Building a framework towards climate-smart agriculture in the Yangambi landscape, Democratic Republic of Congo (DRC)

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Abstract

Purpose – This paper aims to produce a framework for climate-smart agriculture (CSA) in the Yangambi landscape, Democratic Republic of the Congo (DRC). This would enable the authors to identify agricultural practices, assess vulnerability to climate change, identify options for improving agricultural systems from a climate change mitigation and adaptation perspective and finally provide climate-smart agricultural options.

Design/methodology/approach – The study used household survey methods of data collection. The data were collected using a structured questionnaire survey by interviewing 250 farm households, subdivided

using three axes of the Yangambi landscape. Fisher's exact test was used to determine relationships between two or more variables.

Findings – Results of the survey revealed that the vast majority (98%) of respondents perceived changes in temperature, rainfall and weather patterns. Reduction of crop yields and the emergence of new weed species and new crop pests are the main impacts on agricultural activities. Although 87.6% of respondents have no means of adaptation and resilience, some of them use crops rotation, fallow practice, fertilizers and bio-pesticides. A framework for CSA is proposed for the Yangambi landscape.

Practical implications – Policies and strategies to promote CSA in the study area should take into account local farmers' perceptions of climate change and consider first the adequacy of CSA practices for the specific conditions of the target area before its promotion. This study is thus useful for many REDD+ initiatives that are currently being promoted in DRC and particularly in the Tshopo Province.

Originality/value – This study is one of the first studies to focus on CSA in the Yangambi landscape, DRC. It assists the use of agriculture as a response to reducing deforestation while at the same time lowering agriculture's carbon footprint and promoting a resilient and more productive farming system.

Keywords Climate change, Climate-smart agriculture, Congo Basin,
DRC (Democratic Republic of the Congo), Farmers' perceptions, Yangambi

Paper type Research paper

1. Introduction

Climate change is already hampering agricultural activities. According to the Intergovernmental Panel on Climate Change (IPCC), climate change affects crop production, with negative effects more common than positive (IPCC, 2014). Africa is the most vulnerable continent because of its heavy dependence on rain-fed agriculture (IPCC, 2007), widespread poverty, low adaptive capacity and lack of investment in mitigation and resilience-building systems (Bele *et al.*, 2010; Williams *et al.*, 2015).

Over the centuries, farmers have learned to adapt to climate variability, but given the pace and intensity of current and future climate change, their actions are no longer sufficient (Bele *et al.*, 2010). Rural areas are the most vulnerable (IPCC, 2007; FAO, 2016).

However, this vulnerability is greater in Congo Basin countries such as the Democratic Republic of the Congo (DRC) (Sonwa *et al.*, 2012; Ministry of Foreign Affairs, 2018), where about 70% of the population live in rural areas and depend on rain-fed slash-and-burn agriculture to live (Ulimwengu and Kibonge, 2016). In the Yangambi landscape, agriculture is the main activity and accounts for between 70% and 85% of the income of three-quarters of households. Economic opportunities are scarce and more than 80% of households live below the poverty line (CIFOR, 2018a).

Moreover, despite the fact that agriculture is considered as the most vulnerable sector to climate change at both local and national levels (MECNT and UNDP, 2009; Ulimwengu and Kibonge, 2016); several studies have shown that it is a major source of greenhouse gas (GHG) emissions (Pan *et al.*, 2011; Arneth *et al.*, 2019), through the process of deforestation (Potapov *et al.*, 2012; Hufkens *et al.*, 2020), thus contributing to climate change (Kipalu and Mukungu, 2012; AMCEN, 2014). Slash-and-burn agriculture is the main direct cause of deforestation in DRC (MECNT, 2012; Molinario *et al.*, 2015), particularly in the Yangambi landscape (Hufkens *et al.*, 2020). The search for fertile land pushes the population to clear increasingly more forest areas to meet their ever-increasing needs and to cope with greater demographic pressure (Alongo *et al.*, 2013; Kyale *et al.*, 2019).

From the above, it can be seen that there are two major agricultural challenges in the Yangambi landscape:

(1) combating climate change by introducing agricultural practices that aim to reduce GHG emissions, while adapting to climate change (Seguin, 2010); and

(2) increasing agricultural production in order to ensure food security while also preserving forests.

Thus, to alleviate the agricultural challenge in a climate change context, the Food and Agriculture Organization (FAO) of the United Nations suggested climate-smart agriculture (CSA); this is an approach based on three pillars – food security, adaptation and mitigation (Delvaux, 2016). Its agricultural practices increase productivity and resilience in a sustainable manner, reduce GHG emissions intensity, curb deforestation and improve the health of soils, landscapes and forests (FAO, 2016).

CSA is not a prescribed practice or a specific technology that can be universally applied. It requires adoption of an integrated approach that takes into account specific local conditions (FAO, 2014), including site-specific assessments of the social, economic and environmental conditions to identify appropriate agricultural technologies and practices (Williams *et al.*, 2015).

So, within this framework, we conducted this study, of which the main objective is to establish a framework towards CSA in the Yangambi landscape. Specifically, the study aims to:

• identify current agricultural practices and their constraints in terms of yield;
• assess vulnerability to climate change and identify adaptation options;
• identify options for improving the performance of agricultural systems from a climate change mitigation and adaptation perspective; and
• finally, provide climate-smart agricultural options for the Yangambi landscape.

2. Materials and methods
2.1 Study area
This work was carried out in the Yangambi landscape, located in Tshopo Province, in Northeastern DRC (Figure 1). The region corresponds to an area located between 24°16'95" and 25°08'48" E longitude; 0°38'77" and 1°10'20" N latitude. The climate of Yangambi is continental equatorial, belonging to the Af type of the Köppen classification (Van Wambeke and Evrard, 1957). The annual precipitation varies between 1600 and 2200 mm (Mohymont and Demarée, 2006), with an annual average of 1820 mm (Likoko *et al.*, 2019). The annual temperature varies from 24.2°C to 25.8°C, with an annual average of 24.98°C (Kombele, 2004; Likoko *et al.*, 2019). The main activity in the Yangambi landscape is slash-and-burn subsistence agriculture. Cassava, maize, rice, groundnut and plantain are the main crops (CIFOR, 2018a).

2.2 Methods
2.2.1 Research design. The study was carried out in nine sites distributed along three axes in the Yangambi landscape: Yangambi–Ngazi road axis, Yangambi center and Kisangani–Yangambi road axis (Table 1). The Yangambi center or the city of Yangambi is an area housing the National Institute for Agronomic Studies and Research (INERA)/Yangambi, whose activities are mainly influenced by INERA. The Kisangani–Yangambi axis is along the road linking Yangambi to the city of Kisangani, capital city of the province. Activities are more influenced by the city of Kisangani than by the city of Yangambi. The Yangambi–Ngazi axis is a rural area not connected directly to a large city.

2.2.2 Data collection. The study used household survey methods of data collection. The data were collected using a structured questionnaire survey. Information collected includes,
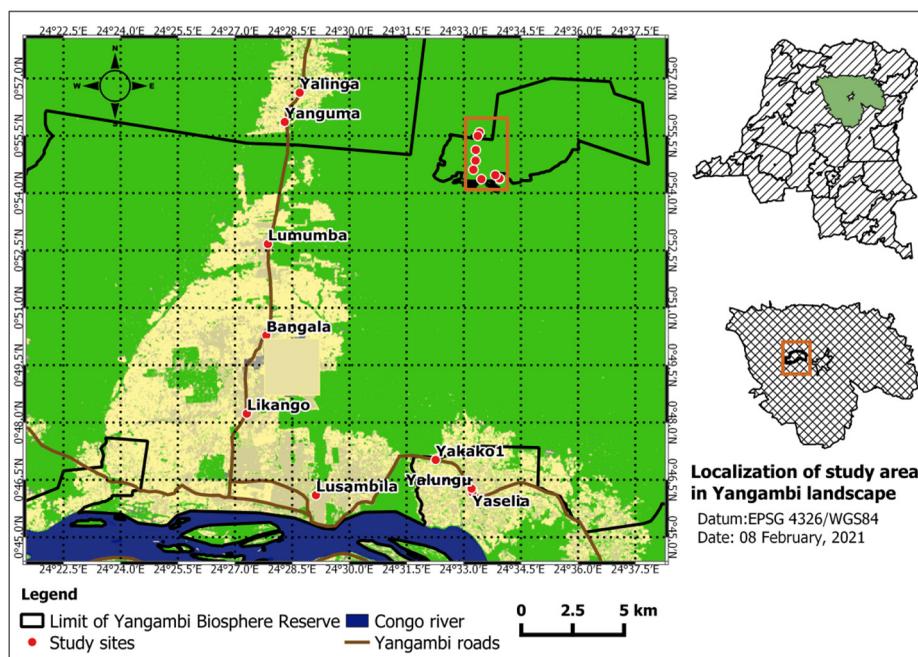
Figure 1.
Localization of the
study area

Axes	Sites	No. of households surveyed	No. of households surveyed per axis
Yangambi center	Bangala	35	140
	Likango	35	
	Lumumba	35	
	Lusambila	35	
Yangambi–Ngazi axis	Yalinga	25	45
	Yanguma	20	
Kisangani–Yangambi axis	Yakako	20	65
	Yalungu	20	
	Yaselia	25	
All three axes		250	250

Table 1.
Study sample

household characteristics, agricultural practices and constraints, and farmers' perceptions of climate change. The survey was administered from 23 May to 12 June 2018. Qualitative and quantitative data were collected from farmers having at least five years of seniority in the site, being head of the household and having a field. A total of 250 households were surveyed. Secondary information was collected through focus group discussions. These consisted of about 10 people at each site before the household survey was administered, to gain a general idea about the region.

2.2.3 Data analysis. Fisher's exact test was used to determine if there was a significant relationship between two or more variables. It was mainly used to establish a relationship between different farmers' perceptions of climate change and belonging to an axis. The acceptable error for the statistical analyses was 5%. When the p-value was less than the

significance level of 5%, this meant that there was a significant relationship between variables. These statistical analyses were performed using RStudio software version 3.3 (Barnier *et al.*, 2020).

3. Results

3.1 Agricultural practices in the Yangambi landscape

Households own on average 1.67 ± 0.79 fields of 0.75 ± 0.52 hectares in the Yangambi landscape (data not shown). Most of them are established on fallow land (85.2%), whereas others are in mature forest (11.6%) or are planted directly after the harvest of another crop (3.2%).

3.1.1 Presence of trees in the fields. Some trees are left in fields by farmers during the establishment of new fields, whereas others grow spontaneously between crops and are retained during maintenance work. The most reported trees are *Petersianthus macrocarpus* (P. Beauv.) Liben (18.4% of respondents), *Persea americana* Mill. (6.8% of respondents), *Albizia ferruginea* (Guill. and Perr.) Benth (4.8% of respondents), *Pychnantus angolensis* (Welw.) Warb. (4.4% of respondents), *Annonidium mannii* (Oliv.) Engl. and Diels (4.0% of respondents) and *Dacryodes edulis* (G. Don) H. J. Lam (2.4% of respondents). Trees are retained in the fields for different reasons. Thus, *Petersianthus macrocarpus* (called "boso" in the local language) is kept for the edible caterpillars it bears, whereas *Persea americana* (avocado tree) and *Dacryodes edulis* (African pear) are kept for their edible fruits.

Apart from trees already in the fields, there are some trees species that respondents would prefer in their fields and would be willing to plant them. The most reported by respondents are *Petersianthus macrocarpus* (40.4% of respondents), *Persea americana* (24.4% of respondents), *Dacryodes edulis* (15.6% of respondents) and *Erythrophleum suaveolens* (Guill. and Perr.) Brenan (13.2% of respondents). *Erythrophleum suaveolens* is preferred for its medicinal properties, whereas other trees are preferred for reasons mentioned above.

3.1.2 Main crops in the Yangambi landscape. The main crops in the Yangambi landscape are cassava (*Manihot esculenta* Crantz, 62% of respondents), rice (*Oryza sativa* L., 22.4% of respondents), maize (*Zea mays* L., 6% of respondents), groundnut (*Arachis hypogea* L., 5.2% of respondents), cowpea (*Vigna unguiculata* (L.) Walp., 2.4% of respondents) and plantain and table banana (*Musa spp.* L., 2.0% of respondents). Apart from cassava, which is the main crop throughout the entire Yangambi landscape, there is a significant difference in the choice of other crops by axes ($p = 0.004$). Thus, rice predominates along the Yangambi–Ngazi axis, whereas cowpea predominates in Yangambi center.

According to destination of harvests (Table 2), most crop production is for sale with a smaller proportion for self-consumption (45.6% of respondents). Farmers who take all their harvests to market and keep nothing for self-consumption total 30.4%; 17.2% consume most of the harvest and sell a small portion; 3.2% divide the harvest equally between self-consumption and sale; and 3.6% practice self-consumption only. Fisher's exact test showed that there is no significant difference in terms of crop destination between the axes ($p = 0.542$). However, a high proportion of farmers practicing agriculture for self-consumption only are found in Yangambi center.

During agricultural activities, farmers face many constraints. Hard work (reported by 40.9% of respondents), lack of means to pay for labor (18.6%), lack of road infrastructure (16.4%) and lack of farming equipment (16.4%) are the main constraints faced by our respondents. The lack of means of conservation and buyers were also mentioned.

Main crops and destination of harvests	Kisangani–Yangambi axis ($n = 65$)	Yangambi–Ngazi axis ($n = 45$)	Yangambi center ($n = 140$)	All Yangambi landscape ($n = 250$)	p-value
Main crop					0.004
Groundnut	2 (3.1)	5 (11.1)	6 (4.3)	13 (5.2)	
Plantain and table banana	2 (3.1)		3 (2.1)	5 (2.0)	
Maize	6 (9.2)	3 (6.7)	6 (4.3)	15 (6.0)	
Cassava	49 (75.4)	20 (44.4)	86 (61.4)	155 (62.0)	
Rice	6 (9.2)	17 (37.8)	33 (23.6)	56 (22.4)	
Cowpea			6 (4.3)	6 (2.4)	
Destination of harvests					0.542
Self-consumption	2 (3.1)		7 (5.0)	9 (3.6)	
Market_selfcons	4 (6.2)		4 (2.9)	8 (3.2)	
Market	21 (32.3)	14 (31.1)	41 (29.3)	76 (30.2)	
Plus_selfcons	9 (13.8)	10 (22.2)	24 (17.1)	43 (17.2)	
Plus_Market	29 (44.6)	21 (46.7)	64 (45.7)	114 (45.6)	

Notes: Legend: Plus_Market = most of the harvest is destined for sale, Market = all the harvest is destined for sale, Plus_selfcons = most of the harvest is destined for self-consumption, Market_selfcons = the proportion sold is equal to the proportion self-consumed, Self-consumption = all the harvest is for self-consumption, X(Y): X = frequency and Y = percentage

Table 2.
Main crops and destination of harvests, expressed as: number of respondents (percentage of respondents)

3.2 Farmers' perceptions of climate change in the Yangambi landscape

3.2.1 Perceptions about climate change. The vast majority (98 %) of respondents perceived changes in temperature, rainfall and weather patterns (Table 3). Thus, 52.4% reported an increase in temperature; 45.2% reported unpredictable rainfall; 27.6% reported a decrease in the amount of rainfall per year; and 27.2% reported an increase in the amount of rainfall per year. Onset and cessation of rainfall creating disruptions to the agricultural calendar (52.4%), strong wind (21.6%) and delayed rainfall (7.2%) were also reported.

Fisher's exact test showed that observation of climate variations does not depend on the axes ($p = 0.244$). This is independent of gender ($p = 0.192$), age ($p = 0.387$), level of education ($p = 0.432$), farmers' main activity ($p = 0.343$) and farmers' seniority in agricultural activities ($p = 0.565$). However, there is a significant difference between axes in terms of decrease and increase in rainfall per year ($p < 0.001$). The decrease is observed more often along the Kisangani–Yangambi axis, whereas the increase is most reported along the Yangambi–Ngazi axis.

Climate variations mentioned above have been observed for 4.5 ± 6.1 years in the Yangambi landscape, with a minimum of 1 year and maximum of 36 years (data not shown). Regarding axes, observations have been made on average along the Kisangani–Yangambi axis for 6.3 years, 4.6 years in Yangambi center and 1.8 years along the Yangambi–Ngazi axis. Thus, it appears that proximity to the large city of Kisangani has an impact on climate variations, the closest sites being the most disturbed.

Farmers attribute observed climate variations to different causes. Although 47.6% do not know the real cause of the changes, 32% attribute them to divine phenomena (God's will/punishment being fulfilled), 7.2% to deforestation, 4.8% to demography and 3.6% to slash-and-burn agriculture. Fisher's exact test showed that knowledge about the causes of the changes depends on the level of education ($p = 0.002$), the seniority of the farmer in agricultural activities ($p = 0.019$) and the main activity of each farmer ($p < 0.001$). Farmers with higher education, i.e. university, cited slash-and-burn agriculture, whereas those with a secondary school diploma mentioned deforestation, demography and slash-and-burn agriculture. Those with a primary school level and those without education alluded to divine phenomena.

Perceptions of respondents Perception based on climate change indicators	Kisangani–Yangambi axis ($n = 65$)	Axes Yangambi–Ngazi axis ($n = 45$)	Yangambi center ($n = 140$)	All Yangambi landscape All Yangambi landscape ($n = 250$)	p-value
Observation of Climate change	62 (95.4)	45 (100.0)	138 (98.6)	245 (98)	0.244
Temperature trends					0.041
Increasing	35 (53.8)	16 (35.6)	80 (57.1)	131 (52.4)	
Rainfall trends					<0.001
Increasing	6 (9.23)	20 (44.4)	42 (30.0)	68 (27.2)	
Decreasing	32 (49.23)	6 (13.3)	31 (22.1)	69 (27.6)	
Unpredictable	27 (41.53)	19 (42)	67 (47.9)	113 (45.2)	
Weather changes experienced					
Delayed rainfall	2 (3.1)	6 (13.3)	10 (7.1)	18 (7.2)	0.129
Early rainfall	0 (0)	2 (4.4)	3 (2.1)	5 (2)	0.301
Strong wind	10 (15.4)	12 (26.7)	32 (22.9)	54 (21.6)	0.309
Onset and cessation of rainfall	32 (49.2)	27 (60.0)	72 (51.4)	131 (52.4)	0.528
Other changes	4 (6.2)	0 (0)	3 (2.1)	7 (2.8)	0.168

Notes: Legend: X(Y): X = frequency; Y = percentage

Table 3.
Climate change perception in the yangambi landscape based on climate change indicators, expressed as: number of respondents (percentage of respondents)

3.2.2 Impacts of climate change on agricultural activities. Climate variations in the Yangambi landscape impact negatively agricultural yields/production. Indeed, 54.8% of respondents reported reduced crop yields; 43.6% reported the appearance of various new crop pests; 69.6% reported the appearance of new weed species; and 22.4% reported crop wilt (Table 4). The most affected crops reported by respondents are rice (31.2%), cowpea (20%) and maize (18%). Rice, maize and cowpea are most affected by the increase in temperature and decrease in rainfall, whereas cassava and groundnut are most affected by the increase in rainfall.

According to axes, Fisher's exact test showed that there is a significant difference in observation of yield reduction (p <0.001) and crop new pest occurrence (p = 0.001) between axes. Yield reduction is most marked in Yangambi center (reported by 66.4% of respondents), followed by the Yangambi–Ngazi axis (44.4%) and the Kisangani–Yangambi axis (36.9%). The appearance of crop pests is more pronounced along the Kisangani–Yangambi axis. The appearance of new weed species has been observed on average for 8.3 ± 7.8 years, with a minimum of 1 year and maximum of 38 years. New pests have been observed on average for 3.3 ± 2.0 years, with a minimum of 1 year and maximum of 10 years.

3.2.3 Crop pests and weeds emerging as a result of climate variations. The most cited new weed species are *Croton hirtus* L'HÉRIT (reported by 52.4% of respondents), commonly called "abisibisi", a word from the Turumbu local language "abisi" meaning "to tickle"; *Mitracarpus villosus* (SW.) DC. (21.2% of respondents), locally called "botola", a word from the Lingala local language, "kobotola" meaning "to delight"; and *Oldenlandia corymbosa* L. (16.8% of respondents), locally called "ebola", in reference to the "Ebola virus" disease because of the damage it causes. Others weeds such as *Chromolaena odorata* (L.) R. King and H. Rob (14.9% of respondents) and *Hyparrhenia familiaris* (Steud.) Stapf were also mentioned (Table 5).

Impacts on agricultural Activities *Impacts of climate variability on crop production/yield*	Axes		Yangambi center (n = 140)	All Yangambi landscape All Yangambi landscape (n = 250)	p-value
	Kisangani–Yangambi axis (n = 65)	Yangambi–Ngazi axis (n = 45)			
Reduction of crops yield	24 (36.9)	20 (44.4)	93 (66.4)	137 (54.8)	<0.001
Appearance of crop pests	41 (63.1)	15 (33.3)	53 (37.9)	109 (43.6)	0.001
Appearance of new weed species	51 (78.5)	32 (71.1)	91 (65.0)	174 (69.6)	0.146
Crop wilt	10 (15.4)	5 (11.1)	41 (29.3)	56 (22.4)	0.012
Others	4 (6.2)	1 (2.2)	3 (2.1)	8 (3.2)	0.331
Most affected crops					
Rice	10 (15.4)	9 (20.0)	59 (42.1)	78 (31.2)	<0.001
Maize	26 (40.0)	7 (15.6)	12 (8.6)	45 (18)	<0.001
Cowpea	5 (7.7)	4 (8.9)	41 (29.3)	50 (20)	<0.001
Cassava	5 (7.7)	3 (6.7)	24 (17.1)	32 (12.8)	0.079
Groundnut	5 (7.7)	5 (11.1)	14 (10.0)	24 (9.6)	0.839
Other	6 (9.2)	1 (2.2)	10 (7.1)	17 (6.8)	0.360

Notes: Legend: X(Y): X = frequency; Y = percentage

Table 4. Impacts of climate change on agricultural activities in the Yangambi landscape, expressed as: number of respondents (percentage of respondents)

Climate impacts	Weed/pest species	Kisangani–Yangambi axis (n = 65)	Yangambi–Ngazi axis (n = 45)	Yangambi center (n = 140)	All Yangambi landscape (n = 250)	p-value
New weed species	*Croton hirtus*	42 (64.6)	26 (57.8)	63 (45.0)	131 (52.4)	0.024
	Pteridium aquilinum		2 (4.4)	13 (9.3)	15 (6)	0.017
	Mitracarpus villosus		17 (37.8)	36 (25.7)	53 (21.2)	<0.001
	Bulbostylis hispidula	9 (13.8)	2 (4.4)		11 (4.4)	<0.001
	Chromolaena odorata	23 (35.4)		3 (2.1)	26 (10.4)	<0.001
	Oldenlandia corymbosa			42 (30.0)	42 (16.8)	<0.001
	Others	8 (12.3)	7 (15.6)	11 (7.9)	26 (10.4)	0.249
New crop pests	*Zonocerus variegatus*	38 (58.5)	13 (28.9)	31 (22.1)	82 (32.8)	<0.001
	Spodoptera frugiperda	9 (13.8)	2 (4.4)	4 (2.9)	15 (6)	0.011
	Aphis craccivora	2 (3.1)	1 (2.2)	22 (15.7)	25 (10)	0.002
	Others	5 (7.7)		2 (1.4)	7 (2.8)	0.028

Notes: Legend: X(Y): X = frequency; Y = percentage

Table 5. Crop pests and weeds resulting from climate variations, expressed as: number of respondents (percentage of respondents)

However, it should be noted that for farmers, not all these weeds have negative effects. This is the case of *Chromolaena odorata*, locally called "likanja ikondo" in the Turumbu local language, which means "foreign". Farmers prefer it to grow after harvest, thus contributing to the restoration of soil fertility in fallow land.

Regarding new pests that have emerged in recent years, 32.8% of farmers cited the variegated grasshopper *Zonocerus variegatus* (Linnaeus, 1758) (locally called "kwalala");

10% reported the aphid *Aphis craccivora* Koch, 1854; and 6% reported the fall armyworm *Spodoptera frugiperda* (J. E. Smith, 1797).

3.3 Adaptation and resilience to climate change
In the case of yield reduction, most respondents have no adaptation techniques (87.6% of respondents). A small proportion adapt by directly resuming the seeding of the same crop (5.6% of respondents), by crops rotation (2.8% of respondents) or by clearing a new field in the forest (2% of respondents). Fisher's exact test showed that adaptation techniques depend on the axis ($p = 0.027$) and on the farmer's main activity ($p < 0.001$). Adaptation is independent of the level of education, age, membership of a peasant association and the farmer's seniority in agricultural activities. Farmers in Yangambi center have a greater diversity of possibilities to adapt than do other farmers.

However, even if they are adopted by a small proportion of respondents, some practices used as solutions can be considered as CSA practices, including use of fertilizers, back to fallow, crops rotation and bio-pesticides. Table 6 below presents the adaptation/resilience options used, sorted as CSA and non-CSA practices in order to show what CSA option can be easily promoted/implemented in the region. Note that CSA practices are those that offer the triple possibility of simultaneously raising productivity, enhancing adaption/resilience and mitigating carbon emissions.

When new crop pests appear, 72.5% of respondents have no means of control, while 22% use mechanical control and 4.5% use bio-pesticides. Of the three axes, pesticides are used only in Yangambi center. This shows that vulnerability to pests increases with increased distance from the INERA/Yangambi national research center.

Apart from the abovementioned options already used by farmers (data not shown), there are other options that they believe to be effective even if they do not yet use them. The proposed options are scientific research (reported by 43.2% of respondents), recourse to God (25 % of respondents) and reforestation (9% of respondents). A proportion of 2.3% of respondents reported that agricultural activities should be reduced and other activities should be considered.

Practice reported Practice based on impacts	Kisangani– Yangambi axis ($n = 65$)	Axes Yangambi– Ngazi axis ($n = 45$)	Yangambi center ($n = 140$)	All Yangambi landscape All Yangambi landscape ($n = 250$)	CSA p-value practice
Agricultural yields reduction					0.027
No adaptation tracks	65 (100.0)	40 (88.9)	114 (81.4)	219 (87.6)	
Directly resume seeding		5 (11.1)	9 (6.4)	14 (5.6)	–
Clearing a new field in forest			5 (3.6)	5 (2.0)	–
Fertilizers			1 (0.7)	1 (0.4)	+
Back to fallow			2 (1.4)	2 (0.8)	+
Crops rotation			7 (5.0)	7 (2.8)	+
Other			2 (1.4)	2 (0.8)	
Crops pests					0.006
No adaptation tracks	49 (75.4)	40 (88.9)	118 (84.3)	207 (82.8)	
Bio-pesticides			9 (6.4)	9 (6.4)	+
Mechanical control	15 (23.1)	5 (11.1)	13 (9.3)	33 (13.2)	–

Notes: Legend: + = CSA practice, – = non-CSA practice, X(Y): X = frequency and Y = percentage

Table 6.
Adaptation and resilience to climate change, expressed as: number of respondents (percentage of respondents)

In addition, to promote agricultural activities in the Yangambi landscape, a large proportion of respondents need farming equipment and need the advice of an appropriate agricultural service to cope with these new challenges. Good agricultural feeder roads, fertilizers, pesticides and improved varieties were also reported.

3.4 Climate-smart agriculture framework

According to respondents' perceptions, Table 7 proposes a CSA framework for the Yangambi landscape. It lists most reported climate risks, their impacts on agricultural activities and the likely pathways for CSA options that have been adapted to the realities of the Yangambi landscape.

4. Discussion

4.1 Agricultural practices

In the Yangambi landscape, each household owns 1.67 ± 0.79 fields of 0.75 ± 0.52 ha, mainly established on fallow land. These results are close to those found by Kyale *et al.* (2019) in the same region. Field sizes are close to the Tshopo Province average (FONAREDD, 2016) but small compared with the national average (Potapov *et al.*, 2012).

The small field area can be explained by the presence of the Yangambi Biosphere Reserve. As farmers are not allowed to open new fields in the forest belonging to the protected area, their children are obliged to divide up the land that belonged to their parent to establish fields. This reality was noted by Kyale and Maindo (2017), who characterized access to land in this area as "essentially hereditary". This mode of access to land would also explain the abundance of fields established on fallow land. The same reality is observed in Gbere village located in the east of Garamba National Park (Semeki *et al.*, 2016) and in villages bordering the Salonga National Park in DRC (ICCN, 2018).

The main crops in Yangambi landscape include cassava, rice, maize, groundnuts and plantain and table banana, which are also the main crops of Tshopo Province (Moonen, 2017). Our findings are similar to those of Semeki *et al.* (2016) in the northeast of the country and of the ICCN (2018) in the central part of the country. Cassava is the country's main crop (Molinario *et al.*, 2015).

Most of the crop harvest is brought to market, as agriculture is subsistence farming (Semeki *et al.*, 2016). The money obtained from the sale is used to pay children's school fees, buy farm equipment, pay debts and buy other nonagricultural products. In addition, a high proportion of farmers practicing agriculture for self-consumption only are found in Yangambi center. This can be explained by the fact that activities are more diversified in Yangambi center than in other areas.

The tree species found in respondents' fields are of some interest to farmers (Batsi *et al.*, 2020). *Petersianthus macrocarpus* and *Persea americana* are the two preferred species; the former is home to edible caterpillars and the latter provides edible fruits. *P. macrocarpus* trees have been preserved in the Yangambi landscape because of the caterpillars (Kyale and Maindo, 2017).

4.2 Farmers' perceptions of climate change

4.2.1 *Climate change perceptions*. Climate variations are observed by the vast majority of respondents. The climate risks differ locally, nationally and regionally (Ministry of Foreign Affairs, 2018).

Climate variations have been mentioned by other researchers in the same region (CIFOR, 2018b; Likoko *et al.*, 2019) and in other regions of the country (Bele *et al.*, 2014; Ulimwengu

Climate risks	Impacts	CSA options	Potential partners/actors
Increase in temperature	Crop wilt	Use of tolerant varieties, mulching, agroforestry	Research institutions, state technical services, nongovernmental organizations (NGOs)
	Reduced crop yields	Use of tolerant varieties, agricultural support service, agroforestry, revival of agricultural technical schools, livelihood diversification and new crops, mulching	
	Delayed crop growth	Use of short-cycle varieties, fertilizer and manure application, mulching	
	Removal of pests	Use of bio-pesticides, consumption of variegated grasshoppers	
Increase in annual rainfall	Removal of pests	Intensive weeding, high seeding density, livelihood diversification, new crops	Local community, research institutions, NGOs
	Cassava tuber rot	Use of tolerant varieties	
Decrease in annual rainfall	Crop wilt	Irrigation, water recycling, lowland development	State technical services, NGOs
	Growth delay	Irrigation, use of resistant varieties, livelihood diversification, new crops	
Onset and cessation of rainfall	Erosion of rain-fed soils supporting rice, groundnuts, and maize	Use of tolerant varieties, change of planting date	Research institutions, state and NGO technical services
	Cassava tuber rot Agricultural yield reduction	Use of improved seeds Agricultural calendar adjustment, diversification of activities, livelihood diversification, new crops, early-maturing varieties, mulching	
Strong winds	Pruning multipurpose trees	Windbreaks, agroforestry, tree planting and protection	Local communities, NGOs
	Pouring of banana trees and other crops	Windbreaks, assisted natural regeneration, reforestation of degraded areas, agroforestry	

Table 7.
Climate-smart agriculture framework according to the Yangambi landscape realities

and Kibonge, 2016). They are also observed in all African regions (Sonwa *et al.*, 2016; Tesfahun and Chawla, 2019; Saalu *et al.*, 2020).

The increase in temperature, onset and cessation of rainfall, decreased rainfall in some areas and increased annual rainfall in other areas are the main climate risks observed in the Yangambi landscape. Likoko *et al.* (2019) mentioned an increase in temperature of 0.44°C between 1931 and 2017 in the same area. Findings of our study corroborate those reported by the National Capacity Needs Assessment (MECNT and UNDP, 2009) and Chinedum *et al.*

(2015) in DRC. They match those found by Chia *et al.* (2016) in Cameroon, Onyeneke *et al.* (2017) in Nigeria, Saalu *et al.* (2020) in Kenya and Oriangi *et al.* (2020) in Uganda.

Regarding the duration of climate variations, hydrometric and meteorological data of 17 national meteorological stations showed that variations have been observed since the 1980s throughout the DRC (MECNT and UNDP, 2009). In the Yangambi landscape, climate variations have been observed for an average duration of 4.5 ± 6.1 years, with a minimum of 1 year and maximum of 38 years. This maximum is close to the 37 years reported by Codjo *et al.* (2015) in Benin.

Even if a large proportion of respondents do not know the causes of these changes, some of them attribute it to divine phenomena (God's will/punishment being fulfilled), deforestation, slash-and-burn agriculture and demography. These findings match those found by Yila and Resurreccion (2014) in Nigeria and Tesfahun and Chawla (2019) in Ethiopia. However, slash-and-burn agriculture as a cause of climate change has been cited at local (Hufkens *et al.*, 2020), national (MECNT, 2012; Molinario *et al.*, 2015) and international levels (Pan *et al.*, 2011; Arneth *et al.*, 2019).

4.2.2 Impacts of climate change on agricultural activities. Impacts of climate variations are inevitable, and even in the most optimistic scenario, they will have adverse effects on agricultural production and yields (Brown *et al.*, 2011). They differ by country and region, as well as by community and individual (Ministry of Foreign Affairs, 2018).

Regional climate models of the Congo Basin predict that a combination of factors, i.e. increase in temperature, rainfall decrease and irregularity or even extreme situations will inevitably result in a significant reduction in agricultural production and yield, a greater sensitivity of crops to pest attacks and a decrease in soil fertility (Lo and Kaéré, 2009). Moiroux *et al.* (2014) and Cilas *et al.* (2015) pointed out that climate change leads to the proliferation of pests transferring from one region to another. Our findings show that the main impacts are the appearance of new weed species, crop yield reduction and the appearance of crop pests, which matches the above viewpoints. Particular emphasis has been placed on yield reduction in rain-fed farming by Bele *et al.* (2014) in eastern DRC, Doukpolo (2014) in Central Africa and Ulimwengu and Kibonge (2016) in western DRC.

Hailu and Campbell (2015) pointed out that cereals are the most vulnerable crops (especially rice and maize). This viewpoint is confirmed by our findings. In addition, our results match the findings of Saalu *et al.* (2020) in Kenya and those of the IPCC in many lower latitude regions (Arneth *et al.*, 2019).

4.2.3 Emerging crop pests and weeds. Peltier *et al.* (2014) reported that forests were being replaced by weeds such as *Chromolaena odorata*, *Pteridium aquilinum* and *Imperata cylindrica* around the city of Kinshasa. However, in the Yangambi landscape, these weeds are rarely mentioned, with the most cited weeds being *Croton hirtus*, *Mitracarpus villosus* and *Oldenlandia corymbosa*.

The variegated grasshopper *Zonocerus variegatus*, the aphid *Aphis craccivora and* the fall armyworm *Spodoptera frugiperda* are the most widespread new pests in the Yangambi landscape. Bakondongama *et al.* (2017) reported *Z. variegatus* in Tshopo Province as a real threat to agriculture. In addition, Goergen *et al.* (2016) noted that in 2016, a new caterpillar (*Spodoptera frugiperda*) arrived in Africa. The FAO mentioned it first in West Africa and Central Africa in early 2016; and in 2018, it was detected and reported in almost all sub-Saharan African countries (FAO, 2018).

4.3 Other constraints on agricultural activities

Apart from climate change-related constraints, agricultural activities and crop yields face other constraints. Hard work, lack of means to pay for labor, lack of road infrastructure and

lack of adequate farming equipment are the main constraints faced by our respondents. In 2018, CIFOR (2018b) reported in the same area, the lack of availability of agricultural inputs, lack of supervision of farmers and nonexistence of cooperatives ensuring the purchase and sale of agricultural products. At provincial level, Van Hoof (2011) pointed out that roads are in poor condition, the many administrative and police hassles and lack of quality seeds.

In the Congo Basin (Cameroon, Central African Republic and DRC), constraints on farmers that make their adaptive capacity weak are the lack of technology, information, skills and infrastructure. Specifically, these are, in Cameroon, the lack of infrastructure and human and financial resources (Brown *et al.*, 2011); in Central African Republic, the lack of equipment, financial and technical resources and above all access to information (Doukpolo, 2014); and in DRC, the lack of basic infrastructure, producer organization, financial resources and processing activities (MINAGRI, 2010).

4.4 Possible solutions

Farmers do not stand idly by in the face of the negative impacts of climate change on agricultural activities. They are proposing certain solutions, either concrete or difficult to implement. Rural communities are the most vulnerable due to their limited adaptation capacities and their high dependence on climate-sensitive resources (IPCC, 2007; Brown *et al.*, 2011; Bele *et al.*, 2014).

In the case of yield reduction, most farmers do not have adaptation/resilient techniques, while some use crops rotation, fallow practice, or replant the same type seed. However, others open up new fields in the forest, posing an additional risk to the forest by accelerating the climate change process through deforestation. These results show that adaptive capacity in the Yangambi landscape is low compared with farmers in other African countries, including Nigeria (Onyeneke *et al.*, 2017) and Ethiopia (Tesfahun and Chawla, 2019). In terms of axes, farmers in Yangambi center have a diversity of solutions compared with other farmers. This may be due to their proximity to the National Institute for Agronomic Studies and Research, INERA/Yangambi.

Chinedum *et al.* (2015) reported eight CSA practices used by farmers at the national level in DRC. Our findings match some of them, especially as regards fertilizers, resumption of use of fallows, crops rotation and use of bio-pesticides. However, these practices are adopted by a very small proportion of respondents and are not yet being promoted. Note that agroforestry is already practiced by famers in some corners of the Yangambi landscape (Batsi *et al.*, 2020) but only by a few. Onyeneke *et al.* (2017) reported that farmers have already adopted CSA practices in southeast Nigeria.

At the national level, to combat climate change, the DRC has set up the PANA program. Its objective is to develop a program covering the entire country and identifying urgent and immediate adaptation activities that respond to the current and anticipated adverse effects of climate change (PANA, 2006). This program presents agriculture as the sector most vulnerable to climate change in DRC (MINAGRI, 2010). The main component of this project concerns the revival of the vital sector of basic agricultural production with a view to achieving food security. The project was carried out in four intervention zones located in the provinces of Katanga, Kasaï Oriental, Bandundu and Bas-Congo (PANA, 2006). Even though it was recommended, in terms of future directions, that particular attention must be paid to carrying out in-depth studies of climatic, socio-economic, cultural and ecological vulnerability to prepare zone-specific responses; to date, nothing has yet been done in the Yangambi landscape under PANA.

In 2008, DRC benefited from the Congo Basin Forests and Adaptation to Climate Change (CoFCCA) project. Its objective was to assess the level of vulnerability to climate change of

local communities in the forests of the Congo Basin and to bring stakeholders, through the participatory action research approach, to design and implement specific adaptation strategies (Sonwa *et al.*, 2014). The study carried out using this approach revealed that the adaptation efforts developed by local communities are no longer sufficient in the face of climatic uncertainties and the speed at which these changes are occurring (Bele *et al.*, 2010).

In the same framework as the fight against climate change, a mechanism called REDD+, of which the DRC has been part since 2009, was launched at the global level. The objectives of the national REDD+ strategy in DRC are to contribute to the mitigation of GHG emissions, poverty reduction and sustainable management of its forest resources, taking into account the valuation of environmental services (MECNT, 2015). The DRC's REDD+ program launched an eastern integrated program in 2016. It aimed at:

- improvement of governance of natural resources; and
- reduction of the impact of economic activities and population dynamics on forests.

However, it should be noted that the Yangambi landscape was not part of the project area. Agriculture was considered for the sole purpose of reducing deforestation (FONAREDD, 2016).

From previous activities, it appears that projects under REDD+ and the national PANA program have not specifically addressed the Yangambi landscape. In addition, agriculture is generally involved by mainly targeting a few main objectives (food security, climate mitigation, climate adaptation or biodiversity conservation) over a specific time period and geographic locations (Sonwa *et al.*, 2020).

Thus, the promotion of agriculture through CSA techniques is crucial for the Yangambi landscape and the well-being of the local population, as it links three important objectives according to the local context of climate change. Its implementation needs support and coordination from many stakeholders around smallholder farmers, including from research institutions, nongovernmental organizations (NGOs) and government institutions (Bele *et al.*, 2010; Sonwa *et al.*, 2020).

The African Ministerial Conference on the Environment (AMCEN, 2014) mentioned that science is the basis for decision-making for Africa, whenever the challenge of climate change needs to be understood or solutions need to be developed. African universities could become centers of innovation and technology transfer for CSA (Hailu and Campbell, 2015). In addition, government policies need to support research and development that focuses on and diffuses climate-smart technologies to help farmers respond to climate variations (Onyeneke *et al.*, 2017).

5. Conclusion

In the Yangambi landscape, farmers perceive climate variations in temperature, rainfall and weather patterns. Increase in temperature, onset and cessation of rainfall creating disruptions in the agricultural calendar and decrease or increase in annual rainfall are the main climate risks. Their impacts on agricultural activities are that many crop yields are reduced, and that new weeds species and new crop pests emerge.

Although a large proportion of respondents have no adaptation and resilience techniques, same of them use crops rotation, fallow practice, fertilizers and bio-pesticides, which can be considered as CSA practices already used in the region. This indicates that even if farmers are not yet receiving external assistance from government or non-governmental organizations to adapt and cope with climate change, they are able to put some CSA techniques into practice. To do so, it is therefore necessary to valorize these

practices and popularize them among farmers in the Yangambi Landscape, as they are accessible and feasible at the local level.

On the other hand, CSA practices to be proposed in the Yangambi landscape according to local realities are multiple, including the adjustment of the agricultural calendar, agroforestry, the use of tolerant and improved varieties, crops rotation, development of lowlands and the use of bio-fertilizers and bio-pesticides. To promote the implementation of CSA in the Yangambi landscape, support from research institutions, NGOs and state institutions is necessary.

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