Evaluation of the Nasho Irrigation Project in Eastern Rwanda

Prepared for the Howard G. Buffett Foundation

August 2024

laterite
DATA | RESEARCH | ANALYTICS

THE HOWARD G. BUFFETT FOUNDATION

ACKNOWLEDGEMENTS

Laterite would like to thank the Howard G. Buffett Foundation and especially Gracie Rosenbach, Alexis Mutunzi, and Alex Lamberts for their time and dedication to this project.

We would also like to sincerely thank the farmers who participated in the household surveys and qualitative interviews, as well as the NAICO management and leadership, Local officials, and MINAGRI representatives for their insights during the qualitative interviews.

Laterite would like to acknowledge our field team for their time, assistance, and insights during this project. We would not have completed this assignment without their hard work and perseverance.

Finally, we also acknowledge the support of Laterite colleagues Anne Wagaturi, Fabiola Niwenshuti, Jessie Ramirez, Judy Korir, Lydie Shima, Nadine Yizere, Sonia Uwimana, Dimitri Stoelinga, Ezron Mucyo, Ishmail Kamara, Jean Claude Rukundo, John DiGiacomo, Jose Rubio Valverde, Martin Gichuru, and Umugisha Dieudonne.

This report was delivered by Laterite's team composed of Laura Baensch, Mercy Muttai, Kevin Kimenyi, and Rik Linssen.

EXECUTIVE SUMMARY

The Nasho Irrigation Project was funded by the Howard G. Buffett Foundation in partnership with the Government of Rwanda through the Ministry of Agriculture and Animal Resources (MINAGRI) to support small-scale farmers in the drought-prone sectors of Nasho and Mpanga of Kirehe District, Eastern Province to increase production, productivity, farmer incomes, and food security. In 2016, the project established a modern irrigation infrastructure to reduce the dependence on rainfall by farmers in the project area. 63 center pivots powered largely by solar energy were installed on 1,173 hectares belonging to about 2,000 farmers. Farmers benefiting from the project were also organized into a farmers' cooperative called the Nasho Irrigation Cooperative (NAICO) to improve collaboration in managing and maintaining the irrigation infrastructure and coordinating purchases of inputs and sales of production. At the time of this study, NAICO plots grew maize, common beans, and soybeans.

The study has three main research objectives:

1. Objective 1: Assess the impact of the Nasho Irrigation Project at the plot level
2. Objective 2: Understand how NAICO and non-NAICO farmers differ at the household level
3. Objective 3: Understand potential unintended consequences of the Nasho Irrigation Project

To meet the above research objectives, we use three distinct research anchors that help generate evidence and meet the relevant research objectives, from the plot and household level, to Nasho treatment and comparison areas, to the district and national level.

Plot and household level differences

This chapter employed a mixed-methods design, using quantitative and qualitative data. In total, we collected data on 2,445 plots, which included 1,215 main plots which were sampled, and 1,230 plots that farm managers farmed in addition to the sampled plot. Of the 1,215 main plots, 607 were outside and 608 were inside the pivots. We also conducted 31 semi-structured interviews with farmers, NAICO management and leadership, local officials, and MINAGRI representatives.

The average yields of maize, common beans, and soybeans are significantly higher on Nasho plots than non-Nasho plots. The average yield of maize on Nasho plots (6,723 kg/ha) is twice as much as on non-Nasho plots (3,039 kg/ha). The average yield of common beans on Nasho plots (1,641 kg/ha) is significantly higher than on non-Nasho plots (1,207 kg/ha). The harvest of soybeans per hectare inside the irrigation scheme is also significantly higher than on non-Nasho plots, though the sample size of non-Nasho plots growing soybeans is small. Overall, NAICO is the largest buyer of harvested produce in our sample. There are, however, significant differences in how NAICO and non-NAICO members market their harvests. We also see some differences by crop. Households that own plots only inside the

Nasho irrigation scheme predominantly sell their maize, common bean, and soybean harvests to NAICO. This may be explained by prices per kg sold being higher for Nasho compared to non-Nasho plots. For mixed households (those that farm Nasho and non-Nasho plots), we see differences by crop. For maize, the majority sells its harvest to NAICO. For common beans, they sell their harvests equally to NAICO and local markets/roadside sellers, but also to farmers/consumers directly or middlemen. For soybeans, the biggest buyer is again NAICO. For non-Nasho households, the biggest buyers for all crops are middlemen or local markets/roadside sellers.

Nasho plots are significantly larger users of inorganic fertilizers, pesticides, certified seeds, and hired labor. The overall usage of organic fertilizers is similar for both groups. In line with this, expenditures per hectare on fertilizers, pesticides, and hired labor are significantly higher for Nasho plots.

Significantly more farmers practice conservation agriculture on Nasho compared to non-Nasho plots (34% vs. 15%)[1]. This is mainly driven by minimum tilling (98% vs. 85%) and crop rotation (100% vs. 77%). There is room for improvement in permanent organic crop cover both for Nasho and non-Nasho plots, with only 35% and 25% implementing this practice, respectively. NAICO farmers report that they apply the skills taught by the project also to their plots outside of the irrigation project. This includes skills such as row planting, use of manure, inorganic fertilizer, pesticides, and improved seeds. During qualitative interviews, NAICO farmers mention that their farming practices have improved from what they practiced before the irrigation project began. This was informed by agricultural training they received as well as field visits from agronomists. Farmers also report that the farming practices implemented within the irrigation pivots are adopted by other farmers in the region with plots outside the irrigation project.

NAICO households are considered less poor than non-NAICO households. NAICO households have an average poverty likelihood of 23.3%, which is considered to be below the national poverty line. Non-NAICO households have a higher likelihood of 28.8% to be below the national poverty line. Further, NAICO households generate most of their income from agricultural activities, while non-NAICO households generate most income from non-agricultural activities. The average income from agricultural activities is significantly higher for NAICO households. For non-agricultural income, there are no significant differences between NAICO and non-NAICO households.

The qualitative interviews showed that the project has had some unintended consequences, mostly due to the perceptions that farmers had prior to project implementation. For example, farmers report that the value of land within the irrigation pivots has increased, while the land outside the pivots has decreased in value. Further, during the project's inception phase, some farmers sold the land they owned inside the future pivots fearing it would be taken away from them. Few older farmers who feared they would be unable to farm inside the pivots as it demanded more labor also reportedly sold their land. Other farmers who

[1] Practicing conservation agriculture is defined as minimum tilling, usage of permanent organic soil cover on at least 30% of the land, and practicing crop rotation (https://www.fao.org/conservation-agriculture/en/).

expected a large financial burden due to the change in farming practices sold their land as well.

Geospatial analysis

The geospatial analysis zoomed out from the plot and household level to assess changes the program has brought about spatially. Using satellite imagery, we looked back in time by comparing changes in greenness, yield, and vegetation proxies before and after the installation of the center pivots between 2015 and 2024.

Analyzing the imagery at key moments in the project timeline revealed that before installing center pivots, vegetation health, and crop quality were low in the areas slated to implement the center pivots. However, directly after the installation in Season B in 2017, we observed a substantial uptick in greenness and vegetation health, indicating early benefits from the irrigation systems. By 2019, the sustained improvements in vegetation health and crop quality within the irrigation zones were evident. This suggests improved yields and higher crop quality from 2017 onwards. Although individual pivots show considerable variation in these yield proxies, overall, we see an upward trend. This suggests the irrigation systems' positive and sustained impact on the yield proxies analyzed.

We used a synthetic control area as a counterfactual and basis of comparison to assess the impacts of the center pivot installation. When comparing the yield indicators in the irrigated areas to the synthetic control, we found that the Nasho areas consistently showed higher vegetation health and productivity values after installing the center pivots compared to similar croplands in the region.

However, there is a significant variability across seasons in these greenness indicators. This seasonal fluctuation introduces a high degree of variance in the outcomes. Consequently, the synthetic difference-in-difference analysis did not yield statistically significant effects as the natural seasonal variability tends to overshadow the uptick in greenness and yield proxies observed after pivot installation in 2017.

Benchmarking

To ensure the accuracy and reliability of the research findings, we compared our results from the household survey with established reputable national surveys. We also incorporated comparisons with the baseline and midline findings.

The average yield of both maize, common beans, and soybeans is substantially greater within and around the Nasho irrigation scheme than the Kirehe district and national averages. The maize yield inside the Nasho irrigation scheme (6,272 kg/ha) and around the scheme (3,000 kg/ha) is above the Kirehe district (2,054 kg/ha) and national averages (1,549 kg/ha), the common beans yield inside (1,437 kg/ha) and around the scheme (1,194 kg/ha) is greater than Kirehe district and national averages (576 kg/ha and 509 kg/ha, respectively), same with the soybeans yield inside (2,176 kg/ha) and around the scheme (777 kg/ha), which is also greater than Kirehe district (301 kg/ha) and national (355 kg/ha) averages.

Over time, there has been a substantial increase in crop yields between the baseline, midline, and endline studies. Maize yield increased from 1,244 kg/ha at baseline in 2015 to

4,077 kg/ha at midline in 2020, to reach 6,272 kg/ha at endline. Common beans yield increased from 988 kg/ha at baseline to 1,100 kg/ha at midline and reached 1,437 kg/ha at endline. Soybeans yield increased from 1,031 kg/ha at midline to 2,176 kg/ha at endline.

NAICO households' monthly and annual income from agricultural activities is significantly higher than that of non-NAICO households, as well as households in the Kirehe district and nationwide. NAICO households reported an average annual agricultural income (1,206,425 RWF / USD 926) that is more than twice the income reported by the households farming around the irrigation scheme (421,217 RWF / USD 323), and more than thrice the average agricultural income at Kirehe district level (503,096 RWF / USD 386) and national level (540,868 RWF / USD 415).

Further, organic fertilizers are less often applied inside and around the Nasho irrigation scheme (64% and 68% respectively) than they are applied at the Kirehe district (79%) and national levels (76%). Inorganic fertilizers on the other hand are more commonly used inside (99%) and around the Nasho irrigation scheme (67%) than they are on average used at Kirehe district (41%) and national levels (31%). Pesticides are also more often applied on the plots inside (99%) and around the Nasho irrigation scheme (63%) than they are applied at Kirehe district (50%) and national levels (46%). Certified seeds are used on 99% and 49% of the plots inside and around the irrigation scheme respectively, and on 45% and 31% of the plots at Kirehe district level and nationally, respectively.

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1. Introduction

1.1 Background

1.1.1 Howard G. Buffett Foundation

The Howard G. Buffett Foundation (HGBF) was established in 1999 and is a US-based private philanthropic foundation, chaired by Howard G. Buffett. The Foundation's mission is to catalyze transformational change to improve the standard of living and quality of life, particularly for the world's most impoverished and marginalized populations. Most of its funding outside the United States is deployed towards efforts to improve food security and mitigate conflict. The Foundation has been working in Rwanda since 1999.

1.1.2 Nasho Irrigation Project

The Nasho Irrigation Project was funded by the HGBF in partnership with the Government of Rwanda through the Ministry of Agriculture and Animal Resources (MINAGRI) to support small-scale farmers in the drought-prone sectors of Nasho and Mpanga of Kirehe District, Eastern Province to increase production, productivity, farmer incomes, and food security. In 2016, the project established a modern irrigation infrastructure to reduce the dependence on rainfall by farmers in the project area. 63 center pivots powered largely by solar energy were installed on 1,173 hectares belonging to about 2,000 farmers. The project area was selected largely due to three factors: i) it´s a drought-prone area, ii) its proximity to a lake as a water source for the irrigation system, and iii) its relatively flat slopes required for pivot irrigation. No selection criteria were used save for a farmer's land ownership in the selected project area. Farmers who lived on the land were relocated into a resettlement village funded by the project in close proximity to, but outside of the pivots. Farmers benefiting from the project retained ownership of their land inside the pivot and were organized into a farmers' cooperative called the Nasho Irrigation Cooperative (NAICO) to improve collaboration in managing and maintaining the irrigation infrastructure and coordinating purchases of inputs and sales of production. Farmers on one particular pivot agree to plant the same crop. After each season, the crops grown are rotated. The cooperative decides the crop to be planted before each season. At the time of this study, NAICO plots grew maize, common beans, and soybeans.

1.1.3 Irrigation in Rwanda

Rwanda has three main agricultural seasons, season A spanning from September to February, season B spanning from March to June, and the short season C from July to September. Rainfall in seasons B and C is scarce, increasing the need for irrigation schemes. Irrigation schemes allow the farmers to be independent of unreliable rains by offering a controlled water source, avoiding uncertainty, variability, and rain deficiency. This permits farmers to choose optimal planting dates keeping in mind the benefits for yields and market prices. It also allows for harvests during otherwise dry seasons and for growing water-intensive crops (Dillon & Fishman, 2019). A study assessing the adoption of irrigation schemes in Rwanda found that irrigation enables horticultural production in the dry season, increasing on-farm profits by 53-71%, predominantly by switching from bananas to more input-intensive crops (Jones et al., 2022). Our study adds to this literature and investigates how the Nasho Irrigation Project impacted farmer yields, practices, use of inputs, and incomes, as well as any spillover effects or unintended consequences.

1.2 Research objectives

The overarching objective of this study is to evaluate the impact of the Nasho Irrigation Project. The project comprises two main interventions:

- The implementation of an irrigation system reaching approximately 2,000 farmers
- The establishment of a cooperative to efficiently coordinate and provide assistance to farmers in the irrigated areas

The study has three main objectives with several research questions corresponding to each.

Objective 1: Assess the impact of the Nasho Irrigation Project at the plot level

4. What is the impact of the Nasho Irrigation Project on plot yields per hectare by crop?
5. What is the impact of the Nasho Irrigation Project on the farmer households' agricultural farming practices at the plot level?
6. What is the impact of the Nasho Irrigation Project on farmer households' use of agricultural inputs at the plot level?
7. What are the spillover effects for NAICO farmers on other plots they manage in terms of the use of agricultural inputs and farming practices?

Objective 2: Understand how NAICO and non-NAICO farmers differ at the household level

8. What are the differences in household income, poverty probability index, and livestock ownership between NAICO and non-NAICO farmers?
9. What are the differences between NAICO and non-NAICO farmers in how they market their produce?

Objective 3: Understand potential unintended consequences of the Nasho Irrigation Project

10. What are the potential unintended consequences of the Nasho Irrigation Project?

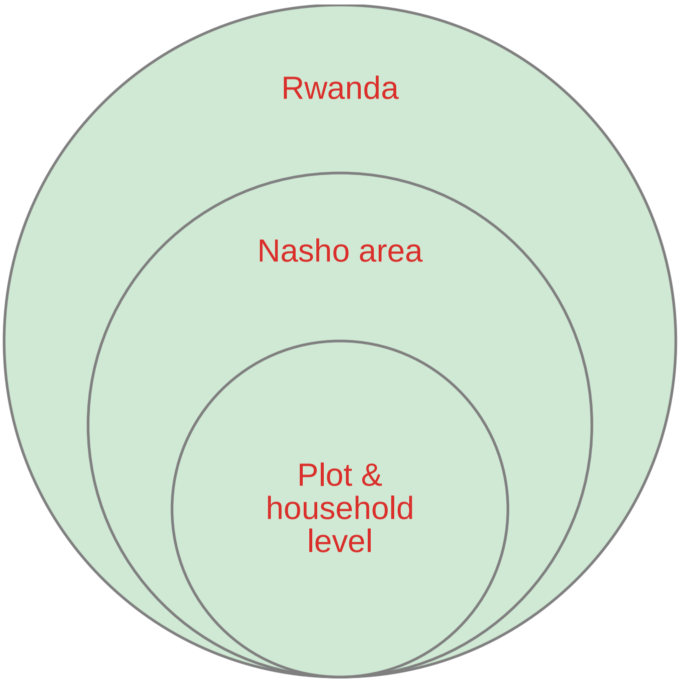
1.3 Approach

To meet the above research objectives, we use three distinct research anchors that help generate evidence and meet the relevant research objectives, from the plot and household level to Nasho treatment and comparison areas, to the district and the national level.

1. **Plot and household level differences:** understanding intended and unintended effects of the Nasho Irrigation Project at the plot level and household level
2. **Geospatial analysis:** Estimate changes over time in the outcomes of the treatment and comparison areas, looking at areas as opposed to individual outcomes
3. **Benchmarking:** Comparing the outcomes in both groups against district averages and national-level secondary data.

The three anchors are described in detail in the respective chapters. The methodology used for each anchor is separate and distinct, thus they are each explained in their respective chapters.

Figure 1 / An illustration of the three research anchors



The remainder of this report is structured as follows. Chapter two presents the objectives, methodology, and findings of the plot- and household-level differences analysis. Chapter three focuses on the analysis of geospatial differences. Chapter four presents the results from the benchmarking exercise. Finally, chapter five summarizes the findings and concludes the report.

2. Plot and household level differences

2.1 Objectives

This chapter aims to achieve the three main research objectives outlined above by answering the research questions and estimating program impacts at plot level on the outcomes of interest, comparing characteristics of NAICO and non-NAICO households, and understanding potential unintended consequences of the project.

2.2 Methodology

2.2.1 Data collection activities

2.2.1.1 Sampling strategy for quantitative data collection

We followed a multi-stage sampling strategy with stratification at the treatment and comparison group levels. We aimed to create a sample of 1,218 plots in total, 609 in treatment areas and 609 in comparison areas. Our sampling and listing strategies are below.

Treatment group plots

To ensure an even geographic distribution of plots within the treatment area, we followed four steps:

1. We divided the area into three bands each with a width of 300 meters (Figure 2).[2] [3]
2. For each band, we sampled the number of pivots proportional to their distribution in the band (following probability-proportional-to-size sampling). To calculate the percentage of land for each pivot lying in the respective bands, we geocoded the individual pivots and overlaid them with the bands. We then estimated the proportion of each pivot that fell under each band. 64% of the 58 pivots have the majority of their land in band 1; 26% of pivots have the majority of their land in band 2 (plots with a distance between 300 and 600 meters towards the edge of the irrigation zone), and 1% of pivots have the majority of their land in band 3 (600 meters to 900 meters from the edge of the irrigation zone).[4]

[2] We planned to draw the sample from four bands; however, upon analysis of the land distribution, noted that only very few plots were in the fourth band and none of the pivots had the majority of their land in the fourth band. We therefore decided to exclude the fourth band (900-1200m from the border) from the treatment group.

[3] Note that because we randomly selected plots in each pivot, the Euclidean distance (as the crow flies) towards the edge of the irrigation zone (the edges of the outermost pivots) is continuously distributed and randomly determined. Thereby the initial choice of the band size (whether 300 meters or 250 or 500 meters) does not affect the probability of selecting a plot.

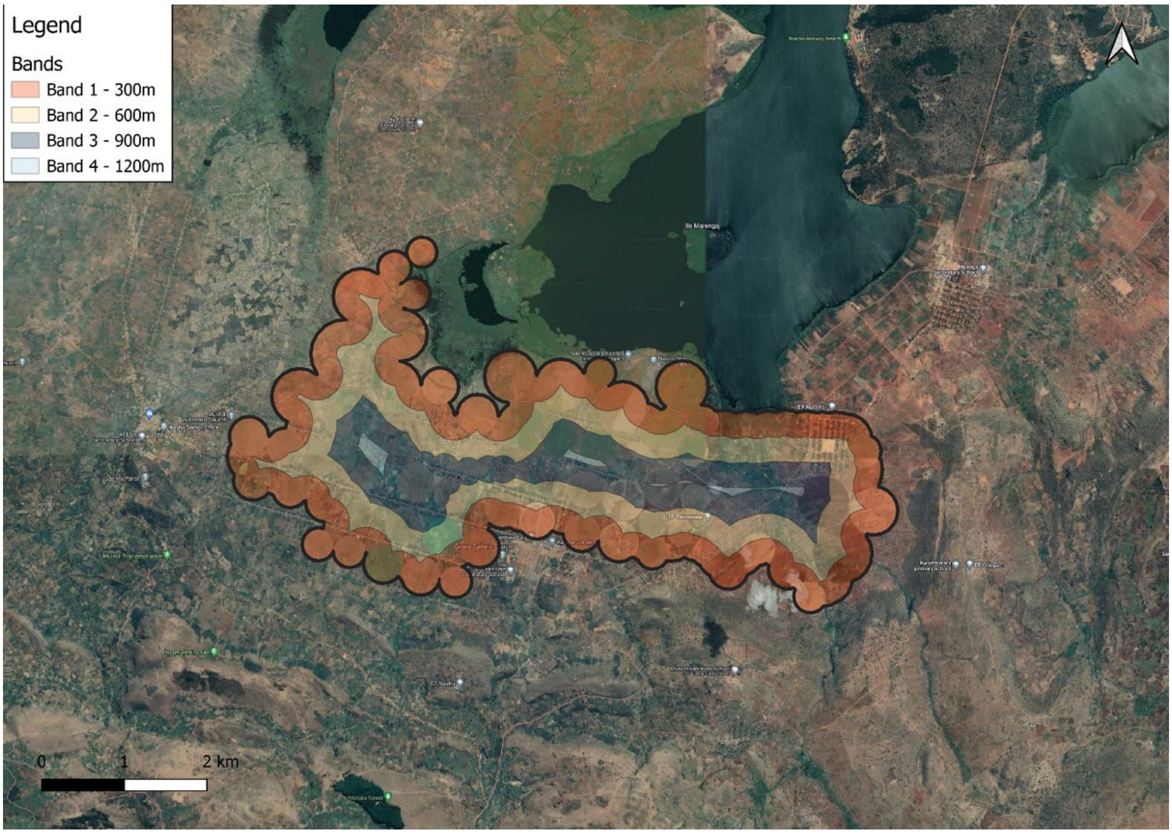
[4] While the project established 63 center pivots, we excluded five of them from our sampling frame. Pivot 5 (P5) is rented by RICA and fully mechanized. P4 and P40 are managed by farmers, but they are fully mechanized except for weeding and harvesting. P34 and P37 were leased by NAICO for the past six years, only being farmed again by farmers in the agricultural season 2024B. These five pivots were therefore excluded from our sampling frame since at this point, they were not representative of a regular pivot farmed by farmers and were significantly different from the control group (in addition to being irrigated).

3. In order to reach a sample size for the primary sample of 600 plots, we sampled a total of 40 pivots.
4. For each sampled pivot, we randomly sampled 15 plots.[5]

The distribution of sampled pivots was therefore as follows:

- **Band 1:** 390 plots from 26 pivots[6]
- **Band 2:** 150 plots from 10 pivots
- **Band 3:** 60 plots from 4 pivots

Figure 2 / Illustration of the three bands and the sampled pivots for the treatment group



The final sample for the treatment group included 600 plots in the primary sample and 353 in the secondary sample.[7]

[5] All pivots in the sample had at least 15 plots; we therefore chose to sample 15 plots per pivot. Alternatively, we could have decreased the number of plots per pivot and increased the number of pivots to be sampled to reach the same sample size. However, for logistical reasons, we opted to sample fewer pivots to ease data collection efforts, while still sampling a significant number of pivots out of the total of 58.

[6] 40 pivots multiplied by 64% equals 26 pivots. 15 sampled plots per pivot results in 390 plots.

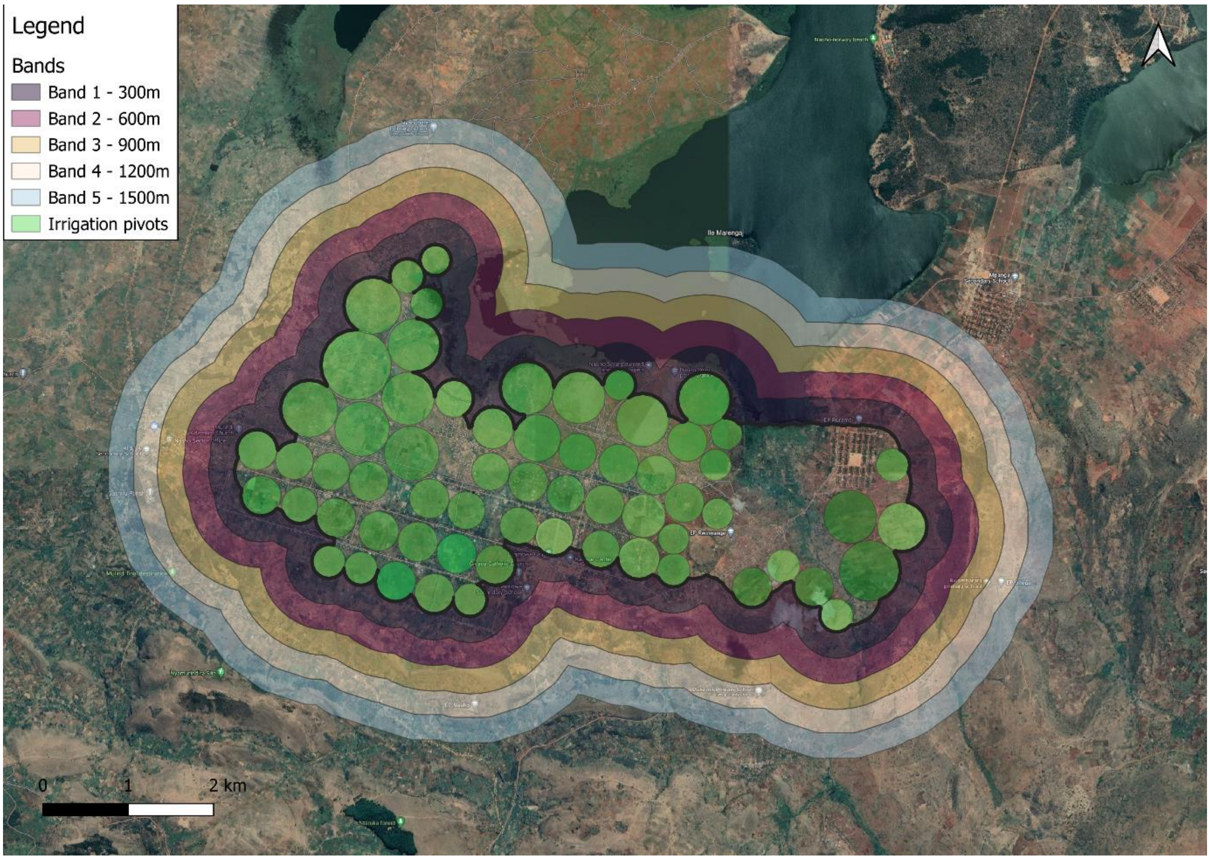
[7] The secondary/replacement sample was used during data collection to draw replacement plots from in case a plot from the primary sample was ineligible or the plot manager was untraceable.

Control group plots

To generate the comparison group, we conducted a listing exercise that established the sampling frame for the comparison group plots that are outside, but close to the Nasho irrigation zone. Our approach is outlined below.

First, we mapped the relevant geographic area, which are the plots under a center pivot (the circles in green in Figure 3), the plots in between the center pivots (in between the green circles in Figure 3), and several buffer zones outside the treatment area in 300-meter band increments up to 1,500 meters outside the irrigation zone. For example, the dark red band in Figure 2 is a maximum of 300m outside the treatment area, and the outermost blue band is between 1,200 meters and 1,500 meters outside of the irrigation zone.

Figure 3 / Map of buffer zones outside of the treatment area



For each of these buffer zones, we overlayed land cover data from Dynamic World (Brown et al., 2022) to determine the plot level sampling frame. This land cover data is a 10-meter resolution near-real-time land use/land cover dataset based on Sentinel 2 satellite imagery. It classifies each pixel in the imagery (10-meter by 10-meter ground surface) in nine different land cover classes ranging from cropland to grass, water, trees, flooded vegetation, bare land, snow and ice, and built environment and the geographic comparability of control buffers to the pivots. This is exemplified in Figure 4 for the 300-meter outer band.

Figure 4 / Pixel type variation of the 300-meter outer band

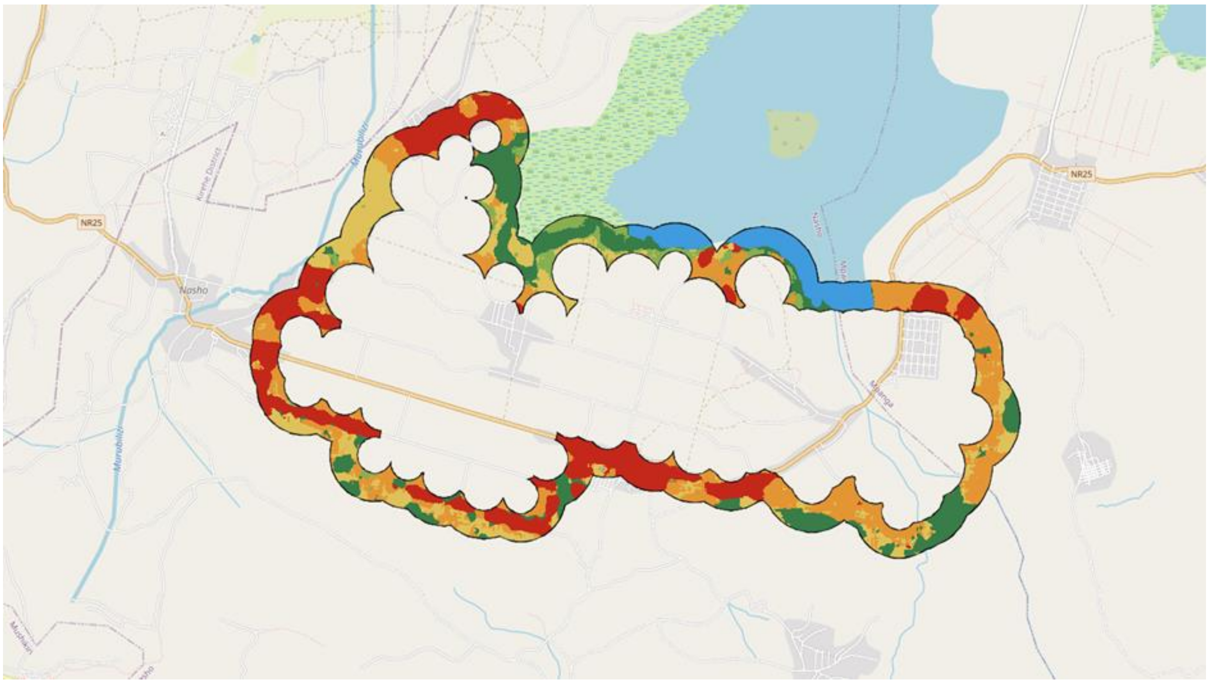


Figure 4 shows that pixels covered by roads or buildings are classified as built-up areas. Similarly, pixels in Lake Cyambwe are classified as water. We then only selected those pixels (10-meter by 10-meter squares) that have the highest probability of being classified as cropland between 2023 and 2024 within each band. Subsequently, we randomly selected 500 cropland pixels in each buffer zone. This resulted in a total of 2,000 pixels which represent small 10-meter by 10-meter areas on the ground that are consistently classified as cropland.

We then added coordinates to the centroid of each pixel in our sampling frame. The first step of the listing survey was then to validate whether these small pixels contained cropland on the ground. This is important because in some cases the Dynamic World data misclassifies a pixel as cropland when it contains grass or trees.

Because these pixels are very small, a single plot of land is always covered by multiple pixels. The second step of the listing survey moved from a pixel-level sampling frame to a plot-level sampling frame. It assessed which pixel belonged to which plot of land. The listing exercise took place in December 2023 and the final number of plots listed in all bands was 956.

During the listing survey, we identified and traced the plot manager of the sampled plot, ensured they were at least 18 years old, obtained basic information about their plots, and collected their contact details and approval to be surveyed during the main household survey. Following the listing exercise, we randomly sampled 609 plots to be part of the primary sample of the household survey, while 239 plots were included as a secondary sample to be used in case a replacement was needed. The remaining 108 plots were included in the pilot sample, with half of them being used as the pilot primary sample.

2.2.1.2 Household survey

Our sampling strategy included the sampling of plots and non-households. We therefore first had to identify the plot manager of the sampled plot, trace them, and interview them. The aim was to interview the plot manager based on the assumption that they oversee most of the decisions related to farming the sampled plot and were the most knowledgeable about the farming practices and yields. Respondents for the treatment group were eligible to participate if they were members of NAICO and were at least 18 years old.

The household survey included twelve modules, some focusing on the plot manager's household, some on the sampled/main plot, and some on all the plots farmed by the farm manager. Questions in modules 5, 6, 7, and 12 referred to the last agricultural season (season 2024A). Data collection took place between March 14th and March 26th, 2024, after most households had finalized harvests thus information about the plots was still fresh in their memory. Table 1 contains more details on the modules.

Table 1 / Plot manager survey modules and descriptions

Module	Description
1 Survey set-up	Survey setup, identification of respondent, and informed consent
2 Socio-demographics and household roster	Marital status and education of respondent and household head, household size, age range of all household members, and membership to agricultural cooperative
3 Poverty Probability Index	Questions proxying probability of living below (nationally and internationally) established poverty line. Captures ownership of durables, construction material of dwelling, and purchases of specific food items; also asking about connection to the grid line and living in a resettlement village
4 Livestock ownership	Number of livestock owned (cattle, goats, sheep, pigs, chicken, other) by the plot manager's household
5 Land ownership	For all plots: land available and ownership by plot, area size, location of plot (inside or outside the pivots), land use by plot (including land rental), crops by plot, and irrigation type
6 Use of agricultural inputs	For sampled plot: for the last agricultural season, use of organic and inorganic fertilizers, pesticides, herbicides, fungicides, certified seeds, hired labor
7 Estimates of yields	For all plots: asks plot managers about their harvested quantities by crop, usage of harvest, revenue from sales, and marketing practices
8 Estimates of income	Estimates income from each livelihood activity over the past month and year, including all agricultural and non-agricultural activities the household engages in; amount saved in the past month

Module	Description
9 Access to loans	Asks if plot manager's household borrowed any money in the last month, the source, purpose, and the amount
10 Social groups	Asks if plot manager's household is a member of any social group (e.g., cooperatives, church, SACCO)
11 Cooperative membership	Questions about financial contributions to cooperatives, and for NAICO farmers questions about how the plot manager's farming life has changed since becoming a NAICO member
12 Agricultural practices	For sampled plot: questions about farming practices, soil type, slope, erosion

In total, we conducted interviews on 1,215 main plots, 607 of which were outside and 608 were inside the pivots. These interviews were conducted with 1,005 unique plot managers as some of the sampled plots belonged to the same plot manager.

2.2.1.3 Qualitative data collection

To contextualize the findings of the quantitative household survey, we conducted 31 semi-structured interviews each spanning about 60-90 minutes, with three distinct groups of stakeholders as depicted in the below table. Interviews took place in March 2024.

During the semi-structured interviews, participants were encouraged to raise topics relevant to their experiences, allowing for a flexible discussion guided by their inputs. The data collection team further explored these themes to gain deeper insights. It is important to note that the qualitative data collected is not representative of the respective target groups, but rather serves to understand people's perceptions, opinions, and beliefs. The qualitative findings presented in section 2.3 should not be generalized to the population(s) of interest.

Table 2 / Breakdown of respondents for semi-structured interviews

Target group	Sample size	Participants
Farmers	20	• 12 NAICO farmers • 8 non-NAICO farmers[8]
NAICO management and leadership	5	• NAICO Management • HGBF Representative at Nasho • NAICO President • NAICO Former President • NAICO Advisor
Local officials and MINAGRI representatives	6	• 1 MINAGRI Minister • 1 MINAGRI DG • 1 RICA Deputy Vice-Chancellor • 2 Sector Agronomists • 1 District Vice Mayor

[8] Sampling of respondents for qualitative data collection took place prior to the household survey. Two respondents who were believed to be non-NAICO farmers actually were NAICO farmers which caused a deviation from the plan to interview 10 farmers of each group.

Respondents for the farmer interviews were randomly sampled from the household survey sample, ensuring an equal representation of men and women. The farmer-centric interviews revolved around the following key topics:

- Experiences of water scarcity and food security
- Interactions with the NAICO cooperative
- Impressions and experiences during the installation of the irrigation system
- Modifications in farming practices over this same period
- Changes to household income, and plots outside the pivot
- Changes in land values
- Challenges

We worked with the Nasho Irrigation Project team to determine the most relevant key informants for the second and third target groups. When conversing with the cooperative management and leaders, our focus shifted to understanding the details of the Nasho Irrigation Project rollout, particularly the functioning of the cooperative. We were interested in hearing about the difficulties faced, solutions implemented, and suggestions for replicating such a model in different contexts. These interviews further delved into the functioning of the cooperative, its role in increasing access to inputs, providing training on farming practices, and promoting the commercialization or marketing of output.

The key informant interviews with local leaders and MINAGRI officials aimed to generate insights into the program's most successful aspects, the challenges encountered, and the implications these experiences have for the future replication of this program.

Interviews were based on four distinct semi-structured interview guides and each respondent was asked a set of open-ended questions. Respondents are free to also bring up themes themselves which would then be probed further by the moderators.

2.2.2 Analytical methodology

Plot level

The Nasho Irrigation Project creates a discontinuity in access to irrigation: plots inside the pivots receive access to irrigation, while plots just outside the pivots do not. We can consider whether plots lie just inside or just outside the pivots as random. Except for the irrigation, the assumption is that the plots are very similar in terms of exogenous factors like soil quality, slope, rainfall, etc. Market circumstances and other external factors could also be considered similar for plots just inside and just outside the border. The effects of the Nasho Irrigation Project at the plot level will therefore be estimated using a geographic regression discontinuity design (RDD) which is a quasi-experimental empirical strategy to estimate local average treatment effects. The demarcation line around the pivots will be used as the discontinuity, determining who is 'treated' and who is in the comparison group. For all plots inside the pivots, the distance in meters to the edge of the (closest) outermost pivots provides the so-called running variable. Similarly, the distance in meters towards the edge of the irrigation zone that provides this discontinuity is the running variable for the control group. Based on the coordinates of each plot we have determined the Euclidean distance (as the crow flies) to the (nearest) edge of the irrigation zone. For any plot outside the Nasho zone, this distance towards the edge of the irrigation zone is negative. For each plot surveyed within the pivots and therefore within the irrigation zone this distance measure is positive. The running variable is thus used to determine the treatment probability of each plot. This design closely follows the seminal approach in geographic RDD put forward by Ali et al. (2014) in their analysis of environmental and gender impacts of land tenure regularization in Kabushenge in Rwanda.

An advantage of an RDD is that it provides high internal validity because the unobservable characteristics (the factors we cannot measure) will on average be the same for those plots just inside and just outside the irrigation zone. Differences in yield levels can therefore be attributed to the intervention. In the season of reference, NAICO plots grew maize, common beans, and soybeans. When presenting crop-specific results, our analysis therefore focuses on these three crops for Nasho and non-Nasho plots.

In our analysis chapters, we first present descriptive statistics, comparing Nasho vs. non-Nasho plots. In the second step, to estimate the program's impact on various plot-level indicators, we run RDD regression models using the distance of the respective plot to the irrigation boundary as the running variable.

<u>Household level</u>

For demographic and socioeconomic indicators, we compare households having at least one plot inside the Nasho irrigation scheme, and therefore are NAICO members, with households having no plots inside the irrigation scheme, consequently non-NAICO members.

It is important to note that although our analysis adjusts for observable differences between NAICO and non-NAICO members (e.g., education level or sex of plot manager), it cannot conclusively demonstrate a net causal effect of the project at the household level. This is for several reasons. First, it is difficult to define a treatment indicator at the household level. A household may farm on plots both inside the center pivots as well as plots outside the irrigation zone. This means that even if we account for differences like education or gender of the plot manager, we cannot isolate the impact of farming on irrigated plots on the entire household. Second, we cannot conclusively capture all possible self-selection effects at the household level. Such effects remain unobserved. For example, households that chose to join NAICO in 2017 may have been more motivated compared to those who did not. These are characteristics that cannot be observed or measured at the time of surveying (in 2024) among both NAICO and non-NAICO members.

To mitigate these issues, we do adjust our analysis for observable differences in household socio-economic background. Moreover, for indicators that are related to farming activities, e.g. use of harvest or ways of marketing produce, we divide the sample into three groups. These are households that only own plots inside the irrigation scheme, households that own plots both inside and outside, and households that only own plots outside the scheme. The division into three groups instead of two groups does give insights into whether the households that own plots outside the scheme but are NAICO members display different behaviors for instance in selling their harvests and marketing their produce compared to NAICO members who are bound to their plots inside the scheme. By analyzing the patterns across these three groups, we gain better insights into the variation in effects across these three groups, thus addressing some of the limitations mentioned earlier and providing a clearer understanding of the project's effectiveness at the household level.

2.3 Findings

2.3.1 Nasho population at plot and household level

2.3.1.1 Nasho and non-Nasho plots

In total, we collected data on 2,445 plots. These are comprised of primary plots that were sampled prior to the beginning of data collection and secondary plots from which we collected data, although not priorly sampled.

Of the plots mentioned above, 1,215 were primary sampled plots. The data for these plots was collected through interviews with the plot managers, as well as through plot observation. Enumerators observed some plot characteristics such as the soil type, the degree of erosion, the organic soil cover, and weeds. They also observed farming practices such as erosion control measures and mulching. The number of primary plots owned by the same farmer ranges from 1 to 5 plots.[9]

We also collected data on 1,230 additional secondary plots. These are the additional plots owned by the farmers cultivating the sampled primary plots. The data for these plots was only recorded through interviews with the plot managers. No plot observations took place, as data collection was only conducted at the primary plot locations. For these plots, we collected data on the plot size, land ownership, irrigation, crop harvest, and harvest usage, as well as whether the plot belongs to the Nasho irrigation scheme. The highest number of secondary plots owned by the same farmer is 12 plots.

A Nasho plot is defined as a plot that lies inside one of the irrigated pivots. A non-Nasho plot is a plot lying outside of the pivots. The distribution of Nasho and non-Nasho plots among the primary and secondary plots is depicted in Table 3. The comparison is done independently of who the plot manager is. For example, a plot manager can have a plot both inside and outside the pivots. Our analysis in this chapter focuses on the plot level.

Table 3 / Full sample size of plot-level analysis

	Nasho plots (n = 1,200)	**Non-Nasho plots** (n = 1,245)
Primary/main plot	608 (51%)	607 (49%)
Secondary plot	592 (49%)	638 (51%)

[9] After the listing exercise, we randomly sampled an even number of plots from both inside and around the irrigation scheme. Sampling took place at the plot level, i.e. regardless of their plot managers. As a result, some farmers had more than one of their plots sampled. Some farmers had multiple plots from both inside and around the scheme sampled.

Full sample plot characteristics

Looking at the cultivated area, the plots inside and outside the Nasho irrigation scheme exhibit significant differences. The plots outside the irrigation scheme are on average larger than the plots inside the irrigation scheme, and this difference is statistically significant (p=0.007[10]). The average plot size outside the irrigation scheme is 0.42 hectares, while the average plot size inside the irrigation scheme is 0.35 hectares.

Significant differences are also observed when considering the crop-allocated area between the two groups. The comparison here is only made for the three crops grown inside the irrigation scheme: maize, soybeans, and common beans. However, we also report the distribution of the other crops grown outside the irrigation scheme.

Table 4 illustrates the differences in land coverage between the plots inside and outside the irrigation scheme.

- **Maize –** More than 43% of the area inside the irrigation scheme is covered by maize, while maize is grown in 33% of the cultivated area outside the irrigation scheme. However, the difference in the average plot area covered by maize between the two groups is not statistically significant (p=0.079).
- **Common beans –** Common beans are the least grown crop inside the irrigation scheme during the agriculture season 2024A, covering 15% of the irrigated area. However, they are grown in 28% of the farmed land outside the irrigation scheme. We also notice a statistically significant difference in the average plot area allocated to common beans between the two groups (p<0.001).
- **Soybean –** Soybeans are grown in 41% of the area inside the irrigation scheme, while only 1% of the farmed land outside the irrigation area is grown with soybeans. The difference in the average area allocated with soybeans between the two groups is statistically significant (p=0.037).

Regarding the cultivated area, banana is the third most grown crop on non-Nasho plots, after maize and common beans. Sorghum, Irish potatoes, sweet potatoes, cassava, and groundnuts are among the other commonly grown crops.

[10] The p-value measures the probability of obtaining the observed results, assuming the null hypothesis is correct, meaning that the effect is null, or the relationship studied is non-existent. The “p” stands for probability and measures the likelihood that any observed difference between groups is due to chance. A p-value of 0.007, for example, means the null hypothesis has a 0.7% chance of being true.

Table 4 / Full sample plot characteristics (based on cultivated area)

	Nasho plots (n = 1,200)	Non-Nasho plots (n = 1,245)	p-value
	Mean (SD) or %	*Mean (SD) or %*	
Average plot area in ha.	0.35 (0.41)	0.42 (0.75)	0.007
Crop-allocated area			
Maize	43.83%	33.00%	0.079
Soybean	41.38%	1.11%	0.037
Beans	14.78%	27.88%	<0.001
Banana	0.00%	14.02%	NA
Sorghum	0.00%	8.37%	NA
Irish potato	0.00%	3.89%	NA
Sweet potato	0.00%	2.76%	NA
Cassava	0.00%	2.62%	NA
Groundnuts	0.00%	2.14%	NA
Vegetables (e.g., cabbage, spinach, onions)	0.00%	0.50%	NA
Fruits (excluding banana; e.g., mango, passion fruit, avocado)	0.00%	0.46%	NA
Sugar cane	0.00%	0.16%	NA
Other crops	0.00%	3.10%	NA

We also notice significant differences in plot ownership and the use and type of irrigation applied between Nasho and non-Nasho plots (Table 5). The differences here are reported in terms of the number of plots, and not in terms of area size.

The number of plots purchased, inherited, or rented inside the irrigation scheme is slightly higher than those outside the scheme, while those gifted, rented free of charge, or accessed through communal rights are slightly higher outside the scheme. The differences in plot access between Nasho and non-Nasho plots are statistically significant ($p<0.001$).

The main significant difference between the two groups is that all plots inside the irrigation scheme are irrigated, compared to the 194 plots (16%) irrigated outside the Nasho irrigation scheme ($p<0.001$).

All the irrigated plots inside the Nasho irrigation scheme are irrigated through pivot irrigation, with few plots (less than 1%) being irrigated through surface and traditional irrigation techniques as well. Sprinkler irrigation is the most common irrigation type used outside the Nasho irrigation scheme (50%), followed by irrigation through a hose connected to water pumps (35%), traditional irrigation (16%), and surface irrigation (1%).

Farmers outside the irrigation scheme spent on average 26,464 RWF (USD 20) per hectare on irrigation during the agricultural season 2024A, while farmers inside the scheme did not spend any money on irrigation, excluding the mandatory seasonal sustainability fee paid to NAICO.[11] The sustainability fee which comprises money for irrigation as well as other services is 103,000 RWF (USD 79) per hectare per season.

Table 5 / Full sample plot characteristics (based on the number of plots)

	Nasho plots (n = 1,200)	**Non-Nasho plots** (n = 1,245)	**p-value**
	N (%)	*N (%)*	
Plot access			<0.001
Purchased	684 (57%)	676 (54%)	
Inherited	190 (16%)	159 (13%)	
Renting (incl. sharecropped)	144 (12%)	121 (10%)	
Gifted	94 (8%)	144 (12%)	
Communal rights/public shared	49 (4%)	67 (5%)	
Renting free of charge	27 (2%)	62 (5%)	
Other	12 (1%)	16 (1%)	
Practiced irrigation	1,200 (100%)	194 (16%)	<0.001
Irrigation type			
Pivot irrigation	1,200 (100%)	0 (0%)	<0.001
Sprinkler irrigation	0 (0%)	97 (50%)	<0.001
Hose connected to water pumps	1 (0%)	67 (35%)	<0.001
Traditional irrigation[12]	1 (0%)	32 (16%)	<0.001
Surface irrigation	2 (0%)	1 (1%)	0.33
Expenditures on irrigation activities per ha. (in RWF)	0 (0)	26,464 (106,471)	<0.001

[11] Using an exchange rate of 1 RWF = 0.00076757 USD from March 20th, 2024.

[12] Traditional irrigation is used when farmers irrigate directly by hand using a bucket, basin, or any other water recipient that they carry themselves to the plot.

Primary plot characteristics

Significant differences in both the plot characteristics and farming practices are also noticed when looking at the data collected through the primary plot observations by enumerators ($p<0.001$)[13]. These differences are reported in terms of the number of plots within each group, and not in terms of the cultivated area (Table 6).

- **Soil type –** Close to one third (31%) of the plots inside the irrigation scheme were reported as having clay loam soil, the most prevalent soil type reported inside the scheme. This is however the least reported soil type outside the irrigation scheme, only reported on 14% of the plots outside the scheme. Clay soil is largely the most predominant soil type outside the irrigation scheme, with more than forty percent of the plots being clay.
- **Slope –** Two-thirds (69%) of the plots inside the irrigation scheme are flat (up to 10 degrees slope), and the most part of the remaining third is of medium slope. Only 1% of the plots inside the scheme have a steep slope (more than 25 degrees slope). Although roughly half (47%) of the plots outside the scheme are flat as well, 9% of the plots in this group are reported as steep.
- **Degree of erosion –** The degree of erosion is very low in both groups, mainly in 78% of the plots inside the irrigation scheme and in 66% of the plots outside. Severe erosion affects only 1% of the plots inside the irrigation scheme and 3% of the plots outside the scheme.[14]
- **Weeds –** There are no weeds visible in 79% of the plots inside the irrigation scheme and in 75% of the plots outside, and only 3% and 5% of the plots inside and outside the scheme respectively had many weeds. The remaining plots have few weeds. Note that these differences are not statistically significant ($p = 0.054$). Only 1% of the plots inside the irrigation scheme have weeds more than 30cm tall, different from the 20% outside the scheme.
- **Mulching –** Fewer plots inside the irrigation scheme are visibly covered with mulch (13%) than plots outside (22%).[15] Note that more than half of the plots covered with mulch outside the scheme (55%) are plots with bananas, for which mulching is generally a common practice. One-fifth of the plots (20%) outside the irrigation scheme were mulch was visible mulching are covered with mulch that is more than 2 cm thick, while only 1% of the plots inside the scheme are covered with such mulch. Out of those plots with visible mulch, mulch covers most of the field in half of the

[13] Given that we had separate enumerator teams observing the Nasho and non-Nasho plots (because of the familiarity enumerators developed with non-Nasho plots and respondents during the listing exercise), we cannot exclude the possibility that enumerator error influenced the observed differences.

[14] The differences in soil type, slope, and degree of erosion between Nasho and non-Nasho plots remain significant when reducing the bandwidth of the sample and only considering plots within the 300m bands inside and around of the boundary.

[15] Differences in weeding and mulching between Nasho and non-Nasho plots may partially be explained by the possibility of plots being in different growing seasons because the irrigation on Nasho plots allows farmers to plant earlier than on non-Nasho plots.

plots outside the irrigation scheme, and slightly higher in the plots inside the scheme (60%).

Soil type and slope are exogenous factors, not impacted by the farmers' practices. Since we see significant differences between Nasho and non-Nasho plots for these two factors, we control for them in our regression analysis estimating the impact of the Nasho Irrigation Project at the plot level.

Table 6 / Main plot characteristics (based on the number of plots) based on enumerator observations

	Nasho plots (n = 608)	**Non-Nasho plots** (n = 607)	**p-value**
	N (%)	*N (%)*	
Soil type			<0.001
Clay	170 (29%)	255 (42%)	
Sandy loam	166 (28%)	128 (21%)	
Clay loam	183 (31%)	88 (14%)	
Sandy	72 (12%)	117 (19%)	
Other	1 (0%)	19 (3%)	
Slope			<0.001
Flat (up to 10 degrees slope)	406 (69%)	287 (47%)	
Medium (10 to 25 degrees slope)	181 (31%)	265 (44%)	
Steep (more than 25 degrees slope)	5 (1%)	55 (9%)	
Degree of erosion			<0.001
Very low (Splash erosion)	462 (78%)	398 (66%)	
Low (Wind erosion)	60 (10%)	89 (15%)	
Moderate (Diffuse overland flow erosion, overland flow erosion, erosion by infiltration)	63 (11%)	100 (16%)	
Severe (Rill erosion, gully erosion, mass movement/landslides)	7 (1%)	20 (3%)	
Weeds underneath the crop			0.054
No weeds	377 (79%)	426 (75%)	
Few weeds	88 (18%)	114 (20%)	
Many weeds	12 (3%)	30 (5%)	

	Nasho plots (n = 608)	**Non-Nasho plots** (n = 607)	**p-value**
	N (%)	*N (%)*	
Size of the weeds			<0.001
Weeds are less than 30cm tall or 30cm spread for grasses	87 (99%)	91 (80%)	
Weeds are more than 30cm tall or 30cm spread for grasses	1 (1%)	23 (20%)	
Mulching			<0.001
Yes	78 (13%)	133 (22%)	
No	514 (87%)	473 (78%)	
Mulch location			0.001
Mulch covering most of the field	47 (60%)	67 (50%)	
Mulch under tree canopy only	31 (40%)	66 (50%)	
Mulch thickness			<0.001
Less than 2cm mulch, bare soil seen	77 (99%)	106 (80%)	
More than 2cm mulch, no soil seen	1 (1%)	27 (20%)	

Note: The 16 plots on Pivot 33 were not observed, given that by the time of data collection, this pivot was rented by NAICO for Season B, so any observables would not have been reflective of the farmers.

Agricultural season 2024B had already started when data collection was conducted; therefore, weeds and mulching were observed on the plots where season B crops were already cultivated. Enumerators couldn't observe weeds in the plots where they hadn't started cultivating for season B yet.

2.3.1.2 Profile of NAICO and non-NAICO Households

A NAICO household is defined as a household in which at least one household member is a member of NAICO. Conversely, a non-NAICO household is a household in which no member is a member of NAICO.

NAICO and non-NAICO households have similarities and a few statistically significant differences between them as seen in Table 7. Some key highlights include:

- **Household size** – On average, there are approximately 5 members in NAICO households and approximately 4.7 members in non-NAICO households (p=0.024).
- **Demographic profile of plot managers:**

  - **Age** – Plot managers in both NAICO households and non-NAICO households are on average 49 years old. However, NAICO plot managers were less likely to be young (7%), as compared to non-NAICO plot managers (13%).[16]
  - **Gender** – NAICO plot managers are more likely to be male (65%), compared to non-NAICO plot managers (53%).
  - **Highest Education Level** – NAICO and non-NAICO plot managers have similar levels of education, with 69% and 67% having attained primary education, respectively.
  - **Marital status** – NAICO plot managers are more likely to be married (80%) than non-NAICO plot managers (72%).
- **Cooperative membership** – All NAICO households confirm their membership in the NAICO cooperative. Additionally, both NAICO and non-NAICO households are affiliated with other cooperatives, with COVAMIS being the most represented by NAICO households (5%) and non-NAICO households (10%).
- **Social group membership** – NAICO households were more likely to indicate memberships to various social groups compared to non-NAICO households, including mutual help and insurance groups, microinsurance groups, and agricultural producer groups.

Table 7 / NAICO and non-NAICO household demographics

	NAICO households (n = 604)	**Non-NAICO households** (n = 401)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Age of Plot Manager	49 (13)	49 (16)	0.79
Sex of Plot Manager			<0.001
Male	391 (65%)	211 (53%)	
Female	213 (35%)	190 (47%)	
Youth Plot Manager	43 (7%)	52 (13%)	0.002
Marital Status of Plot Manager			0.020
Married	485 (80%)	289 (72%)	
Widowed	68 (11%)	57 (14%)	
Divorced	26 (4%)	30 (7%)	
Single	25 (4%)	25 (6%)	

[16] In Rwanda, youth are typically defined as individuals ranging in age from 16 to 30 years. https://www.gov.rw/highlights/social-transformation

	NAICO households (n = 604)	**Non-NAICO households** (n = 401)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Highest Education Level of Plot Manager			0.72
Primary	419 (69%)	270 (67%)	
Secondary	74 (12%)	49 (12%)	
University	15 (2%)	8 (2%)	
No education	96 (16%)	74 (18%)	
Household Size	5.0 (1.9)	4.7 (1.9)	0.024
Cooperative Membership			
NAICO	604 (100%)	0 (0%)	<0.001
COVAMIS	29 (5%)	41 (10%)	0.001
Nasho coffee cooperative	4 (1%)	14 (3%)	<0.001
Cooperative of banana plantation farmers	2 (0%)	3 (1%)	0.36
MPANGA	1 (0%)	0 (0%)	0.41
Social Group Membership			
Mutual help or insurance group (including burial societies)	500 (83%)	299 (75%)	0.002
Credit or microfinance group (including SACCOs /merry-go-rounds/VSLAs)	482 (80%)	238 (59%)	<0.001
Agricultural/ livestock/ fisheries producer's groups (including marketing groups)	380 (63%)	47 (12%)	<0.001
Water users' group	108 (18%)	30 (7%)	<0.001
Religious group	74 (12%)	69 (17%)	0.028
Trade and business association group	23 (4%)	11 (3%)	0.32
Civic group (improving community) or charitable group (helping others)	19 (3%)	11 (3%)	0.71

	NAICO households (n = 604)	**Non-NAICO households** (n = 401)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Forest users' group	4 (1%)	0 (0%)	0.10
No group membership	11 (2%)	24 (6%)	<0.001

2.3.1.3 Socioeconomic characteristics of NAICO and non-NAICO households

Overall, when examining household income, poverty probability index, and livestock ownership, NAICO and non-NAICO households exhibit significant differences in their socio-economic characteristics. This detailed comparison is provided in Table 9 and Table 10 a few pages below.

Household income

During the survey, plot farmers shared insights into household income generation, detailing how income is generated at the household level. Farmers reported involvement in both agricultural and non-agricultural income-generating activities.

Agricultural income-generating activities

All NAICO households and non-NAICO households engage in cropping activities to generate income. The majority of NAICO households (82%) and non-NAICO households (80%) also engage in livestock keeping to generate income. Other agricultural income-generating activities mentioned include forestry, beekeeping, and aquaculture/pisciculture.

NAICO households are significantly more likely to report earning income from agricultural activities than non-NAICO households (p<0.001). When examining monthly income, both NAICO and non-NAICO households predominantly state earning less than 250,000 RWF (USD 192). Specifically, 45% of NAICO households and 54% of non-NAICO households fall into this income bracket. Additionally, more NAICO households report earning in higher income categories. Notably, 18% of NAICO households earn more than 250,000 RWF (USD 192) per month, compared to 6% of non-NAICO households. The median monthly income from agricultural activities also differs significantly between these groups, with NAICO households having a median monthly income of 20,000 RWF (USD 15), while non-NAICO households have a median monthly income of 10,000 RWF (USD 8) (p=0.045).

In terms of annual income from agricultural activities, NAICO households are more likely to fall into higher income brackets than non-NAICO households (p<0.001). Most NAICO (28%) and non-NAICO (47%) households earn more than zero but less than 500,000 RWF (USD 384) annually from agricultural activities. However, 23% of NAICO households and 10% of non-NAICO households earn between 500,001 RWF and 1,000,000 RWF (USD 384-768). Additionally, 20% of NAICO households earn between 1 and 2 million RWF (USD 768-1,535), compared to 9% of non-NAICO households. Furthermore, 18% of NAICO households earn more than 2 million RWF (USD 1,535) annually from agricultural activities, compared to just 4% of non-NAICO households. Only 8% of non-NAICO households report not generating annual income from agricultural activities. The median annual income from agricultural activities of NAICO and non-NAICO households also shows significant differences, with NAICO households having a median annual income of 700,000 RWF (USD 537), compared to 180,000 RWF (USD 138) for non-NAICO households (p<0.001).

"The income increased; it is not like before. I have two cows at home. I bought one cow from NAICO's farming, and I received another cow from a friend." – **Male NAICO farmer**

"The changes are that the money we receive helps us to improve our economy. For example, when you have harvested, and you take the production to the market you get money. This gives an opportunity to use the remaining money after your expenses to buy like a goat and improve your economy, which is a mode of saving. If you get a chance to get an additional field, you grow crops again, and things become better and better." – **Female NAICO farmer**

Non-agricultural income-generating activities

NAICO households and non-NAICO households engage in various non-agricultural income-generating activities. These include daily labor (both agricultural and other sectors), fishing, hunting and gathering, skilled labor, purchase and sale of agricultural products, purchase and sale of livestock, informal sales, handicrafts, transport activities, salaried work, pension income, self-employment/owning a business, Vision 2020 Umurenge Program (VUP) public works, and remittances.[17] These activities contribute significantly to their livelihoods. Specifically, 13% of NAICO households engage in daily labor (both agricultural and other sectors), and 7% report being self-employed. In contrast, 32% of non-NAICO households engage in daily labor (agriculture and other sectors), and 4% report being self-employed.

Non-NAICO households are significantly more likely to report generating income from non-agricultural activities than NAICO households (p<0.001). When looking at monthly income, 31% of NAICO households and 49% of non-NAICO households generate less than 250,000 RWF (USD 192) per month from non-agricultural activities. 2% of NAICO households and another 2% of non-NAICO households earn more than 250,000 RWF (USD 192). The median monthly income also shows some differences: NAICO households have a median monthly income of 0 RWF (USD 0), while non-NAICO households have a median monthly income of 1,750 RWF (USD 1) (p<0.001).

When examining annual income, the majority of non-NAICO households (47%) and NAICO households (28%) earn less than 500,000 RWF (USD 384) annually from non-agricultural activities. Furthermore, 4% of non-NAICO households earn between 500,001 RWF and 1,000,000 RWF (USD 384-768) annually, compared to 3% of NAICO households. Additionally, 3% of NAICO households and 2% of non-NAICO households earn between 1 and 2 million RWF (USD 768-1,535) annually. Lastly, 2% of NAICO households and 1% of non-NAICO households earn more than 2 million (USD 1,535) annually. 64% of NAICO households and 45% of non-NAICO households report not generating annual income from non-agricultural activities. The median annual income further highlights significant

[17] The Vision 2020 Umurenge Program (VUP) is a social protection program by the Government of Rwanda aimed at supporting the poor. VUP social works provides participants with public work such as working in the construction of community infrastructure like roads, schools, etc.

differences between the two groups, with NAICO households reporting a median income from non-agricultural activities of 0 RWF (USD 0) and non-NAICO households reporting a median annual income of 15,500 RWF (USD 12) ($p<0.001$).

Access to credit facilities

25% of NAICO households and 27% of non-NAICO households currently have a loan ($p=0.34$). The most prevalent source of loans for both groups is the Tontine community savings group, with 19% of non-NAICO households and 17% of NAICO households reporting a loan from this source ($p=0.46$). Additionally, some households mention taking loans from other credit channels, including relatives, friends, or neighbors, credit cooperatives, farmer cooperatives (both NAICO and non-NAICO), microfinance institutions, and Savings and Credit Cooperative Organizations (SACCOs).

NAICO households have on average taken significantly higher loans from the Tontine community compared to non-NAICO households ($p=0.023$).[18] On average, NAICO households borrowed 115,353 RWF (USD 89) in the last 30 days, whereas non-NAICO households borrowed 75,080 RWF (USD 58).

The primary reason for taking loans among both NAICO and non-NAICO households was to purchase agricultural inputs, with 16% of NAICO households and 14% of non-NAICO households doing so ($p=0.15$). Additionally, 9% of NAICO households accessed credit for agricultural equipment, while 9% of non-NAICO households used loans for education expenses. Other reasons for taking loans included acquiring livestock, expanding businesses, making home improvements, procuring household items, covering medical treatment costs, and financing ceremonies such as marriages, funerals, and baptisms.

Farmer savings

NAICO households have significantly higher savings than non-NAICO households in the last 30 days ($p=0.002$). Specifically, NAICO households saved an average of 94,197 RWF (USD 72), while non-NAICO households saved an average of 42,811 RWF (USD 33) during this period.

Poverty probability index

This study uses Rwanda's 2017 Poverty Probability Index (PPI) to score NAICO and non-NAICO households with a poverty likelihood value for the National Poverty Line (NPL). The PPI is based on data from Rwanda's 2016/17 Integrated Household Living Conditions Survey (EICV5) produced by the National Institute of Statistics Rwanda (NISR) and the Ministry of Finance and Economic Planning and was released in December 2019.[19] The PPI comprises ten questions asked during the survey, which together strongly predict poverty for each household. Points are allocated for each question after adjusting for the nine other questions in the PPI scorecard. The poverty likelihood value for the NPL is calculated for each household which is then averaged for NAICO and non-NAICO households to obtain the poverty rate using the NPL.

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[18] A "tontine" is a traditional, informal savings organization (Balkenhol et al., 1994).

[19] https://www.povertyindex.org/

One in four sampled households is considered poor. The average probability of the sampled households being below the national poverty line in 2016/2017 is 25.5%. The national poverty rate recorded in 2016/2017 stood at 38.2%.[20]

NAICO households are considered less poor than non-NAICO households ($p<0.001$). NAICO households have an average poverty likelihood of 23.3% to be below the national poverty line, while non-NAICO households have a higher likelihood of 28.8% to be below the national poverty line.

Ubudehe category

The Ubudehe categories in Rwanda classify households based on income, determined through a community participatory approach that considers the economic status of each household. In this study, we collected self-reported information on the Ubudehe category to which each household belonged, based on the 2015 categorization released by the Minister for Local Government and Social Affairs in Rwanda.[21]

Table 8 / Ubudehe categories and descriptions

Category	Description
Category one	Includes very poor and vulnerable citizens who are homeless and unable to feed themselves without assistance
Category two	Comprises households that can afford some form of rented or low-class owned accommodation, are not gainfully employed, and can only afford to eat once or twice a day
Category three	Includes households with gainfully employed members or those who are employers, such as small farmers who have moved beyond subsistence farming or owners of small and medium-scale enterprises
Category four	Consists of households with members who are chief executive officers of large businesses, employees with full-time jobs in organizations, industries, or companies, government employees, shop or market owners, and owners of commercial transport vehicles or trucks

Within our sample, there are significant differences between NAICO and non-NAICO households' Ubudehe categories ($p<0.001$). About half (49%) of the NAICO households reported belonging to Category 3. Another 46% of NAICO households reported belonging to Category 2, and 5% reported being in Category 1. Only one NAICO household in our sample reported being in Category 4.

[20] NISR Statistical report: https://www.statistics.gov.rw/publication/eicv-5-rwanda-poverty-profile-report-201617.

[21] This study captured self-reported Ubudehe categories, which was asked to both NAICO and non-NAICO households, using the question, “Which Ubudehe category does the household belong in?”. These categorisations can be traced to the latest published categorisations released in 2015. Further information on re-categorizations due to appeals by the households were not explored in this study.

For non-NAICO households, the majority reported being in Category 2, with 60% indicating this. Additionally, 32% reported belonging to Category 3, while 7% reported being in Category 1.[22]

Livestock ownership

NAICO households own significantly more livestock than non-NAICO households (p=0.020). Specifically, NAICO households own on average about six animals compared to non-NAICO households that own about four animals.

The majority of NAICO and non-NAICO households own goats and cattle, with notable differences in livestock ownership patterns. Specifically, NAICO households significantly own more cattle, chicken, and sheep, compared to non-NAICO households. The same proportion of NAICO households (55%) and non-NAICO households (56%) keep goats (p=0.88). NAICO households (39%) own significantly more cattle than non-NAICO households (31%) (p=0.014). Additionally, NAICO households (33%) significantly rear more chickens than non-NAICO farmers (25%) (p=0.015). In addition, 16% of NAICO households and 8% of non-NAICO households keep sheep. Another 15% of NAICO households own pigs compared to 15% of non-NAICO households (p=0.93).

Furthermore, 19% of NAICO households and 21% of non-NAICO households do not own any livestock (p=0.30).

Electricity access

Non-NAICO households have greater access to main grid electricity than NAICO households. Specifically, 46% of non-NAICO households have access to main grid electricity, while only 36% of NAICO households do, highlighting significant differences in electricity connection between the two groups (p=0.005). All NAICO households residing in resettlement villages report that they are connected to the main grid electricity.

Land ownership

NAICO households own significantly more land compared to non-NAICO households. On average, NAICO households own on average 0.87 hectares of land, while non-NAICO households own 0.66 hectares (p=0.002).

Resettlement village

9% of NAICO households and 2% of non-NAICO households reside in resettlement villages. Of these, 5% of NAICO households live in villages built by the Nasho Irrigation Project (p<0.001). Resettlement villages built by the government (MINAGRI) have 4% of NAICO households and 2% of non-NAICO households residing there (p=0.25).

[22] 1% of non-NAICO households either refused to report their Ubudehe category or reported an unspecified category. The unspecified category is used for households that have not yet been classified into the four standard categories due to reasons such as unresolved appeals regarding their assigned category. See the changes made to the Ubudehe categorization here: https://rwandapedia.rw/hgs/ubudehe/poverty-level-categories

"Previously, some of the residents were staying in bad habitats but they built a village to connect them, and the village allowed the introduction of infrastructures nearby. For example, there is a health post, an Early Childhood Development service, and a hall, all of these have been introduced because the residents got together as a result of the introduction of the irrigation system. Everyone who was living in the pivots zones was relocated and they got them in one place and then started introducing those infrastructures, such as roads, electricity, and water even though it is not enough, but again residents can fetch water without going a long distance, because they were relocated and live together." – **Male NAICO farmer**

"They came to measure the land and determined where the pivots would be placed. They informed the residents that they needed to relocate because their current homes were in the irrigation area. Before relocating, they built new houses for the residents. Once the houses were completed, they handed them over, and the residents moved to their new homes without any issues. The old areas are now irrigated like other farms." – **Female NAICO farmer**

Table 9 / NAICO and non-NAICO households' socioeconomic characteristics

	NAICO households (n = 602)	**Non-NAICO households** (n = 403)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
National Poverty Line	23.2% (17.7)	28.8% (19.2)	<0.001
Ubudehe Category			<0.001
Category 1	30 (5%)	28 (7%)	
Category 2	277 (46%)	239 (60%)	
Category 3	294 (49%)	129 (32%)	
Category 4	1 (0%)	0 (0%)	
Don´t know / Refuse to say	1 (0%)	2 (0%)	
Unspecified category	1 (0%)	3 (1%)	
Resettlement village			
Built by Government/ MINAGRI	23 (4%)	10 (2%)	0.25
Built by Nasho Irrigation Project	29 (5%)	0 (0%)	<0.001
Electricity main grid connection	179 (36%)	141 (46%)	0.005
Total land size (of all plots) in hectares	0.87 (1.17)	0.66 (0.77)	0.002

	NAICO households (n = 602)	**Non-NAICO households** (n = 403)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Total number of livestock	6.22 (16.14)	4.26 (5.79)	0.020
Livestock owned			
Goats	333 (55%)	223 (56%)	0.88
Cattle	234 (39%)	125 (31%)	0.014
Chicken	197 (33%)	102 (25%)	0.015
Sheep	95 (16%)	33 (8%)	<0.001
Pigs	90 (15%)	59 (15%)	0.93
Other livestock	31 (5%)	17 (4%)	0.52
No livestock	112 (19%)	85 (21%)	0.30
Agricultural income activities			
Cropping	604 (100%)	401 (100%)	
Livestock	495 (82%)	319 (80%)	0.34
Forestry	45 (7%)	21 (5%)	0.17
Beekeeping	9 (1%)	9 (2%)	0.38
Aquaculture/Pisciculture	0 (0%)	1 (0%)	0.22
Other	3 (0%)	3 (1%)	0.61
Monthly agricultural income			<0.001
1 - 250,000 RWF	271 (45%)	216 (54%)	
250,001 - 500,000 RWF	50 (8%)	17 (4%)	
500,001 - 1,000,000 RWF	35 (6%)	8 (2%)	
More than 1,000,001 RWF	23 (4%)	0 (0%)	
No income	225 (37%)	160 (40%)	
Median monthly agricultural income (RWF)	20,000	10,000	0.045
Annual agricultural income			<0.001
1 - 500,000 RWF	239 (40%)	278 (69%)	
500,001 - 1,000,000 RWF	138 (23%)	40 (10%)	

	NAICO households (n = 602)	**Non-NAICO households** (n = 403)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
1,000,001 - 2,000,000 RWF	121 (20%)	35 (9%)	
More than 2,000,001 RWF	106 (18%)	15 (4%)	
No income	0 (0%)	33 (8%)	
Median annual agricultural income (RWF)	700,000	180,000	<0.001
Non-agricultural income activities			
Daily labor (agricultural and others)	76 (13%)	129 (32%)	<0.001
Own business/self-employed	42 (7%)	18 (4%)	0.11
Informal sale	33 (5%)	19 (5%)	0.61
Skilled labor	21 (3%)	28 (7%)	0.012
Purchase and sale of agricultural products	12 (2%)	13 (3%)	0.21
Salaried work	14 (2%)	10 (2%)	0.86
Fishing, hunting, gathering	8 (1%)	9 (2%)	0.27
Handicrafts	10 (2%)	6 (1%)	0.84
Purchase and sale of livestock	9 (1%)	1 (0%)	0.052
VUP public works	4 (1%)	3 (1%)	0.87
Other non-agricultural activities	3 (0%)	1 (0%)	0.54
Pension	1 (0%)	2 (0%)	0.34
Remittances from friends and relatives	1 (0%)	0 (0%)	0.41
No non-agricultural activities	378 (63%)	179 (45%)	<0.001
Monthly non-agricultural income			<0.001
1 - 250,000 RWF	185 (31%)	198 (49%)	
250,001 - 500,000 RWF	14 (2%)	7 (2%)	

	NAICO households (n = 602)	**Non-NAICO households** (n = 403)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
No income	405 (67%)	196 (49%)	
Median monthly non-agricultural income (RWF)	0	1,750	<0.001
Annual non-agricultural income			<0.001
1 - 500,000 RWF	169 (28%)	189 (47%)	
500,001 - 1,000,000 RWF	20 (3%)	17 (4%)	
1,000,001 - 2,000,000 RWF	20 (3%)	8 (2%)	
More than 2,000,001 RWF	10 (2%)	6 (1%)	
No income	385 (64%)	181 (45%)	
Median annual non-agricultural income (RWF)	0	15,500	<0.001
Households with credit (%)			
Tontine (community)	102 (17%)	75 (19%)	0.46
Borrowed from relative, friend, or neighbor	13 (2%)	9 (2%)	0.92
SACCOs	12 (2%)	6 (1%)	0.57
Cooperative (incl. for inputs) - NAICO	8 (1%)	1 (0%)	0.08
Credit Cooperative	4 (1%)	2 (0%)	0.74
Microfinance	4 (1%)	2 (0%)	0.74
Informal lenders	1 (0%)	1 (0%)	0.77
VUP financial services loan	2 (0%)	0 (0%)	0.25
Farmer Cooperative (incl. for inputs) - non-NAICO	0 (0%)	1 (0%)	0.22
Other credit	8 (1%)	13 (3%)	0.037
No credit	456 (75%)	292 (73%)	0.34
Credit amount (RWF)			
Tontine (community)	115,412 (138,521)	75,080 (74,227)	0.023

	NAICO households (n = 602)	**Non-NAICO households** (n = 403)	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Purpose of credit			0.15
Agricultural inputs	23 (16%)	15 (14%)	
Education	10 (7%)	10 (9%)	
Medical treatment	10 (7%)	7 (6%)	
Purchase of household items	9 (6%)	7 (6%)	
Business expansion	7 (5%)	8 (7%)	
Agricultural equipment	13 (9%)	1 (1%)	
House improvement	5 (3%)	6 (6%)	
Livestock purchase	6 (4%)	1 (1%)	
Ceremony (marriage, funeral, baptism)	3 (2%)	1 (1%)	

Table 10 / NAICO and non-NAICO households' income and savings

	NAICO households (n = 602)	**Non-NAICO households** (n = 403)	**Difference**	**p-value**
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	*%*	
Average monthly agricultural income (RWF)	164,738 (369,151)	58,350 (134,078)	+182%	<0.001
Average annual agricultural income (RWF)	1,206,425 (1,420,180)	421,217 (691,187)	+186%	<0.001
Average monthly non-agricultural income (RWF)	23,405 (74,607)	21,031 (51,610)	+11%	0.551
Average annual non-agricultural income (RWF)	190,217 (643,768)	149,487 (418,613)	+27%	0.237
Savings (RWF) in last 30 days	95,166 (310,451)	42,395 (160,226)	+124%	0.002

Note: The monthly and annual agricultural and non-agricultural income reported were winsorized at 99%.

2.3.2 Impact of the Nasho Irrigation Project

In this section, we assess the impact of the Nasho Irrigation Project on plots, households, and the community in the Nasho area.

2.3.2.1 Plot level

In this subsection, we first present descriptive statistics on agricultural inputs, labor requirements, harvests, and yields, before estimating the average treatment effects of the Nasho irrigation scheme at the plot level.

Table 11 / Averages for hired labor, use of agricultural inputs, and agricultural practices by plot type

	Nasho plots (n = 608)	**Non-Nasho plots** (n = 607)	**p-value**[1]
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Use of hired labor			
Weeding	541 (89%)	406 (67%)	<0.001
Planting	517 (85%)	402 (66%)	<0.001
Land preparation	516 (85%)	379 (62%)	<0.001
Harvesting	503 (83%)	330 (54%)	<0.001
Spraying of fertilizer, herbicides, or pesticides	266 (44%)	131 (22%)	<0.001
Threshing	207 (34%)	124 (20%)	<0.001
Residue management	120 (20%)	56 (9%)	<0.001
Mulching	22 (4%)	47 (8%)	0.002
Other	50 (8%)	10 (2%)	<0.001
None	50 (8%)	138 (23%)	<0.001
Minimum tilling	596 (98%)	516 (85%)	<0.001
Permanent organic soil cover	213 (35%)	153 (25%)	<0.001
Crop rotation[2]	608 (100%)	463 (77%)	<0.001
Practices conservation agriculture[2 3]	209 (34%)	91 (15%)	<0.001
Residue usage			
Compost of residue within the plot	350 (58%)	331 (55%)	0.29

	Nasho plots (n = 608)	Non-Nasho plots (n = 607)	p-value[1]
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Chop and spread residue on the plot	188 (31%)	78 (13%)	<0.001
Remove for feeding animals	85 (14%)	133 (22%)	<0.001
Remove for mulching other crops	29 (5%)	129 (21%)	<0.001
Remove for cooking	8 (1%)	6 (1%)	0.59
Other	30 (5%)	18 (3%)	0.078
Use of organic fertilizers			
Manure	204 (34%)	306 (50%)	<0.001
Compost	190 (31%)	121 (20%)	<0.001
None	220 (36%)	194 (32%)	0.12
Use of inorganic fertilizers			
DAP	571 (94%)	303 (50%)	<0.001
Urea	417 (69%)	328 (54%)	<0.001
Other	35 (6%)	27 (4%)	0.30
None	4 (1%)	199 (33%)	<0.001
Use of pesticides			
Profex super	445 (73%)	239 (39%)	<0.001
Cypermethrin (Thioda)	218 (36%)	80 (13%)	<0.001
Dithane	166 (27%)	36 (6%)	<0.001
Rocket	30 (5%)	74 (12%)	<0.001
Other	108 (18%)	68 (11%)	0.001
None	4 (1%)	225 (37%)	<0.001
Use of certified seeds	604 (99%)	296 (49%)	<0.001
Agricultural practices			
Weeding	585 (96%)	579 (95%)	0.47
Plowing[6]	582 (96%)	578 (95%)	0.67

	Nasho plots (n = 608)	Non-Nasho plots (n = 607)	p-value[1]
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	
Planting in rows	598 (98%)	337 (56%)	<0.001
Plant spacing	404 (66%)	232 (38%)	<0.001
Anti-erosion practices	103 (17%)	176 (29%)	<0.001

[1]This p-value compares Nasho to non-Nasho plots. It reflects a chi-squared test for categorical variables and a t-test for continuous variables. [2]Sample size for non-Nasho plots is n=602. [3]Practicing conservation agriculture is defined as minimum tilling, usage of permanent organic soil cover on at least 30% of the land, and practicing crop rotation (https://www.fao.org/conservation-agriculture/en/). [6]Plowing is defined as preparing the land before sowing either by humans, animals, or tractors and can include minimal or deep tilling.

Table 12 / Average expenditures on hired labor and agricultural inputs

	Nasho plots (n = 608)	Non-Nasho plots (n = 607)	Difference	p-value
	N (%) or Mean (SD)	*N (%) or Mean (SD)*	*%*	
Hired labor expenditure per ha (RWF)[1]	385,504 (301,815)	163,307 (229,715)	+136%	<0.001
Expenditures on org. fertilizers per ha (RWF)[1]	117,635 (197,522)	64,991 (153,467)	+81%	<0.001
Expenditures on inorg. fertilizers per ha (RWF)[1]	199,043 (171,644)	83,623 (144,419)	+138%	<0.001
Expenditures on pesticides per ha (RWF)[1 2]	69,964 (72,491)	23,303 (43,578)	+200%	<0.001

[1]Observations that did not spend money on the inputs were assigned the value zero. [2]Sample size for Nasho plots is n=607 and for non-Nasho plots n=606.

Table 11 and Table 12 present averages for hired labor, use of agricultural inputs, and agricultural practices as reported by the respondents. Overall, we see significant differences between Nasho and non-Nasho plots for most indicators described in more detail below.

Hired labor

Significantly more farmers employed labor on Nasho plots compared to non-Nasho plots (92% vs. 77%, p<0.001). Consequently, farmers spent on average significantly more money on hired labor per hectare on Nasho plots than on non-Nasho plots (421,272 vs. 172,350 RWF, 323 vs. 132 USD, p<0.001).

"I use a worker in harvesting the grown crops like soya beans. This worker has to be paid for the job done." – **Female NAICO farmer**

"Today, because of irrigation, people come here, and we employ them; even now, a worker has already arrived. They are paid 2,000 RWF and they are sometimes given 3,000 RWF if they cultivated a whole piece of land." – **Female NAICO farmer**

Agricultural inputs

The proportion of plots that did not receive any organic fertilizer is similar for Nasho and non-Nasho plots (36% and 32%, respectively). 50% of non-Nasho plots receive manure, compared to 34% of Nasho plots ($p<0.001$). Conversely, 31% of Nasho and 20% of non-Nasho plots receive compost ($p<0.001$). Even though the proportion of plots using any organic fertilizer is similar for Nasho and non-Nasho plots, the expenditures per hectare on organic fertilizers are significantly higher for Nasho plots (128,363 vs. 70,100 RWF, 99 vs. 54 USD, $p<0.001$).

"We work with some local cooperatives that sell agricultural inputs. When we need them, we send vehicles to pick them up from some people who produce fertilizers. People in Ndego are the ones who mostly make them because they have livestock. They mix their waste with some leftover grass to make the fertilizers. I have never received fertilizers from NAICO." – **Male non-NAICO farmer**

In terms of the usage of inorganic fertilizers and pesticides, we see significant differences between Nasho and non-Nasho plots. Generally, the usage of inorganic fertilizers and pesticides is higher on Nasho plots. The most commonly used inorganic fertilizers are Urea and DAP, followed by a few plots using other types. Most (94%) Nasho plots receive DAP, compared to only 50% of non-Nasho plots ($p<0.001$). This is followed by the use of Urea: 69% of Nasho and 54% of non-Nasho plots are sprayed with Urea. 33% of non-Nasho plots do not receive any inorganic fertilizers, compared to only 1% of Nasho plots ($p<0.001$).

The most commonly used pesticides are Profex super, Cypermethrin (Thioda), Dithane, and Rocket, with Nasho plots consistently using more than non-Nasho plots.[23] 37% of non-Nasho plots receive no pesticides, compared to only 1% of Nasho plots ($p<0.001$).

"This is when we started farming using the modern farming practices they trained us such as using inorganic fertilizer which we did not use before, they also trained us about using compost and we learned how to produce it." – **Male NAICO farmer**

"I plant two maize seeds 40 cm apart from each other and in the holes I put in both compost and DAP fertilizers, then put on a small amount of soil and then use a small hoe to plant 2 maize seeds in the hole." – **Male NAICO farmer**

In line with the higher use of inorganic fertilizers and pesticides, the expenditures per hectare are significantly higher for Nasho than non-Nasho plots for both inorganic fertilizers

[23] Dithane is a fungicide; Profex super, Cypermethrin, and Rocket are insecticides against fall army worm.

(220,563 vs. 91,210 RWF, 169 vs. 70 USD, p<0.001) and pesticides (78,914 vs. 24,628 RWF, 61 vs. 19 USD, p<0.001).

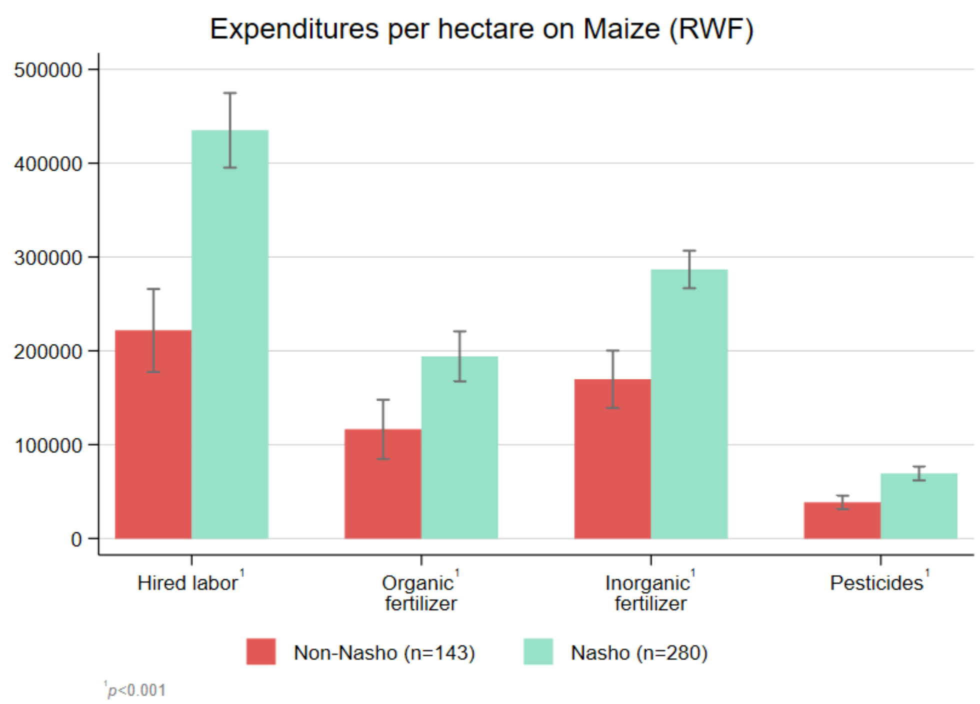
Certified seeds were used on almost all (99%) Nasho plots and 49% of non-Nasho plots (p<0.001).

> *"So, when we started farming, we started by growing maize; they [NAICO] provided good seeds, and the seeds gave excellent harvest and we were happy about it."* – **Female NAICO farmer**

By crop

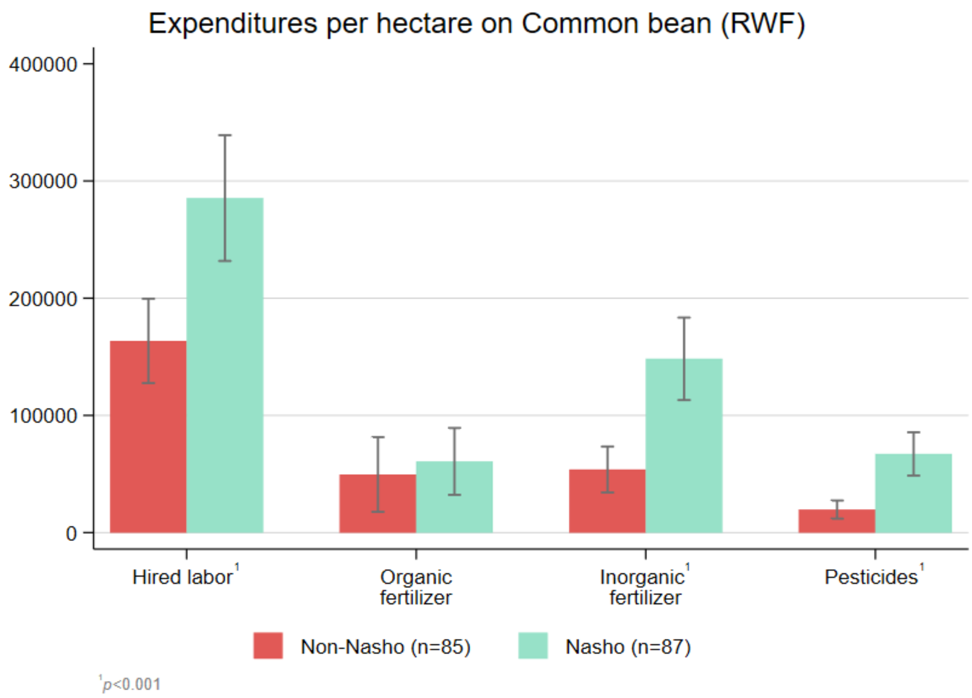
Figure 5 and Figure 6 show the expenditures on the different inputs per hectare by crop for maize and common beans. In order to assess the expenditures on each crop, we restricted the sample to plots that only grow one crop (given that the data collected was for input usage for the entire plot, but not for each crop on the plot individually).

Figure 5 / Expenditures per hectare on maize



For maize, we see that significantly more money is being spent on all four inputs (hired labor, organic fertilizer, inorganic fertilizer, and pesticides) on Nasho plots. Expenditures on hired labor are almost twice as high on Nasho plots than on non-Nasho plots (438,421 vs. 221,674 RWF, 337 vs. 170 USD, p<0.001).

Figure 6 / Expenditures per hectare on common bean



For common beans, the expenditures are again significantly higher for Nasho plots for hired labor, inorganic fertilizer, and pesticides. The difference for organic fertilizer is not significant (p=0.61).

The small sample size of non-Nasho plots that only grow soybean (n=4) does not allow us to compare expenditures on inputs between Nasho and non-Nasho for this crop. However, we see that the expenditures on soybean on Nasho plots on each of the four inputs are similar to those for maize and common beans (Figure 24 in the annex).

Agricultural practices

Plot managers were asked about agricultural practices employed on the sampled plot. Overall, more practices were reported to be practiced on Nasho plots than on non-Nasho plots. Weeding and plowing (land preparation before sowing) are reported to be most commonly practiced (95-96%), with no significant differences between the two groups. The rates for weeding differ slightly from the enumerator observations reported in Table 6 which may also be due to the fact that enumerator observations took place after harvest. Further, while farmers may practice some weeding (as self-reported), few or many weeds may still remain on the plot (as observed by the enumerators) if weeding is not practiced thoroughly and/or regularly. The third most common practice is planting in rows which is reported by almost all (98%) Nasho plots but significantly less by non-Nasho plots (56%). Plot managers are also more likely to practice plant spacing (66%) on Nasho plots than on non-Nasho plots (66% vs. 38%, p<0.001). However, plot managers are more likely to report practicing anti-erosion measures on non-Nasho plots than on Nasho plots (29% vs. 17%, p<0.001). The self-reported rates differ slightly from the enumerator observations which are higher: enumerators indicated that 60% of non-Nasho and 28% of Nasho plots practice anti-erosion measures ($p<0.001$).[24] Among those plots that exhibit anti-erosion measures, the most commonly observed measures for Nasho plots are water channels (74%), followed by trenches (19%), and water drainage (13%). For non-Nasho plots, trenches are most commonly observed (68%), followed by water channels (28%), and trees/ windbreak/ shelterbelt (15%).

> *"Row planting goes well; plants give space to each other. When we plant crops, we maintain some cm; they recommended us to do it. we don't plant crops in a disordered manner; we space them instead so that crops can breathe and give good harvests. For maize, you find that the maize is fat."* – **Female NAICO farmer**

Conservation agriculture

Overall, more Nasho plots are pursuing conservation agriculture than non-Nasho plots (34% vs. 15%, $p<0.001$). The three main pillars of conservation agriculture are i) minimum soil disturbance (no or minimum till), ii) permanent organic soil cover (either through cover crops and/or crop residue) on at least 30% of the plot, and iii) crop rotation. More farmers practice minimum or no tilling on Nasho plots compared to non-Nasho plots (98% vs. 85%, $p<0.001$). Similarly, the soil on Nasho plots is also more likely to be permanently covered by cover crops or crop residue (35% vs. 25%, $p<0.001$). This is being translated into the uses of residues. Farmers are significantly more likely to remove the crop residue from non-Nasho plots compared to Nasho plots. As for erosion control measures and weeding, we also see differences between the self-reported data for residue usage and the observations made by enumerators for mulching which could be explained by different reference periods (enumerators reported what they saw on the land at the time of the survey while respondents were asked about their practices in the entire last agricultural season 2024A). Finally, crop rotation is practiced on all (100%) of Nasho plots and on 77% of non-Nasho plots ($p<0.001$).

> *"They attract insects and the insects feed on them. When those insects feed on them, compost is produced. So, they help in producing compost; the plant residues are broken down in the soil and when you come to apply the fertilizer, you find that the soil has natural fertilizer."* – **Male NAICO farmer**
>
> *"Min-till farming [minimum tillage farming] is good because we don't dig the soil deeper. We remove [the] topsoil and we also use a rope when planting."* – **Male NAICO farmer**

In addition, NAICO farmers were asked which of their farming practices have changed since becoming NAICO members (Figure 23 in the annex). The most named practice is sowing (93%), followed by fertilizer use (86%), land preparation (75%), pesticide use (69%), weeding (66%), and harvesting (46%). Mulching is the least reported practice to have changed, indicated by only 12%.

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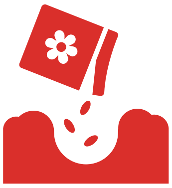
[24] The difference between Nasho and non-Nasho plots in adopting anti-erosion measures remains when focusing on plots with flat slopes only: 26% of Nasho and 55% of non-Nasho plots practice anti-erosion measures on flat plots.

"What changed in my farming is that we use compost, inorganic fertilizers, and pesticides; it changed a lot." – **Female NAICO farmer**

Spillover effects

NAICO farmers report that they apply newly taught skills also to their plots outside the irrigation scheme. Further, farmers also report that practices applied within the irrigation pivots were adopted by other farmers in the region who own plots outside the irrigation project.



Transferable skills: The skills taught to farmers were applied to farms that were outside the irrigation project. Skills such as row planting, use of manure, inorganic fertilizer, pesticides, and improved seeds were adopted by NAICO farmers in plots outside the irrigation project.

"I even started growing crops in rows in the outside fields." – **Female NAICO farmer**

"In the irrigation, there are the skills we learned from NAICO. So, we use the skills learned elsewhere, where it is possible. As a result, when you do it, you find that it goes well." – **Male NAICO farmer**

9 out of 12 NAICO farmers[25]

Adoption of farming practices by other farmers: Farmers also report that farming practices applied within the irrigation pivots were adopted by other farmers in the region who own plots outside the irrigation project.

"The Kabuye people learned our farming practices as well; they were expanded to Kabuye." – **Male NAICO farmer**

"It is the development of farming practices. Even farmers of outside fields started to adopt the efficient use of manure. They started copying farming practices that are used by the irrigation project and when they are lucky, the rain comes, and crops grow as they are fertilized. This adoption and copying of the same farming practices is the main reason for the increase of land value." – **Female NAICO farmer**

"We learned a lot from them [NAICO]. For instance, when you plant beans using row planting, they give a different harvest than beans that were planted in a disordered manner. We also used to plant maize scattered. However, today, we planted them in rows, and as a result, the harvest has increased. Many things have changed. For instance, I would not harvest more than one sack but today, I cannot fail to get 10 sacks of harvest." – **Male non-NAICO farmer**

9 out of 12 NAICO farmers; 5 out of 8 non-NAICO farmers

[25] The theme of "transferable skills" was mentioned in 9 out of 12 NAICO farmer transcripts. It's important to note that the absence of this theme in the remaining 3 transcripts does not imply its negation among those farmers, but rather that it was not discussed during those interviews. This consideration is pertinent for all qualitative assessments conducted throughout the report.

Harvest and sales

Table 13 compares the overall harvest, harvest that was sold, revenue from sales, and the price per kg sold for maize, common bean, and soybean, respectively.[26] [27] We see that the total harvest per hectare in kg as well as the harvest per hectare in kg that was sold is significantly higher on Nasho plots for all three crops. When looking at the amount of harvest per hectare in kg that was kept for home consumption, however, we do not see significant differences for any crop between the two groups (Table 24 in the annex).[28] This shows that the needs for home consumption are the same for Nasho and non-Nasho plots. We again see considerable differences between Nasho and non-Nasho plots in terms of the revenue per hectare for each of the three crops, with the revenue for maize being the highest for both groups (2,129,478 and 908,032 RWF, 1,635 vs. 697 USD, per hectare, respectively).[29] The prices secured per kg sold are similar between Nasho and non-Nasho plots for common beans and soybeans. For maize, secured prices are higher for Nasho plots than non-Nasho plots (361 vs. 292 RWF, 0.28 vs. 0.22 USD, p<0.001).

Table 13 / Overall harvest, harvest sold, revenue, and price per kg sold for maize, common bean, and soybean

	Nasho plots	Non-Nasho plots	Difference	p-value[1]
	Mean (SD)	*Mean (SD)*	*%*	
Harvest in kilogram per hectare				
Maize (n = 1,108)	6,272 (4,143)	3,000 (3,560)	+109%	<0.001
Common bean (n = 783)	1,437 (1,292)	1,194 (1,266)	+20%	0.025
Soybean (n = 516)	2,176 (1,014)	777 (664)	+180%	<0.001
Harvest in kilogram per hectare that was sold				
Maize (n = 1,108)	5,596 (6,788)	1,382 (2,931)	+305%	<0.001
Common bean (n = 782)	592 (1,055)	245 (608)	+142%	<0.001
Soybean (n = 516)	2,001 (1,695)	513 (626)	+290%	<0.001
Revenue per hectare (RWF)[30]				

[26] We restricted our analysis to the plots that had completed the harvest of the respective crop for the relevant season (agricultural season 2024A) by the time we collected the data.

[27] The sample size for all soybean-related averages is small for the non-Nasho plots (N=32 and less) and the comparison between Nasho and non-Nasho for soybean should therefore be seen only indicatively.

[28] Other harvest uses in addition to sales and keeping for home consumption, are storing, sharecropping out, saving for feed, giving away, animal feed, using for wages, and lost post-harvest. Few observations report these uses and they are therefore not reported in this table.

[29] Revenue is defined as the money received from selling the harvest (in RWF).

[30] Means exclude observations that did not sell the harvest of the respective crops.

	Nasho plots	Non-Nasho plots	Difference	p-value[1]
	Mean (SD)	*Mean (SD)*	*%*	
Maize (n = 755)	2,129,478 (2,375,035)	908,032 (1,119,720)	+135%	<0.001
Common bean (n = 286)	599,383 (658,411)	406,186 (564,868)	+48%	0.009
Soybean (n = 485)	1,481,041 (1,180,289)	461,422 (408,171)	+221%	<0.001
Price per kilogram sold (RWF)				
Maize (n = 755)	361 (93)	292 (122)	+24%	<0.001
Common bean (n = 286)	567 (255)	493 (389)	+15%	0.083
Soybean (n = 485)	714 (291)	624 (82)	+14%	0.14
Total sales per hectare (RWF) (n = 2,445)	1,522,018 (1,851,625)	330,976 (1,508,349)	+360%	<0.001

When considering total sales per hectare from all crops combined, sales for the Nasho plots are considerably higher than for the non-Nasho plots (1,522,018 vs. 330,976 RWF, 1,168 vs. 254 USD, p<0.001). A possible explanation for this is that NAICO buys the produce from its members and can secure a market as well as higher prices.

The above findings are corroborated by the qualitative interviews with NAICO farmers who report positive changes to their plot yields.

Reliable harvest: Farmers report that they enjoy consistent harvest regardless of the weather conditions.

"The good thing today is that when there is no rain, our crops are irrigated, and we get the harvest." – **Female NAICO farmer**

3 out of 12 NAICO farmers

Increased yield: Most farmers mention that they now enjoy increased yields.

"For instance, previously, I harvested around 600 kilograms on the farm, which equated to the 5 sacks of sorghum I mentioned. However, now I yield approximately 2 tons of maize. As soybeans fetch a different price compared to maize, I harvest at least 900 kilograms of soybeans. When considering their respective prices, you can observe a significant difference in the yield compared to what was previously obtained." – **Male NAICO farmer**

"So, the success has been also in those areas where the yield in some cases is

tenfold. So, I would say production is a big big success." – **NAICO Management**

7 out of 12 NAICO farmers; 2 NAICO Management and Leadership team

Average treatment effects of the Nasho Irrigation Project at the plot level

We present the average treatment effects of the Nasho Irrigation Project as estimated by the RDD model both in tables and plots. Figure 7 and Figure 8 below, and Figure 26, Figure 27, and Figure 28 in the annex plot the linear regressions of the outcome measures on the distance from the boundary of the treatment area. Table 25, Table 26, and Table 27 in the annex present the corresponding point estimates from the linear RDD regressions.

Harvests

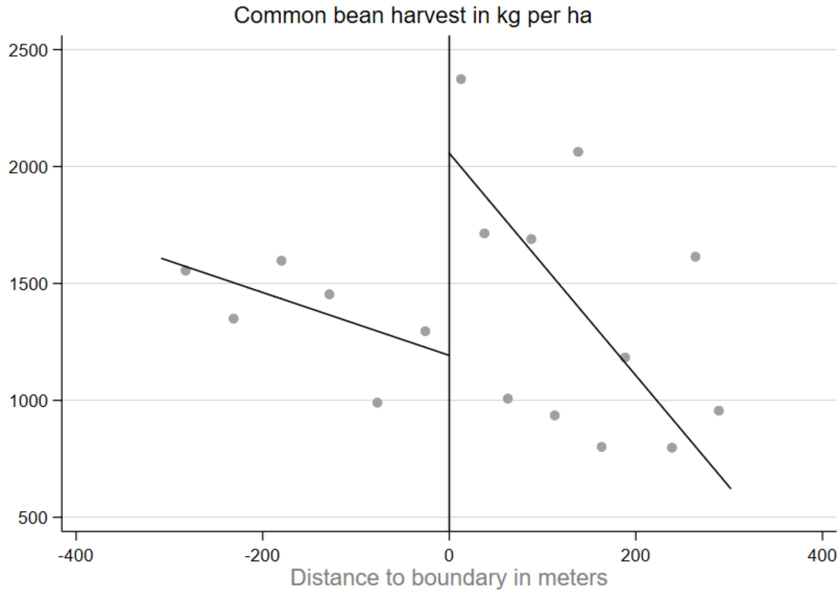
The RDD regressions show a significant effect of the Nasho Irrigation Project at the plot level on the harvest (Table 25 in the annex). The project on average increased the harvest of maize by 3,204 kg per hectare ($p<0.001$). The jump at the cutoff line is also clearly visible in Figure 7.[31]

Figure 7 / Effect of the Nasho Irrigation Project on maize harvest

The increase in the harvest of common beans is positive in magnitude (996 kg), but statistically insignificant ($p=0.081$). The lack of significance is supported by the relatively small jump in the cutoff in Figure 8.

[31] Figure 7 visualizes the results of the regression discontinuity calculations. The x-axis depicts the distance to the pivot boundary in meters, a positive distance (between 0 and 400) meaning that the plot is inside a pivot, and a negative distance (between -400 and 0) meaning that the plot is outside of a pivot, e.g., at a distance of 400 meters. The y-axis shows the maize harvest in kg per hectare. The jump of the maize harvest at the cutoff depicts the effect of the irrigation pivots.

Figure 8 / Effect of the Nasho Irrigation Project on common bean harvest



The project also increased the harvest of soybeans significantly on average by 1,302 kg; however, we need to note that the sample size for the control plots (i.e., plots outside the irrigation scheme) is very small with N=17; the results for soybeans are therefore only indicative (Figure 26 in the annex).

Agricultural inputs

We see significant impacts of the Nasho Irrigation Project on the usage of various agricultural inputs. The project increased the expenditures per hectare on organic and inorganic fertilizers on average by 42,964 RWF (USD 33) ($p=0.039$) and 148,167 RWF (USD 114) ($p<0.001$), respectively (Table 26 in the annex). Expenditures on pesticides were on average increased by 71,532 RWF (USD 55) per hectare ($p<0.001$). Lastly, the intervention also increased average expenditures on hired labor on plots of 148,104 RWF (USD 114) ($p<0.001$). These significant improvements are confirmed visibly by the clear jumps along the cutoff line in Figure 27 in the annex.

Agricultural practices

Finally, the Nasho Irrigation Project also significantly affected agricultural practices employed on the plots. The intervention increased minimum tilling and planting in rows by 15.3 ($p=0.006$) and 47.4 percentage points ($p<0.001$), respectively (Table 27 in the annex). Permanent organic soil cover is also more likely to be seen on Nasho plots than non-Nasho plots, but the effect is only marginally significant ($p=0.061$). These results are substantiated by the plots in Figure 28 in the annex.[32]

Soil quality

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[32] As a robustness check, we ran all regressions controlling for the plot´s soil type, slope and degree of erosion as we saw significant differences for these indicators between Nasho and non-Nasho plots. The results remain robust to the inclusion of these variables.

In the household survey, NAICO farmers were asked how the soil quality of the plot inside the irrigation scheme has changed since the start of the project and the feedback was overwhelmingly positive (Figure 25 in the annex).[33] 48% reported that it improved a little bit and 48% reported it improved significantly. 2% stated it stayed the same and only 2% stated the quality worsened. Further, when asked which of their plots has the best soil quality in their opinion, 76% of NAICO farmers stated that their plot with the best soil quality is a plot that lies inside the Nasho irrigation scheme.

2.3.2.2 Household level

In this section, we compare outcomes for three different groups: plot managers who farm plots inside the Nasho irrigation area only (Nasho only), plot managers who farm plots both inside and outside the Nasho irrigation area (mixed), and plot managers who only farm plots outside the irrigation area (non-Nasho only). The division into three instead of two groups gives insights into whether the households that own plots outside the scheme but nevertheless are NAICO members display different behavior compared to NAICO members who are bound to their plots inside the scheme. By comparing variations in means, we can assess how different the three groups are.

Harvest use

Table 14 shows how households use their harvests by presenting the proportion of each use for Nasho-only, non-Nasho, and mixed households of mixed and non-Nasho households (for all crops combined).

Table 14 / Proportion of harvest uses by group

	Nasho-only (n = 331)	**Nasho and non-Nasho** (n = 439)	**Non-Nasho only** (n = 445)
	% (SD)	*% (SD)*	*% (SD)*
Sold[1]	76% (28)	70% (25)	34% (32)
Kept for consumption[1]	19% (24)	22% (20)	46% (34)
Stored[1]	2% (10)	5% (15)	13% (26)
Sharecropped out[1]	1% (6)	0% (3)	2% (9)
Saved for feed[1]	0% (4)	0% (2)	2% (6)
Given away	1% (5)	1% (4)	1% (6)
Used for wages/labor	1% (5)	1% (3)	0% (3)
Animal feed	0% (0)	0% (1)	0% (0)
Lost post-harvest	0% (1)	0% (3)	0% (1)

[1]The difference between the three groups is statistically significant (p<=0.05) using a one-way ANOVA test.

[33] The results are based on farmer perceptions; soil quality was not tested as part of this study.

As expected, Nasho-only and non-Nasho-only households differ the most. Mixed households lie either between or are not statistically significantly different from Nasho-only households. The key difference between Nasho (both Nasho-only and mixed) and non-Nasho households is that Nasho households sell a significantly higher proportion of their harvest and therefore use a lower proportion for home consumption and storage. Non-Nasho-only households sell on average 34% of their harvest, while Nasho-only households sell 76%. The difference between Nasho-only and mixed households is smaller: mixed households sell on average 70% of their harvest. Non-Nasho households keep on average 46% of their harvest for home consumption, while Nasho-only and mixed households only keep 19% and 22%, respectively. Further, non-Nasho-only households store on average store 13% of their harvest, while mixed and Nasho-only households only store 5% and 2%, respectively.

Ways of marketing produce

Overall, NAICO is the biggest buyer of harvested produce in our sample (Table 15). We see, however, significant differences in how NAICO and non-NAICO members market their maize, common beans, and soybean harvests.[34] Households that own plots only inside the Nasho irrigation scheme predominantly sell their maize harvest to NAICO (97%). For mixed households (those who farm Nasho and non-Nasho plots), the majority (79%) still sells its maize harvest to NAICO, but also to some other buyers such as other cooperatives (7%), farmers/consumers directly (5%), or local markets/roadside sellers (5%). For non-Nasho households, the distribution of maize buyers is more diverse. 27% predominantly sell to middlemen and local markets/roadside sellers, respectively; 21% sell to other cooperatives, and 12% sell to the farmer/consumer directly.

> *“We cultivated and they [NAICO] promised to find the market for us. So, they found a market for us, and they asked us to cut the maize plants on the same day and peel the leaves off on the same day as well.”* – **Female NAICO farmer**
>
> *“We sold it [harvest] to COVAMIS.”* – **Female non-NAICO farmer**

For common beans, the picture looks slightly different. Only 70% of Nasho-only households sell their harvest to NAICO. This is followed by local markets/roadside sellers (13%), and farmers/consumers (11%). Mixed households sell their common bean harvest equally to NAICO and local markets/roadside sellers (28% each). Farmers/consumers (21%) and middlemen (20%) are other common buyers. 44% of non-Nasho households predominantly sell their common bean harvest to local markets/roadside sellers. This is followed by middlemen (33%) and farmers/consumers (19%).

[34] For each harvested crop that the farm manager sold, they were asked to whom they primarily sell the crop's harvest.

For soybeans, the majority of Nasho-only (93%) and mixed households (85%) sell their harvest to NAICO. Few households sell to farmers/consumers, local markets/roadside sellers, or middlemen.[35]

Table 15 / Ways of marketing produce by household type

	Nasho-only	Nasho and non-Nasho	Non-Nasho only
	N (%)	*N (%)*	*N (%)*
Maize[1]	**(n = 220)**	**(n = 366)**	**(n = 169)**
Cooperative (NAICO)	214 (97%)	288 (79%)	9 (5%)
Local market/ roadside seller	2 (1%)	18 (5%)	46 (27%)
Cooperative (non-NAICO)	1 (0%)	27 (7%)	35 (21%)
Middlemen	1 (0%)	11 (3%)	46 (27%)
Farmer/consumer	1 (0%)	17 (5%)	21 (12%)
Processor	0 (0%)	3 (1%)	6 (4%)
Commercial company	0 (0%)	0 (0%)	2 (1%)
Other	1 (0%)	2 (1%)	4 (2%)
Common beans[1]	**(n = 53)**	**(n = 125)**	**(n = 108)**
Local market/ roadside seller	7 (13%)	35 (28%)	48 (44%)
Cooperative (NAICO)	37 (70%)	35 (28%)	2 (2%)
Middlemen	2 (4%)	24 (20%)	36 (33%)
Farmer/consumer	6 (11%)	26 (21%)	21 (19%)
Commercial company	1 (2%)	1 (1%)	1 (1%)
Cooperative (non-NAICO)	0 (0%)	1 (1%)	1 (1%)
Other	0 (0%)	1 (1%)	1 (1%)
Soybeans[1]	**(n = 201)**	**(n = 270)**	**(n = 14)**
Cooperative (NAICO)	186 (93%)	230 (85%)	4 (29%)

[35] The sample size of non-Nasho households that harvest and sell soybeans is too small to make a meaningful assessment on how they market their produce.

	Nasho-only	Nasho and non-Nasho	Non-Nasho only
	N (%)	*N (%)*	*N (%)*
Middlemen	7 (3%)	9 (3%)	2 (14%)
Local market/ roadside seller	5 (2%)	13 (5%)	6 (43%)
Farmer/consumer	1 (0%)	15 (6%)	1 (7%)
Cooperative (non-NAICO)	1 (0%)	1 (0%)	1 (7%)
Commercial company	1 (0%)	1 (0%)	0 (0%)
Other	0 (0%)	1 (0%)	0 (0%)

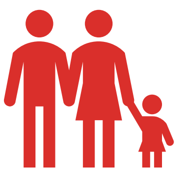
[1]The difference between the three groups is statistically significant ($p<0.001$) using a Chi-square test.

Time spent farming

NAICO farmers report spending more time on their farming activities since becoming members (Figure 29 in the annex). 47% report spending a little more and 37% report spending a lot more time. Around 6% report spending less time and 10% reported no change.

Livelihoods

NAICO farmers mention that their livelihoods have improved, for example by being able to afford school fees or having access to electricity.



Improved livelihoods: Farmers have experienced improvements in their livelihoods as a result of the irrigation project.

"We [have] light; we charge and we sleep in a place that has light. We even light the outside. I recently bought this closet; I bought it for 100,000 RWF. I improved my food as well." **– Female NAICO farmer**

"Another thing, it was difficult to send our children to school, but nowadays I can say that in 3 or 4 months I will have the produce and then talk to the school about when I will pay the school fees. So those are some of the positive impacts. I can afford to pay the community health insurance, without having to worry about it."

- Male NAICO farmer

5 out of 12 NAICO farmers[36]; 1 NAICO Management and Leadership team

[36] Each respondent was asked a set of open-ended questions based on a semi-structured guide. However, respondents are free to bring up themes themselves as well which would then be probed further by the moderators. 5 out of 12 NAICO farmers mentioning improved livelihoods means that this theme came up in 5

NAICO farmers were also asked about their perception of whether the money they have left over at the end of each month has decreased or increased by a randomly created number ranging from -25,000 RWF (meaning a decrease of 25,000 RWF (USD 19)) to +100,000 RWF (meaning an increase by 100,000 RWF (USD 77)) since becoming a member (Figure 30). We see that the majority of those who were assigned a positive value confirmed and the majority of those who were assigned a negative value denied. We can therefore say that most respondents perceive that their profits have increased since becoming a NAICO member.

Non-cash benefits

NAICO farmers highlight key benefits experienced as a result of being part of the irrigation project:

Food availability and accessibility: Food is accessible to the community because of the irrigation project. A variety of foods have been made available to the community members.

"Before, food was not enough. However, today, one cassava which is the size of this arm costs 1,000 RWF." – **Female NAICO farmer**

"Generally, food accessibility is easy; it is not very expensive compared to other places that don't irrigate." – **Male NAICO farmer**

6 out of 12 NAICO farmers

Received training: NAICO management as well as agronomists mention that the cooperative invested in providing agricultural training to farmers. Farmers also mention how valuable these training sessions were to their farming practices.

"So, the foundation [HGBF] even paid for a group from South Africa to give farmers training on agronomy, farm management, and conservation agriculture."

– **NAICO Management**

"Mostly they [trainings] focus on preparing farms and encouraging farmers to cultivate. During the season we train them on preventing certain crop diseases and about weeding. The training takes place at the start, during, and at the end of the season. At the end of the season, we teach them about storage of the harvest and hanging their harvest so that it can dry." – **Sector Agronomist**

"They [NAICO] helped us after the irrigation system came; they trained us, they trained us that practicing row planting is better and leads to a harvest and it is seen. A person who practiced row planting cannot get the same harvest as a person who planted crops in a disordered manner. I may say that those are the benefits we got after the irrigation system came." – **Male NAICO farmer**

6 out of 12 NAICO farmers; 2 NAICO Management and Leadership team; 1 Sector Agronomist

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NAICO farmer interviews. It does not mean that the other 7 NAICO farmers stated to have not experienced improved livelihoods.

Reliable water supply: Access to continuous water supply is a key benefit of the irrigation project.

"Importantly, there is no problem with water. No one struggles with water pipes when irrigating." – **Male NAICO farmer**

"I was optimistic because we were not used to having rain. They told us that they were going to irrigate, and we would cultivate each season without stopping. Before, we would harvest and stop and wait for the rain. When it rains, we would dig up the land and when it rains again, we would make the land well and plant crops. However, today because the irrigation systems always irrigate, we don't have to stop farming; we continue to farm each season instead." – **Female NAICO farmer**

3 out of 12 NAICO farmers

Access to agricultural inputs on credit: Farmers receive agricultural inputs on credit from NAICO.

"Since we know our members, we can give them fertilizers in case they don't have money and get our money back at the time of harvest. I think that it is a good thing because it prevents our farmers from getting fertilizers from anywhere else since they know that they can get fertilizers whether they have money or not, and if they don't have money, they pay back in the harvest season." – **NAICO Leadership**

"We started working with them [NAICO] then, we approached them, and they lent us seed crops. We harvested and gave them the yields. They sold it and took the amount corresponding to the loan they gave us as repayments." – **Female NAICO farmer**

2 out of 12 NAICO farmers; 2 NAICO Management and Leadership team

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Ready market for harvest: Another benefit enjoyed by NAICO farmers is a ready market sourced by the cooperative.

"We choose to sell to them because they offer a market for our produce. The price offered by NAICO cooperative for our harvest differs from that of other markets; NAICO's prices are slightly higher." – **Male NAICO farmer**

"The cooperative agrees to contract with buyers, they will search the buyers and usually that offer the best price. They will consolidate the harvest and it is a benefit to the farmer to get a better price, but it is also a benefit to the buyer to get a consolidated harvest; so, they can just load one truck at once or 10 trucks at once. It is more efficient, and it is faster for them." – **NAICO Management**

7 out of 12 NAICO farmers; 2 NAICO Management and Leadership team

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2.3.2.3 Community level

The wider Nasho community has seen improvements to its roads, the creation of a health center, and increased employment.

Road improvements: The community now enjoys better road systems.

"The tarmac road leads us to development as well. The way the road is leading us to development, we now travel well. We travel from there to Kigali in good conditions." – **Male NAICO farmer**

"They have helped us to construct roads, every pivot is surrounded by a road. The farmers would easily access fertilizers and their harvest would be easily accessed too. They did not only help us with that alone." – **NAICO Leadership**

6 out of 12 NAICO farmers; 1 Local leadership and MINAGRI; 1 NAICO Management and Leadership team

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Increased employment: The irrigation project has led to an increase in job opportunities for farmers in the area.

"When we have suffered from the sunshine or are suffering from hunger, we go to work for them [NAICO farmers] and get paid, and if the payment is money; they pay or if it is food they pay, you are paid in what you have chosen." – **Female non-NAICO farmer**

"So, I think it has had a positive impact on job creation. In the irrigation project, we have more than 1,000 employees who work there every day, and sometimes they can go beyond, for instance, in this season we get about 2,000 employed residents. So, it has decreased the burden of unemployment, so residents are making money." – **Local Leadership**

5 out of 8 non-NAICO farmers; 3 Local leadership and MINAGRI

Built a health center: Nasho residents also have access to health facilities.

"Regarding health care, Before the irrigation came, it was not clear enough. For instance, the roads were bad; we had made path walks and the hospitals/health centers were few. However, after the irrigation came, there were health centers. Were those health centers there before? The health centers were not there before. […]. Even in the places where hospitals/health centers existed, they expanded them. Before, getting medication was difficult but today, it is no longer difficult because roads are there, and patients reach the hospitals/health centers on time." – **Male NAICO farmer**

"For example, there is a model village in which they have relocated residents who had farms at the project site, that also [has] infrastructure such as a health post. All these developments stemmed from the residents being gathered in one location, enabling access to essential infrastructure that supports their daily livelihoods." – **Sector Agronomist**

2 out of 12 NAICO farmers; 1 Local leadership and MINAGRI

Built education facilities: Residents also have access to learning facilities.

"There are other infrastructures as well such as a toddlers' school, an early childhood development (ECD) facility and there is the Integrated Crafts Production Centers (Agakiriro)." – **Sector Agronomist**

"For example, there is a health post, an ECD, and a hall, all of these have been introduced because the residents got together as a result of the introduction of the irrigation system." – **Male NAICO farmer**

2 out of 12 NAICO farmers; 1 Local leadership and MINAGRI

2.3.2.4 Unintended consequences

Farmers noted both positive and negative unintended consequences of the project during the qualitative interviews. NAICO farmers highlighted a positive unintended consequence: land value within the irrigation pivots has increased. Non-NAICO farmers also noted this trend and added that land value outside the irrigation pivots remains much lower. Some farmers also mention negative unintended consequences, mostly due to their perceptions before the project´s implementation, whereby during the inception phase, older or poor farmers sold their land, as well as farmers who feared their land would be taken from them. It is important to note that this was a fear of the farmers but in practice, no land was taken from farmers and farmers were not forced to sell their land; farmers remaining land owners was a key component of the project.

Increased land valuation inside the pivot: NAICO farmers attribute the increase in value of land within the pivots to the irrigation project.

"The monetary value of the land in the pivots has increased and no one can sell it; it is useful to us." – **Female NAICO farmer**

"We now wish to join. For instance, if you were to sell a plot of land here, they cannot give you beyond 150,000 RWF or 200,000 RWF. However, for the plot of land in the irrigation scheme, its value multiplied. You cannot discuss this with them if you don't have 500,000 RWF. So, except for the harvest that is obtained from there, the value of their land increased as well." – **Male non-NAICO farmer**

11 out of 12 NAICO farmers; 5 out of 8 non-NAICO farmers

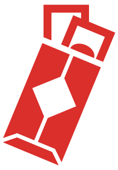
Decreased land valuation outside the pivot: Some NAICO and non-NAICO farmers report that they have seen the value of land outside of the irrigation area decrease.

"My plot suddenly reduced [in value] because it would be purchased for about a million, then when they come, they reduce the value, saying why should I buy here and what will I invest in? They immediately account for like three hundred or seven hundred and so it is worthless because I, myself, if I had money at this time, I would not want to buy a farm around here. I want to accept, go and get the

expensive one in irrigation [pivot].” – **Female non-NAICO farmer**

“The reason why the land inside the irrigation scheme led to the decrease of land value of the land outside the pivot, is it is not irrigated; when the sun shines, it affects that land yet the person who has the land in the pivot weed his/her crops without any problem and his/her crops grow healthier. That is the impact it had on the land outside the pivots.” – **Male NAICO farmer**

4 out of 8 non-NAICO farmers; 5 out of 12 NAICO farmers



People sold land because of fear that it would be taken from them: Some farmers feared that their land ownership would be removed; however, in practice, farmers retained ownership.

“It is not easy. It is not easy because many people sold their lands by the time the project took their lands. They would say that instead of giving my land to the white man for free, let me find someone who can give me less money. Some people bought many plots of land in that way; it was like the people who were selling the plots of land were getting rid of them saying that it was for the white man but later, they regretted that they did not know that it could go like how it happened.” – **Male NAICO farmer**

“Today, some farmers have less financial ability. So, after having less financial ability, they decide to sell the land and give space to the farmers who have the ability. For instance, I no longer have fertilizer to use on my land. As a result, I may decide to sell one piece of land and buy livestock and remain with 3 pieces of land. The livestock would help me to get compost to use the land I remained with. In this case, you can sell the land. If you don’t sell it and fail to get fertilizer, you can get a tiny maize harvest and consequently, NAICO can come and take your land away.” – **Female NAICO farmer**

2 out of 12 NAICO farmers

Poor farmers sold land inside the pivots: Some farmers sold land because of the perception of additional financial requirements.

“Additionally, there are other poor people who have lands. So, they realize that they are unable to buy fertilizer, they are unable to get money to buy pesticides, and they are unable to get money for the workers and they then decide to sell the land. That is how the land is sold.” – **Male NAICO farmer**

1 out of 12 NAICO farmers

Older farmers sold land inside the pivots: Some older farmers were reported to have sold land fearing higher labor requirements.

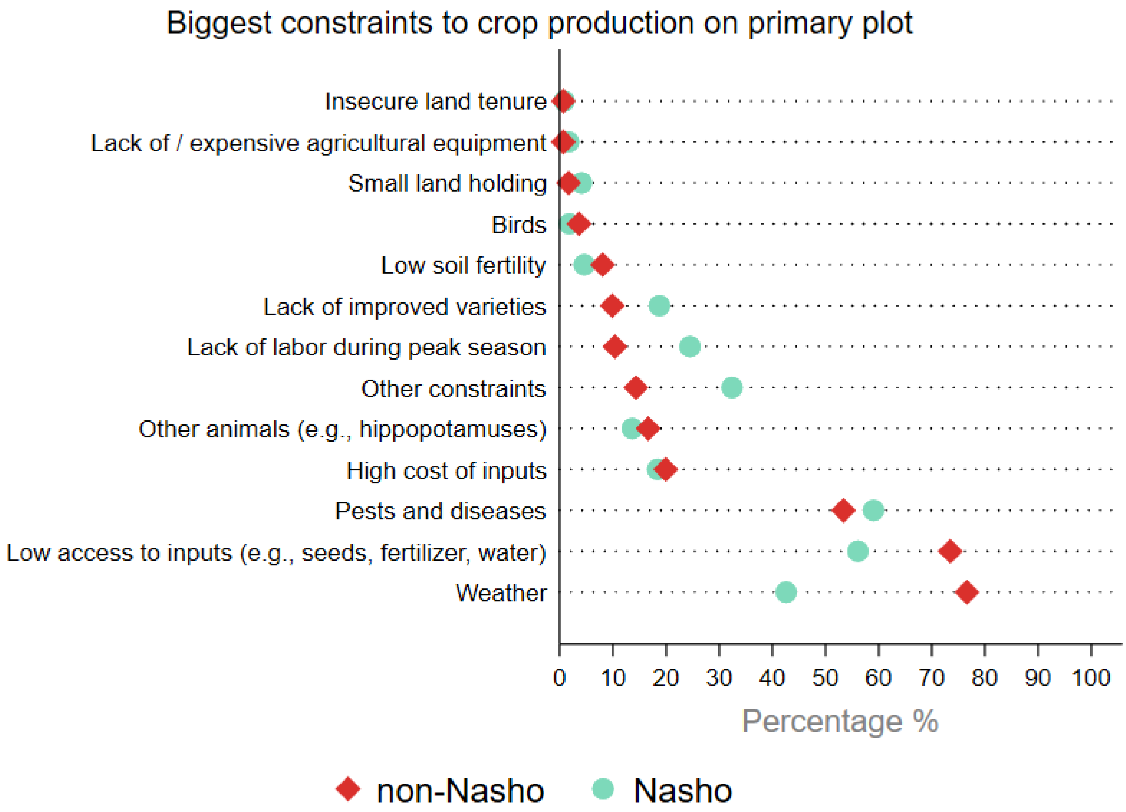
“If the irrigation took a plot for an old man, sometimes a person gets children, and the children get married. So, an old man realizes that he is not able to work and the old lady is not able to work as well. The land in MINAGRI requires frequent visits; so, the old people realize that they are unable to do it and decide to sell the land.” – **Male NAICO farmer**

1 out of 12 NAICO farmers

2.3.3 Farmers’ challenges

Overall, the most-mentioned constraints to crop production are low access to inputs (65%), the weather (60%), and pests and diseases (56%). However, we do see some differences between Nasho and non-Nasho plots (Figure 9).

Figure 9 / Biggest constraints to crop production by plot type



For Nasho plots, the most-mentioned constraint is pests and diseases (59%), followed by low access to inputs (e.g. seeds, fertilizer) (56%), the weather (43%), and other factors (32%).[37] The most common other factors that were mentioned for Nasho plots are non-functioning pivots (8%), delays by NAICO in delivering inputs (6%), weeds (4%), lack of capital (3%), and lack of know-how (2%). Other factors that were mentioned that are related to the Nasho Irrigation Project are delay in irrigation (2%), waterlogging on the farm (2%), delay in payments from NAICO (2%). Less than 1% of respondents mentioned high charges by NAICO through sustainability fees or on the production sold, delay by NAICO in collecting the production, and delay in receiving permission from NAICO to harvest.

For non-Nasho plots, the most-mentioned constraint is the weather (77%), followed by low access to inputs 74%), and pests and diseases (53%). The most common other

[37] Weather as a constraint includes drought, too much sun, and lack of rain.

factors mentioned for non-Nasho plots are weeds (6%), lack of know-how (2%), and theft (2%).

Some of these challenges were reiterated during the qualitative interviews, described below.

Market challenges

Unreliable market: Farmers mention that upon harvesting they face the challenge of getting a market for their produce or sometimes they face delays when selling their produce.

"The challenges I would highlight that affected all of us planting soya in general. We planted them and got an excellent harvest. However, we did not get a buyer for them; they asked us to harvest and store the harvest. Now, imagine getting a soya harvest without having beans or maize yet they are the ones to depend on. When you call them that you are facing hunger, they ask us to find ways out of the situation because they don't have a soya buyer."[38] – **Female NAICO farmer**

"The challenge in the last season was not getting the market for our produce on time, we had a delay in obtaining the market. Even after obtaining the market, they asked us to first dry the maize and soybeans under the sun and they [the crops] started breaking." – **Male NAICO farmer**

3 out of 12 NAICO farmers

Lower sale margins sale price of produce: Farmers highlight that seed prices have gone up and the farmgate crop prices increases were smaller, resulting in lower margins.

"The problem is that before we could buy 1 kg of maize seeds at 1,500 RWF and one pack at 3,000 RWF but now the price has increased. The problem lies in selling that harvest at a low price compared to the cost of the seed." – **Female NAICO farmer**

7 out of 12 NAICO farmers

Increase in fertilizer price: Farmers report that the prices of fertilizer have gone up because the government stopped its subsidies.

"They [The Government] have stopped the subsidy. So, if you have a hectare of land, you can imagine the number of sacks of fertilizer that will be used on that hectare because we should fertilize the land three times; it may not take below two sacks of fertilizer." – **Male NAICO farmer**

2 out of 12 NAICO farmers

[38] Buyer delays can be caused by NAICO working to negotiate the highest price, or buyers waiting until multiple pivots have harvested and the production has been aggregated.

Increase in prices of pesticides: Farmers report that the prices of pesticides have gone up.

"The price for pesticides and workers' wages have increased as well." – **Male NAICO farmer**

1 out of 12 NAICO farmers

Challenges with NAICO

High agricultural input charges: Some farmers report that the prices of agricultural inputs such as seeds and fertilizers, obtained from NAICO have increased and have become strenuous for them. However, input prices at other agro-dealerships have also increased.

"They could deduct the normal charges but the money for seeds and agricultural inputs was high. For the deduction of seed money, that is where it is expensive for us. Additionally, when you grow the seed, they have given you, the price they sold the seed to you, and compare it with the harvest they are going to buy for you, you realize that you are facing a loss." – **Male NAICO farmer**

"The change is that we buy seeds at high prices and after growing crops, we lose the market for them. For example, 1 kg of maize is 4,750 RWF today. The problem is that before we could buy 1 kg of maize seeds at 1,500 RWF and one pack at 3,000 RWF but now the price has increased. The problem lies in selling that harvest at a low price compared to the cost of the seed." – **Female NAICO farmer**

3 out of 12 NAICO farmers

High cooperative contributions: Some farmers report that the recurring financial contribution made to the cooperative is quite high. The financial contribution is made each season in order to sustain the costs of the irrigation infrastructure.

"For example, the farmers are still burdened by the maintenance fees they have to pay, for instance, per hectare a farmer pays 103,000 RWF. The farmers complain that this amount is deducted from their harvest, "It is hard for me, and I have other matters to solve" they say, meaning you have to provide for your family, pay children's school fees and other costs such as health insurance, for which farmers complain that it is a burden for them. So, if the maintenance fees can be decreased the farmers would farm without having anything being a burden for them." – **Male NAICO farmer**

"The recurrent financial contribution takes almost a full sack of harvest. So, isn't that a loss? Paying the recurrent financial contribution is like paying for mutuelle/health insurance." – **Female NAICO farmer**

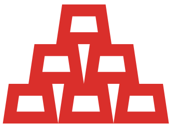
4 out of 12 NAICO farmers

Delayed payments for harvest: One NAICO farmer reports that they experience delays in receiving harvest payments from the cooperative compared to traders. The delays are in turn affecting cultivation for the next farming season.

"If the money continues to be delayed, it would not be good. A person can wonder what happened to the cooperative and if they don't have money." – **Female NAICO farmer**

1 out of 12 NAICO farmers

Financial challenges



Lack of capital: A few farmers report that they lack sufficient capital to sustain themselves during the farming season or to purchase agricultural inputs.

"In my farming, there was no problem when my father was there. However, today, I am responsible for all the things. For instance, in farming, after all the money I had was finished, I asked people to lend me money. I planted these maize crops after asking people to lend me money; so, gave me money that I should pay back. I don't even know what will happen when the time for the weeding comes. That is a challenge to me." – **Female NAICO farmer**

"Another thing is insufficient fertilizers, we have some compost fertilizers which are not sufficient, so it would be good if we get money and buy livestock, so it is a challenge." – **Male NAICO farmer**

5 out of 12 NAICO farmers

Increase in laborer's wages: Some farmers report that wages of farm labor have also increased.

"For instance, we have a challenge of expensive workers; a casual worker is paid 2,500 RWF and he/she works from morning up to noon. Today, the price of 1 kg of maize is 200 RWF; consequently, you find that this sack for harvest can only pay no more than ten workers who only prepare the land. When you make calculations and you look at the land where workers worked, the fertilizer you used, the seeds you planted, the workers who prepared the land, the workers who planted seeds, and the workers who weeded, you find that you have got losses." – **Male NAICO farmer**

"The price for workers' wages has increased as well. Before, we used to pay workers 1,200 RWF or 1,000 RWF. However, today, a worker is paid 2,500 RWF. When you harvest and calculate what you used, they say that the maize price is 300 RWF and 280 RWF in NAICO. So, when you calculate the money you used on fertilizers and workers, you find that you are getting losses." – **Male NAICO farmer**

4 out of 12 NAICO farmers

Environmental challenges

Soil erosion: NAICO management and leadership report that they have seen soil erosion destroy land sections within these areas.

"There were challenges but the biggest of all was erosion. You see that this valley is amidst mountains. When it rains, water flows down those mountains and comes here. We had terrible erosion in 2018 that took a large portion of the land, destroying crops in the process." – **NAICO Leadership**

"Anyway, there are times when erosion hits hard although I told you that the government built drainage channels. Sometimes, due to channels that extend beyond the roads, little bridges they installed are overpowered by water and consequently, water goes into the pivot and destroys crops." – **NAICO Management**

2 NAICO Management and Leadership team

2.3.4 Suggestions for NAICO

Farmers provide suggestions for changes that will improve their experience with NAICO. These include widening the market to obtain better prices, providing timely technical assistance and security, expanding the project area, and adding additional crops to be grown.

Wider market for better prices: Some farmers suggest that the produce market be widened so that farmers enjoy more competitive sale prices and therefore increase the profit they make.

"In my view, what can be done is finding the market for the harvest; they can offer a good price, so we can get profit and money we invested." – **Male NAICO farmer**

"Another thing is they can expand the markets. They can expand the market from different corners for us to get a high price for our harvest. Today, things have changed and fertilizers are costly." – **Male NAICO farmer**

3 out of 12 NAICO farmers

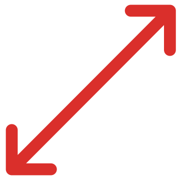
Timely technical assistance and security: A few farmers report that the irrigation system requires timely technical assistance especially when the machines break down. The lag time for repair should be reduced.

"There should be technicians who can continue to look after the project so they can track the changes on the project. […] If they cannot look after the system, it can get destroyed. Importantly, we need to also take care of it as our project." – **Male NAICO farmer**

"Considering the contribution we pay, if suddenly a machine stops working it would be difficult for us to repair it ourselves. So, I think it would be better if we had support. This is why I say that the cooperative should not be only for

the farmers, the government can also be involved so that they can support us because it would be difficult for farmers to repair a pivot on their own." – **Male NAICO farmer**

2 out of 12 NAICO farmers



Project expansion: A few farmers mention that since the project is beneficial to plots within the pivots, they would like to see the project expand further to incorporate plots that are outside the irrigation project.

"Something else can be done; there is a part with those who irrigate and a bigger part that has no way of irrigating their crops, and those who have no way of irrigating have many challenges. Yes they can buy food nearby, but it would be more beneficial if the project expanded and reached other parts as well." – **Male NAICO farmer**

"For example, it would be better if they would give water pipes to farmers to irrigate the remaining part that is not included in the pivot area. I think that is the best they can do for us." – **Female NAICO farmer**

2 out of 12 NAICO farmers

Additional crop suggestions: Farmers provide suggestions for additional crops to be planted inside the pivots to increase the variety within the area. Farmers suggested that crops like groundnuts, peas, tomatoes, Irish potatoes, and rice would be valuable additions to the pivot, both financially and nutritionally.

"What I feel would have been included is peanuts and give us time to cultivate them. Peanuts are a good crop that gives high production and can be stored. Giving us peanuts and storing them can be of good help to us as we can grow them during summer. They can also encourage us to grow Irish potatoes so that we develop financial and additional food choices." – **Female NAICO farmer**

6 out of 12 NAICO farmers; 1 out of 8 non-NAICO farmers

3. Geospatial analysis

3.1 Objectives

The objective of our geospatial analysis was to zoom out of the plot and household level and assess changes that the program has brought about spatially. This in turn put the results of the plot and household level in context. By using geospatial analysis techniques, we went back in time before the installation of the center pivots to assess shifts and trends. We looked back from 2015 – prior to the implementation of the project and the installation of the center pivots until now – and investigated whether we see indications of impact. Using remotely sensed yield proxies, we investigated to what extent changes in yield proxies can be attributed to the program by comparing the program areas to comparable areas in the region.

3.2 Methodology

We used satellite imagery to assess changes to the landscape and particularly the yield proxies brought about by the program. The basis of our analysis is Sentinel 2 data, enriched by a broad range of geospatial data on weather conditions and land cover data from 2015 onwards. Based on the data generated through and derived from this imagery, we traced back changes to the landscape and yield proxies for the Nasho area before and after building the center pivots. We did the same for a set of comparison areas that are close and comparable to the Nasho areas – the counterfactual that represents a scenario without the Nasho project in general and the installation of the center pivots specifically.

We constructed a synthetic control area based on the trends in yield proxies observed before the installation of the center pivots in Nasho and non-Nasho areas. We used the trends in yield proxies, land cover, and weather data observed before building the center pivots in the irrigation zone and comparable areas within a 3-kilometer region to construct this synthetic control. This synthetic control is a weighted average of the comparison areas that represents what would have happened without center pivots installed. We used data on yield proxies collected prior to the 2017 season B when both treatment and comparison areas were not under irrigation and thus comparable to a synthetic control. Our objective was to estimate a model where the trends in yield proxies for the comparison areas closely mimic those observed in the treated areas before implementing the center pivots. This was to establish that the treated area's yield proxies before implementing the pivots correspond with say, 0.4 times those of a first comparable patch of land in the region and 0.6 times those of a second. After building the center pivots, that is September 2017 or later, this synthetic control represents the counterfactual situation that would have happened without the center pivots. The impact of the program is then established by comparing the differences between the observed yield proxies in the treatment areas (the center pivots) and those for the synthetic control areas.

3.3 Data sources

Greenness indices: Sentinel-2

Sentinel-2 is a multi-spectral imaging mission within the Copernicus Program, designed to provide high-resolution optical imagery for various land monitoring purposes. Launched by the European Space Agency (ESA), the mission consists of two satellites. Sentinel-2A orbits Rwanda with a revisit time of approximately 10 to 15 days. Sentinel-2 imagery is widely used in agriculture, forestry, land cover classification, and environmental monitoring applications. The high spatial and temporal frequency and spatial resolution make it particularly valuable for tracking changes in vegetation health and calculating indices like the Normalized Difference Vegetation Index (NDVI), which captures crop health and productivity over time. Sentinel 2 imagery is available from July 2015 onwards for the relevant areas.

Land cover data: Dynamic World

Dynamic World is a near-real-time global land cover dataset created by Google in collaboration with the World Resources Institute (WRI). This dataset uses Sentinel 2 imagery as its input to a classification model that provides detailed estimates of land cover (Brown et al., 2022). It covers ten distinct land cover classes, including forests, grasslands, croplands, wetlands, shrublands, urban areas, bare ground, snow/ice, and water bodies. Dynamic World imagery has a high spatial (10 meter by 10 meter) and temporal resolution (it is collected every five to ten seven days). We used this data to assess changes in land cover and select suitable control patches of land outside the irrigation zone. This data is available from 2015 onwards for the relevant areas.

Precipitation data: CHIRPS

The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a global rainfall dataset that integrates satellite imagery with weather station data on Earth to provide high-resolution, reliable precipitation estimates from 1981 onwards. The datasets offer daily, pentadal (5 days), and monthly data. We used monthly estimates of precipitation for the relevant areas. The CHIRPS data is available at a 5,556-meter resolution and is the highest resolution dataset available for Rwanda, covering the relevant period (2015 onwards). Precipitation data is used as a control variable in our analysis. A coarse resolution of 5,556 meters (against 10 meter by 10 meter for the other datasets) means that some of the areas in both treatment and control are covered by the same pixel in the imagery resulting in the same or similar values of estimated precipitation or mean areal rainfall for each month.

3.4 Key outcome indicators

We used the following key outcome indicators to assess changes over time in vegetation and crop health:

- **Normalized Difference Vegetation Index (NDVI)**: NDVI is a widely used remote sensing metric for assessing vegetation health and density. It assesses whether live green vegetation is present in an area (or a pixel in an image) and is particularly useful for monitoring overall vegetation cover but can be influenced by soil background and atmospheric conditions. NDVI is also commonly used to assess crop vigor and serves as a proxy for yield.

- **Enhanced Vegetation Index (EVI)**: EVI is an advanced vegetation index that improves upon NDVI by reducing the influence of atmospheric conditions and soil background signals. Its values provide a more accurate assessment of vegetation health in areas with dense canopies and varying soil types.
- **Green Normalized Difference Vegetation Index (GNDVI)**: GNDVI is a variant of NDVI that uses the green band instead of the red band in its calculation. GNDVI values are more sensitive to the chlorophyll content of vegetation and crops, making it a good indicator of photosynthetic activity and crop health for more mature plants.
- **Normalized Difference Water Index (NDWI)**: NDWI an accurate indicator of plant humidity, especially in irrigated farmland. It includes the water absorption band which is more closely connected with moisture than chlorophyll in GNDVI whose light-absorbing property is used in the calculation of NDVI.

Using a combination of these spectral indices, NDVI, EVI, NDWI, and GNDVI, we captured a comprehensive picture of vegetation and crop health, and vegetation and crops' water content as proxies for yield and productivity.

3.5 Data collection: Image retrieval and processing

3.5.1 Image retrieval

A satellite image can be construed as a dataset that is a raster of rows and columns where each pixel is a cell, that contains data about a spectral band (e.g., its measurement of infrared light, red, blue, or yellow) and the location of a particular pixel on earth. For the Sentinel images, each pixel or cell in these image datasets thus represents the value of say, near-infrared for a 10 meter by 10 meter square on the globe. To collect the images, we first selected the area of interest through the geocoded circle pivots and lines shown in Figure 3. We used Google Earth Engine to retrieve the images from the Sentinel 2 satellite from July 2015 until June 2024. Images before July 2015 are not available and note that images between July and October 2015 are of lower quality. We then stacked these images on top of each other, creating a stack of datasets with data for each image ordered by the date the images were taken by the satellite. This generates a stack of 1,144 individual images. We then pre-process this data using the operations below.

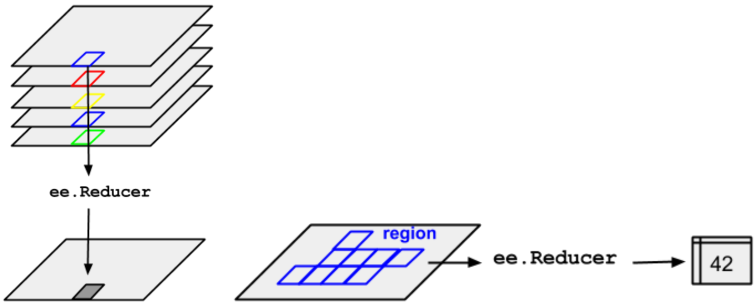
3.5.2 Cloud masking

Clouds obstruct the view of the earth's surface in satellite imagery. Moreover, clouds could distort our outcome measures (NDVI, EVI, and NDWI) by indicating lower vegetation health, as clouds can obscure the reflected light from the vegetation and are represented as white pixels (indicating low NDVI). We used Google Earth Engine's built-in algorithm to identify and remove these cloudy pixels. These algorithms analyzed specific spectral bands and used characteristics such as brightness to identify cloudy pixels. Once identified, these cloudy pixels were masked out, or ignored, in subsequent analyses.

3.5.3 Compositing: generating high-quality images by month

To ensure the most accurate representation of vegetation health over time, we composited satellite images into a greenest pixel mosaic for each month. This process involves selecting those pixels who have the 95th percentile highest vegetation index value, such as NDVI, from a series of images taken within a given month or season. We then reduced the images taken from each month (or season) to a single image where each pixel represents that highest value. This is schematically depicted in Figure 10 where we reduced or composited a stack of images to a single image that represents the highest pixel values within a given month (left). We then computed statistics of image regions (right).

Figure 10 / Compositing high quality satellite images by month



By doing so, we created a composite image where each pixel reflects the peak vegetation condition for that period. Moreover, this method helps to mitigate the effects of artifacts like clouds or cloud shadows, which may obscure the view in individual images. The resulting greenest pixel composites provide a clearer and more consistent view of vegetation dynamics in a month or season.

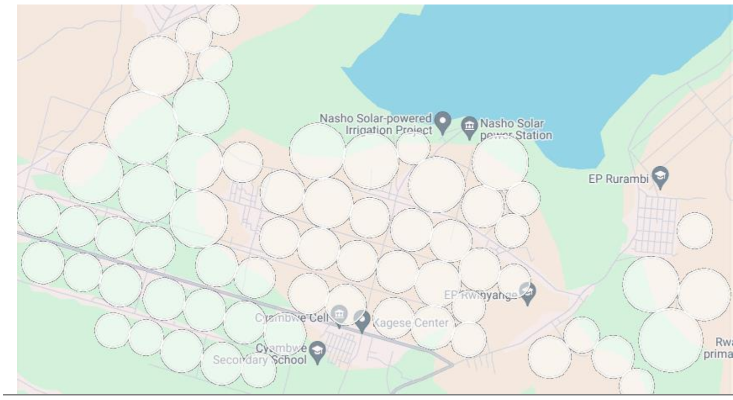
3.5.4 Regional reduction: computing statistics for relevant areas

Subsequently, for each of these monthly composites, we apply regional reducers. The center pivots or circles drawn on a map represent the regions of interest. The monthly composite values of all the pixels within a region (pivots in our case) are then used to compute the relevant statistics, such as an average best-pixel-NDVI value in a month per pivot (or for the area covered by all pivots combined). Note that pixels are squares of 10 meter by 10 meter, in case circular edges of a pivot cross these squares, averages are weighted by the area that crosses each pixel.

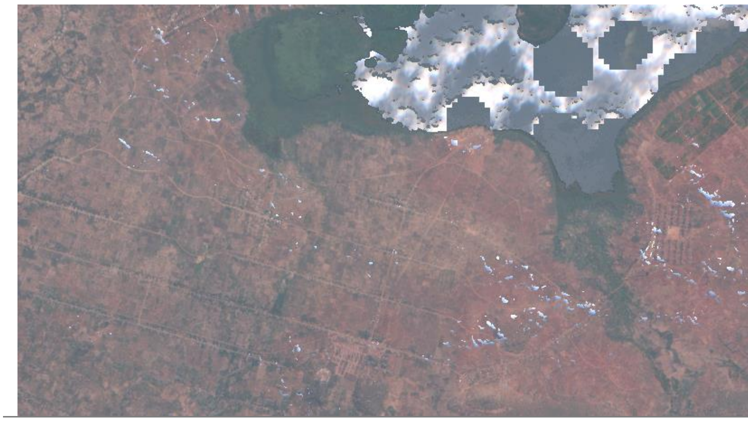
The cloud masking and compositing lead to the images in Table 16. We present the pre-processed imagery using seasonal composites (i.e., images averaged out over a whole season) for key moments in the project's timeline. These key moments include pre-treatment or before the installation of the pivots in season A in 2016, season B in 2017 when the pivots were just becoming operational, and season C in 2019. We can clearly distinguish the center pivots from space in the second and third pictures (B and C). The first picture (A) shows the situation before the pivots were built. Here, we see small patches of land that Nasho farmers used to farm on. We see some coarser white or transparent pixels masked due to cloud coverage in the underlying individual images, especially in Lake Cyambwe in the top right corner of the picture.

Table 16 / Sentinel 2 imagery featuring key moments in the project timeline

Processed Sentinel 2 imagery



Reference map: Sentinel 2 images are bounded to the area shown on the map with the pivots indicated.



A: Pre-treatment – Seasonal composite for Season C 2016 (July to September), no pivots have been constructed, and the area around the pivots consisted of regular cropland.

B: Treatment – Seasonal composite for season B 2017 (March to July) irrigation pivots are starting to become operational. Some pivots already hold green crops, others do not hold any crops.

C: Post-treatment – Season C 2019 (July to September) pivots are operational, and the greenness of crops and circle pivots are noticeable from space.

We used the same process for compositing and defining regional statistics for the precipitation and land cover data that we used to construct a synthetic control. Once the imagery was processed, we generated monthly and seasonal statistics for the relevant regions, morphing this information into regular tabular datasets that represent trends on our outcome indicators. We then processed them using software suitable for the econometric techniques applied.

3.6 Findings

3.6.1 Trends in yield proxies in the Nasho areas

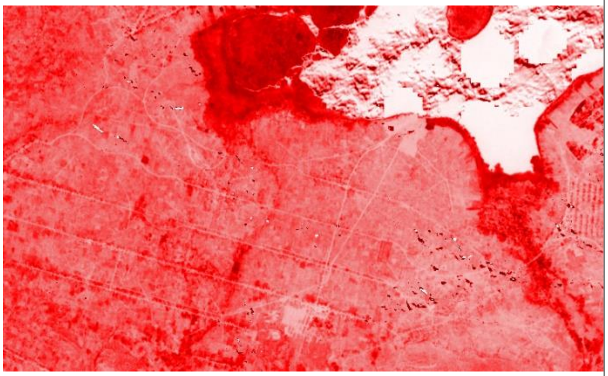
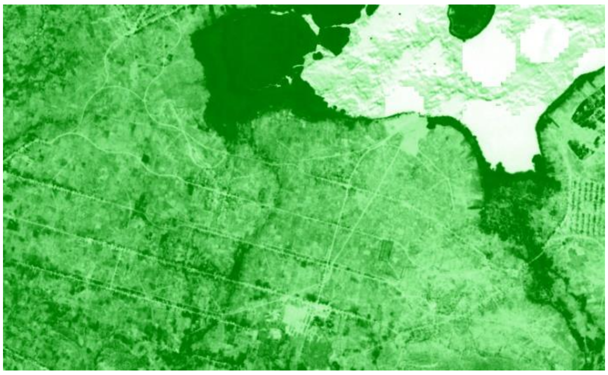
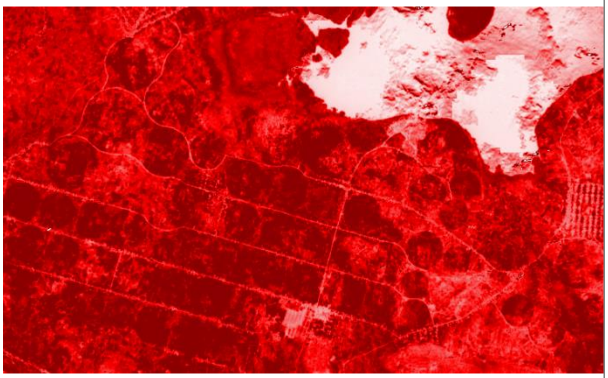
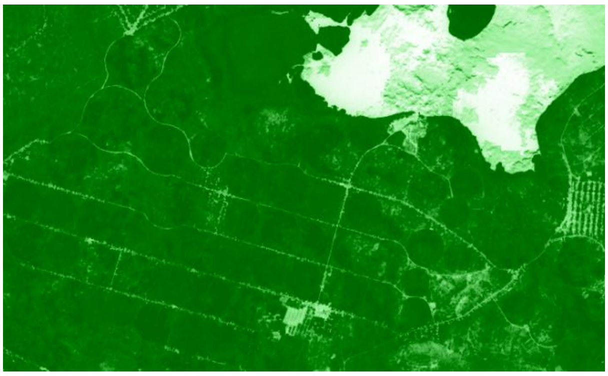
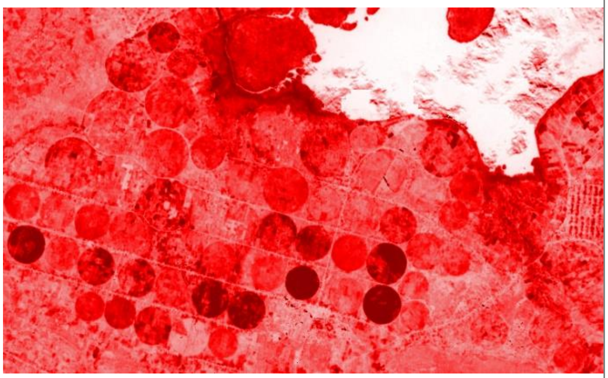
We started by looking at the images generated above that hold a selection of outcome indicators at key points in the project timeline to assess whether it is possible to pick up the signal that indicates improvements in vegetation health and crop productivity due to the implementation of center pivots. First, we assessed whether we could distinguish the areas under irrigation from those that are not under irrigation using satellite imagery. Second, if so, the expectation is that, in the event that center pivots would affect crop yields, we would find low productivity and vegetation health prior to implementing the center pivots compared to when the irrigation systems are operational.

Table 17 presents the EVI index (left) and the NDVI index values (right) at a 10-meter pixel scale of the best-quality composite for each season. Pre-treatment or pre-installation of the pivots (A) in 2016, we see that no pivots have been constructed. This represents the status quo or baseline situation before the project's implementation. Panel A shows that the areas where the pivots are placed and the area surrounding the pivots do not display much greenness. The EVI image, characterized by its red hues, indicates areas with varying levels of vegetation vigor, but overall, the region in and around the planned pivot installations shows low crop quality and sparse vegetation. The NDVI image, shown in green, similarly reveals low greenness, suggesting limited vegetation cover and crop health prior to the start of the project.

The second row (B) represents the treatment phase, during which the pivots began to operate. The NDVI image on the right shows a marked increase in greenness across the region (both outside and inside the center pivots), this is indicative of a favorable growing season. The early benefits of the irrigation systems can already be distinguished as the circular pivots are slightly greener compared to the neighboring areas. The EVI image on the left reflects high crop quality, especially within the areas starting to be serviced by the pivots.

In the final row (C), the EVI and NDVI images for Season C 2019 depict a landscape that has been under the influence of the pivots for over two years. The EVI image highlights high-quality crops within the pivot areas, showing robust vegetation health and productivity. The NDVI image, contrastingly, displays overall greenness and vegetation presence especially within the circular pivots and less so in the neighboring plots (in the bottom right corner) that depend on rainfed irrigation. The imagery analysis demonstrates that the center pivots have enhanced vegetation health and crop quality, as evidenced by the substantial increase in EVI and NDVI at key moments in the project timeline.

Table 17 / Imagery analysis using EVI and NDVI images

EVI images (red=high EVI)	NDVI images (green=high NDVI)
A: Pre-treatment – Seasonal composite based on monthly greenest pixel for Season C 2016 (July to September). No pivots have been constructed for both. The area where pivots are to be installed and the areas around the pivots do not display greenness (NDVI) or high crop quality (EVI).	
	
B: Treatment – Seasonal composite for season B 2017 (March to July) based on monthly greenest pixel. NDVI shows greenness across the board during a relatively rainy season (right). Pivots are starting to become operational, and EVI indicates high crop quality inside the pivots.	
	
C: Post-treatment – Season C 2019 (July to September) pivots have been operational for more than two years. EVI indicates high-quality crops and vegetation inside some center pivots. NDVI shows greenness in center pivots, but not for other plot areas during a relatively dry season in the year.	
	

Next, we assessed trends in NDVI, EVI, and NDWI from 2015 to 2024. The results of combining the NDVI values for this period are presented in Figure 11. The figure shows the NDVI for the areas where center pivots are installed, both before and after installing these center pivots. This figure plots a 3-month rolling average to filter out the spikes and cliffs due to seasonality and possible cloud cover. The 3-month rolling average combines the NDVI estimates for more than 68,000 data points (with a maximum of 1,143 images per center pivot for 60 center pivots). Low-quality images due to cloud cover have been removed.

We see an apparent uptick in NDVI values shortly after the pivots were operational in March 2017 (denoted by the vertical line). Before the pivots are installed, NDVI values are markedly lower than after the installation of the pivots. Moreover, we see a consistent pattern of an uptick shortly after the pivots are installed for all center pivots, shown by the green dotted lines. This indicates a trend towards higher crop productivity and improved yields in the irrigated zones.

Figure 11 / Rolling average (3 months) for NDVI for a selection of pivots and all pivots combined 2015-2024

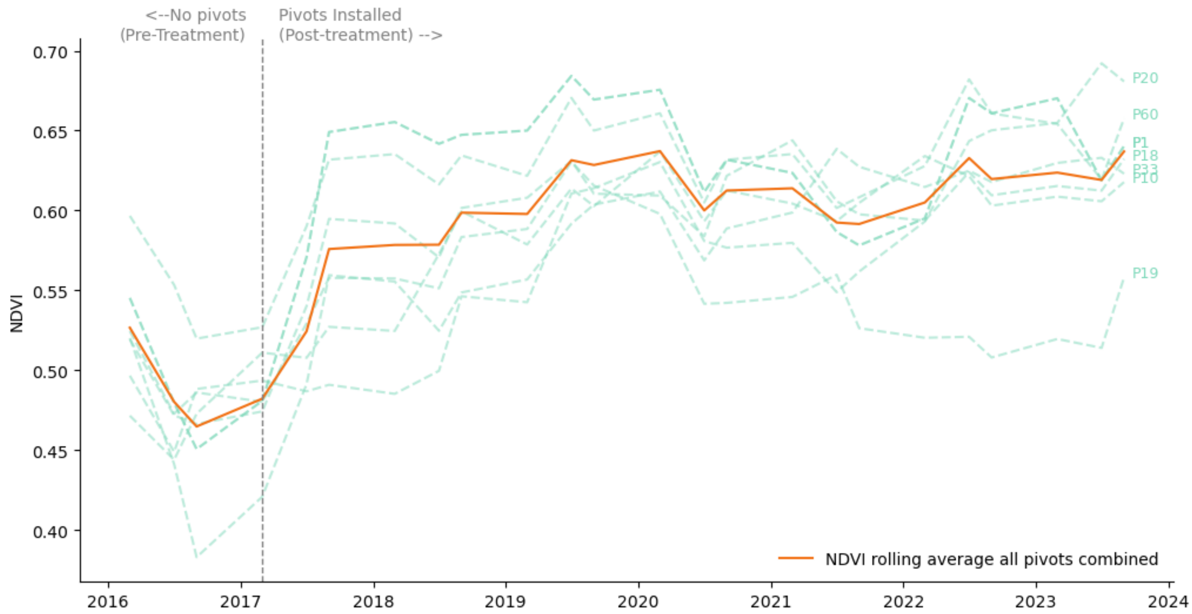
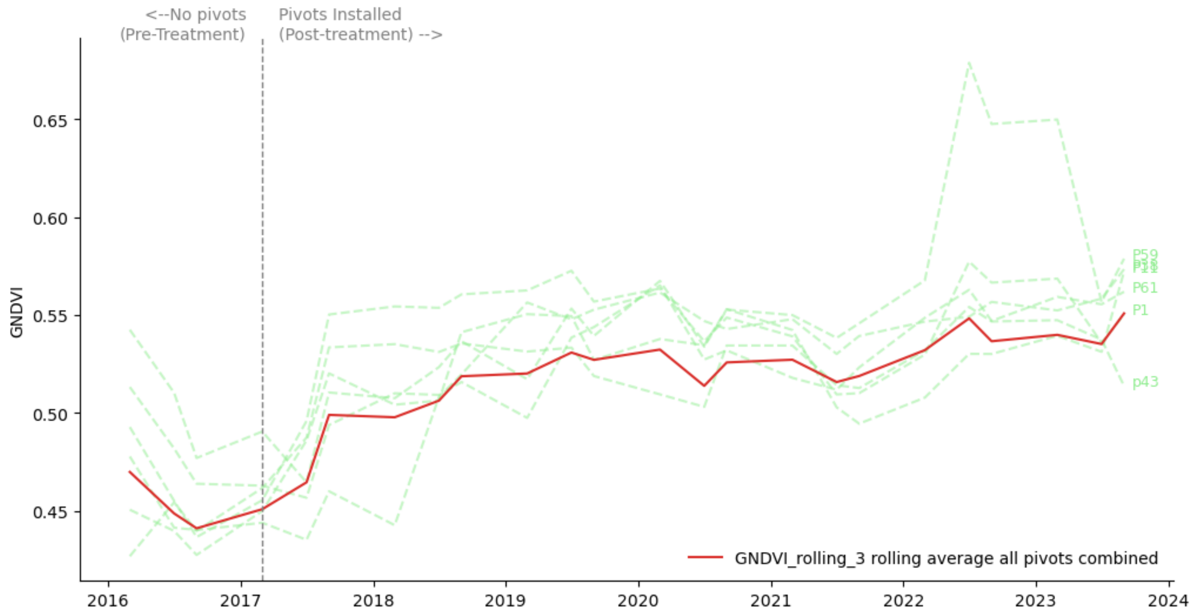
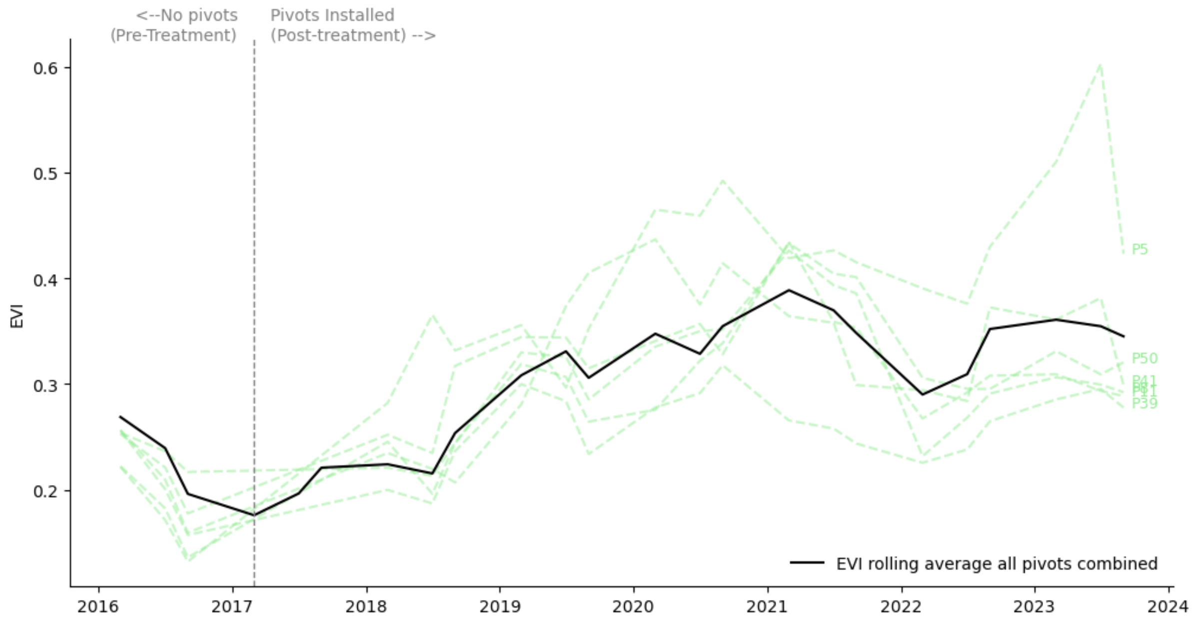


Figure 12 / Rolling average (3 months) for GNDVI for a selection of pivots and all pivots combined 2015-2024



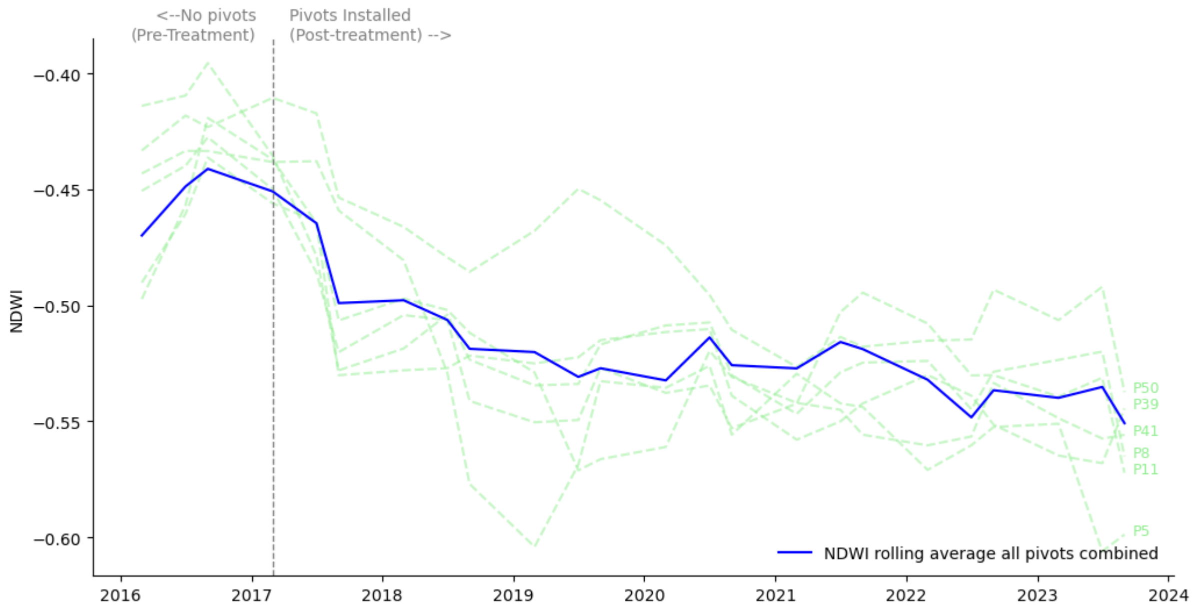
The GNDVI shows a similar uptick after the installation of the pivots (Figure 12). Both for most individual pivot fields (dashed green lines) and the overall average (solid red line). There is some variation among individual pivot fields, but the overall trend is upward, indicating increased greenness in the irrigation zones. Despite the variability among the pivots, the overall trend suggests a positive impact of the pivot irrigation systems on vegetation greenness.

Figure 13 / Rolling average (3 months) for EVI for a selection of pivots and all pivots combined 2015-2024



For the EVI, we find a noticeable upward trend in its values, indicating improvements in vegetation quality following the installation of the pivots (Figure 13). The overall average shows a gradual increase after the installation of the pivots. Individual pivot fields display more variability in their EVI values post-treatment. Some center pivots (we used a random selection of those in the graph) exhibit significant fluctuations, especially in the later years, suggesting differential impacts per pivot, and also likely per crop type grown, of the irrigation intervention on EVI.

Figure 14 / Rolling average (3 months) for NDWI for a selection of pivots and all pivots combined 2015-2024



The NDWI demonstrates a downward trend (Figure 14). Unlike NDVI and EVI, which are expected to increase due to improved vegetation health and greenness from irrigation, a declining NDWI is expected as efficient irrigation practices optimize water usage. Post-treatment, there is a noticeable downward trend in the NDWI also among the individual center pivots.

3.6.2 Comparing Nasho areas against similar non-Nasho areas

Selection of comparable control areas

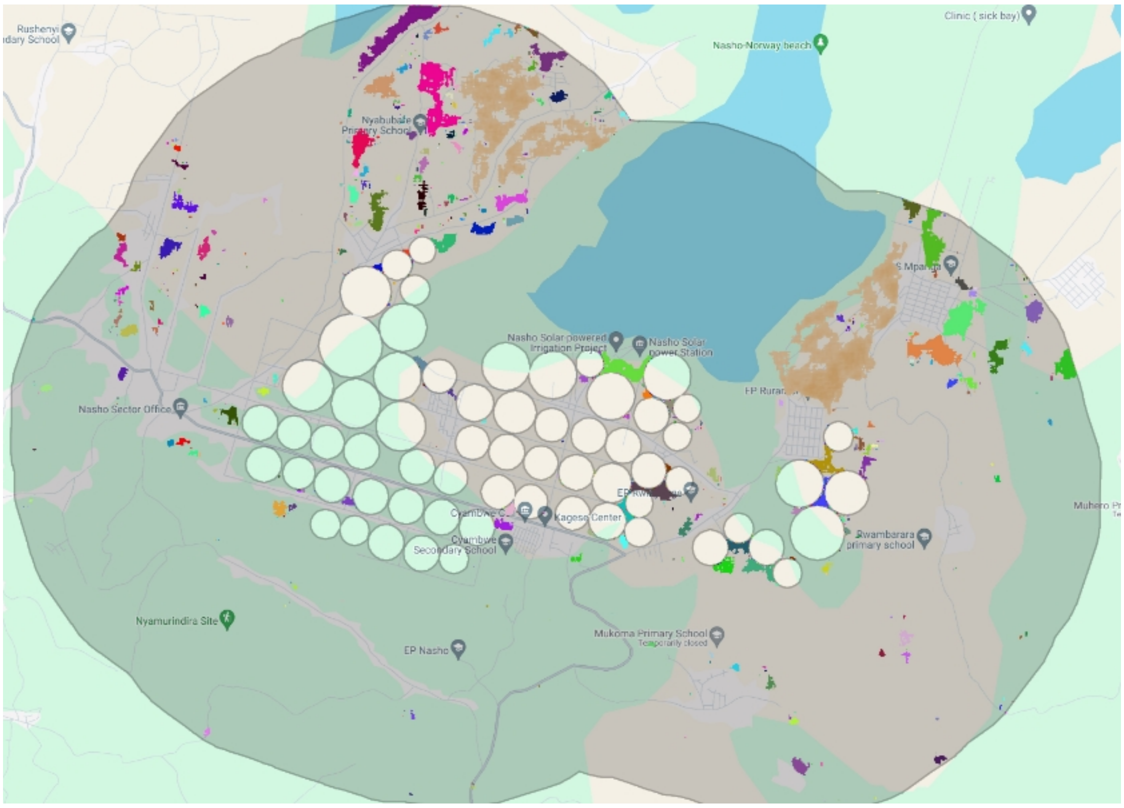
The key impacts of the projects on these indicators can be established when comparing these trends against a reasonable counterfactual. As mentioned at the beginning of this chapter, the counterfactual consists of a synthetic control pivot. To select comparison areas and generate synthetic plots, we employed Dynamic World land cover and land use data to find and select comparable areas in the following way:

1. We classified all pixels (10 by 10 meter) within a 3-kilometer buffer zone outside the center pivots. We then selected only those pixels that were consistently classified as cropland one year before treatment, specifically for Season A in 2016. We selected all pixels where we were confident that these contain cropland, that is those pixels where the median probability of being classified as cropland is greater than 0.6 in Season A in 2016. We are aware that this may seem a relatively low threshold with a median probability of cropland classification greater than 0.6. However, note that early in the growing season, when plants and vegetation do not cover the soil, the algorithms classify these areas as bare land or bare soil.

2. Using Google Earth Engine, we applied an algorithm that identifies contiguous regions of these cropland pixels, forming clusters or "control patches" of comparison group cropland. This algorithm groups adjacent cropland pixels into larger, connected areas based on their spatial proximity. This process yielded over

270 contiguous clusters within the 3-kilometer buffer zone outside the center pivots. The result of this process is shown in Figure 15. Here we see the 3-kilometer buffer zone highlighted in black and the areas under the pivots in white. The clusters of cropland identified are highlighted with different colors on the map.

Figure 15 / Identification of comparison group cropland. Three kilometer buffer zone shown in black, and clusters of cropland highlighted with various colors.



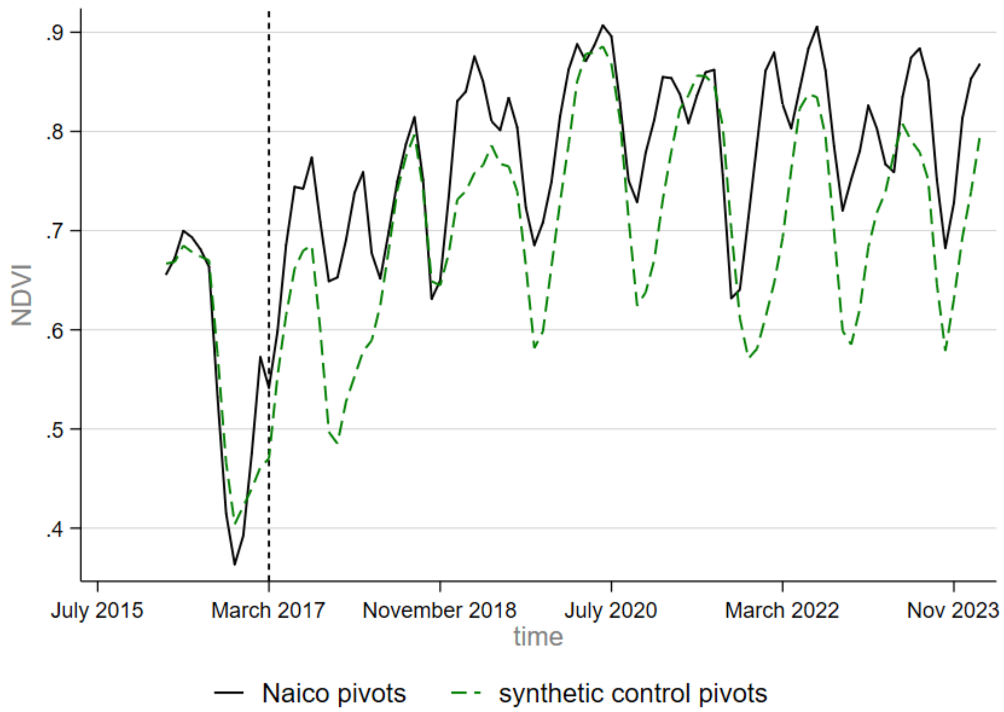
3. Subsequently, we randomly sampled 50 of these clusters for computational efficiency. This provides a donor pool of 50 pre-treatment comparable patches of land to construct a synthetic control.
4. The synthetic control region is then generated by mimicking the pre-treatment trends for the treatment group as closely as possible, consisting of a weighted average of those patches of land in the donor pool. Additionally, we used the monthly areal rainfall derived from CHIRPS data as a covariate or predictor of the levels of the pre-treatment outcome in the areas covered by the center pivots. Precipitation is strongly correlated with the seasonal variation in NDVI and other outcome measures. Additionally, we used lagged measures of the outcome (the value of the previous 3 months) as predictor and outcome. This is to account for the typical seasonal variation that results in spikes and cliffs in our outcome measures.

This approach results in approximately 1,000 pre-treatment observations (control patch of land times month). Some month and control-patch combinations are excluded because these patches could be covered by clouds.

3.6.3 Impacts: synthetic control

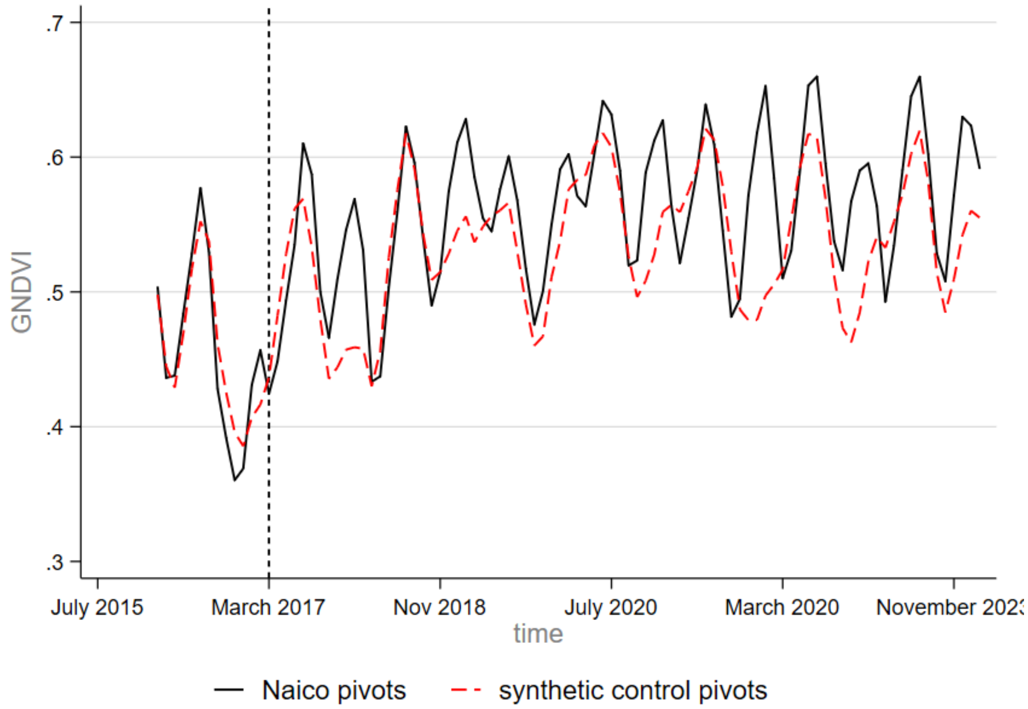
Figure 16 present the results of the synthetic controls. The vertical dashed line marks March 2017, indicating the installation of the NAICO pivots (post-treatment period). Before the installation, the NDVI values of the NAICO pivots and the synthetic control were relatively closely aligned, reflecting similar levels of vegetation and greenness. This did not hold shortly before the installation of the center pivots. Here, we see that the lines of the synthetic control and the center pivots diverge. Post-treatment, the NAICO pivots exhibit markedly higher NDVI values than the synthetic control, particularly during peak growing seasons. The observed fluctuations in the NDVI values correspond to seasonal variations, but the pivots consistently outperform the synthetic comparison patches of land post-treatment. However, the difference between the NDVI values for the center pivots and the synthetic control and the treatment pivots (the size of the gap between the green and black lines) is not consistent over time. This suggests improved vegetation health and increased greenness in the areas covered by the center pivots compared to a random selection of other cropland in the neighborhood. The resulting enhancement in greenness implies that the pivots have positively influenced crop yield. The consistent outperformance of the NAICO pivots over the synthetic control further underscores the effectiveness of the irrigation intervention in boosting agricultural productivity. However, when testing these effects for statistical significance using a synthetic difference-in-difference, we did not find a statistically significant treatment effect. We find that the seasonal fluctuation and variance across seasons in NDVI values is likely bigger than the uptake we see when installing the pivots.

Figure 16 / Synthetic control: Normalized Difference Vegetation Index



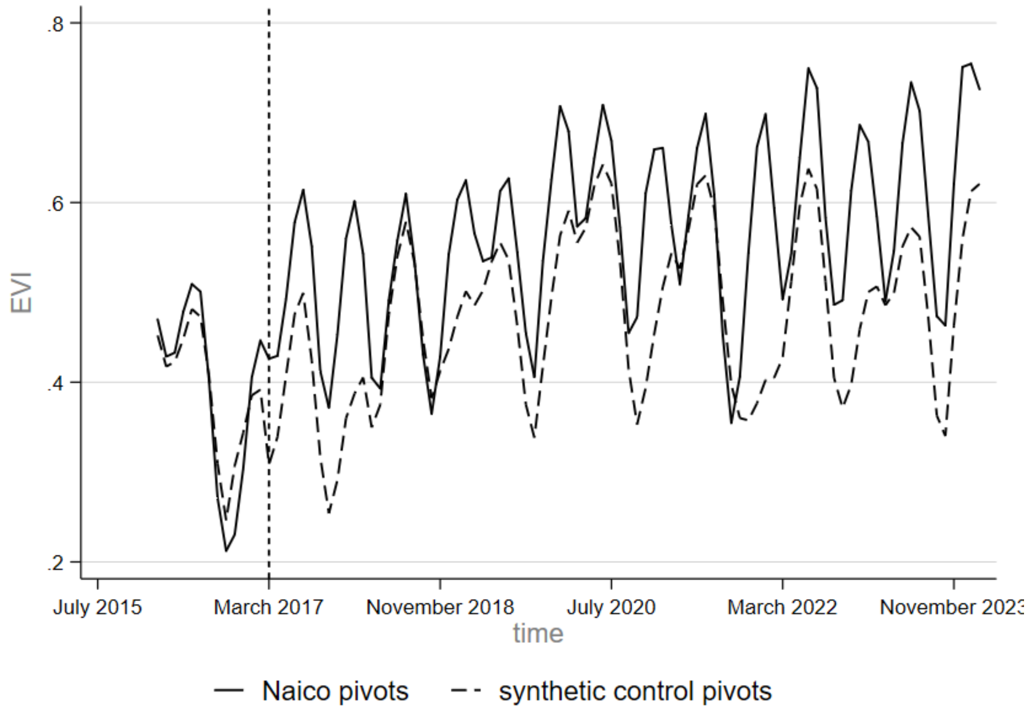
The GNDVI paints a similar picture (Figure 17). We see an uptick at the time of treatment, and the pivots outperform their synthetic control, but when applying a synthetic difference-in-difference, the variance across seasons is larger than the uptick in GNDVI created by the pivots, in 2017.

Figure 17 / Synthetic control: Green Normalized Difference Vegetation Index



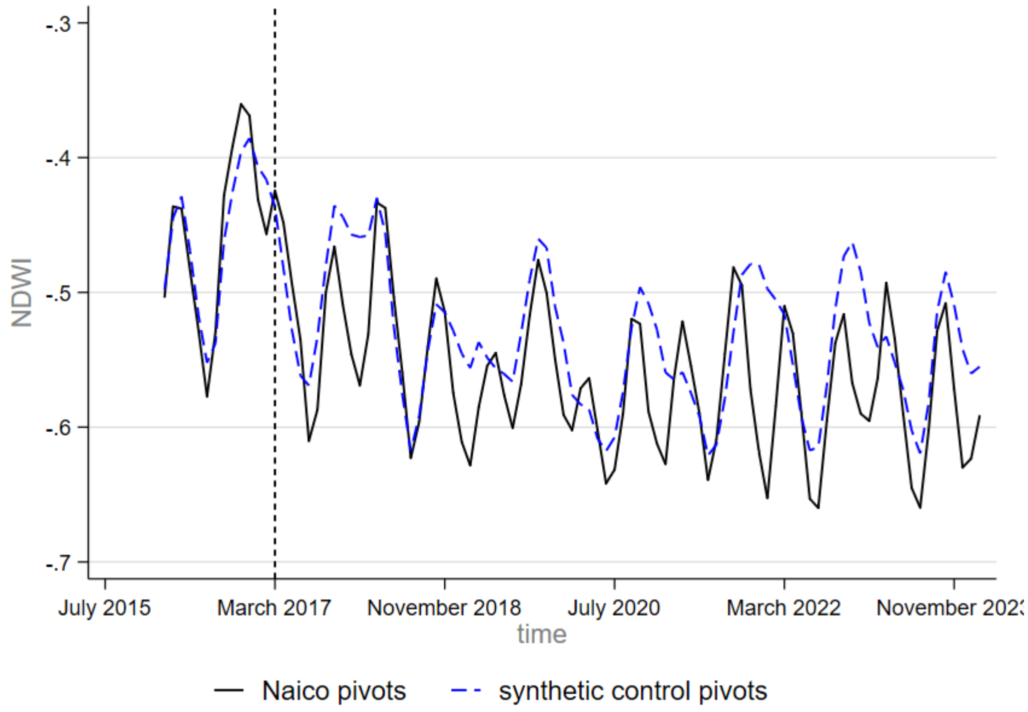
The EVI is used predominantly as a measure of crop quality and displays a similar picture to the NDVI. We do see an uptick at the time of installing the pivots, and generally, the crops in the pivots outperform the synthetic control after installing the pivots (Figure 18). However, similar to the NDVI, we do not find that the difference between the synthetic control and the pivots is statistically significant when performing a synthetic difference-in-difference. This is again likely due to the seasonal fluctuations and associated high variance in EVI measures.

Figure 18 / Synthetic control: Enhanced Vegetation Index



The NDWI shows a downward trend (Figure 19). The NDWI is an index used to measure the water content in vegetation and soil and proxy water stress. From the graph, it is evident that before the installation of the pivots, the NDWI values for the NAICO pivots and the synthetic control are closely aligned, indicating similar water content levels in both areas. Post-treatment, the NDWI values for the NAICO pivots exhibit some divergence from the synthetic control. We apply the synthetic difference-in-difference approach to test for statistical significance. Here, we estimate the treatment effect of pivot installation by comparing a 3-month moving average of NDWI values before and after the installation for the irrigated pivots to those of the synthetic control. The results show that the difference between irrigated pivots and synthetic control patches is not statistically significant (the average difference-in-difference of NDWI values equals -0.0128, p=0.638). This shows that the effect we find due to the installation of the pivots dwarfs the overall seasonal fluctuations in NDWI.

Figure 19 / Synthetic control: Normalized Difference Water Index



3.6.4 Key findings

Looking back in time using satellite imagery, we see fingerprints of the impacts of the program in increased greenness since the pivots' installation in 2017.

Before the implementation of the project, the imagery from 2015 to 2017 showed minimal greenness and vegetation vigor and low vegetation health in the areas slated for pivot installation and their surroundings.

By 2017, with pivots starting to operate, there was a noticeable increase in greenness and related yield proxies, shortly after the installation of the center pivots. This suggests improved yields and higher crop quality from 2017 onwards. Individual pivots show considerable variation in these yield proxies, but overall, we see an upward trend, suggesting a positive and sustained impact of the pivot irrigation systems on the yield proxies analyzed.

When comparing these results to a synthetic control, the areas with pivot irrigation systems consistently display higher values on the yield proxies analyzed. The Nasho areas thus consistently outperformed comparable patches of cropland in the surrounding area since 2017.

The substantial seasonal fluctuations in vegetation indices such as NDVI, GNDVI, and EVI introduce a high degree of variance in the outcomes. This variability across seasons likely overshadows the estimation of treatment effects in the synthetic difference in difference.

4. Benchmarking

4.1 Objectives

In order to ensure the accuracy and reliability of research findings, we compare the results from the household survey presented in chapter two with established reputable national surveys. The aim is to confirm and validate findings obtained from the first two research anchors at the level of individual farmer households, as well as at their plot level.

The benchmarking exercise involves analyzing subsets of small-scale farmers selected from relevant auxiliary datasets. By comparing outcomes such as income, yields, and farming practices observed among members of NAICO with those of other farmers in Rwanda, we can determine differences and similarities. Although the analysis focuses more on description rather than inference, it should provide a reliable indication of how the yields, income, and farming practices of NAICO members compare to other farmers in Rwanda. We made these comparisons both at the national and district levels. Additionally, we incorporated comparisons with the baseline and midline findings.

4.2 Methodology

4.2.1 Data collection

There is no primary data collection involved in implementing this research anchor. Instead, we compiled and organized existing high-quality household survey data collected among small-scale farmers in Rwanda. We used the following auxiliary data sources in Table 18.

Table 18 / Sources of outcomes to be benchmarked

Source	Domain	Relevant outcomes	Relevant modules/sections of focus	Timeframe
Seasonal Agriculture Survey (SAS)	Agricultural production	Use of inputs, agricultural practices, yields	Sections II, III, and IV	Season A 2023
Agriculture Household Survey (AHS)	Socio-demographics & farm characteristics, livelihood activities	Land use, savings, and credit	Sections II, IV, V	2020
Integrated Household Living Conditions Survey (EICV)	Socio-demographics and living conditions, assets, agriculture	Wages and income sources	Sections 6, 7, 8	2017

We benchmarked data on agricultural inputs, yields, and farming practices from the household survey against the NISR's Seasonal Agriculture Survey (SAS) microdata. The indicators from the SAS included the type of seeds sown, quantity and cost of fertilizers used, the quantity and cost of pesticides used, erosion control measures, plowing methods, cost and source of water for irrigation, the amount spent on hired labor, crop yields, and the use of harvests. All these indicators were benchmarked at the plot level.

Outcomes on agriculture practices at the household level such as farming practices, and livestock ownership were benchmarked against the NISR's Agriculture Household Survey (AHS). Other outcomes such as group membership, savings practices, and access to credit were also compared using this data, while other outcomes such as household income and income sources were benchmarked against the NISR's Integrated Household Living Conditions Survey (EICV) data.

Table 19 details the mapping of the different outcomes against each of the three sources of data to use for benchmarking.

Table 19 / Detailed mapping of outcomes

Outcomes	SAS	AHS	EICV
Farmer yields/production	Yes	No	No
Farmer revenue/profit	Yes	No	Yes
Farm management practices (including input use, utilization of pivots, conservation agriculture practices, etc.)	Yes	Yes	No
Farmer commercialization / marketing practices	Yes	No	Yes
Other farmer financial sustainability indicators (including savings practices, farm investments, access to credit, other sources of income, changes to expenditures, etc.)	No	Yes	Yes

The household's socio-demographics were used to better inform the comparisons on different outcomes. These demographics include data at the household and the farmer level such as the household size, and the plot manager's age, education, and marital status.

4.2.2 Analytical methodology

From the endline survey data, we computed the means of each of the outcomes to be benchmarked and compared these against the means from the secondary data.

Comparisons are made between the plots inside the Nasho irrigation scheme, those around the irrigation scheme, the averages at the Kirehe district level, and the national level averages. We benchmarked the outcomes at the farmer and household levels and presented the results in tables.

The outcomes at the farmer level are demographics such as the farmer's age, marital status, and education level. Those at the household level are socioeconomic outcomes such as the household's Ubudehe category, the number of household members, any cooperative membership, savings and credits, and the household's agricultural income.[39]

The outcomes at the plot level are the plot size, the average crop yield for maize, common beans, and soybeans, the amount of harvest sold per hectare, the type of market in which farmers sell their harvest, the usage of irrigation, and the type of irrigation used.

4.3 Findings

4.3.1 Plot level

We conducted plot-level comparisons using the data from NISR's SAS. This is the data collected during the agricultural season 2023A, as the final microdata of the season 2024A have not been published at the time of report drafting. However, its report that has already been published states that across the country there was an increase in the production of major crops compared to Season A of the previous years. This is most likely the result of heavy rainfall.

We are benchmarking the outcomes derived from our full sample plots separately from those only derived from the primary sample plots.

The SAS collects data from both small-scale and large-scale farmers. Large-scale farmers are defined as farmers cultivating a consolidated land of at least 10 hectares. For this benchmarking exercise, we excluded the data from the large-scale farmers in order to compare farmers of the same socio-economic background.

Full sample plot comparisons

On average, the plots in the Nasho irrigated area and its surrounding area are bigger than the average plots in the country. Those inside the irrigation area (0.35 ha) are five times bigger than the national average (0.07 ha), while those around the irrigation area (0.42 ha) are six times bigger (Table 20). They are also two to almost three times bigger than the average plots in Kirehe district, which are 0.15 ha on average.

We also find differences in crop yields between the plots in and around the Nasho irrigated area and those in the remaining parts of the country (Figure 20). Our comparisons focus on the three crop types that are grown on Nasho plots, namely maize, common beans, and soybeans.

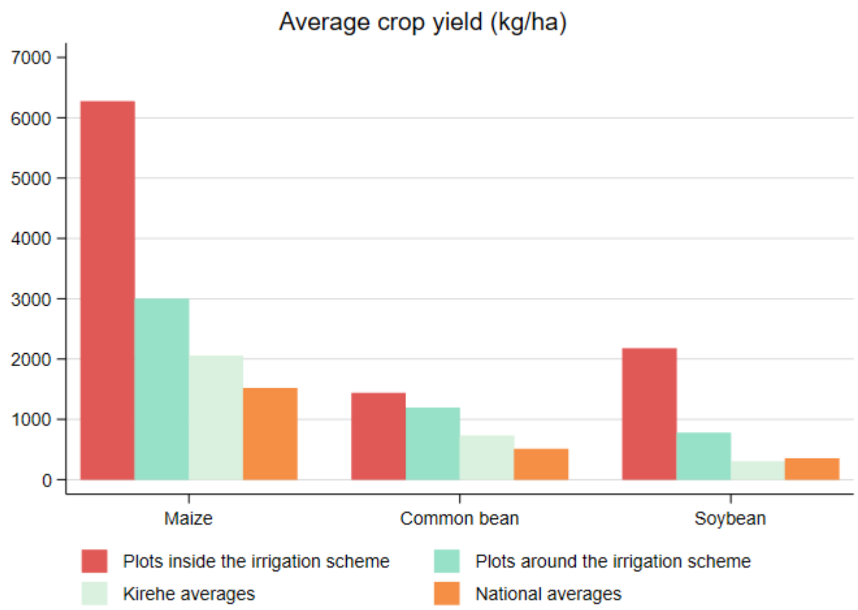
- **Maize –** The average yield of maize in the Nasho irrigation scheme (6,272 kg/ha) is four times greater than national averages (1,519 kg/ha), and three times greater than Kirehe district averages (2,054 kg/ha). The yield of maize in the plots around the irrigation scheme (3,000 kg/ha) is twice the national average and 1.5 times the Kirehe yield averages.
- **Common beans –** The yield of common beans in the plots inside the irrigation scheme (1,437 kg/ha) is approximately three times higher than national and Kirehe district averages (509 kg/ha and 726 kg/ha respectively), while the yield of the plots

[39] In this section, to ensure comparability between the different time periods, we report monetary values only in RWF and not in USD.

around the irrigation scheme (777 kg/ha) is about double the national and Kirehe district averages.

- **Soybeans –** The harvest of soybeans per hectare inside the irrigation scheme (2,176 kg/ha) is seven and six times greater than national and Kirehe district averages, which are 355 kg/ha and 301 kg/ha respectively. The soybean yield around the irrigation scheme (1,194 kg/ha) is around double the national and Kirehe district averages.

Figure 20 / Benchmarking of average crop yields by region



We notice differences in the share of harvest sold per hectare when comparing the plots inside and around the Nasho irrigation area, with both the Kirehe district and the national averages. The biggest difference is seen in the share of soybeans harvest sold, with the share of harvest sold per hectare inside the irrigation scheme (86%) being more than eight times the Kirehe averages (10%), and more than six times the average share of harvest sold per hectare nationally (13%). The share of common beans harvest sold per hectare is higher at the Kirehe district and national levels (47% and 23%, respectively) than in and around the Nasho irrigated area (39% and 17%, respectively). The percentage of maize harvest per hectare at Kirehe district level (87%) is about the same as in the Nasho irrigated area (81%), but more than twice in its surroundings (31%). Nationally, half of the maize harvest per hectare is sold (51%).

Looking at the market for the farmers' harvest, we see big differences in who the farmers primarily sell their harvest to. It is to be noted that the following figures are averaged at the plot level, and not at the farmer level.[40]

[40] Differences in the numbers reported here (Table 20) and those in Table 15 arise because in this section we compare Nasho vs. non-Nasho plots, whereas in section 2.3.2.2 we compare Nasho-only households vs. mixed households vs. non-Nasho-only households.

- **Cooperative / Company / Association –** This is by far the most common market for the farmers who cultivate inside the Nasho irrigation scheme, and the least common looking at national and Kirehe district averages. Maize is sold at 98% by the farmers cultivating inside the Nasho irrigation scheme to this group, soybeans at 91%, and common beans at 71%. A third of the maize harvested around the irrigation scheme (34%) was sold to this group, while a quarter of the soybean harvest (23%) was sold to this group. Only 2% of the common beans harvested around the irrigation scheme were sold to this group. Looking at national averages, maize is the most common crop sold to this group (5%), followed by soybeans at 3%, and 0% for beans. At Kirehe district level, only 0.2 % of the maize harvested was sold to this group.
- **Market / Middlemen –** Physical markets and middlemen are the most common buyers of the harvest from the plots around the irrigation scheme, at Kirehe district level, and nationally, although 65% of the common beans harvested at Kirehe district level are sold to fellow farmers or consumers. This is also the second most common group to whom NAICO members sell their harvest, with 18% of common beans, 6% of soybeans, and just 1% the maize harvested, being sold to this group.
- **Farmer / Consumer –** This is the third most common market for farmers at all levels, although no maize harvested inside the Nasho irrigation scheme was sold to this group.

Another big difference lies in the practice of irrigation, with all the plots in the Nasho irrigation scheme being irrigated, against 13% of the plots at the national level. Although only 16% of the plots around the Nasho irrigation scheme are irrigated, the numbers rise to 30% when taken at the Kirehe district level.

Pivot irrigation is the most common type of irrigation used inside the Nasho irrigation scheme (100%), and second when looking at averages at the Kirehe district level (26%). This is however not used on the plots around the irrigation scheme and is used on 6% of the plots nationally. Traditional irrigation[41] is the most common method of irrigation at all levels, besides within the Nasho irrigation scheme. Half of the plots irrigated around the irrigation scheme and at the national level are irrigated through traditional irrigation. While sprinkler irrigation is the second most common irrigation type used around the irrigation scheme (50%), it is only used at 5% nationally, with surface irrigation being the second most common at the national level (22%).

[41] As opposed to how irrigation methods are classified in section 2.3.2.1, in this table irrigation through a hose connected to a water pump or source is classified as traditional irrigation, to match the categorization in the secondary data.

Table 20 / Benchmarking of crop-level outcomes and irrigation practices

	Nasho plot (n = 1,200)	**Non-Nasho plot** (n = 1,245)	**Kirehe district averages**	**National averages**
	Mean (SD) or %	*Mean (SD) or %*	*Mean (SD) or %*	*Mean (SD) or %*
Plot area in ha	0.35 (0.41)	0.42 (0.75)	0.15 (0.23)	0.07 (0.10)
Maize yield (kg/ha)	6,272 (4,143)	3,000 (3,560)	2,054 (1,322)	1,519 (1,340)
Common bean yield (kg/ha)	1,437 (1,292)	1,194 (1,266)	726 (405)	509 (397)
Soybean yield (kg/ha)	2,176 (1,014)	777 (664)	301 (167)	355 (322)
Share of maize harvest sold (%)	81%	31%	87%	864 (3,954)
Share of common beans harvest sold (%)	39%	17%	47%	123 (614)
Share of soybeans harvest sold (%)	86%	57%	10%	60 (318)
Buyer of maize				
Cooperative/Company/ Association	98%	34%	0.2%	5%
Market/ Middlemen	1%	48%	51%	57%
Farmer/ Consumer	0%	15%	48%	37%
Other	0%	2%	0%	1%
Buyer of common beans				
Cooperative/ Company/ Association	71%	2%	0%	0%
Market/ Middlemen	18%	73%	35%	54%
Farmer/ Consumer	10%	23%	65%	46%
Other	0%	1%	0%	0%
Buyer of soybeans				
Cooperative/Company/ Association	91%	23%	0%	3%
Market/ Middlemen	6%	55%	93%	71%
Farmer/ Consumer	3%	18%	7%	27%

	Nasho plot (n = 1,200)	Non-Nasho plot (n = 1,245)	Kirehe district averages	National averages
	Mean (SD) or %	*Mean (SD) or %*	*Mean (SD) or %*	*Mean (SD) or %*
Other	0%	5%	0%	0%
Practiced irrigation	100%	16%	30%	13%
Irrigation type				
Pivot irrigation	100%	0%	26%	6%
Surface irrigation	0.2%	0.5%	13%	22.2%
Traditional irrigation	0.2%	50.5%	21.7%	46.4%
Sprinkler irrigation	0%	50%	21.7%	5%
Flood irrigation	0%	0%	17.4%	16.9%

Main plot comparisons

In this section, we compare the data collected at the main plot level in our survey against the outcomes from the SAS data. We will compare plot-level outcomes on agriculture inputs and erosion.

Organic fertilizers

Organic fertilizers are less often applied inside and around the Nasho irrigation scheme (64% and 68% respectively) than they are applied at the Kirehe district (79%) and national levels (76%). This trend is also observed through the money spent on organic fertilizers per season. At Kirehe district and national levels, a bit more than 189,000 RWF is spent on average on organic fertilizer per hectare, an amount higher than the 117,635 RWF and 64,991 RWF spent on average on organic fertilizer per hectare for the plots inside and around the scheme respectively.

Inorganic fertilizers

Inorganic fertilizers on the other hand are more commonly used inside and around the Nasho irrigation scheme than they are on average used at Kirehe district and national levels. While inorganic fertilizers were reported to be used in 99% of the plots inside the irrigation scheme and in two-thirds of the plots around the scheme (67%), they only applied in less than half of the plots at Kirehe district level (41%), and less than a third of the plots nationally (31%). Consequently, farmers spend more money on inorganic fertilizers per hectare per season on the plots inside the scheme (199,043 RWF). Nationally, the money spent on average on inorganic fertilizers per hectare is 87,632 RWF, which is a bit higher than the amount spent on the plots around the irrigation scheme (82,473 RWF). The average amount spent at Kirehe district level is 52,129 RWF.

Pesticides

Pesticides are also more often applied on the plots inside and around the Nasho irrigation scheme than they are applied at Kirehe district and national levels. They are used in 99% of the plots inside the scheme and in 63% of the plots around the scheme. This is higher than Kirehe district and national averages, where they are used in about half of the plots (50% and 46% respectively). The average amount of money spent on pesticides per hectare per season on the plots inside the scheme (69,959 RWF) is slightly lower than the national average (76,570 RWF). However, this is more than three times the amount spent on the plots around the irrigation scheme (23,160 RWF) and about double the amount spent on average at Kirehe district level (38,098 RWF).

Certified seeds

Certified seeds are used on almost all (99%) Nasho plots and in about half of the plots around the scheme and at Kirehe level (49% and 45%, respectively). On a national level, they are used on 31% of plots.

Hired labor

The average amount of money spent on hired labor per hectare per season on the plots inside the irrigation scheme (385,504 RWF) is more than twice the money spent on the plots around the scheme (162,121 RWF), six times the national averages (60,505 RWF), and eight times Kirehe district averages (49,433 RWF).

Erosion and erosion control

76% of the plots inside the Nasho irrigation scheme have a very low degree of erosion, which is slightly lower than Kirehe district levels (79%). This is however substantially higher than the average degree of erosion of the plots around the irrigation scheme (66%) and the national average (45%). Around a fifth of the plots inside the irrigation scheme (20%) have a low to moderate degree of erosion, similar to the average Kirehe district levels (22%). At national level, about half of the plots have a low to moderate degree of erosion (53%), while this is for about a third of the plots around the irrigation scheme.

While erosion control measures are applied on 86% of the plots both nationally and at Kirehe district level, these are only applied on 28% of the plots inside the Nasho irrigation scheme, and to 60% of the plots around the scheme.

Table 21 / Benchmarking of agricultural inputs and erosion

	Nasho plot (n = 608)	**Non-Nasho plot** (n = 607)	**Kirehe district averages**	**National averages**
	Mean (SD) or %	*Mean (SD) or %*	*Mean (SD) or %*	*Mean (SD) or %*
Usage of organic fertilizers	64%	68%	79%	76%
Expenditures on organic fertilizer per ha (RWF)[1]	117,635 (197,522)	64,991 (153,467)	189,426 (235,777)	189,851 (181,626)
Usage of inorganic fertilizers	99%	67%	41%	31%
Expenditures on inorganic fertilizer per ha (RWF)[1]	199,043 (171,644)	82,473 (141,657)	52,129 (77,687)	87,632 (98,873)
Usage of pesticides	99%	63%	50%	46%
Expenditures on pesticides per ha (RWF)[1]	69,959 (72,486)	23,160 (43,560)	38,098 (97,416)	76,570 (130,377)
Usage of certified seeds	99%	49%	45%	31%
Expenditures on hired labor per ha (RWF)[1]	385,504 (301,815)	162,121 (228,277)	49,433 (110,019)	60,505 (104,507)
Degree of erosion				
Very low (Splash erosion)	76%	66%	79%	45%
Low (Wind erosion)	10%	15%	18%	35%
Moderate (Diffuse overland flow erosion, overland flow erosion, erosion by infiltration)	10%	16%	4%	18%
Severe (Rill erosion, gully erosion, mass movement/ landslides)	1%	3%	0.1%	2%
Usage of erosion control measures	28%	60%	86%	86%

[1]Observations that did not spend money on the inputs were assigned the value zero.

Benchmarking against the midline and endline findings

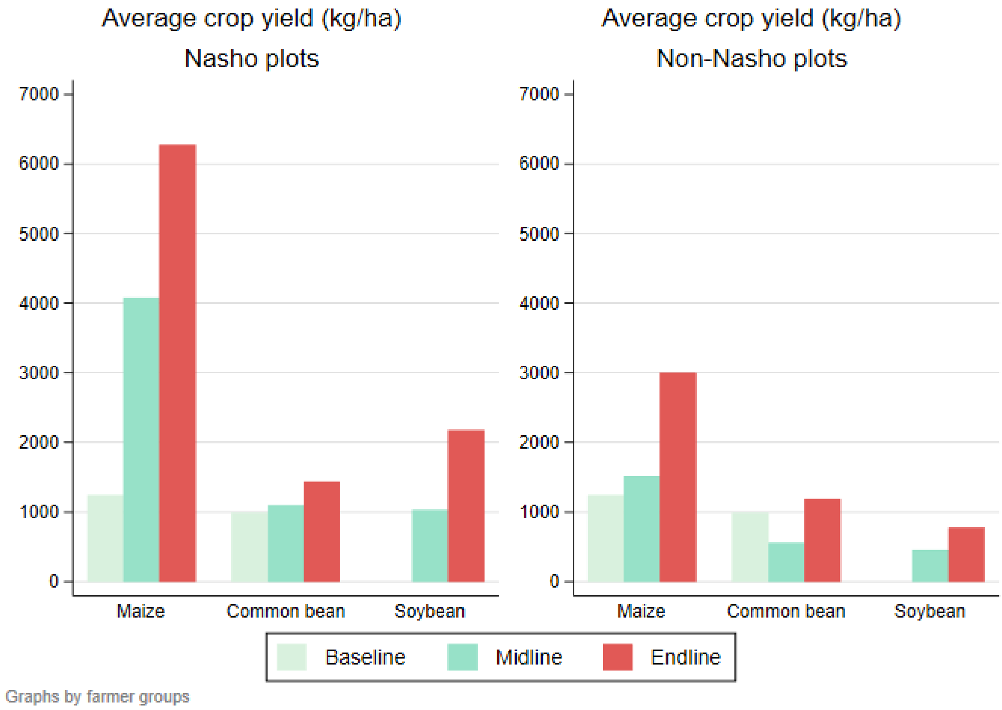
In this subsection, we compare the crop yields reported in the baseline and midline studies on the Nasho Irrigation Project with our findings during endline (Table 22).

The baseline study took place during the agricultural season 2015B, while the midline study was conducted during the agricultural season 2020A. It is to be noted that the reported data from the baseline study does not differentiate the yields between the plots that were to be part of the Nasho irrigation scheme, and those that were not, although 299 plots out of the 420 plots in the study sample were expected to benefit from the irrigation project.

There has been a substantial increase in the yield of maize, common beans, and soybeans inside and around the Nasho Irrigation Project since the baseline study in 2015 (Figure 21).

- **Maize –** Maize is the crop that has seen the biggest increase in yield throughout the project timeline. For the plots inside the irrigation area, the maize yield tripled between the baseline and the midline studies, growing from 1,244 kg/ha to 4,077 kg/ha. Between midline and endline, the maize yield increased 1.5 times higher for the same plots, to reach a yield of 6,272 kg/ha. Although there was a little increase in the maize yield for the plots grown around the irrigation scheme between baseline and midline (from 1,244 kg/ha to 1,518 kg/ha), the yields doubled between midline and endline, to reach 3,000 kg/ha.
- **Common beans –** There has been a regular increase in the common beans yield on the plots inside the irrigation scheme throughout the study. The yield of common beans grew from 988 kg/ha during baseline, to 1,100 kg/ha during midline, and 1,437 kg/ha during endline. For the plots around the irrigation scheme, the yield of common beans dropped from 988 kg/ha to 556 kg/ha between baseline and midline but then increased again to 1,194 kg/ha at endline.
- **Soybeans –** Soybeans were not grown in the Nasho study area when the baseline study took place. For that reason, we will only compare the changes in yields between the midline and the endline studies. Inside the Nasho irrigation scheme, the soybeans' yield doubled from 1,031 kg/ha during midline, to 2,176 kg/ha during endline. The soybeans yield in the plots grown around the irrigation scheme also increased, namely from 459 kg/ha at midline to 777 kg/ha at endline.

Figure 21 / Crop yield comparison between baseline, midline, and endline



Again, it is to be noted that across Rwanda there was an increase in the production of major crops compared to Season A of the previous years, as reported in the NISR' SAS 2024A report. This increase is also seen in the yield of maize, common beans, and soybeans.

Table 22 / Crop yield comparison between baseline, midline, and endline

	Baseline	Midline		Endline	
	Nasho & non-Nasho plot (n = 420)	**Nasho plot** (n = 415)	**Non-Nasho plot** (n = 145)	**Nasho plot** (n = 1,200)	**Non-Nasho plot** (n = 1,245)
	Mean	*Mean*	*Mean*	*Mean*	*Mean*
Maize yield (kg/ha)	1,244	4,077	1,518	6,272	3,000
Common bean yield (kg/ha)	988	1,100	556	1,437	1,194
Soybean yield (kg/ha)	-	1,031	459	2,176	777

4.3.2 Household level

In this part, we discuss the benchmarking of the data on demographic outcomes depicted in Table 23. We used the latest NISR's AHS data for comparing most of the outcomes in this section, whose data was collected in 2020. We benchmarked the data on household income using the latest published NISR's EICV5 data, which was collected in 2017. The demographic data reported below are at the farmer level, while the economic outcomes are reported at the household level.

Age

The average age of the farmers interviewed in our survey is 49 years, for both those farming inside and those farming around the Nasho irrigation scheme. This is slightly higher than the age of the farmers interviewed in 2020 in the AHS who are on average 46 years old nationally, and on average 44 years old at the Kirehe district level.

There is a substantial difference in the share of youth farmers between the farmers who cultivate inside and around the irrigation scheme, and the national and Kirehe averages. One fifth of the farmers at national level (21%) and a quarter at Kirehe district level (25%) were youth, while only 7% of the NAICO farmers and 13% of the farmers cultivating around the irrigation scheme are youth. Youth is defined as being 30 years of age or younger.

Education level

The level of education of NAICO farmers and those farming around the Nasho irrigation scheme is slightly higher than the average educational level of farmers at national and Kirehe district levels. The main difference is seen in the level of those who attended primary school, where 69% and 67% of NAICO farmers and those farming around the irrigation scheme attended primary school, respectively, while on average 62% and 60% of farmers at national and Kirehe district levels attended primary school.

Ubudehe categorization

Based on the Ubudehe categorization, NAICO households are wealthier than those farming around the Nasho irrigation scheme, and wealthier than the average farming households at both Kirehe district and national levels. About half of the NAICO households (49%) belong to Category 3, while about a third of the households in the other groups belong to this category, which is the wealthiest category for farming households, since less than 1% of them belong to the wealthier Category 4. The households farming around the irrigation scheme are less poor than the average farming households at Kirehe district and national levels. 17% of the farming households at national level, and 15% at Kirehe district level belong to the Ubudehe Category 1, the poorest category. This is double the number of households that farm around the irrigation scheme and belong to this category (7%) and triple the number of NAICO households that belong to this category (5%).

Household composition

80% of NAICO farmers are married. This is higher than the average number of married farmers, which is about 72% for the farmers cultivating around the Nasho irrigation scheme, as well as for Kirehe district and national level averages. A higher number of farmers at national level (20%) and at Kirehe district level (18%) are widowed, compared to those farming inside (11%) and around the scheme (14%).

Looking at the average number of household members, the average NAICO household size (5.0) is slightly higher than the average size of the households farming around the Nasho irrigation scheme (4.7). This is also slightly higher than the average farming household size both at Kirehe district level and nationally, which is 4.5.

Membership in a cooperative

By definition, all NAICO households belong to a cooperative. At Kirehe district level, on average more households belong to a cooperative (22%) than for the households farming around the Nasho irrigation scheme (18%). The national average number of farming households belonging to a cooperative is slightly lower with 13%.

Savings and credit

We also benchmarked the data on savings and credit albeit having asked about these referring to the last 30 days in our survey, while the reference was on the last 12 months in the AHS. More NAICO households (77%) and households cultivating around the Nasho irrigation scheme (72%) reported having savings in the last 30 days, than the national average number of farming households that reported having savings in the last 12 months (68%). However, that is slightly lower than the Kirehe district average, which is 80%. This is despite the reference period for NAICO and non-NAICO households being shorter.

Regarding credit, a quarter of the households farming inside and around the irrigation scheme took a credit in the last 30 days (25% and 27% respectively), which is substantially lower than the average number of farming households having taken a credit in the last 12 months at Kirehe district level (46%), and nationally (38%). Given that the reference period for NAICO households and those farming around the irrigation scheme is the last 30 days, it might be the case that these households would reach or go beyond the levels that are noticed at Kirehe district and national levels for 12 months.

Household income

We benchmarked the data on household income using the EICV data collected in 2017. Given that the EICV survey represents all the households in the country, and not just the households that practice agriculture as do the surveys of the other two secondary data used so far, we only compared the income coming from agricultural activities to keep comparability between our samples (Figure 22). NAICO households reported an average annual agricultural income (1,206,425 RWF) that is more than twice the income reported by the households farming around the irrigation scheme (421,217 RWF), and more than thrice the average agricultural income at Kirehe district level (503,096 RWF) and national level (540,868 RWF)[42].

[42] The agricultural income at Kirehe district and national level was adjusted for inflation, using the NISR's monthly published Consumer Price Index (CPI). Inflation was adjusted using the rural CPI reported in March 2017 and the rural CPI of March 2024.

Figure 22 / Benchmarking of annual agricultural income by region (in RWF)

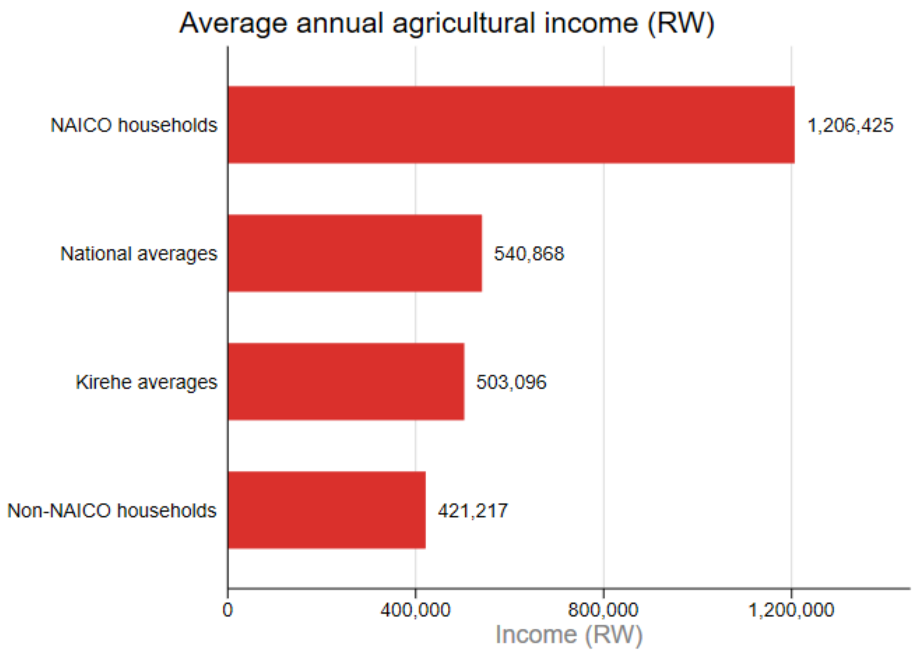


Table 23 / Benchmarking demographic outcomes

	NAICO households (n = 604)	**Non-NAICO households** (n = 401)	**Kirehe district averages**	**National averages**
	Mean (SD) or %	*Mean (SD) or %*	*Mean (SD) or %*	*Mean (SD) or %*
Farmer's age	49 (13)	49 (15)	44 (15)	46 (16)
Youth farmers	7%	13%	25%	21%
Female farmers	35%	47%	52%	56%
Highest level of education				
Primary	69%	67%	60%	62%
Secondary	12%	12%	16%	13%
University	2%	1%	1%	2%
No education[43]	16%	18%	22%	23%
Marital status				
Single	4%	6%	2%	3%

[43] 1% of NAICO farmers reported that they went to IGA or Ibibeho, which are schools that teach adults how to read, write, and count.

	NAICO households (n = 604)	**Non-NAICO households** (n = 401)	**Kirehe district averages**	**National averages**
	Mean (SD) or %	*Mean (SD) or %*	*Mean (SD) or %*	*Mean (SD) or %*
Married	80%	72%	73%	72%
Widowed	11%	14%	18%	20%
Divorced	4%	7%	7%	5%
Ubudehe category				
Category 1	5%	7%	15%	17%
Category 2	46%	60%	46%	43%
Category 3	49%	32%	34%	38%
Category 4	0%	0%	0%	0%
Unspecified category	0%	1%	5%	3%
Household size	5.0 (1.9)	4.7 (1.9)	4.5 (1.8)	4.5 (2.0)
Cooperative membership	100%	18%	22%	13%
Have savings in the last 30 days (or the last 12 months)[44]	77%	72%	80%	68%
Took credit in the last 30 days (or the last 12 months)	25%	27%	46%	39%
Agricultural annual income (RWF)	1,206,425 (1,411,676)	421,217 (691,796)	503,096 (738,822)	540,868 (897,569)

[44] We asked about savings and credit in the last 30 days, while the AHS referred to the last 12 months.

5. Summary of research questions

In this section, we summarize the findings by answering the research questions presented in chapter 1 using key findings from chapters 2, 3, and 4.

Objective 1: Assess the impact of the Nasho Irrigation Project at the plot level

1. **What is the impact of the Nasho Irrigation Project on plot yields per hectare by crop?**

The average yields of maize, common beans, and soybeans are significantly higher on Nasho plots than on other plots in the Nasho area, the Kirehe district, and nationally.

The average yield of maize on Nasho plots (6,272 kg/ha) is twice as much as the yield on non-Nasho plots (3,000 kg/ha). It is four times greater than the national average (1,549 kg/ha), and three times greater than the Kirehe district average (2,054 kg/ha).

The average yield of common beans on Nasho plots (1,437 kg/ha) is significantly higher than the yield on non-Nasho plots (1,194 kg/ha). It is approximately three times higher than the national and Kirehe district averages (509 kg/ha and 576 kg/ha respectively).

The harvest of soybeans per hectare inside the irrigation scheme (2,176 kg/ha) is seven and six times greater than the national and Kirehe district averages, which are 355 kg/ha and 301 kg/ha respectively. The yield on Nasho plots is also significantly higher than on non-Nasho plots, though the sample size of non-Nasho plots growing soybeans is small.

Over time, there has been a substantial increase in crop yields between the baseline, midline, and endline studies. Maize yield increased from 1,244 kg/ha at baseline in 2015 to 4,077 kg/ha at midline in 2020, to reach 6,272 kg/ha at endline. Common beans yield increased from 988 kg/ha at baseline to 1,100 kg/ha at midline and reached 1,437 kg/ha at endline. Soybeans yield increased from 1,031 kg/ha at midline to 2,176 kg/ha at endline.

During qualitative interviews, NAICO farmers also reported that they enjoy consistent harvests regardless of the weather conditions thanks to the irrigation system.

The geospatial analysis shows low greenness and crop vigor before 2017 in the areas scheduled for center pivot implementation. This indicates low yield and productivity before installing the center pivots.

There was a noticeable uptick in greenness and related yield proxies shortly after the installation of the center pivots in 2017 and an overall upward trend till 2024. Individual pivots show considerable variation in these yield proxies. Still, overall, we see an upward trend, suggesting a positive and sustained impact of the pivot irrigation systems on the yield proxies analyzed.

Nasho plots consistently outperform comparable plots in the region on all yield proxies analyzed. There is, however, substantial seasonal variation. This variability across seasons likely overshadows the effect of the uptick in yield proxies observed in 2017.

2. What is the impact of the Nasho Irrigation Project on the farmer households' agricultural farming practices at the plot level?

Overall, more practices are reported to be practiced on Nasho plots than on non-Nasho plots. Weeding and plowing (land preparation before sowing) are most commonly practiced (95-96%), with no significant differences between the two groups. They are followed by planting in rows which is practiced by almost all (98%) Nasho plots but significantly less by non-Nasho plots (56%). Plot managers are also more likely to practice plant spacing on Nasho plots than on non-Nasho plots (66% vs. 38%). However, plot managers are more likely to report practicing anti-erosion measures on non-Nasho plots than on Nasho plots (29% vs. 17%). The self-reported rates differ slightly from the enumerator observations which are higher: enumerators indicated that 60% of non-Nasho and 28% of Nasho plots practice anti-erosion measures ($p<0.001$). At the district and national levels, the percentage of farmers practicing erosion control measures is even higher with 86% each. Among those plots that exhibit anti-erosion measures, the most commonly observed measures for Nasho plots are water channels (74%), followed by trenches (19%), and water drainage (13%). For non-Nasho plots, trenches are most commonly observed (68%), followed by water channels (28%), and trees/windbreak/shelterbelt (15%).

Significantly more farmers practice conservation agriculture on Nasho compared to non-Nasho plots (34% vs. 15%).[45] This is mainly driven by minimum tilling (98% vs. 85%) and crop rotation (100% vs. 77%). There is room for improvement in permanent organic soil cover (either through cover crops and/or crop residue) both for Nasho and non-Nasho plots, with only 35% and 25% implementing this practice, respectively.

During qualitative interviews, NAICO farmers mention that their farming practices have improved from what they practiced before the irrigation project began. This was informed by agricultural training they received as well as field visits from agronomists.

3. What is the impact of the Nasho Irrigation Project on farmer households' use of agricultural inputs at the plot level?

Nasho plots are significantly larger users of inorganic fertilizers, pesticides, certified seeds, and hired labor.

Nasho plots use significantly more inorganic fertilizers and pesticides than non-Nasho plots. The overall usage of organic fertilizers is similar for both groups. In line with this, expenditures per hectare on fertilizers and pesticides are significantly higher for Nasho

[45] The three main pillars of conservation agriculture are 1) minimum soil disturbance (no or minimum till), 2) permanent organic soil cover (either through cover crops and/or crop residue) on at least 30% of the plot, and 3) crop rotation.

plots. We also see a higher use of inorganic fertilizers and pesticides on Nasho plots than at the Kirehe and the national level.

Certified seeds are used in 99% of Nasho plots and about half of the plots around the scheme and at Kirehe level (49% and 45%, respectively). On a national level, they are used on 31% of plots.

Significantly more farmers employed labor on Nasho plots than non-Nasho plots in the last agricultural season (92% vs. 77%). Consequently, farmers spent significantly more money on average on hired labor per hectare on Nasho plots than on non-Nasho plots. The average amount of money spent on hired labor per hectare on the plots inside the irrigation scheme in the last agricultural season (385,504 RWF / USD 296) is more than twice the money spent on the plots around the scheme (163,307 RWF / USD 125), six times the national averages (60,505 RWF), and eight times Kirehe district averages (49,433 RWF).[46]

4. **What are the spillover effects for NAICO farmers on other plots they manage in terms of the use of agricultural inputs and farming practices?**

NAICO farmers report that they apply the skills taught by the project also to their plots outside of the irrigation project. This includes skills such as row planting, use of manure, inorganic fertilizer, pesticides, and improved seeds. Farmers also report that the farming practices implemented within the irrigation pivots are adopted by other farmers in the region with plots outside the irrigation project.

Objective 2: Understand how NAICO and non-NAICO farmers differ at the household level

5. What are the differences in household income, poverty probability index, and livestock ownership between NAICO and non-NAICO farmers?

NAICO households are considered less poor than non-NAICO households. NAICO households have an average poverty likelihood of 23.3%, which is considered to be below the national poverty line. Non-NAICO households have a higher likelihood of 28.8% to be below the national poverty line. Majority of NAICO households belong to Ubudehe Category 3 while majority of non-NAICO households belong to Ubudehe Category 2.[47]

All NAICO and non-NAICO households engage in cropping activities to generate income. The majority of NAICO households (82%) and non-NAICO households (80%) also engage in livestock keeping to generate income. NAICO households own significantly more livestock than non-NAICO households.

NAICO households generate most of their income from agricultural activities, while non-NAICO households generate most of their income from non-agricultural

[46] Using an exchange rate of 1 RWF = 0.00076757 USD from March 20th, 2024.
[47] The Ubudehe categories in Rwanda classify households based on income. The higher the category, the wealthier the household.

activities. All NAICO and non-NAICO households engage in agricultural activities. 55% of non-NAICO and 37% of NAICO households report engaging in non-agricultural income activities. Out of those engaging in non-agricultural activities, the most common activity is daily labor (32% of non-NAICO and 13% of NAICO households), followed by self-employment and informal sales.

NAICO households' monthly and annual income from agricultural activities is significantly higher than that of non-NAICO households, as well as households in the Kirehe district and nationwide. NAICO households reported an average annual agricultural income (1,206,425 RWF / USD 926) that is more than twice the income reported by the households farming around the irrigation scheme (421,217 RWF / USD 323), and more than thrice the average agricultural income at Kirehe district level (503,096 RWF / USD 386) and national level (540,868 RWF / USD 415).

There are no significant differences in the average reported monthly and annual income generated from non-agricultural activities between NAICO and non-NAICO households. NAICO households report earning on average 190,217 RWF (USD 146) and non-NAICO households on average 149,487 RWF (USD 115) per year from non-agricultural activities.

6. What are the differences between NAICO and non-NAICO farmers in how they market their produce?

Overall, NAICO is the largest buyer of harvested produce in our sample. There are, however, significant differences in how NAICO and non-NAICO members market their harvests. We also see some differences by crop.

Households that own plots only inside the Nasho irrigation scheme predominantly sell their maize, common bean, and soybean harvests to NAICO. This may be explained by prices per kg sold being higher for Nasho compared to non-Nasho plots. The household survey showed that there is a significant difference in prices achieved for maize: 361 vs. 290 RWF/kg. Farmers in qualitative data corroborated the finding that NAICO pays slightly higher prices.

For mixed households (those that farm Nasho and non-Nasho plots), we see differences by crop. For maize, the majority sells its harvest to NAICO. For common beans, they sell their harvests equally to NAICO and local markets/roadside sellers, but also to farmers/consumers directly or middlemen. For soybeans, the biggest buyer is again NAICO.

For non-Nasho households, the biggest buyers for all crops are middlemen or local markets/roadside sellers. This is followed by selling to farmers/consumers directly or other cooperatives.

Objective 3: Understand potential unintended consequences of the Nasho Irrigation Project

7. What are the potential unintended consequences of the Nasho Irrigation Project?

Farmers report that the value of land within the irrigation pivots has increased, while the land outside the pivots has decreased in value.

During the project's inception phase, some farmers sold the land they owned inside the future pivots fearing it would be taken away from them. Similarly, few older farmers who feared they would be unable to farm inside the pivots as it demanded more labor also reportedly sold their land. Other farmers who expected a large financial burden due to the change in farming practices sold their land as well.

REFERENCES

Ali, D. A., Deininger, K., & Goldstein, M. (2014). Environmental and gender impacts of land tenure regularization in Africa: Pilot evidence from Rwanda. *Journal of Development Economics*, 110, 262- 275.

Balkenhol, B., & Gueye, E. H. (1994). Tontines and the Banking System—is there a case for building linkages?. *Small Enterprise Development*, *5*(1), 47-55.

Dillon, A., & Fishman, R. (2019). Dams: Effects of hydrological infrastructure on development. *Annual Review of Resource Economics*, *11*, 125-148.

Jones, Maria, Florence Kondylis, John Loeser and Jeremy Magruder (2022). Factor Market Failures and the Adoption of Irrigation in Rwanda. *American Economic Review*, 112 (7): 2316-52.

APPENDIX

Impact of the Nasho Irrigation Project at the plot level

Agricultural practices

Figure 23 / Reported changes in agricultural practices by NAICO farmers

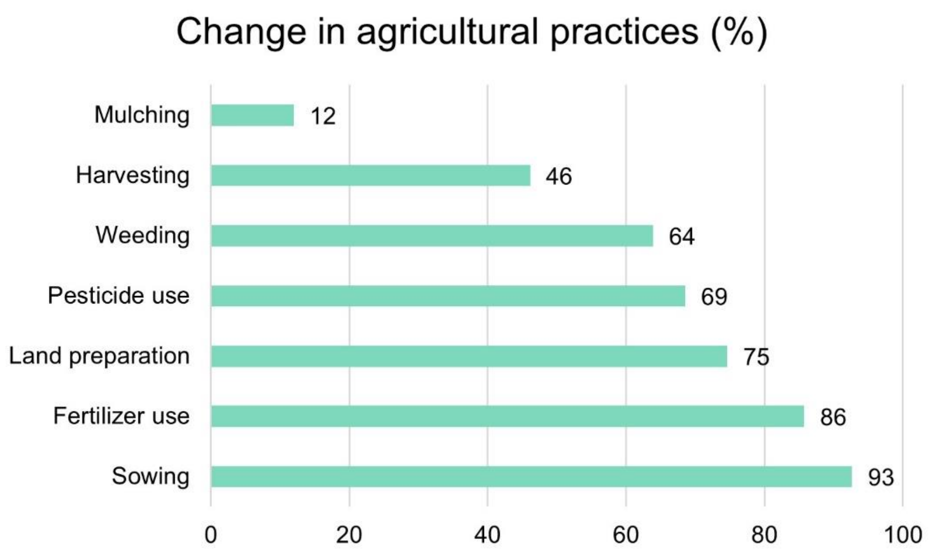
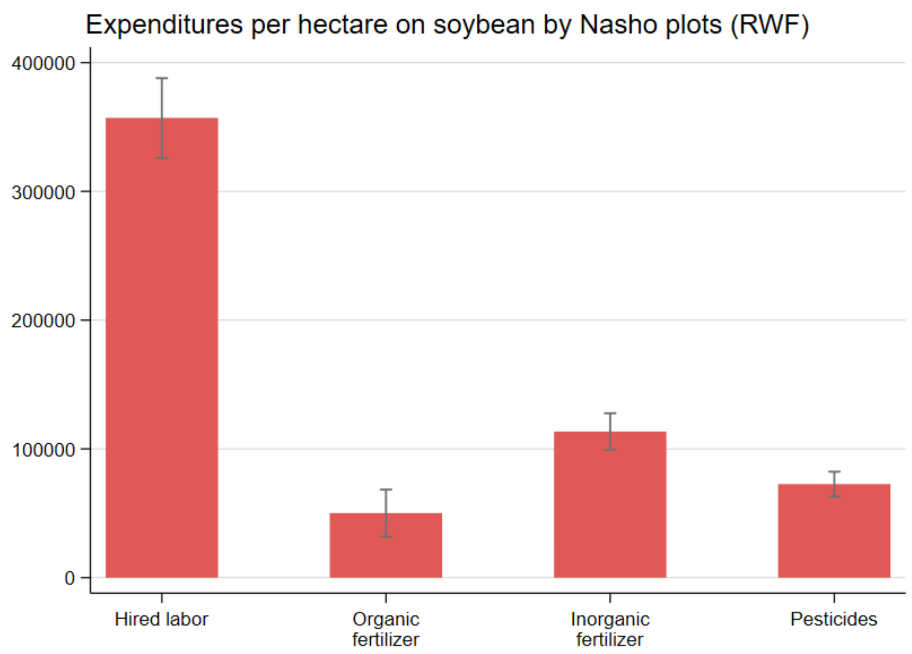
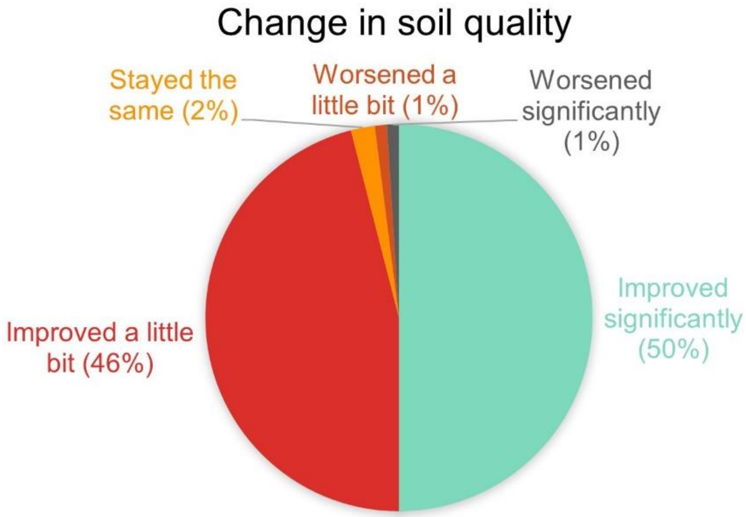


Figure 24 / Expenditures per hectare on soybeans



Soil quality

Figure 25 / Reported changes to soil quality by NAICO farmers



Harvest kept for home consumption

Table 24 / Harvest kept for home consumption for maize, common bean, and soybean

	Nasho plot	Non-Nasho plot	p-value
	Mean (SD)	*Mean (SD)*	
Harvest in kg per ha that was kept for home consumption			
Maize (n = 1,108)	955 (2,066)	1,298 (9,562)	0.82
Common bean (n = 782)	845 (3,256)	707 (1,058)	0.37
Soybean (n = 516)	153 (390)	248 (416)	0.19

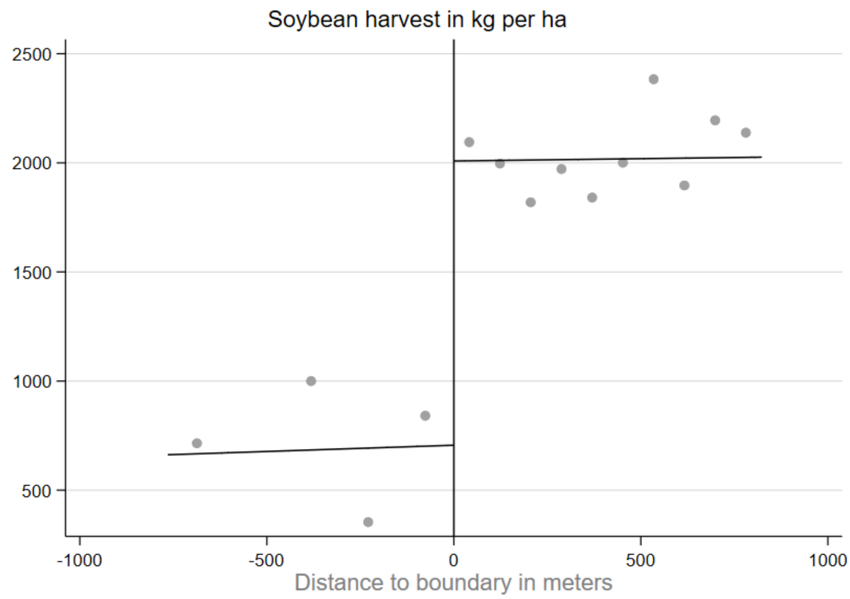
Harvests

Table 25 / Regression-estimated increases in harvests

	Harvest of maize per hectare	Harvest of common beans per hectare	Harvest of soybean per hectare
RD estimate	3,204.2***	995.8*	1,302.3***
(SE)	*(950.6)*	*(570.8)*	*(422.3)*
p-value	*0.001*	*0.081*	*0.002*
Observations	639	408	257

*** p<0.01, ** p<0.05, * p<0.1

Figure 26 / Regression-estimated increases in soybean harvest



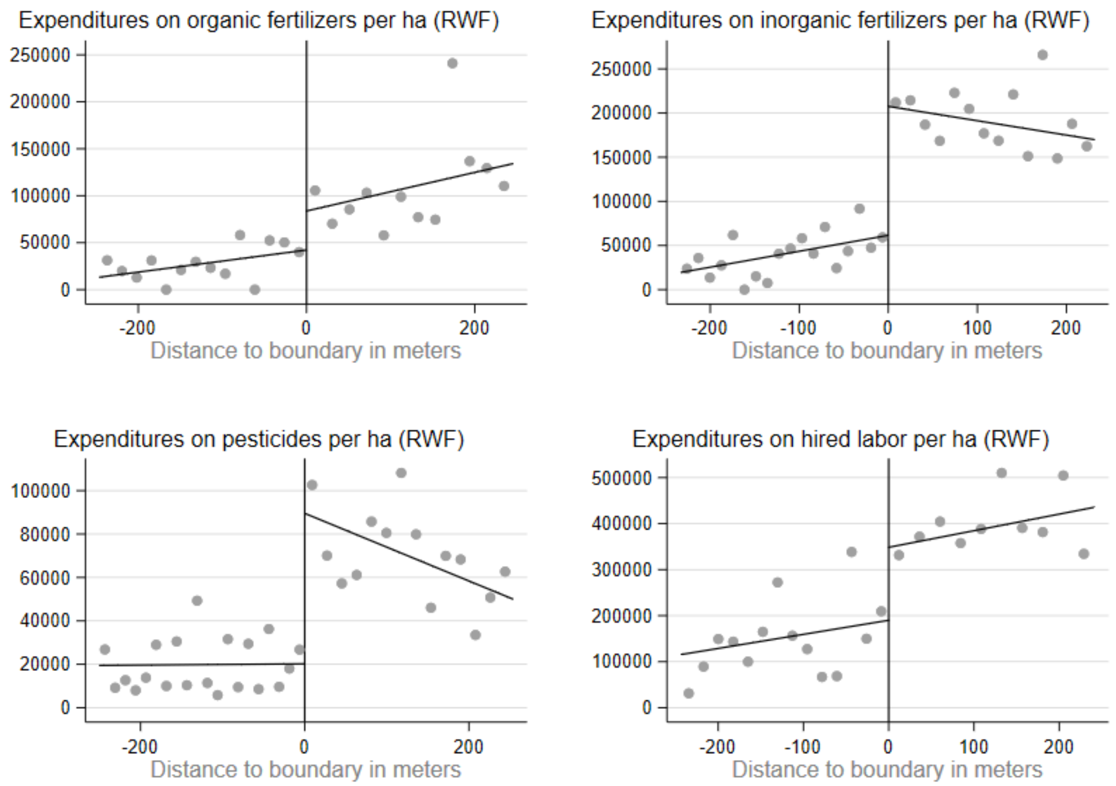
Agricultural inputs

Table 26 / Effect of the Nasho Irrigation Project on the usage of agricultural inputs

	Org. fertilizer expenditures per hectare	Inorg. fertilizer expenditures per hectare	Pesticide expenditures per hectare	Hired labor expenditures per hectare
RD estimate	42,963.6**	148,167.0***	71,532.0***	148,103.6***
(SE)	*(20,786.1)*	*(18,975.0)*	*(10,078.9)*	*(43,143.9)*
p-value	*0.039*	*0.000*	*0.000*	*0.001*
Observations	1,214	1,214	1,212	1,214

*** p<0.01, ** p<0.05, * p<0.1

Figure 27 / Effect of the Nasho Irrigation Project on the usage of agricultural inputs



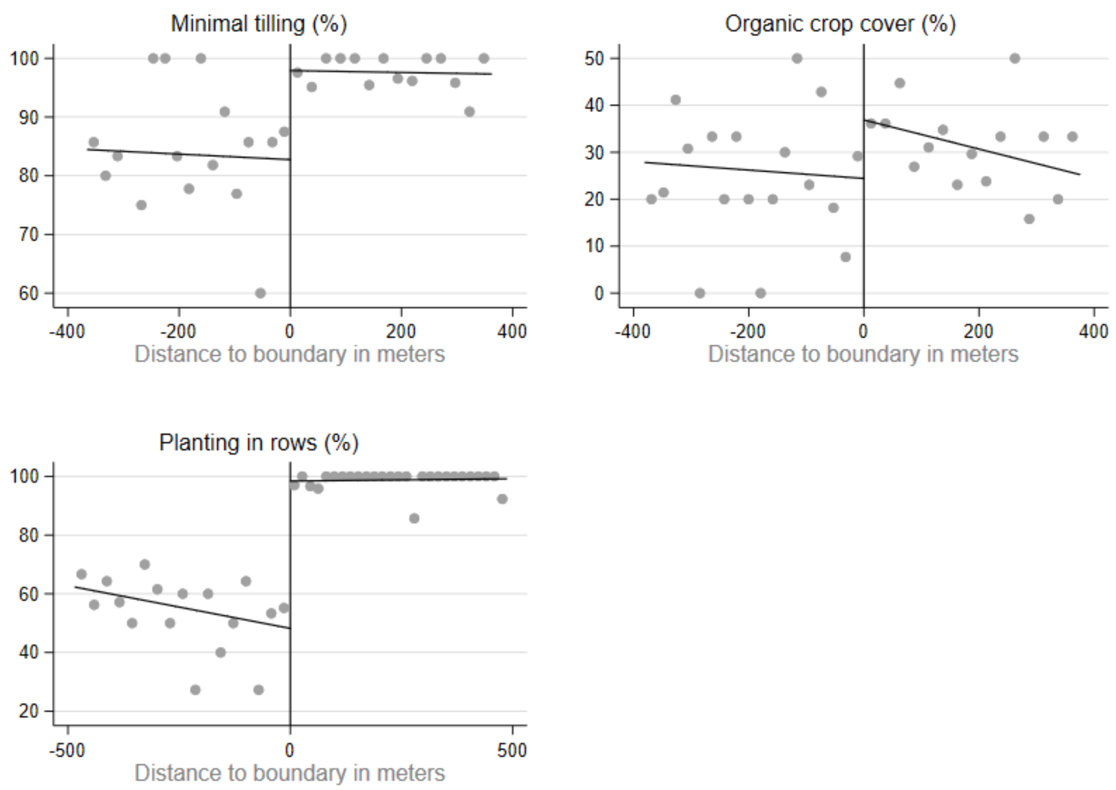
Agricultural practices

Table 27 / Effect of the Nasho Irrigation Project on agricultural practices

	Minimum tilling	Permanent organic soil cover	Planting in rows
RD estimate	0.153***	0.137*	0.474***
(SE)	*(0.055)*	*(0.073)*	*(0.063)*
p-value	*0.006*	*0.061*	*0.000*
Observations	1,214	1,214	1,214

*** p<0.01, ** p<0.05, * p<0.1

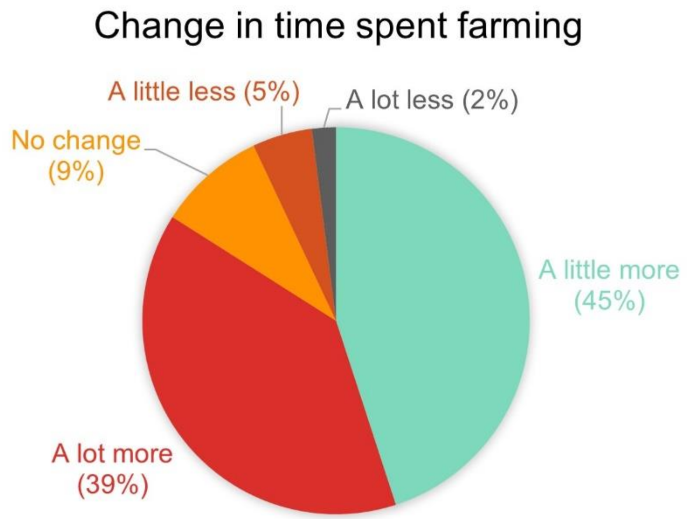
Figure 28 / Effect of the Nasho Irrigation Project on agricultural practices



Impact of the Nasho Irrigation Project at the household level

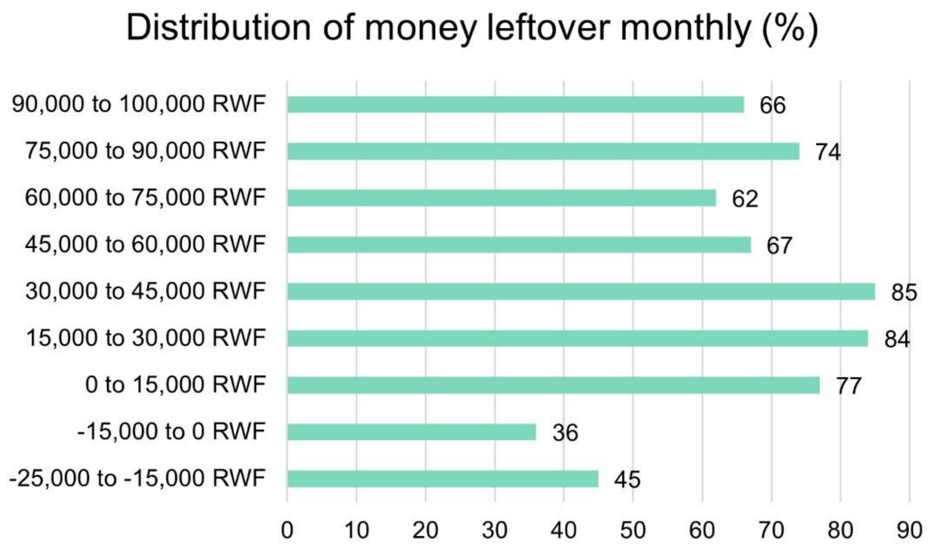
Time spent farming

Figure 29 / Reported changes to time spent farming by NAICO farmers



Profit

Figure 30 / Distribution of money leftover monthly



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