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Securing the Harvest for the Smallholder Farmer in Rwanda: Fragmented or Consolidated Farmland Use?

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Abstract: The year 2007 marked the beginning of a journey to secure food in Rwanda. The country introduced the Crop Intensification Program (CIP), which promotes the farmland use consolidation (LUC). This study assesses the effect of farmland use changes on the agriculture production. We collected data at four research sites and considered three agriculture years to assess the effect of the fragmented or consolidated farmland use on the harvest. The study confirms that the CIP/LUC program converted perennial crops, mainly banana plantations, into seasonal crops, which were prioritized by the program. Overall, we conclude that the shift in farmland use has created an increase in both the harvest and monetary yields of the prioritized crops. However, within that general trend, we observe differences: farmers with smaller and/or fewer farm plots did not realize as great a yield increase as those who joined the CIP/LUC program with larger and/or multiple farm plots. While contributing to an understanding of the ongoing agriculture transformation program in Rwanda, this study followed a statistical approach that could be used by new studies assessing the benefits and outcomes of development policies.

Keywords: land use; farmland use consolidation; agriculture production; Rwanda

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1. Introduction

Across Africa, recent decades have seen countries undertaking developmental policy-informed programs with the aim of improving the agriculture harvest for their growing population. Lately, consolidating farmland has been prioritized. In fact, the continued land fragmentation reportedly discourages investments in mechanization or the adoption of innovative farming techniques [1,2]. This is particularly the case in many sub-Saharan African countries where farming areas are being fragmented, due to inheritance. To reverse the effects of land fragmentation, countries proceed with land consolidation. For Rwanda, Muyombano and Espling [3] found that at first, land fragmentation was often not seen as a problem among the local farmers. This was because fragmented landholdings favored the traditional agricultural system of shifting cultivation, which provided a better risk management for the landholders.

However, over the course of the past twenty years, the country registered an increasing population growth (average 2.5% annual increase) and a declining per capita agricultural land size (currently less than 0.5 ha). In addition, studies on Rwandan agriculture enumerate other challenges, such as inadequate agricultural technology, over-cultivation and the low use of agricultural inputs, land fragmentation, and imperfect financial markets [4–7]. Despite all of these problems, the agriculture sector in Rwanda remains the backbone of the economy, in terms of employment and income generation for the majority of households [8].

Aiming to sustain the food production on the farm level and to secure food for its growing population, the Rwandan government decided to consolidate the use of (farm) land and improve farming practices. These are the two main pillars of the Crop Intensification

Program (CIP), that was introduced in 2007 by the Ministry of Agriculture and Animal Resources (MINAGRI) as a solution to land fragmentation, the low use of agricultural inputs, and the low access to extension services [5]. The CIP aims at improving agricultural productivity, which has long been a challenge in Rwanda, due to land scarcity and agricultural intensification strategies that exhausted the country's natural resources [1,3,6,9,10].

From the global perspective, the process of land consolidation dates back to the 18th century. The first consolidation initiatives were carried out in Denmark in the 1750s, as part of a profound social reform to free people from obligations to noble landlords, by establishing privately-owned family farms [11]. However, the research output on the land consolidation remained scant until the 2000s when more studies on the subject emerged [12]. Since, as in current rural Africa, this process of consolidation is focused on optimizing the conditions in the agricultural sector through the re-allocation or exchange of parcels, and the provision of additional lands from land banks [13]. While the consolidation of fragmented holdings resulted in improved agricultural productivity in Europe, in Africa, this process is new [14]. Only recently, its diverging outcome in several African settings started to emerge in the scholarly literature [13,15,16].

Land use consolidation (LUC) emerged as the main pillar of the CIP, with the goal to stop the land fragmentation. The ministerial order determines the models of land use consolidation in Rwanda. It stipulates that through the LUC program, participating farmers commit to consolidating aspects of their operations while retaining individual ownership of their farm plots [17]. This joint cultivation of large areas, comprising multiple adjacent smallholder plots over which the farmers retain their individual land rights, is expected to deliver important economies of scale in the production of selected crops [3,6,18,19]. Prior to the beginning of the agricultural season, farmers commit to their participation in the program and agree to forego traditional intercropping techniques in favor of cultivating a single, government-approved crop, in collaboration with neighboring farmers. By joining the LUC program, farmers gain access to various services under the CIP, such as: (i) the delivery of inputs (improved seeds, fertilizers), (ii) extension services, (iii) post-harvest handling and storage facilities, (iv) irrigation and mechanization by public-and private stakeholders and (v) markets for the inputs and outputs [13,17].

The CIP focuses on eight priority staple crops: maize, wheat, rice, Irish potato, beans, cassava, banana, and soybean [18]. The crop rotation system is based on the crop suitability in a specific agroecological zone and its contribution to the overall food security [5,10]. While credited with increasing yields of select crops, both the CIP and LUC have been linked to the reduced decision-making authority over land and, in some cases, the decreased tenure security for participating smallholder farmers—thus discouraging them to expand their investment in agriculture [20,21]. However, the effect of the consolidated farmland use on the food production of smallholder farmers in Rwanda remains mostly the task of government surveys, as few empirical studies on that effect are lacking. Hence, it is not clear whether the shift from the fragmented to consolidated farmland use secures food for the smallholder farmer.

This paper uses four case studies in Rwanda to assess the effect of farmland use change on the agricultural production of smallholder farmers in Rwanda. The assessment is based on a dataset retrospectively compiled from three agricultural years: 2006/2007, 2012/2013, and 2016/2017. Our results suggest that crop yields increased statistically with the start of the CIP in 2007 and the beginning of land use consolidation. Total production quantities for the CIP priority crops grew by more than 150 per cent between 2007 and 2017 in the CIP-supported plots, and yields of all the targeted commodities improved. However, the yield increases did not vary in the same way for all farmers—some of them lost yields on the change. As we will discuss in the following sections, the LUC prioritized a number of crops, which conditioned the trend in yield increase. Prior to doing this, we will explain our research methodology.

2. Materials and Methods

2.1. Primary Data Collection

2.1.1. Study Area Selection and Sampling

This study used a dataset made of a sample of 400 smallholder farmers in Rwanda. Considering the aforementioned agriculture reform programs, we selected four research sites, one in each of the Provinces of Rwanda, namely Gatwe in the Eastern Province, Nyabubare in the Southern Province, Rusebeya in the Western Province, and Rutemba in the Northern Province (Figure 1). These research sites are located in the districts that were involved in the pilot trials of the land tenure regularization, representing areas where the formalization of land rights started in the country. Other selection criteria included the reported performance of the sites in the CIP/LUC program, number, and size of the farm plots per household and agriculture zoning (Table 1).

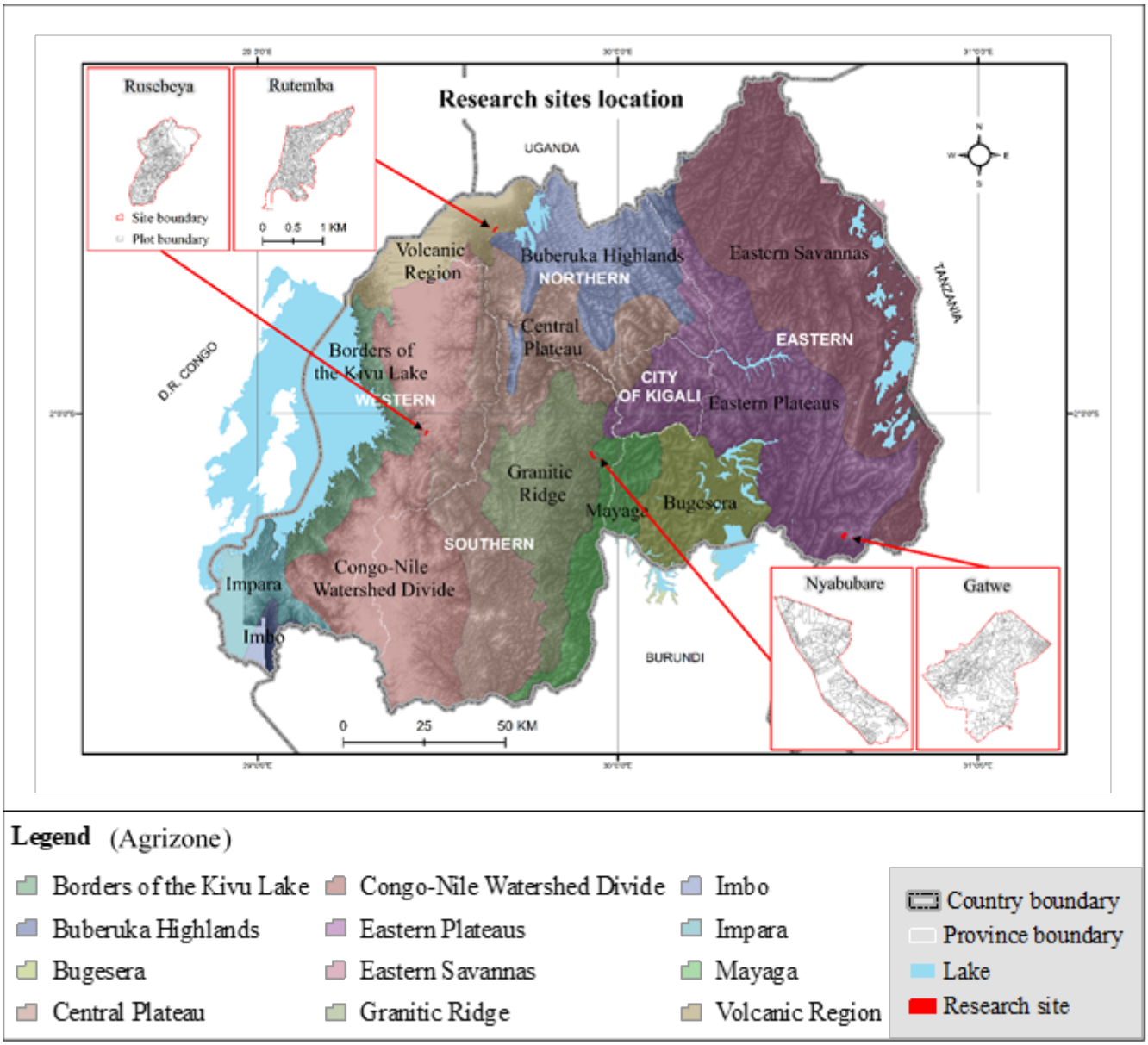


Figure 1. Research sites location.

Table 1. Research sites selection.

Study Area	Selection Criteria
Gatwe Eastern Province	High performer in the CIP/LUC program Less populated and fewer grouped settlements (larger farm plots) Eastern lowlands with a tropical climate Agrizone: Eastern plateaus
Nyabubare Southern Province	Respondent farmers have not yet joined the CIP/LUC program Big size of the farm plots but fewer in number per farmer Central plateau with granitic ridge alternating hills Agrizone: Granitic ridge
Rusebeya Western Province	CIP/LUC started in 2014 (six years after Gatwe and Rutemba) Average size of farm plots Western mountainous landscape with a rainy climate Agrizone: Congo-Nile watershed divide
Rutemba Northern Province	High performer of the CIP/LUC program High number of farm plots but small sized plots Volcanic fertile soil and a rainy climate Agrizone: Volcanic region

Source: [22].

The variations of each of the selected criteria per research site offered the possibility to perform a comparative spatio-temporal analysis. Therefore, given that the land tenure regularization program proceeded systematically over the country [22], as well as the CIP/LUC program, we assumed that farmers at the research sites shared an awareness of these programs–which was confirmed when visiting the sites. Hence, at each of the four research sites, we administered a questionnaire to the first 100 random farmers who accepted to be part of the study.

2.1.2. Research Period and Primary Data Collection

To collect the data, we conducted two fieldwork studies. The first one consisted of a preliminary visit and survey at the Gatwe research site, during the period from July to September 2018. The survey at the three remaining sites was conducted from July to October 2019. We applied three techniques of data collection. Inspired by the initial analysis of the published materials, we designed a semi-structured questionnaire for the farmers; semi-structured face-to-face interviews with officials working in land management and agriculture, including local agronomists and land management officers, and focus group discussions with farmers and their cooperatives. However, not all data could be collected from farmers, their cooperatives, or local authorities in charge as we preliminarily planned. In that case, we asked the farmers to retrace their tenure and agricultural activities which allowed us to collect the retrospective data over three research periods, coinciding with three agriculture years/seasons (Table 2).

Table 2. Research period.

Research Period	Rationale
2006/2007 Prior to the formal registration of land rights	Insights on the land tenure arrangement and the status of land tenure security before registration. In addition, the study looks at the land use change, if the land was used for agriculture then, identify the farming techniques and production.
2012/2013 During the systematic land registration	During this period, the systematic land registration took place. Land rights holders registered their rights for the first time through land demarcation and adjudication. In addition, the country undertook agricultural transformation programs starting with the implementation of the crop intensification program that launched the land use consolidation. The research investigates both processes and identifies the correlations.
2016/2017 Following the systematic land registration	Five years after the land registration, the research assesses the effect of (legal) land tenure security brought by the land tenure regularization program and, in particular, land registration and titling.

Source: [22].

2.1.3. Secondary Data

The information found in the scholarly literature contributed not only to design this study but also to fully retrace the changes in farmland use and agriculture production within the ten year period of this study. The gathered information included plot indexes and associated information on land registration, tenure and use from the Ministry of Environment (MoE), the Rwanda Land Management and Use Authority, and the district one-stop centres. Additional information was collected in the libraries of the Rwanda Ministry of Agriculture and Animal Resources (MINAGRI), agriculture projects on the site, and farmers' cooperatives archives, from local government offices at the district, sector, and cell levels, where data on the use and management of land, as well as information on the implementation of LTRP and CIP/LUC could be found.

2.2. Farmland Use Change

To validate and compare the changes, as found in the primary and secondary data, we used satellite images retrieved from Google Earth on 7 September 2021 (Table 3).

Table 3. Satellite images description.

Research Site	**Time Period**		
Gatwe	07/2006	09/2013	08/2018
Nyabubare	07/2007	06/2013	06/2019
Rusebeya	09/2002	01/2015	08/2018
Rutemba	10/2006	07/2014	01/2020

We created feature classes containing place marks of the four research sites and exported them as shape files to Google Earth. The images with marked places were imported into ArcGIS 10.5 for further processing. The images were georeferenced, using the placemarks priori created and marked in Google Earth and projected to WGS_1984 Transverse Mercator. The images used are not of the same period of the years. Hence, we were not able to determine the variability in the seasonal crops. Nonetheless, the perennial crops, such as banana and trees, could be identified. These can be used as indicators of land use change, as those perennial crops tend to be on separate farm plots and were therefore removed when adopting the land use consolidation approach. A combination of supervised classification using sample signatures and the digitization of discrete areas on the images was applied. The classification followed a maximum likelihood technique.

2.3. Yield Variation

To be able to compare the developments of harvests across years and research sites, we converted the harvest amounts into monetary value. To measure the variation in the monetary yield across the research periods, the year 2007 was taken as the baseline. We calculated the farmers ability to buy the same food that they used to harvest, before the farmland use consolidation in the other two research periods. For example, for the research period 2013, the harvest of 2013 was subtracted from that of 2007 (calculation: a, c). Then, we multiplied the obtained additional harvest with the crop prices of 2013 (calculation: b. d). With reference to Table 1, we were able to calculate the additional yield for the crops that are prioritized by the land use consolidation program, and for the remaining crops harvested by the farmer. We repeated the same calculations for the research period 2017, keeping 2007 as reference. Please note that we did not study the nutritional value of the harvests nor the ability to actually buy the food with the money earned.

Calculation:

Using the example of the Gatwe research site, here we calculate the additional yields for the research period 2013.

LUC crops	(a) Harvest 2013 (maize, beans, rice) − Harvest 2007 (maize, beans, rice) = AH (maize, beans, rice)
	(b) AH (maize, beans, rice) * Price 2013 (maize, beans, rice) = AY (maize, beans, rice)
Other crops	(c) Harvest 2013 (banana, coffee) − Harvest 2007 (banana, coffee) = AH (banana, coffee)
	(d) AH (banana, coffee) * Price 2013 (banana, coffee) = AY (banana, coffee)

AH, additional harvest; AY, additional monetary yield.

2.4. Sign Test

We used the sign test to determine if there were increases in the median of the yield between different years. The sign test is a non-parametric test that does not make assumptions about the underlying distribution of the variables. As such, it is more conservative than, say, a t-test, which assumes the normality of the underlying distribution. The sign test determines the chance that the median yield from one year is larger than the median yield from another year. We calculate the chance that the number of farms with an increase in yield could be explained by random chance and subtract this chance from one. So, if for a given year, there are 62 out of 100 farms with a yield higher than the median yield of a previous year, we calculate what the chance would be that this is due to random chance. Or, if we would flip a fair coin 100 times, what would be the chance that it lands on head 62 times. This follows a binomial distribution and the chance would, in this case be 0.60%—which means there is a chance of 99.4% this is not due to random chance.

3. Results

3.1. Land Use

In Table 4, we show the shift from the fragmented to consolidated land use for each of the research sites. We also show the different years that the research sites joined the LUC program. Land use consolidation has seen the harvest of some crops abandoned or considerably limited, mainly due to the prioritization of crops that are deemed most suitable for the farming site—as shown in Table 5.

Table 4. Plot identification.

Number of Farm Plots	Gatwe	Nyabubare	Rusebeya	Rutemba	Mean
Total number	291	171	287	310	
Total size (Ha)	79.05	62.21	85.20	27.06	63.38
Mean size per site (Ha)	0.27	0.36	0.30	0.09	
Included in the LUC program					
2006/2007	0	0	0	0	0
2012/2013	100	0	0	78	44.50
2016/2017	100	0	98	78	69

Table 5. Types of crops harvested per site and per farmland use type.

Research Site	Crops Prioritized in Consolidated Farmland Use	Crops Harvested in Fragmented Farmland Use
Gatwe	maize, beans, rice	banana, coffee
Nyabubare *	n.a.	maize, beans, sweet potatoes, sorghum, banana, rice, peanuts
Rusebeya	maize, beans	sweet potatoes, Irish potatoes, sorghum
Rutemba	maize, beans, Irish potatoes	Sorghum

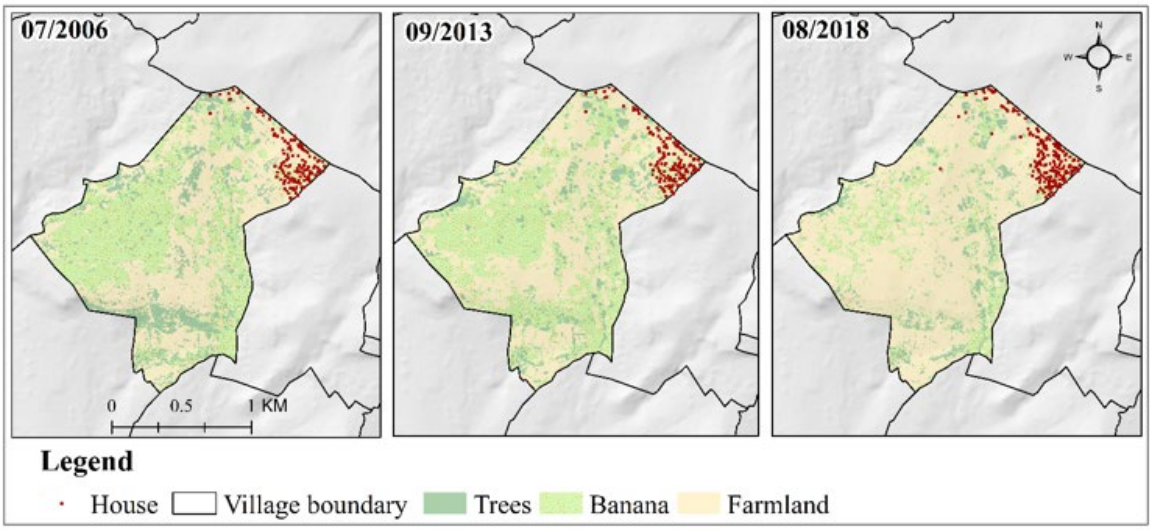
* Nyabubare research site kept the harvest of the same crops since it has not joined the consolidated farmland use at the time of the data collection (September 2019).

Figures 2 and 3 illustrate these changes with respect to the three research periods of our study. We observe that in the three areas where land consolidation has been important, the areas of permanent crops that are visible (especially banana) have reduced in size (Figure 2a–c). At the Gatwe research site (Figure 2a), areas of banana plantation that used to cover half of the farmland on the image of 2006, reduced noticeably on the images of 2013 and 2018. Indeed, our survey revealed that the area that used to grow banana has been converted into seasonal cropping, including maize and beans. Land use that has expanded is the residential area. Within the research period, more and more houses appear on the images on both sides of the road that crosses the site in the north. This area has been delineated for residential purpose by the Kirehe district land use plan, with the aim to prevent a housing extension on farmland areas.

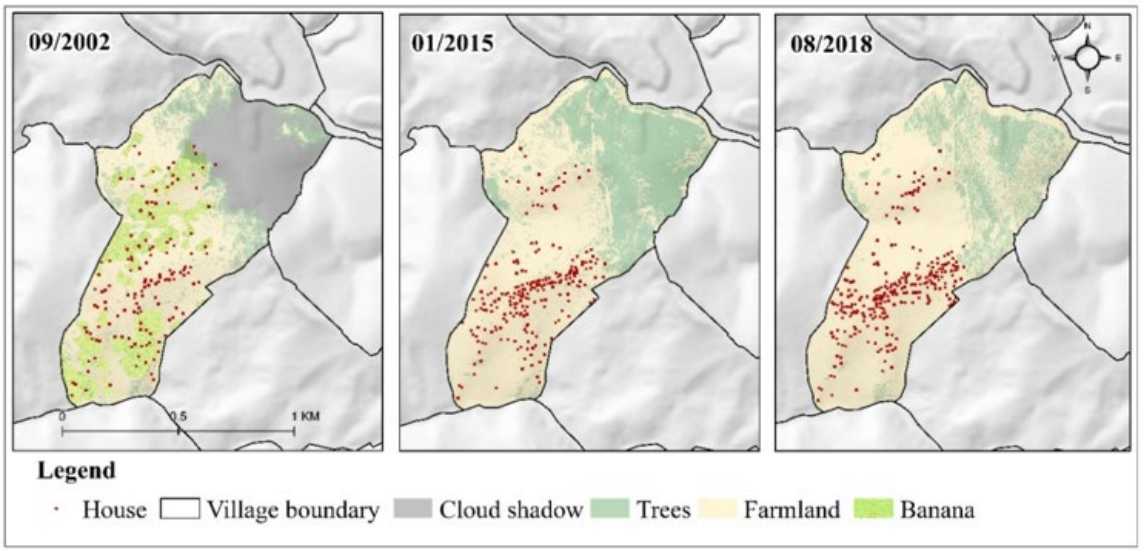
At the Rusebeya research site, the image of 2002 shows areas covered with banana plantations (Figure 2b). The satellite image of 2015 looks remarkably different, with the disappearance of the banana plantations and the emergence of terraces. In fact, the terraces were created by a government sponsored program that was implemented in 2014. The area terracing, coupled with the prioritization of maize and beans, brought about by the CIP/LUC made banana growing disappear at the Rusebeya site. In line with the other LC-districts, the Rutemba research site denotes the same conversion of banana plantation into farmland with seasonal cropping (Figure 2c) over the period of 2006, 2014, and 2020. Banana was found surrounding the residential houses on the image of 2006, but it is completely absent on the images of 2014 and 2020. The other class that extended is (again) residential houses. The classified images show more and more houses along the roads as we advance in our research period. The area is being urbanized especially because of the proximity to the centre town of Musanze. The new settlers on the Rutemba site are mainly coming from Musanze, and also from Kigali, as reported by the respondents.

The satellite images of the Nyabubare site show a different change in land use. In fact, only the housing class showed tangible changes over the course of the research period (Figure 3). The image of 2013 shows that residential houses have amassed along the road that constitutes the western boundary of this site. This trend continued as detected on the image of 2019. The farmland extends from the road towards the lower altitudes and the wetlands.

(a) Gatwe



(**b**) Rutemba



(**c**) Rusebeya

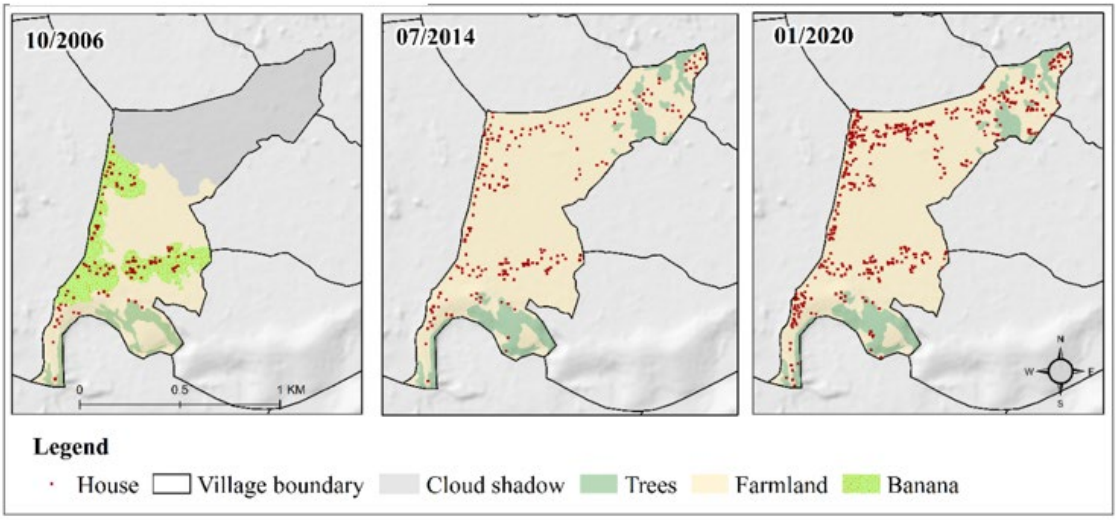


Figure 2. Land use changes at the land consolidation sites ((**a**) Gatwe/(**b**) Rutemba/(**c**) Rusebeya).

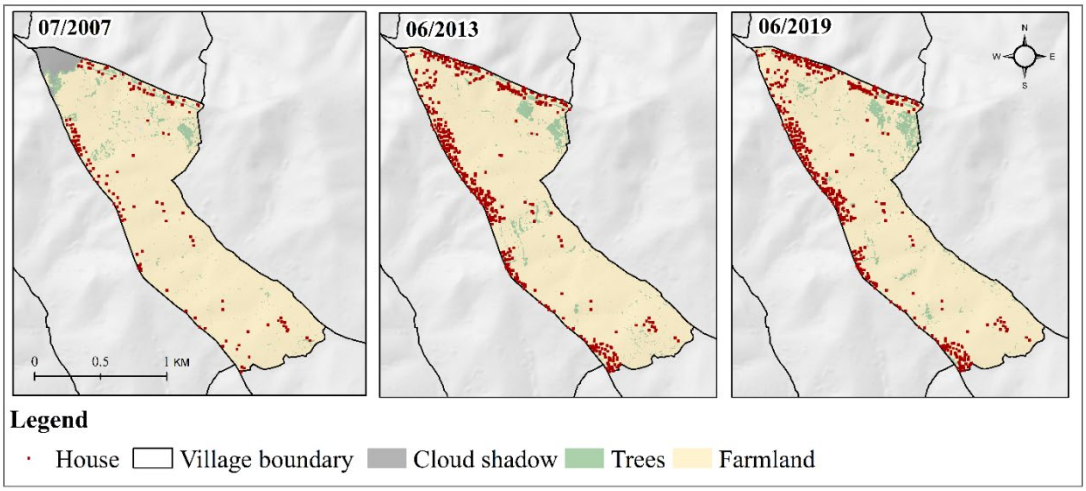


Figure 3. Land use changes at the Nyabubare research site.

3.2. Harvest and Yields

3.2.1. Overall Increase per Research Site

Overall, the three research sites that had joined the LUC program at the research period time, reported an increase of the yield, per farmer, between the three research periods of this study (Table 6). The Nyabubare research site (that had not started the LUC program just yet) does not show such an increase. However, the overall increases do not happen to all farmers alike. With reference to the harvest of 2007, a decrease of the yield indicates that the farmer produced a smaller harvest in 2013 or 2017. Table 7 shows that some farmers kept a negative additional yield from the crops that were not prioritized by the LUC program, even after adding the yield from LUC crops.

Table 6. Chances that the median of a yield in a given year (expressed in USD) is larger than the median of the harvest in the other year, for all four research sites.

	P(M2013 > M2007)	P(M2017 > M2013)	P(M2017 > M2007)
Gatwe	1.00	0.93	1.00
Nyabubare [a]	0.31		
Rusebeya	0.99	1.00	1.00
Rutemba	1.00	0.76	1.00

[a] In Nyabubare, the yield in 2017 was lower than the yield in 2013.

Table 7. Number of farmers with a negative (additional) yield with, reference to the harvest of 2007.

		Farmers Having a Negative (Additional) Yield			
	Harvest Year	LUC Crops	Other Crops	Total AY	Other Crops in Total AY
Gatwe	2013	15	7	15	2
	2017	13	9	15	6
Rusebeya	2013	33	45	43	41
	2017	6	83	15	15
Rutemba	2013	20	64	30	18
	2017	11	64	32	25

(P(M2017 < M2013 = 1.00)), the yield in 2017 was lower than the yield in 2007 (P(M2017 < M2007 = 1.00)), and the yield in 2013 was lower than the yield in 2007 (P(M2013 < M2007 = 0.76)).

3.2.2. Variation of the Monetary Yield per Farmer

Our four research sites have not joined the LUC program at the same time. The Gatwe and Rutemba research sites joined the LUC program at the beginning, from the agriculture year 2007/2008. The program started in 2014 at the Rusebeya research site when the government proceeded with the terracing of the farmland on its hilly landscape. The Nyabubare site had not joined the program during the period of this research (2006–2017). Figure 4 displays an almost similar trend in the yield variation per farmer for the three sites that joined the LUC. However, in Figure 5, a unique display is observed which suggests that at the Nyabubare research site, the additional yield does not follow a trend. The variation of yield observed cannot be related to the LUC program package. Let us explore these yield patterns in more detail.

Figure 4a–c show the variations of the yield between the first research period (2006/2007) and the second (2012/2013) and third (2016/2017), respectively, for each of the research sites. The figures display three curves: (1) additional yield per farmer realized from the harvest of the crops prioritized by the LUC program; (2) additional yield per farmer from the crops that are not considered for the LUC program; and (3) total yield per farmer of the later research period. Based on these figures, we can observe that more farmers lost their yield from the additional harvest of crops not prioritized by the LUC program in 2013 and 2017. This is the case in the Rusebeya and Rutemba research sites, while in Gatwe, the negative additional yield was found among the farmers who joined the LUC program.

At the Gatwe research site, the crops prioritized by the LUC program, include maize and beans. In addition, we added rice production because it is harvested in cooperatives of interviewed farmers in a similar setting, concerning plot used as the LUC system. The remaining crops considered as non-LUC for this research are banana and coffee. Most farmers realized a positive additional yield from both the LUC and non-LUC crops. The additional yield from the LUC crops and the total yield per farmer clearly show a variation trend among the farmers. The trend indicates that the farmers with a higher additional yield from the LUC crops earned higher total yields as well, which suggests that the LUC contributed to the total yield per farmer for most farmers. Fifteen farmers in 2013 and 13 farmers in 2017 realized a negative additional yield from the LUC crops. The additional yield from the non-LUC crops varied slightly more per farmer in the research period of 2017.

Prior to 2014, farmers at the Rusebeya research site reported that the agriculture production included the harvest of maize, beans, sweet potatoes, Irish potatoes, and sorghum. When the LUC program started, maize and beans were selected as priority crops. Moreover, the site introduced the harvest of a variety of vegetables and fruits. The Rusebeya research site's farmland is situated on a hilly landscape that had been difficult to cultivate. This morphology has seen the site as less productive because of the difficulties to cultivate on steep slopes. Therefore, the additional yield per farmer is slightly varying and near zero for the harvest of 2013. This has been the case for the crops later selected for the LUC program and the other crops. However, after the terracing of the area, the yield increased considerably for the priority crops, while the yield from non-LUC crops dropped to negative for most of the farmers. The same trend observed at the sites where the LUC program started, can be seen in the Figure 4c for the 2017 yield. This is the quasi-alignment of the curve of the yield from the LUC crops and the total yield per farmer, which suggests that the LUC contributed to the increase of the total yield per farmer. Indeed, the yield from the crops that were not selected for the LUC program declined for all farmer respondents of this study.

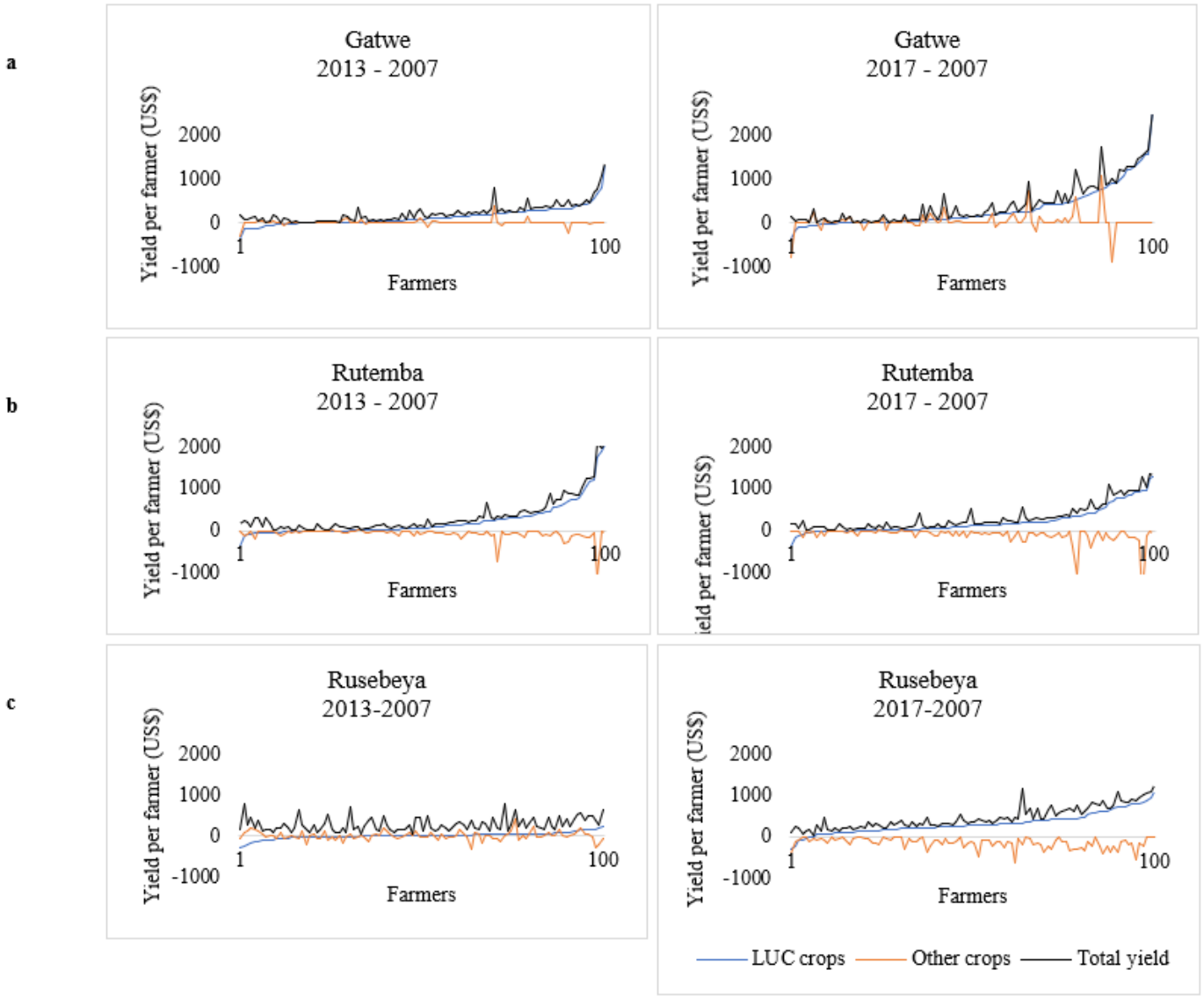


Figure 4. (**a**–**c**) Variation of yield per farmer and per research site.

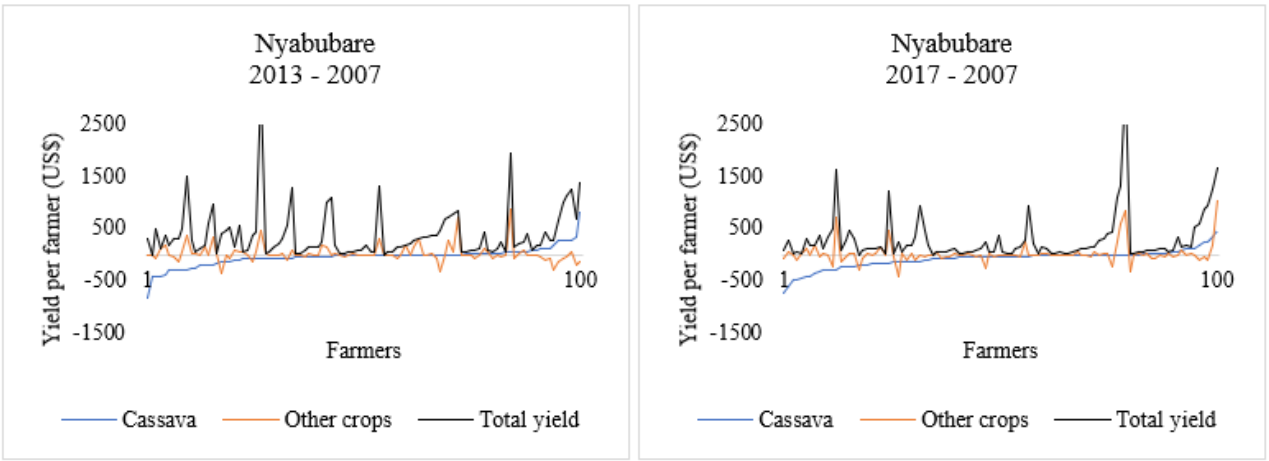


Figure 5. Variation of the yield and total yield per farmer at the Nyabubare research site. Correlation between the additional yield and selected variables.

Farmers at the Rutemba research site reported the harvest of maize, beans, Irish potatoes, and sorghum before the LUC program was introduced. The program started in 2008, prioritizing maize and beans. This allowed for calculating the additional yield for 2013 and 2017. Both research periods display a similar figure as the one of the Gatwe research site, where the additional yield of the LUC crops aligns with the curve of the total yield per farmer. This can be explained by the fact that the LUC program started in the same agriculture year 2007/2008 at both research sites. However, farmers at the Rutemba research site lost the yield that they had earned from the harvest of 2007, as shown on the graph of 2013. More loss was observed in 2017. This decline in the yield concerns the crops that were not selected for the LUC program. Therefore, while farmers joined the LUC program, they reduced or sometimes abandoned the harvest of the crops not selected for the program.

The Nyabubare research site is an exception because the types of crops harvested and the farmland used did not change along our research period. Cassava constitutes the main crop at the site. It is supplemented by the harvest of maize, beans, sweet potatoes, sorghum, banana, rice, and peanuts. The harvest of cassava dropped in the agriculture year 2013/2014, mainly due to the cassava brown streak disease (CBSD) that attacked the cassava crops. CBSD is a devastating disease that causes the loss of the cassava root (tuber) production and quality. Root rot, resulting from the viral disease renders the cassava tuber inedible [23]. To assess the additional yield for the Nyabubare research site, we calculated the additional yield from the cassava harvest separately from the other crops. Figure 5 shows that half of the farmers have seen their cassava yield decline in 2013 and in 2017. Furthermore, the other crops' additional yield did not increase for all farmers. Those who succeeded in securing an increase of yield are the farmers of rice who realized higher yields following the systematic wetland development by the government of Rwanda. As such, agricultural policies do explain (partially) the unequal distribution of changing harvests between farmers in this area too.

Building on these first explorations on the variation of the yield concerning the LUC program, and to extend the explanation on the causes and effects of the yield variation, we selected variables, such as the average monthly income, the size of the household, the size(s) of the farmland plot(s), the number of owned plots, and the use of subsidized fertilizers. Respectively, the correlations allowed us to detect the alignment of the agricultural yield with the farmer's monthly income; to determine whether the yield realized depends on the number and size of farm plots possessed by the farmer; and finally, to find out whether accessing subsidized fertilizers contributed to the increase of the yield. Tables 6 and 7 show that the variation of the additional yield statistically correlates with most of the variables for those crops prioritized by the LUC program at the research sites that joined the program. The additional yield of 2007–2013 from the LUC crops statistically correlates significantly with monthly income and the LUC subsidies to production at the Gatwe and Rutemba research sites (Table 8). This coincides with the fact that, among the four research sites, the LUC program had only started at these two sites. The Nyabubare and Rusebeya research sites did not show any significant correlation for the LUC crops between these research periods.

Table 8. Correlation between the additional yield (2007–2013) and the selected variables.

	Gatwe	Rutemba	Rusebeya	Nyabubare
Selected variables		*Yield of crops selected for LUC (USD)*		
Average monthly income (USD)	0.344 **	0.443 **	0.07	0.03
Number of owned plots	0.05	0.214 *	0.16	0.08
Size of the plots (Ha)	0.233 *	0.06	0.08	0.1
Subsidized fertilizers (Kg)	0.460 **	0.474 **	0.11	−0.05
		Yield of other crops (USD)		
Average monthly income (USD)	0.05	−0.285 **	0	−0.02
Number of owned plots	−0.03	−0.303 **	−0.13	0.208 *
Size of the plots (Ha)	−0.264 **	−0.18	−0.08	−0.11
Subsidized fertilizers (Kg)	−0.13	−0.261 **	0.03	0.501 **

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

The correlations remained significant in the period 2007–2017 for Gatwe and Rutemba, with the Rusebeya research site joining the early LUC adaptors (Table 9). Again, the correlation coincides with the Rusebeya site joining the LUC program in 2014, after the area was terraced, to improve farming activities on its hilly farm plots. The reason for that coincidence finds its explanation in the fact that in rural areas of Rwanda, farming constitutes the main source of income. Therefore, after joining the LUC program, and hence introducing the use of government subsidies of mainly mineral fertilizers, farmers see both their yield and monthly income increase. In most cases, the number and size of farm plots correlate with the additional yield of crops selected for the LUC program. We observe a negative correlation for the crops that are not prioritized by the LUC program. On one hand, this suggests that fewer plots and the smaller size of plots per farmer coincide with a higher yield in crops that are not selected for the LUC program. This relates possibly to the observation that these farmers use home-produced organic fertilizers, instead of the subsidized mineral fertilizers. On the other hand, farming using mineral fertilizers through the LUC program earn more yield for the farmers that possess more farm plots and/or larger plots.

Table 9. Correlation between the additional yield (2007–2017) and the selected variables.

	Gatwe	Rutemba	Rusebeya	Nyabubare
Selected variables		*Yield of crops selected for LUC (USD)*		
Average monthly income (USD)	0.402 **	0.561 **	0.225 *	−0.16
Number of owned plots	0.18	0.16	0.514 **	−0.241 *
Size of the plots (Ha)	0.19	0	0.16	−0.234 *
Subsidized fertilizers (Kg)	0.549 **	0.427 **	0.13	0.06
		Yield of other crops (USD)		
Average monthly income (USD)	−0.04	−0.247 *	0.02	−0.01
Number of owned plots	0.03	−0.300 **	−0.362 **	0.15
Size of the plots (Ha)	−0.332 **	−0.18	−0.02	−0.13
Subsidized fertilizers (Kg)	0.16	−0.235 *	−0.06	0.583 **

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

4. Discussions

Our findings demonstrate that in Rwanda, the consolidation of farmland use earned an overall increase of the monetary yield among the participant farmers. In each of the four research sites, the farming counts on a subsidy package of the CIP program that encompasses inputs, such as mineral fertilizers and selected seeds. In addition, farmers use the proximity of agronomist guidance. To understand the link between the CIP package and the increase of farm yield, we conducted a statistical correlation analysis between the yield and a set of variables, which confirmed the relation between the increase of the yield and the monthly income, the subsidized fertilizers, as well as the size and number of the farm plots.

It is evident that the CIP/LUC approach in Rwanda has contributed to the growth of yields per farmer, on average. As mentioned, this increase of yield mainly involves the crops that are selected for the program–maize and beans, in most cases. Three research sites witnessed the impact of the CIP/LUC program on their agricultural yield, in particular. The Gatwe and Rutemba research sites have demonstrated an increase in yield per farmer after five years of the first implementation of the CIP/LUC program. The program started in 2014 at the Rusebeya research site, which showcases an increase in yield in 2017. Overall, most of the farmers who joined the program realized an increase of yield, compared to the yield of the agricultural years before the CIP/LUC program. This increase comes from the crops selected for the program at each site. Farmers reduced or, in most cases, abandoned the harvest of crops neglected by the land use consolidation program. Furthermore, the case of Nyabubare, as the site that had not joined the LUC program, confirmed the impact of the CIP/LUC program on its yields. Apart from the harvest of cassava that dealt with a disease, the yield did not increase at the Nyabubare site, as it was observed at the other three research sites.

Our previous research article looked into the perception of the farmers on the CIP/LUC program. The article found that farmers are generally positive about the LUC and believe it has brought them benefits, which translates into the increase of their yield [22]. However, as this study demonstrated, the increase in yield did not happen to all farmers, nor did it take a similar trend across our research period. We could not study the implications of a decrease in yields on the availability of food for the farmer's household. What we could observe is that on all four research sites, farmers did not report a clear increase of the number of meals per day over time. This phenomenon needs to be studied in more detail, and is beyond the scope of this paper. We did not assess the capacity of the farmers to buy what they used to produce either, nor the effects on the farmer's household diet. Although still underexplored, these aspects of the CIP/LUC program have featured in the scholarly literature. For example, despite the growth in yield, Del Prete and Ghins [1] found that the diets of those participating in the land consolidation program diversified less quickly than those of the non-participants. The consumption for some nutrients also declined, as a result of participation. While both satisfaction and agricultural productivity of the land are high, it is important to note that food insecurity, vulnerability to shocks, access to the market, and poverty remain serious problems for LUC farmers [24].

5. Conclusions

This paper assessed the effect of farmland use change on the agricultural production of smallholder farmers in Rwanda. The study was based on a dataset constituted from four research sites and three research periods. The research periods corresponded with the period before, during and after the systematic land registration, as well as the periods when the research sites joined the LUC program. The four research sites, one in each of the provinces of Rwanda, represent the variability in the agricultural zone. For each research site, we studied farmland use, harvest, and monetary yield per farmer and per research period. The assessment used a statistical sign-test and correlations.

When a research site joined the LUC program, farmers adopted the harvest of the regionally selected crops. This shift from the harvest of perennial crops, such as bananas, to seasonal crops, such as maize and beans, is clearly seen on the classified satellite images of the Gatwe, Rusebeya and Rutemba research sites. The LUC is also accompanied by the concentration of expanding the residential areas along the roads. Both processes aim to increase the agricultural land and improve farming activities. The shift from traditional, fragmented land use to the consolidated land use was found to correlate with the overall farm-level yields increasing over the course of the considered 10 year span, based on the three research periods. This was confirmed by the yields at the three research sites that had joined the LUC program at the time of the data collection. The Nyabubare research site, which did not join the LUC, has seen yields declining.

Although the yields increased for most farmers, some farmers saw their yields decrease. Such a decline in yields was correlated with the size and the number of farm plots, per farmer, at the three LUC sites. Farmers with more and larger farms realized higher yield increases, while those who possess only one and smaller farm plots did not. This found its explanation in the use of mineral fertilizers that benefited larger farms, while those farming on smaller plots, kept using home produced compost fertilizer, instead of the subsidized mineral fertilizers.

Our findings that consumption did not necessarily increase, even when crop production increased, might suggest that the LUC did not necessarily improve the overall food security for farmers in Rwanda. Detailed analysis of this phenomenon goes beyond this paper, but we can speculate that, given the monoculture nature of the LUC program, some food types may be(come) less available and more expensive to buy on the market–some crops may even have completely disappeared. Hence, farmers who earn more money from the LUC program may not be able to diversify their everyday meals in the same way as they used to.

Overall, this study showed that the LUC program (and the whole package of government subsidies channeled to the farmer through the crop intensification program) contributed to a general increase of harvests and monetary yields in Rwanda. Our findings suggest important farmland use and agriculture policy implications on three aspects: (1) we observe the clear shift in crops harvested by farmers; (2) we observe that the increases of yields did not take the same trend per research site, nor per farmer; (3) we show that some farmers with fewer farm plots and/or smaller holdings, registered a decrease in yield. Therefore, we conclude that although consolidated farmland use appears to earn higher yields, compared to fragmented land use, the aim to reverse the effect of fragmented use farming is not fully achieved (yet) in Rwanda. Furthermore, this study contributed to an understanding of the ongoing agriculture transformation program in Rwanda, with regard to the smallholder farmers. The statistical approach followed, could be used by new studies assessing the benefits and outcomes of the rural development policies, among others.

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