar RAAIS workshops to identify entry points for sustainable intensification and diversification of tree-crop systems in West Africa (Cameroon, Nigeria and Ghana) confirm these findings (average need for 23% productivity, 7% NRM and 69% institutional innovation) (Hinnou et al., 2014a, 2014b; Schut et al., 2015a). When zooming in on above-average connected constraints (Fig. 4b), the need for institutional innovation becomes even more evident. This does not mean that we believe that institutional innovation will automatically solve all productivity- and NRM-related constraints for sustainable intensification. On the contrary, as institutional barriers are lifted over time, new productivity and NRM constraints will emerge and vice versa.

Acknowledging the need of integrated productivity, NRM and institutional innovations for the sustainable intensification of agricultural systems implies that addressing productivity constraints at farm level needs to go hand in hand with addressing above-farm level constraints. As demonstrated in this study, institutional, but also productivity and NRM innovations require action across different levels. A good example is related to poor crop yields in the Central Highlands region (Table 1). High population pressure, small farm sizes and nutrient mining are leading to severe problems of soil fertility decline and erosion, which makes closing nutrient cycles at the farm level crucial (Lambrecht et al., 2015). For instance, livestock introduction to increase the availability of organic manure in cropping systems was identified as a cross cutting entry theme for sustainable intensification in the Central Highlands. Additional NRM innovation such as the introduction of perennial tree crops systems with deep-rooted vegetative cover year-round could be needed to combat soil erosion (Vanlauwe et al., 2014). The introduction of livestock or trees at farm level is in itself not so complicated, but needs to be accompanied by above-farm level institutional innovations such as better access to finance (e.g. to invest in appropriate livestock housing), improved access to high quality (veterinary) services, and capacity development for farmers and other stakeholders in the system. This is confirmed by other studies that suggest that in order to accelerate the impact of productivity and NRM innovation on resilient livelihoods of farmers, investment in service delivery mechanisms to farmers, policy, markets, and other enabling institutional conditions are required (e.g. Jayne et al., 2004; Vanlauwe et al., 2014). Understanding synergies and trade-offs between different types of innovation for various stakeholder, gender and age groups is important for sustainable intensification of agricultural systems (McDermott et al., 2010; Ndiritu et al., 2014; Zimmerer et al., 2015).

4.2. What explains limited experimentation with, and investment in, institutional innovation for sustainable intensification of agricultural systems?

A better understanding of the institutional dimension of sustainable intensification, and how it is interlinked with productivity and NRM dimensions needs to be accompanied by concrete investments in institutional experimentation. Building on some of the entry points identified in this study, this can include the design and testing of innovative credit, input and service delivery models, fund-raising, land tenure arrangements, and new modes of partnerships and multi-stakeholder collaboration. But why is this so difficult?

First, many studies and projects apply a narrow perspective on sustainable intensification, simply not identifying, or acknowledging the importance of institutional innovation above farm level. A second reason is related to the mandates of and available expertise in (inter) national agricultural research for development (AR4D) organisations. Previous studies point out that there is limited capacity to respond to constraints that are of institutional nature (Schut et al., 2016). Institutional domains such as capacity development, policies, markets and multi-stakeholder processes are historically less strongly represented in the AR4D system as compared to productivity and NRM domains (e.g. breeding and agronomy). Third, results from this study show that sustainable intensification requires short- and middle-term productivity and institutional innovations, combined with middle- to long-term

NRM innovations. Typical 3 to 4 year projects–cycles form an obstacle for working on middle- and long-term constraints (Botha et al., 2014). Fourth, institutional experimentation at national (policy) levels can easily be seen as being political (Cash et al., 2003; Schut et al., 2014). It can criticise democratic processes, expose ineffective extension systems and propose new incentive structures that may result in win–win situations for some stakeholders, but at the same time result in win–lose situations for other stakeholders (Giller et al., 2008). Fifth, the direct impact or return on investment of institutional innovation (e.g. increased capacity to innovate) is difficult to measure (Leeuwis et al., 2014). Institutional innovation is shaped by interactions between stakeholders and organisations across different levels (Kilelu et al., 2013; Klerkx et al., 2010). This makes it more difficult to delineate and 'control' the boundaries of institutional innovation processes (Klerkx et al., 2012b). This complexity may refrain researchers or research organisations from engaging in institutional innovation processes.

Several of the opportunities for productivity, NRM and institutional innovation identified in this study (Table 8) have been translated into concrete R4D activities, which have been progressively implemented as part of the Humidtropics programme from September 2014 onwards. Our experiences demonstrate that several of the above-mentioned reasons resulted in a strong focus on productivity and NRM innovation at community and farm level. Multi-stakeholder innovation platforms at community and national level to foster stakeholder collaboration form the most concrete example of institutional innovation implemented under the programme (Schut et al., 2016).

4.3. Reflection on research, policy and development agendas for sustainable intensification of agricultural systems

The agricultural innovation systems approach to sustainable intensification provides a more holistic image of the complex interrelations between different types of constraint dimensions, faced by different stakeholder groups, across different levels. Compared to more narrow approaches that focus on understanding and alleviating biophysical and technological constraints for improved yields and revenues at plot or farm level, this offers a better starting point for identifying site-specific entry points for productivity, NRM and institutional innovation.

We believe that the process of identifying, analysing and prioritising constraints and entry points for innovation requires close collaboration between stakeholder groups. The involvement of different stakeholder groups provides better insight in the different constraint dimensions, causes, and what type of innovations are economically and institutionally feasible, and social-culturally and politically acceptable (Schut et al., 2014). Furthermore, it supports stakeholder groups (including researchers) in becoming more aware of their fundamental interdependencies (shown by this study) and can facilitate negotiation that is needed for concerted action to address their constraints and reach their objectives (Leeuwis, 2000). As expressed earlier, it is impossible to ban power dynamics and politics from participatory processes. However, the process needs to be organised in such a way that it avoids pre-analytical choices leading to path dependence based on merely researcher or development interests and biases (Röling et al., 2004; Struik et al., 2014b). Comparing the different results from Tables 7 and 8 in this paper (most important constraints based on constraint network analysis versus constraints prioritised by stakeholders) reveals space for improvement of the RAAIS methodology for that matter. The results from the constraint network analysis could perhaps be fed back to stakeholders so that it provides an evidence-base for the prioritisation of entry points for innovation based on feasibility and potential development impact. Other opportunities for improving the methodological approach include more in-depth analysis of root causes of constraints.

Several studies have shown that the success of technological innovations is strongly correlated with institutional innovations (Amankwah et al., 2012; N'cho et al., 2014; Totin et al., 2012). So if governments and development partners are truly concerned about alleviating smallholders' constraints and stretching their windows of opportunity, then purposefully experimenting with alternative institutional arrangements is essential (Struik et al., 2014a). Active engagement between researchers and other stakeholders (including policymakers) should not be perceived as a treat to the credibility of research, but as an attempt to produce more legitimate and impactful strategies for sustainable intensification. Farmer resistance to change was among the key constraints identified by stakeholders in each of the sites. Scholars have questioned whether farmers are resistant to change, or whether top-down policy and development approaches and methods do not capture sufficiently the needs and livelihood options as perceived by farmers (Van Asten et al., 2009), as well as by other public and private stakeholders (Hall et al., 2003). Other studies suggest that the multiplicity of development projects, each with their own objectives, approaches and innovations can easily lead to the spread of contradictory advice to farmers (Schut et al., 2015c), and that this impedes farmers' willingness to engage in activities (Schut et al., 2015d). Consequently, better coordination and collaboration among research and development programmes, and better alignment of these programmes with government, farmer and private sector priorities is needed.

5. Conclusions

This paper provides agricultural innovation systems analysis of constraints and opportunities for sustainable intensification. This approach provides a holistic image of (relations between) constraints faced by different stakeholder groups, the dimensions and causes of these constraints, and intervention levels, timeframes and types of innovations needed to overcome these constraints. Our data shows that constraints for sustainable intensification of agricultural systems in the Central Africa Highlands are mainly of economic and institutional nature. Constraints are caused by the absence, or poor functioning of institutions such as policies and markets, limited capabilities and financial resources, and ineffective interaction and collaboration between stakeholders. Addressing these constraints would mainly require short- and middle-term productivity and institutional innovations, combined with middle- to long-term NRM innovations across farm and national levels. Institutional innovation is required to address 69% of the constraints for sustainable intensification in the Central Africa Highlands. This needs to go hand in hand with productivity innovation and NRM innovation that are needed to address the remaining constraints. Constraint network analysis shows that institutional innovation to address government constraints at national level related to poor interaction and collaboration will have a positive impact on constraints faced by other stakeholder groups.

We conclude that much of the R4D investments and innovations in the Central Africa Highlands remain targeting household productivity at farm level. Reasons for that include (1) a narrow focus on sustainable intensification, (2) institutional mandates and pre-analytical choices based project objectives and disciplinary bias, (3) short project cycles that impede work on middle- and long-term innovation, (4) the likelihood that institutional experimentation can become political, and (5) complexity in terms of expanded systems boundaries and measuring impact. To overcoming these issues, research, policy and development agenda setting for sustainable intensification of agricultural systems needs to be embedded in multi-stakeholder structures and processes. This can enhance stakeholder interaction and collaboration and facilitate the implementation of coherent multi-level strategies for the sustainable intensification of agricultural systems.

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