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Sustainability Assessment of Banana (*Musa* spp.) Yield Gap Reduction through Value Chain Development Interventions in Smallholder Farming Systems in Manicaland, Zimbabwe

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Abstract

This study evaluated the effectiveness of donor supported agricultural value chain development projects in sustainably narrowing yield gaps for banana smallholder farmer producers in Manicaland, Zimbabwe. The study used a mixed methods research design that relied on farmers records for the quantitative analysis and focus group discussion and in-depth interviews for key experts for the qualitative aspects. A mix of regression analysis, t-tests, Pearsons's correlation and analysis of variance statistical methods were used for the quantitative analysis while thematic response analysis was used for the qualitative engagements. The findings showed that by the end of the activity, the project had successfully narrowed the banana yield gaps to 18.66 tons per hectare working with a potential yield base of 40 tons. However, 5 years after the project closure the yield gap had fallen to 24.7 tons indicating a lack of sustainability of yield gap reduction. However, the yield gap slump does not override the fact that farmers on average were still able to sell approximately 5 tons per every 6 months after 5 years from the project closure which is beyond any poverty threshold. This suggests genuine upward economic mobility. Additionally, in analyzing what factors had the greatest influence on yield gap reduction, the access to fertilizer ranked highest where genetics, irrigation and improved agronomy followed in that respective order. The study further showed that farmers who receive value chain development support whilst at an already commercialized state tend to maintain productivity thresholds higher in comparison to those who are at a pre commercial state. This is evidenced by the fact that the pre commercial farmers had a yield reduction of 30.83 percent after 5 years of the project closure whereas the former realized a productivity growth of 7.84%. In conclusion, whilst the intervention was successful in transitioning farmers out of poverty, more investment should be made towards transitioning smallholder farmers to integrated soil fertility management practices and improvement of agronomic efficiency through stronger on field collaboration between research institutions, the government and development institutions.

Keywords

Yield Gap, Value Chain Development, Soil Health, Varietal Replacement Rate, Sustainability and Economic Mobility

1. Introduction

Agriculture in Zimbabwe continues to be a fundamental instrument for social development and poverty reduction, with over 70% of the population dependent on it for their livelihoods [1]. Despite this interdependence on agriculture, poverty remains deeply entrenched in the rural farming areas of Zimbabwe [2]. Yield gaps, a key factor, are pervasive in African smallholder agriculture and are large for almost all crops in all regions [3]. Therefore, non-governmental organizations (NGOs) in Zimbabwe's Manicaland province have sought to address yield gaps in the banana perennial smallholder farming cropping systems through an integrated value chain development approach. Value chain development (VCD) is a common term in today's development discourse, where its use tends to conjure inspirational ideas about how development programming can support smallholder participation in growing markets in the interest of economic growth, job creation, gender empowerment, and sustainable use of natural resources [4]. There are various claims that endeavor to substantiate yield gap reduction through this approach but evident absenteeism of evidence that proves the sustainability of these productivity gains considering the short term nature of development projects [5]. A multiplicity of institutional donors in Zimbabwe have sought to address productivity constraints often faced by smallholder farmers through this approach in cropping systems that include bananas [6]. These include the lack of high yielding varieties, the absence of effective irrigation systems where the agroecology and geography permits, financing to purchase key inputs and low levels of mechanization [7]. Considering the projects come to an end, it is important to determine if the efforts to address the productivity constraints and their subsequent gains, are maintained when the farmers do not have the support of implementing non-governmental projects.

Banana is an agriculture commodity which is not only utilized for food purposes but also plays an important role in generating income for smallholders in developing countries [8]. This implies the existence of real incentives for smallholder farmers to sustain yield gains. Banana farming in Zimbabwe has been found to produce more profit as compared to maize and tomatoes as far as the dollar to ton ratio is concerned and therefore can be a major contributor to the economy of the country [9]. Smallholder farmers in east and southern Africa have traditionally employed low input systems, minimal agronomic management, susceptible cultivars to diseases and poor irrigation system despite the motivation to supply local and regional markets [10]. This is the general characteristic of smallholder farmers in Chimanimani as well. The low investment in smallholder farmer banana cropping system invariably results in yields gaps which infer sub optimization of rural livelihoods. In addition, smallholders' banana production and yields in many sub-Saharan African countries are severely affected by a variety of biotic and abiotic factors such as soil degradation, access to clean planting material, management of pests and diseases, postharvest losses, value addition, and market access [11]. Across the region, investments by donors and NGOs through a value chain development approach have endeavored to address these yield gaps influenced by these factors and overall viability of smallholder farmers in the production of bananas [12] [13].

Banana's production in Zimbabwe increased from 41,000 tons in 1973 to 197,458 tons in 2022 growing at an average annual rate of 3.80% [14]. In addition, despite the well documented evidence of productivity growth and high profitability attributed to yield gap reduction within the banana value chain in Manicaland from donor interventions [15], it is still unclear the extent to which the yield gap reduction is sustainable in the long run. This study essentially endeavors to analyze the yield performance relative to farmer practices comprising of soil fertility management, agronomy, irrigation and the genetic materials planted by farmers post the closure of NGO driven value chain development initiative in Manicaland.

2. Literature Review

Global food production needs to be increased by 60% - 110% between 2005 and 2050 to meet growing food and feed demand. Intensification and/or expansion of agriculture are the two main options available to meet the growing crop demands [16]. Because the maximum possible yields achieved in farmers' fields might level off or even decline in many regions over the next few decades, reducing the gap between average and potential yields is critical [17]. Yield gaps can be defined as the difference between actual and attainable yields, provide a framework for assessing opportunities to increase agricultural productivity [18]. Public investments generally focused on reducing yield gaps and improving productivity in cereal and stapple cropping systems with regional examples such as Zambia [19] where farmers received significant input support for seed, fertilizers and crop chemicals. Consequentially, most of the yield gap studies have looked at the yields of grain crops (esp. wheat, maize or rice), while the yields and yield gaps of RTB crops have generally been given less attention [20]. Low yields of East African highland bananas (*Musa* spp. AAA-EA) are often attributed to poor and declining soil fertility, which outweighs other biophysical factors and management practices [21]. Research on highland bananas has mostly focused on pest constraints [22] probably because farmers rank pests as the most important constraint [23]. According to [24], yield is a complex trait that is influenced by genotype, environment (E), and genotype-by-environment interactions (GEIs). [3] provides a yield gap analytic framework as depicted below in **Figure 1**:

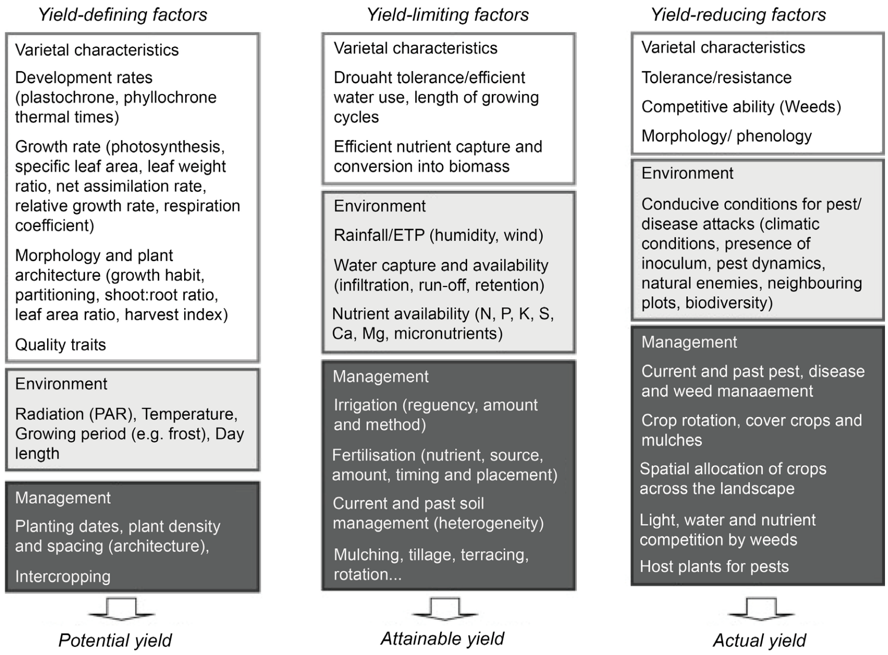


Figure 1. Yield defining, limiting and reducing factors (Tittonel, P and Giller, K.E 2009).

These factors combined are what value chain development initiatives driven by NGOs and the private sector endeavor to address. Whilst there is documentation of successful yield gap reduction, there is no scientific evidence of the ranking of core contributors and secondly, it is yet to be determined whether the productivity gains are being sustained post the value chain development program. The Zimbabwe Income and Employment Development is an example of one such project in Manicaland where it is documented to have increased income, improved employment and food security for over 180 000 farmers in Manicaland province [13]. In Honde valley, semi commercial farmers transitioned to full commercialization leading to approximately 5000 banana producers fully integrated into markets [13]. An analysis of the farmers who already had established banana enterprises will be helpful in ascertaining not only if the project improved productivity but also if the project empowered them to remain at the same level of productivity post its closure.

There is growing evidence that many smallholder farmers can benefit from market-oriented agriculture. However, smallholders often face several barriers to accessing the markets [25]. To overcome these barriers, NGOs and private sector institutions have employed the value chain development approach. The methodology and framework of value chain development and analysis is used by researchers, businesspeople, and donors, with entirely different goals: from increasing commercial profits to improving the competitiveness of the chain [26]. This makes it a socio-economic development approach with incentives for many actors in a given society.

According to [27], an agricultural value chain vertically links or networks business organizations through processing, packaging, storage, transport, and distribution. The value chain approach has the potential to increase agricultural productivity, and household welfare and build social capital [28]. [29] further states that several market-based interventions, such as value chain development, are gaining ground that not only facilitate farmers' entry into remunerative markets but also serve as a means to fight against challenges of food insecurity and poverty. This, therefore, explains why multiple sectors prefer to use this approach to improve the economic plight of smallholder farmers.

The agriculture value chain development approach, however, originates from the work of Michael Porter in 1985 [30]. At the center of the system according to him, is value created and distributed. [31] defines value as the maximum amount an individual is willing to pay to procure a good or avoid something undesirable from a provider. On the other hand, [32] describes value as the perceived worthiness of a subject matter to a socioeconomic agent that is exposed to and can make use of the subject matter in question. This is essential as the evolution and extension of the approach to agriculture maintains the same priority of value creation and distribution, therefore, presenting the question as to whether the value chain development projects are resulting in added value and improved distribution for smallholder farmers. This approach is growingly being deployed by Non-governmental organizations (NGOs) as such organizations have seen themselves playing a role in areas that government has underinvested of neglected such as horticulture [33].

3. Methods and Data Collection

This study employs a conceptual framework build upon the yield defining, yield limiting and reducing factors by [3] and contemporary value chain and sustainability constructs as demonstrated by **Figure 2**. The study employed a mixed methods research design. [34] defines mixed methods as the combination of both qualitative and quantitative approaches to adequately answer a research problem. The design was chosen because whilst yield gaps are inherently a quantitative measure, their sustenance requires qualitative explanations. As opposed to merely describing the whether the smallholder farmers have been able to maintain the same levels of productivity realized during the value chain development project post its closure, it is beneficial to allow the smallholder farmers themselves to explain the post project resultant productivity from their perspective. From a quantitative perspective, 177 questionnaires were administered to

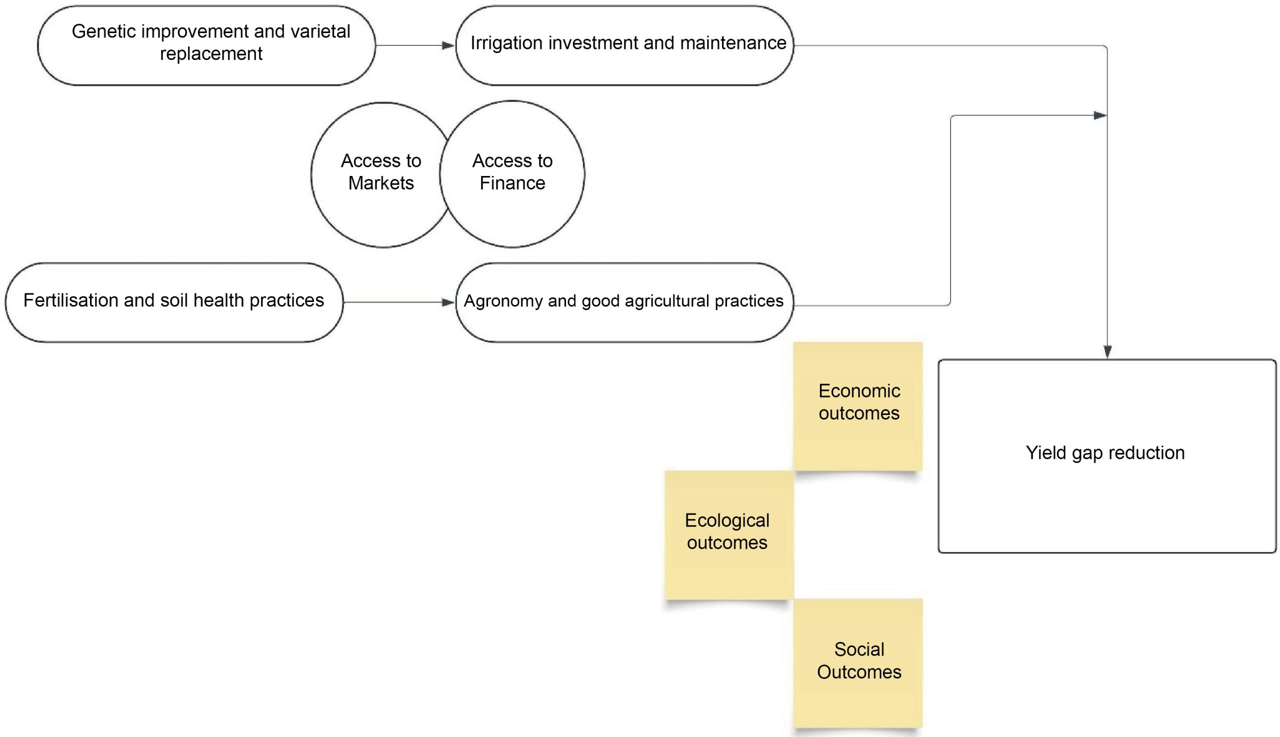


Figure 2. Conceptual framework.

smallholder farmers on a stratified random sampling basis. The districts and wards in which the project had been implemented were identified and local public extension officers were requested to randomly mobilize the smallholder farmers in a predefined geographic catchment area. Any farmer within the location who responded to the mobilization call would be served with a questionnaire. From each of the 10 mobilization points, 6 farmers would be identified to participate in focus group discussions to give meaning to the quantitative figures' elements captured within the questionnaire. A cumulative total of 60 farmers participated in 8 focus group discussions. Key expert interviews were conducted with the 5 extension officers from the areas of project implementation, an extension supervisor at a zonal level, District Agriculture Extension officer for Chimanimani district and the Manicaland Agricultural Provincial Extension officer.

3.1. Genetic Improvement and Varietal Replacement

Varietal replacement is required to translate genetic gains to on-farm productivity and help farmers adapt to climate change [35]. There are two major channels of banana production: those cultivated for export and those reserved for local markets. The main banana varieties cultivated for export, known as "Grande Naine", "Poyo" and "Williams" [36]. For this study, adoption of improved banana varieties was analyzed in relation to yield outcomes. Secondly, continuity of varietal replacement post the project was measured in relation to yield outcomes to determine the sustainability of genetic gains. The data was collected on a time series analysis basis using farmer records and recall at three intervals, pre project, during project and post project.

3.2. Fertilization and Soil Health Practices

Soil health is the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans, and connects agricultural and soil science to policy, stakeholder needs and sustainable supply chain management [37]. Furthermore, Substantial growth in inorganic fertilizer use is a prerequisite for sustained agricultural growth in sub-Saharan Africa [38]. For this study, the number of soil health practices and fertilization rates were counted at 3 intervals, namely; pre project intervention, during project intervention and post project intervention using farmers records and recall.

3.3. Irrigation Investment and Maintenance

[39] found that smallholder irrigation increases productivity, household incomes and employment. The average crop yields per hectare from irrigated land were found to be 2.3 times more than those under rainfed agriculture [40]. Irrigation projects in sub-Saharan Africa are mostly unsustainable because of lack of maintenance by their users or government planners [41]. For the purposes of this study, the investment made in irrigation, the maintenance frequency and the yield outcomes were measured through analysing the farmers records and recall.

3.4. Agronomy and Good Agriculture Practices

The adoption of GAP is critical to recuperating agricultural sustainability [42]. Smallholder farmers being exposed to better agronomic practices not only bosters smallholder farmers productivity but can have a significant impact on incomes [43]. The impact of improved agricultural practices introduced by the project was analysed through the qualitative focus group discussions. These impact of these were also analysed in relation to access to markets and finance.

3.5. Economic, Social and Environmental Effects

The income returns relative to the value chain intervention on a time series analysis was done in order to determine the sustainability of the intervention. Social and environmental effects were determined through the indepth discussions with the extension agents operating in the area.

4. Analysis and Discussion

4.1. Varietal Replacement

Of the 177 smallholder farmers engaged, a mean of 83.28% of the farmers from their records showed replacement from the traditional landraces there had been accustomed to growing to the tissue cultured sweet William variety that was imported from neighboring South Africa. The previously grown varieties not only had lower yields according to the smallholder farmers but had quality and shelf-life challenges. A standard deviation of approximately 18.91% and a 3rd quartile of 100 demonstrates that in terms of improving the genetics that increase the prospects of yield gain, the project was highly successful in transitioning the majority of the farmers to high potential genetics. Secondly, while the minimum was 30% varietal replacement, such farmers were identified to be possessors of huge tracts of land were obtaining sufficient seed to replace their already established plots was not feasible and they did not want to disrupt existing cashflows therefore had a preference for gradual varietal replacement. The varietal replacement **Table 1** below gives a description of the sweet William varietal adoption rates.

Table 1. Descriptive statistics for varietal replacement.

	varietal replacement %
Mean	83.28
Median	90
Mode	100
Std. Deviation	18.91
Variance	357.41
Minimum	30
Maximum	100
Range	70
Quartile 1	80
Quartile 2	90
Quartile 3	100
Interquartile Range	20
Median absolute deviation	10
Skew	−1.08
95% Confidence interval for mean	80.43 - 86.12

Genetic material is a key factor in addressing yield gaps. However, the study showed that farmers who are at a pre-commercial stage were more ready to adopt newer varieties as compared to farmers who had some degree of commercialization. **Figure 3** provides a normal probability plot which demonstrates the higher percentage of the farmers being adopters of the improved varieties. The mean percentage yield replacement was 90% for the pre-commercial farmers whereas 53% for the commercialized farmers. This was a result of the established commercial farmers having revenue flows from the older varieties which they did not want to disturb. However, the realization of higher yield and improved quality with the sweet William tissue cultured variety, the farmers on average committed to changing their planting materials up to half their fields. With the improved agronomy and exposure to good agricultural practices courtesy of the private sector extension trainings, farmers described that even for the old varieties, an improvement in yield was realized although not at the same level as the improved variety. However, due to the decreased market incentives and in availability of credit finance post the project, the regression analysis indicated a minimum to no effect of increasing yield on the basis of having improved genetics.

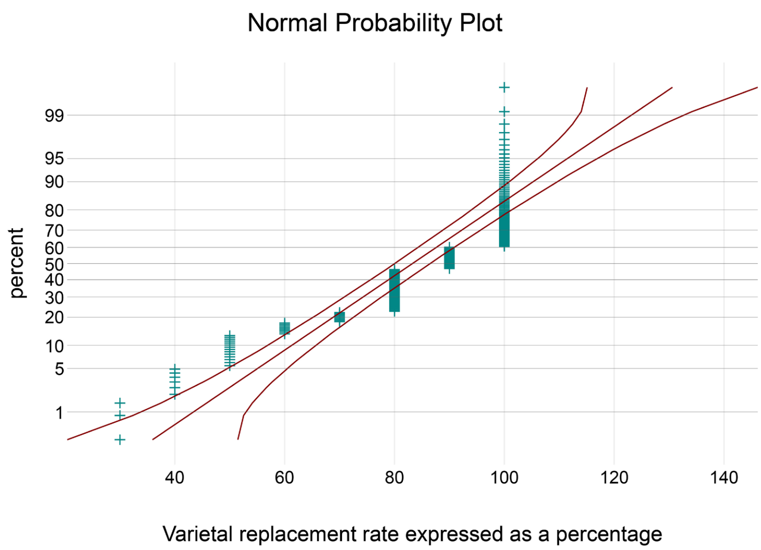


Figure 3. Normal probability plot for varietal replacement.

The effectiveness of the demonstration plots in showcasing the yield performance of the new variety in comparison to the traditionally grown varieties is demonstrated by the Normal probability plot which showcases a high concentration at the 100% level. Feedback from the smallholder farmers indicated that in areas with huge population densities where demonstration plots were established, a near absolute total adoption rate was achieved. The adoption rate grew lesser towards the left side of the plot which were areas where more land endowed farmers were located and slightly further from the demonstration plots. Secondly, farmers indicated shortages of sufficient seedlings to adequately cover the large smallholder farm sizes.

4.2. Comparison of Pre Commercial and Commercialized Farmers

In order to analyze if there were any statistical differences between farmers who had already commercialized their banana production and those that did not, a t-test was conducted. This was important because it is important to understand what the barriers of adoption may be depending on where the smallholder farmer lies within the continuum of commercialization. Understanding the differences was also important in determining whether the incentives would be the same for a pre-commercialized farmer with one that is already commercialized. The descriptive statistics are as illustrated in **Table 2**:

Table 2. Comparative descriptive statistics table for precommercial and post commercial farmers.

	Pre-commercialized farmers varietal replacement	Post-commercialized farmers varietal replacement
Mean	88.13	53.04
Std. Deviation	14.35	15.79
Minimum	30	30
Maximum	100	100

The data shows that the mean average for pre-commercialized farmers (88.13%) is comparatively higher than for the post commercialized (53.04%) at project commencement. In addition to the revenue flow disruption that the smallholder farmers who were already commercialized avoided, there was transfer of good agronomy practices associated with the old variety plantations and hence the productivity also increased for those crops thus reducing their demand for the new variety seedlings. Whilst no formal comparison was made of the yields pre project and post project for the existing pre project varieties, the majority of the farmers indicated that the application of compound J fertilizer and improved irrigation facilities helped increase productivity of their old plantations. Secondly, the smallholder farmers who already have been commercialized at a project commencement state (post), could not achieve a higher varietal replacement due to the standardization of seedling packages being sold. In order to ensure that as many farmers benefited from the varietal replacements, the project implementors set a threshold in making seed available and farmers would self organize to ensure as many of their peers could access the seedling which then affected the already established farmers in achieving a higher variety replacement value. The t-test hypothesis was as below in **Table 3** to validate the statistical differences.

The pre-commercialized farmers varietal replacement group had higher values ($M = 90$, $SD = 12.43$) than the post-commercialized farmers varietal replacement group ($M = 53.04$, $SD = 15.79$). A t-test for paired samples showed that this difference was statistically significant, $t(22) = 9.74$, $p =< 0.001$, 95% Confidence interval as per **Table 4** [29.09, 44.83].

This results in a p-value of <0.001, which is below the specified significance

Table 3. t-test hypothesis table for varietal replacement.

Null hypothesis	Alternative hypothesis
There is no difference in the mean value between the variables pre-commercialized farmers varietal replacement and post-commercialized farmers varietal replacement	There is a difference in the mean value between the variables pre-commercialized farmers varietal replacement and post-commercialized farmers varietal replacement

Table 4. 95% interval difference table.

	Mean	Std. Deviation	Std. Error Mean	Lower limit	Upper limit
Pre-commercialized farmers varietal replacement - Post-commercialized farmers varietal replacement	36.96	18.2	3.79	29.09	44.83

level of 0.05. The t-test result was therefore significant for the present data and the null hypothesis was rejected. Therefore, it is assumed that both samples were from different populations.

Effect size

The effect size d was 2.03. With d = 2.03 there was a large effect.

	d
small effect	0.2
medium effect	0.5
large effect	0.8

t-Test for paired samples

	t	df	p	Cohen's d
Pre-commercialized farmers varietal replacement - Post-commercialized farmers varietal replacement	9.74	22	<0.001	2.03

The box plot in **Figure 4** demonstrates the variety replacement rates by the two distinct constituencies. This is indicative of a seed system shortcoming where demand was not adequately met with supply. Due the project being generally market oriented, focus too rapidly shifted to the agribusiness components according to public agronomy staff who were supporting the initiative from the state level participation perspective. While the agribusiness components of the project were important, it would have been beneficial to invest in long term seedling production system such that the farmers demand could be adequately matched in the long run.

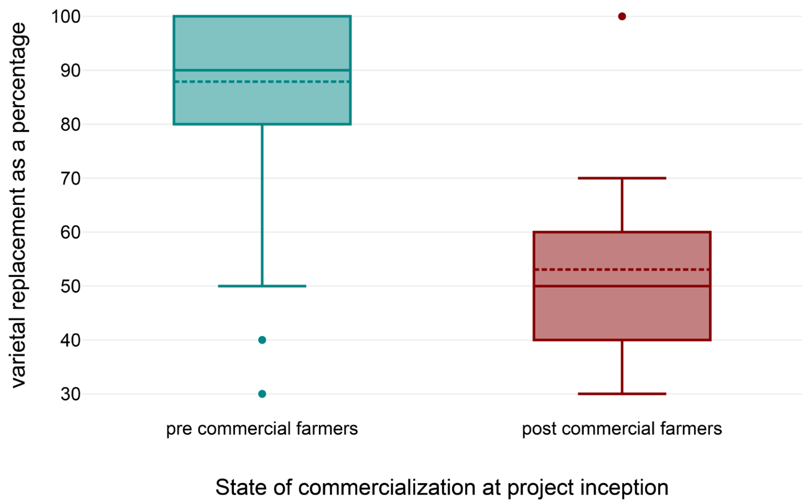


Figure 4. Box plot comparing pre and post commercialized smallholder farmers varietal replacement.

4.3. Yields at Project Closure Versus Yield after 5 Years

There was a marked difference between the yields at project closure and 5 years after the project had ended. As the descriptive statistics below in Table 5(a) demonstrate, the mean for the end of project yields was 6.7 tons during the peak 4 months of marketing were as 5 years after the project closure the yields slumped to 4.79. A standard deviation of 3.96 compared against 3.16 after 5 years of project closure demonstrates a closer uniformity of the farmers with regards to aggregate yield reduction. Although the yield gap increase of 1.91 tons is characteristic, using a base price of $0.20 demonstrates that the farmers incomes are still significant to indicate that the project did transition the farmers out of poverty over the long term although the intervention were not sufficient to sustain yield gap reduction momentum.

Table 5. (a) Descriptive statistics for yield comparison; (b) Hypothesis table for comparison of project closure yields and 5 years post project closure.

(a)

End of project yields	End of project yields	End of project yields	End of project yields	End of project yields
After 5 years project yields	After 5 years project yields	After 5 years project yields	After 5 years project yields	After 5 years project yields

(b)

Null hypothesis	Alternative hypothesis
There is no difference in the mean value between the variables End of project yields and After 5 years project yields	There is a difference in the mean value between the variables End of project yields and After 5 years project yields

In order to affirm statistical significance of the difference in the two production eras, (project closure and 5 years after the project), a t-test was conducted with the hypothesis shown below in Table 5(b).

T-test for paired samples

	t	df	p	Cohen's d
End of project yields - After 5 years project yields	12.83	174	<0.001	0.97

This table reports the results of a paired samples t-test, which is a statistical method to compare the means of two groups that are related to see if the difference is meaningful. Here's what each element of the table means.

t (t-value)

This is the t-statistic value that the test produces, which is 12.83 in this case. A t-statistic measures how big the difference between the two groups is compared to the variation in the data. A higher absolute value of the t-statistic indicates a larger difference between groups. The positive sign shows the direction of the difference, suggesting that the End of project yields group has a higher mean score than the After 5 years project yields group. Figure 5 demonstrates yield differences between the two time intervals.

Figure 5. Yield at project closure comparison to 5 years post project.

df (degrees of freedom)

The degree of freedom for this test is 174. This value is calculated by subtracting the number of groups being compared, which is two, from the number of subjects in the study. It's used to find the p-value for a given t-value.

p (p-value)

The p-value is <0.001, indicating the chance of getting these test results, or more extreme, if there was no difference between the groups, which is called the null hypothesis. A p-value of <0.001 means there is a 0% chance of getting these results if the null hypothesis were true. Usually, a p-value of less than 0.05 is considered to show a meaningful difference, so this result suggests that there is a significant difference between the means of the End of project yields and After 5 years project yields groups.

Cohen's d

This is a measure of effect size, which describes how large the difference between the two groups is. A Cohen's d of 0.97 is a large effect size. The effect size helps to understand the importance of the difference in practice, as well as in statistics.

4.4. Most Determining Factor to Yield Growth

In the quest to ascertain whether the value chain could sustain yield gap closure, the influence of each key productivity factor was important to understand why the gap was either increasing or decreasing. As such, a multiple linear regression analysis was performed to examine the influence of the variable's varietal replacement %, Fertilizers bags per quarter during project and Irrigated land investment percentage on the variable Yield at project closure.

4.5. Model Summary

The regression model showed that the variables varietal replacement %, Fertilizer bags per quarter during project and Irrigated land investment percentage explained 78.66% of the variance from the variable Yield at project closure. An ANOVA was used to test whether this value was significantly different from zero. Using the present sample, it was found that the effect was significantly different from zero, $F = 208.86$, $p =< 0.001$, $R^2 = 0.79$.

4.6. Regression Coefficients

The following regression model is obtained:

Yield at project closure = 3.42 - 0.02 · varietal replacement % + 2.19 · Fertilizer bags per quarter during project - 0.01 · Irrigated land investment percentage

- **Constant:** When all independent variables are equal to zero, the value of the variable Yield at project closure is 3.42.
- **Varietal replacement %:** If the value of the variable varietal replacement % changes by one unit, the value of the variable Yield at project closure changes by -0.02.
- **Fertilizer bags per quarter during project:** If the value of the variable Fertilizer bags per quarter during project changes by one unit, the value of the variable Yield at project closure changes by 2.19.
- **Irrigated land investment percentage:** If the value of the variable Irrigated land investment percentage changes by one unit, the value of the variable Yield at project closure changes by −0.01.

4.7. Standardized Regression Coefficients

The standardized coefficients beta are independent of the measured variable and are always between −1 and 1. The larger the amount of beta, the greater the contribution of the respective independent variable to explain the dependent variable Yield at project closure. In this model, the variable "Fertilizer bags per quarter during project" has the greatest influence on the variable Yield at project closure.

p-value

The calculated regression coefficients refer to the sample used for the calculation of the regression analysis; therefore, it is of interest whether the individual coefficients only deviate from zero by chance or whether they also deviate from zero in the population. To test this, the null hypothesis was made for each coefficient that was equal to zero in the population.

The standard error now indicates how much the respective coefficient will scatter on average when the regression analysis is calculated for a further sample. The test statistic t is then calculated from the standard error and the coefficient. The errors are depicted in Table 6 with the residual statistics in Table 7.

Varietal replacement %: The p-value for the coefficient of varietal replacement % was .036. Thus, the p-value is smaller than the significance level of 0.05 and the null hypothesis that the coefficient of varietal replacement % is zero in the population is rejected. Thus, it is assumed that the coefficient for the variable varietal replacement % in the population is different from zero.

Fertilizer bags per quarter during project: The p-value for the coefficient of Fertilizer bags per quarter during project was <0.001. Thus, the p-value is smaller than the significance level of 0.05 and the null hypothesis that the coefficient

Table 6. Standardized and unstandardized coefficient for regression analysis.

	Unstandardized Coefficients	Standardized Coefficients				95% confidence interval for B	
Model	B	Beta	Standard error	t	p	lower bound	upper bound
(Constant)	3.42		0.76	4.47	<0.001	1.9	4.93
varietal replacement %	−0.02	−0.08	0.01	−2.12	0.036	−0.03	0
Fertilizer bags per quarter during project	2.19	0.88	0.09	24.69	<0.001	2.01	2.36
irrigated land investment percentage	−0.01	−0.08	0.01	−2.19	0.03	−0.02	0

Table 7. Residual statistics table.

	Min	Q1	Median	Q3	Max	Mean	SD
Residual	−4.68	−1.4	−0.07	1.25	5.78	0	1.83
Std. Residual	−2.61	−0.76	−0.04	0.69	3.16	0	1

of Fertilizer bags per quarter during project is zero in the population is rejected. Thus, it is assumed that the coefficient for the variable Fertilizer bags per quarter during project in the population is different from zero.

Irrigated land investment percentage: The p-value for the coefficient of Irrigated land investment percentage was 0.03. Thus, the p-value is smaller than the significance level of 0.05 and the null hypothesis that the coefficient of Irrigated land investment percentage is zero in the population is rejected. Thus, it is assumed that the coefficient for the variable Irrigated land investment percentage in the population is different from zero.

Model summary

R	R^2	Adjusted R^2	Standard error of the estimate
0.89	0.79	0.78	1.85

ANOVA

Model	df	F	p
Regression	3	208.86	<.001

The above regression analysis together with the Pareto diagram of standardized effects in **Figure 6** demonstrates that the major factor to reducing yield gaps among irrigation investment, varietal replacement and fertilizer use was actually fertilizer use. This is validated by a yield effect change of 2.19 for every 50 kg bag of fertilizer added. When fertilizer use dropped from an average of 2 .46 bags to 0.85 bags per farmer, the yield correspondingly dropped by 1.91 tons on average per farmer. This therefore suggests that it is not necessarily the genetics or the water constraints which the smallholder farmers face that are the major limitation to the closure of the yield gap. However, smallholder farmers reduce investment in fertilizers when market incentives reduce. Farmers within the project indicated that post the departure of FAVCO and the scale back Matanuska, middlemen buyers returned and were offering comparatively lower prices that what the formal market buyers were offering. For example, farmers in particular wards focus group discussion indicated that the prices had shifted to from as high as US $30c per kg to US $14c per kg depending on the season. With rising fertilizer prices emanating from geopolitical conflicts (*i.e.* Russia and Ukraine) where a bag of the compound J was US$39, smallholder farmers are now forced to buy it at US$55. The upward movement of input costs and the downward movement of market prices disincentivizes that smallholder farmers from investing and practicing the good agricultural practices they had adopted when the market and input costs aligned in their favour. Sustainability through the value chain development approach cannot be attained unless there is some form of

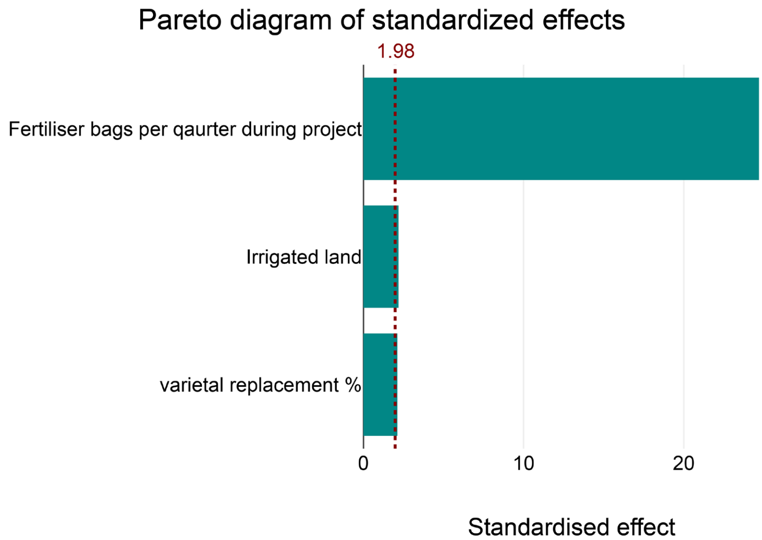


Figure 6. Pareto diagram of standardized effects.

regulation of trade as the current status quo indicates that the middlemen are harvesting the bulk of the economic rents.

Overall, yield gap reduction was not sustained between the project closure period and 5 years later. The introduction of the tissue cultured sweet William Variety, financing support for the smallholder farmers to buy irrigation equipment and crop appropriate fertilizers (compound J) did result in substantial yield growth, however, without project support or a government agency providing the farmers support or coordinating the ecosystem, yield slumps are resultant.

4.8. Yield and Fertilizer Relationship Post 5 Years

A fertilizer usage comparison was first made to understand to what extent had farmers adopted the technology in order to enhance their productivity during the end of project phase and the 5 years post project phase. The results demonstrate that there was a fertilizer mean usage rate of 123 kg of compound J when the project came to an end where as 5 years post the project closure the fertilizer application rate dropped to 42.5 kgs. Whilst this is higher than most crop commodities grown in the geography, this demonstrates a significant decline of invest in soil fertility by at least 65%. The mode of 2 at the time of project closure compared to a mode of 0 after 5 years post the project is indicative of a disincentive to use the technology which also increases the yield gap. Maximum usage of 7 bags during the project compared to at the end of 5 years where it was 4 bags indicates that even for the most endowed farmer or farmer who had adopted the technology, their disinvestment was almost higher than 50%. This therefore points towards the resilience of fertilizer markets and how even when the yield growth rates have been proven to be significant with the usage of fertilizers, other factors can still disincentivize its usage resulting in yield gap reduction being reversed. In addition, the commercialized farmers at project start as shown by

Figure 7 had more yield growth stability than the non commercialized farmers especially after 5 years of project closure. The use changes can be observed in Table 8 for the two select intervals.

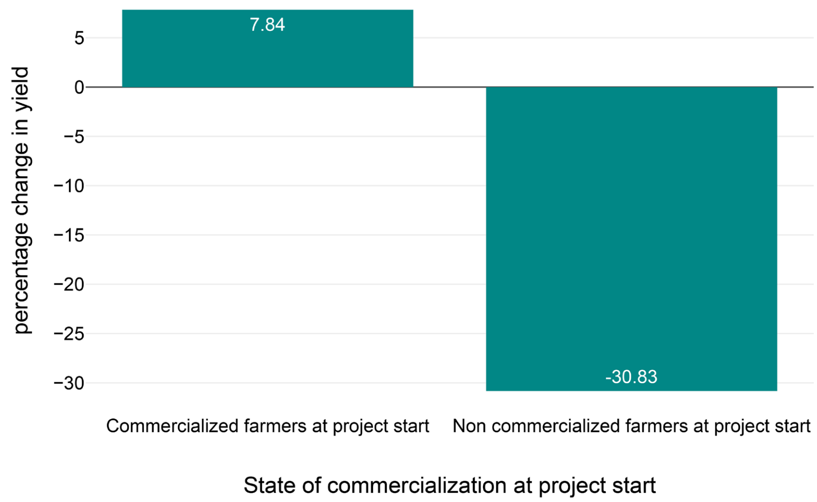


Figure 7. comparison yield changes dependent on commercialization level.

Table 8. Fertilizer use changes from project closure to 5 years post closure.

	Fertilizer use post 5 years	Fertilizer bags per quarter during project
Mean	0.85	2.46
Median	1	2
Mode	0	2
Std. Deviation	0.92	1.58
Variance	0.85	2.5
Minimum	0	0
Maximum	4	7

The relationship between fertilizer application and yield responses was further analyzed in the context of farmers who were not pre commercial at the project start and those that had a degree of commercialization. The descriptive statistics below demonstrate that those that were at a pre-commercial stage at the start of the project, due to their divestment in fertilizer application, their mean percentage decline in yield was 30.83% which is however contrary to a mean percentage growth rate in yield of the post commercial farmers who actually had a productivity growth of 7.84%. This is depicted in Table 9. The qualitative engagements with the smallholder farmers for both groups indicated that there was higher agronomic efficiency amongst those who were at a post commercialization status when the project commenced compared to those that did not. A significant market price decline from an average 33c to as low as 20c per kg demotivate the pre commercialized farmers more than it demotivate the post commercialized farmers.

Table 9. Yield change comparison dependent on level of commercialization.

	Percentage change in yield for precommercial	Percentage change in yield for post commercial
Mean	−30.83	7.84
Median	−33.33	−9.09
Mode	−50	−14.29
Std. Deviation	25.86	61.49
Variance	668.67	3780.93
Minimum	−64.29	−50
Maximum	100	250

To validate these findings a correlation test was done analyzing if there was a positive correlation between the application of fertilizers post the 5 year project closure period yields. The result of the Pearson correlation showed that there was a high, positive correlation between yield 5 years after project closure and Fertilizer use post 5 years. The correlation between yield 5 years after project closure and Fertilizer use post 5 years was statistically significant, $r(173) = 0.56$, $p =< 0.001$. The hypothesis was represented as shown below in **Table 10**.

Table 10. Hypothesis table for correlation test for yield and fertilizer use.

Null hypothesis	Alternative hypothesis
There is no correlation between *yield 5 years after project closure* and *Fertilizer use post 5 years*	There is a correlation between *yield 5 years after project closure* and *Fertilizer use post 5 years*

Correlation

	r	p
yield 5 years after project closure and Fertilizer use post 5 years	0.56	<0.001

Strength of correlation

Amount of r	Strength of the correlation
0.0 < 0.1	no correlation
0.1 < 0.3	low correlation
0.3 < 0.5	medium correlation
0.5 < 0.7	high correlation
0.7 < 1	very high correlation

Nutrient use efficiency is a factor that was demonstrated to be he highly varied amongst smallholder farmers. Whilst there was a high correlation of 0.57 between fertilizer use and yields, farmers who cut their fertilizer investment by 70% in some instances still harvested the same yields as those who hadn't cut their yield. The scatter diagram in **Figure 8** shows the fertilizer application rates post 5 years of project closure. The explanation given by farmers to this was that over the project tenure and the first three years post the project, farmers had made an effort to be consistent with the application rates which they had been accustomed to during the project. However, a growing realization that the markets were not going to be as rewarding as they had previously been resulted in farmers minimizing fertilizer expenditure and some resorting to manure and other organic material they could apply as a substitute. As such, one can draw the conclusion that the fertility builds up during the high market incentive period plus the addition of manure is to a greater extent sufficient for the harvesting of a sufficiently marketable yield output. A conclusion which can be drawn is that when there has been a significant period in which nutrients were being added to soil, as in this instance a minimum of 5 years, the fertilizer response rates will vary depending on farmers soil fertility management practices such that even low applications can result in high yields comparable to high fertilizer applications. However, without sustained organic matter addition and fertilizer application, such high conversion ratios will begin to diminish with smallholder farmers continued mining of nutrients.

Figure 8. Scatter diagram for fertilizer use and yield 5 years after project closure.

Farmers who had a degree of commercialization managed to sustain or improve their yields as compared to farmers who were not at a pre-commercial status prior to the project commencement. The t-test confirms status significance with an effect size of 0.6. Some of the reason cited included that the commercial farmers once adopted a good agricultural practice courtesy of the extension training, they were consistent in doing it in comparison with the pre commercialized farmers. An example was the quick removal of suckers by commercial farmers as compared to the pre commercialized farmers who did not always do the pruning with the necessary urgency. Secondly, the experience of diseases identification and usage of crop protection pesticides was higher on the commercialized farmers side as compared to the pre commercial group therefore resulting in difference in marketable yield. This therefore demonstrates genetic improvement can only be optimized when both on-field and off-field management practices are optimized.

4.9. Soil Health Practices

This study showed a negative relationship between smallholder farmers who apply manure and other organic material to their crops and fertilizer use as demonstrated by **Figure 9**. Farmers who used manure on average only applied 33 kg of fertilizer within a quarter whereas those who did not add any organic material to their crop applied 46 kg of fertilizer compound J. The varied application rates based on whether farmers apply organic matter are a result of a variety of reasons. Firstly, farmers who have no significant livestock consider the best way of addressing fertility is through fertilizers whereas those with poultry projects and significant cattle holdings consider the manure as like for like substitute hence with the addition of manure, little to no fertilizer must be used. Engagement with both the private sector and government agronomists indicated that the soil fertility trainings focused on the value of using crop specific fertilizers but gave very little emphasis on soil organic matter addition. In addition, farmers indicated that the organic matter at their disposal had competing needs

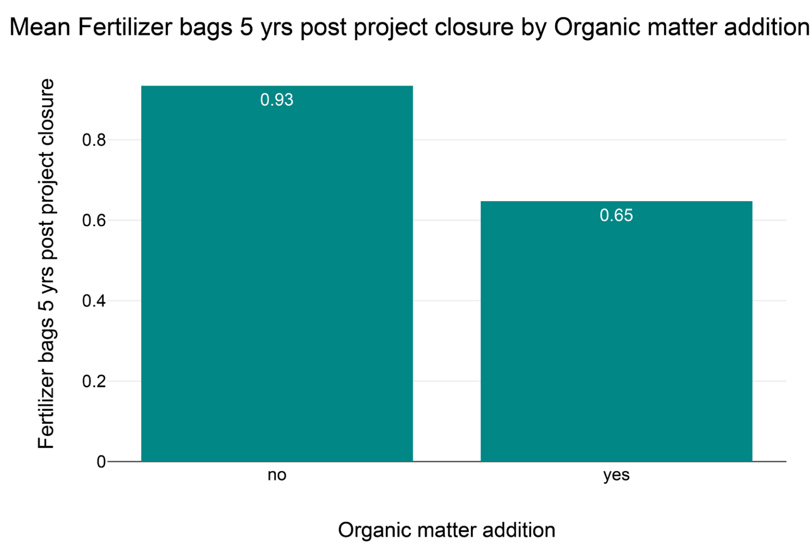


Figure 9. Analysis chart of investment in fertilizer relative to addition of organic matter.

such as the homestead vegetable garden and annual cereal crops like maize. Lastly, government conservation agriculture approach focusing on cereals and legumes (Pfumvudza) where farmers are only awarded inputs if they judiciously follow the protocol has resulted in the neglect of cash crop perennials like bananas.

4.10. Aggregate Yield Gap Analysis

At project closure, the yield gap was on average at 18.66 tonnes as depicted in the descriptives in Table 11. The documented yield potential for the tissue cultured sweet William variety was 40 tonnes per hectare. The monthly income average of approximately $440 though is a very significant in terms of poverty eradication and economic upward mobility, it masks the existing productivity shortfalls still being realized by farmers. The median of 20 at project closure implies that the project ended with farmers at a productivity threshold of 50% of their genetic potential. Whilst yield gaps for perennial fresh produce crops like bananas should always be reconciled with quality at both an infield and at a post-harvest stage, the media demonstrates that income could be doubled if the agronomy intervention measured yield gaps per farmer and not just production resulting into decent income. The extension model had high emphasis on production as opposed to productivity although the general project design was focused on productivity. The private sector nature of extension delivered to the farmers was focused on achieving a supply chain target indicating that there is need for a noncommercial actor to be able to analyze the production level and contextualize them in terms of yield gaps. The importation of the tissue cultured variety was inherently imported to improve the productivity, quality and shelf life of the fruit. As such, agronomic emphasis should be focused on ensuring that the productivity is as close to the genetic potential as possible.

Table 11. Descriptives statistics for yield gaps per farmer at project closure.

	yield gap per farmer at project closure
Mean	18.66
Median	20
Mode	10
Std. Deviation	9.83
Minimum	-10
Maximum	35
Quartile 1	10
Quartile 2	20
Quartile 3	27.5

Post 5 years from project closure, without the support of the programming team the yield gaps increased from a mean of 18.66 tons to 24.75. This can be best observed by **Figure 10** which shows the project yields at project closure and **Figure 11** which compares project closure to 5 years post project closure. This is a visualization of the investment needed to transition smallholder farmers from low productivity to high productivity and sustain them at that level. Whilst market factors influence the production levels of farmers, productivity should not follow market prices as this demonstrates a migration from intensification to extensification. In addition, **Table 12** outlines the descriptive statistics for two interval periods and an indication of the respective yield gaps.

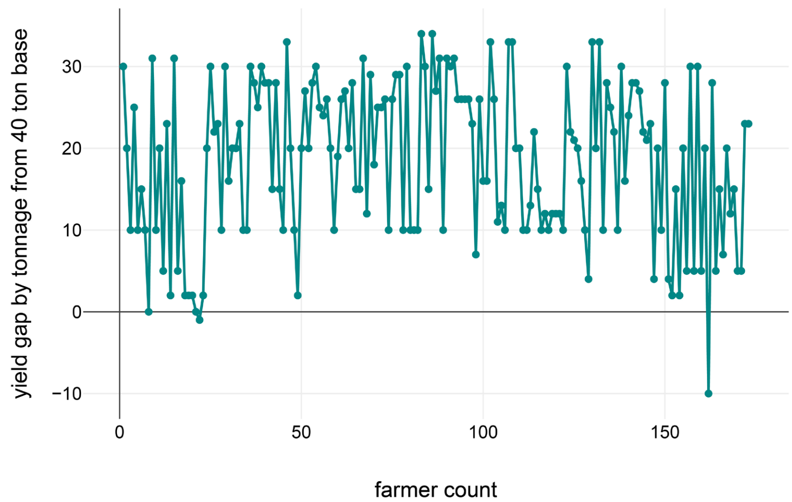


Figure 10. Yield gap assessment at project closure.

Table 12. Yield gap comparison descriptive statistics at project closure against 5 years post closure.

	yield gap per farmer at project closure	yield gap per farmer post 5 years
Mean	18.66	24.75
Median	20	25
Mode	10	30
Std. Deviation	9.83	8.47
Minimum	-10	-18.33
Maximum	35	37.5
Quartile 1	10	20
Quartile 2	20	25
Quartile 3	27.5	30
Interquartile Range	17.5	10
Median absolute deviation	8.64	5

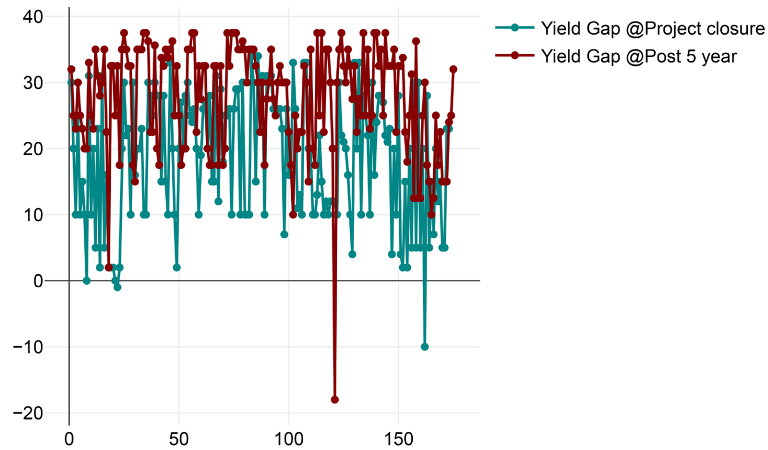


Figure 11. Yield gap analysis at project closure versus 5 years post closure.

4.11. Delivery of Advisory Services for Agronomic Gain

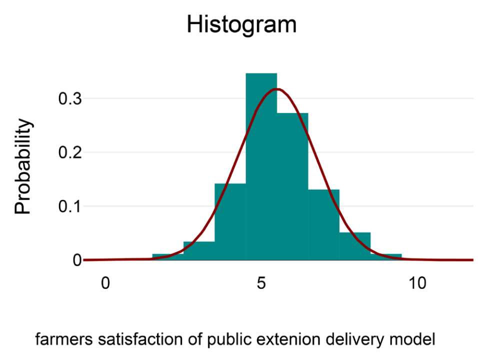
As this study was done using a real-world example leveraging on farmers records and recall, it was not possible to objectively quantitatively attribute extension trainings (agronomy and good agricultural practices) to direct yield outcomes. However, categorical data was collected to assess the farmers' attitudes towards the trainings and their perceptions towards the effect on yield growth. From the descriptive statistics, the farmers ranked the private sector driven approach higher than the public extension model. A mean score of 7.62 compared to the public extension model of 5.49 was attributed towards the practical demonstrations of the extension training. Farmers defined the planting depth, plant population, fertilization, pest and disease management and irrigation calendars as the top extension messages that helped them reduce the yield gap. Public extension had resource limitations where demonstrations were only possible when private sector companies of NGOs donated inputs. As the agricultural systems is dominated by cereal and legume crops, the public extension system hardly provided useful practical learning sessions for the smallholder farmers. Although with a mode of 9 in comparison with 5 for the public extension approach, the private approach was criticized for being totally a group approach whereas the public system does have individual visits that farmers and provides site specific recommendations. Table 13 shows the descriptive statistics of both the public and private sector extension models satisfaction by the smallholder farmers in comparative manner.

	Statistics	p
Kolmogorov-Smirnov	0.18	<0.001
Kolmogorov-Smirnov (Lilliefors Corr.)	0.18	<0.001
Shapiro-Wilk	0.94	<0.001
Anderson-Darling	5.08	<0.001

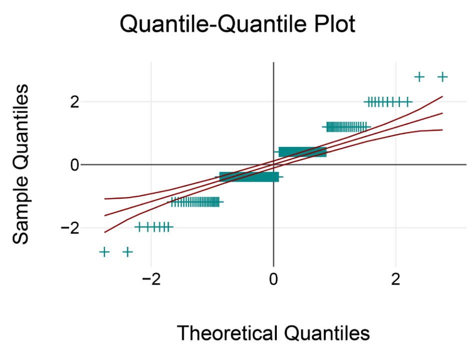
Table 13. Tests for normal distribution of farmers satisfaction of public extension delivery model.

	farmers satisfaction of public extension delivery model	Farmer satisfaction of private extension delivery model
Mean	5.49	7.62
Mode	5	9
Std. Deviation	1.26	1.35
Minimum	2	4
Maximum	9	10
Range	7	6
Quartile 3	6	9
Mean ± Std.	5.49 ± 1.26	7.62 ± 1.35

The normal distribution for the public extension satisfaction as depicted in Figure 12(a) is not skewed to the right as in the instance of the normal distribution curve for the private extension depicted in Figure 13(a). This further validated by a similar comparison of the quantile-quantile plot for the private sector in Figure 13(b) and those of the public sector in Figure 12(b). This is suggestive that a public private extension agenda focused on a specific commodity could be transformative for smallholder farmers. The qualitative engagements indicate



(a)

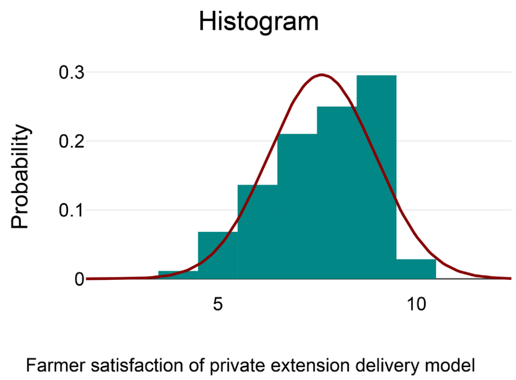


(b)

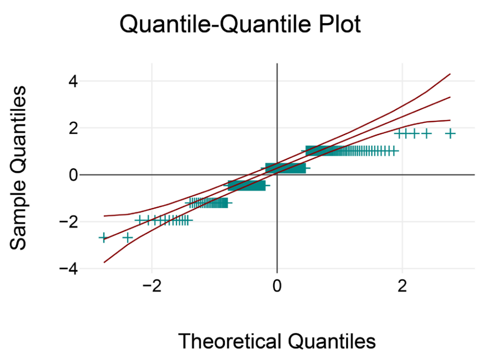
Figure 12. (a) Normal distribution curve for satisfaction of public extension and (b) Quantile-Quantile plot for extension satisfaction of public extension.

that the public extension workers are generalists who had little knowledge of the technicalities of Banana production. A common example was that public extension workers advocated for 80 cm depth for planting banana's yet in actual fact bananas are a shallow rooted crop which instead need a shallow planting depth of 30 cm instead. The concentration of nutrients at a topsoil level compared to a sub-surface level resulted in improved plant nutrient use and hence improved productivity even for the old varieties.

	Statistics	p
Kolmogorov-Smirnov	0.18	<0.001
Kolmogorov-Smirnov (Lilliefors Corr.)	0.18	<0.001
Shapiro-Wilk	0.91	<0.001
Anderson-Darling	6.17	<0.001



(a)



(b)

Figure 13. (a) Normal distribution curve for satisfaction for farmers relating to private extension delivery and (b) Quantile to Quantile chart.

5. Conclusions and Recommendations

1) It's evident that such value chain interventions can transform the economic livelihoods of smallholder farmers however, should also be a catalyst of transitioning to sustainable intensification through optimized agronomy. Such opti-

mization can be achieved if the project designs incorporate Research institutions which have expertise in studying yield gaps and designing agronomic response advisories to the critical yield limiting factors. Whilst the project invested in improved genetics and access to irrigation facilities and fertilizers, it was equally important to understand the optimizing ratios of these essential inputs. Conversations with both private and public agronomist, the fertilizer response rates and nutrient use efficiencies were unknown hence the project is closed at a yield gap of approximately 50%, whilst this yield gap is better than for commodities such as maize and soya which are as high as 80% in the region (Silva *et al*., 2023).

2) There is an imperative for smallholder farmers to adopt an integrated soil fertility management approach which combines the use of both organic matter and inorganic eternal fertilizers in order to establish the highest nutrient use efficiency. Considering that only 28.25% were adding organic material to their banana plantations at least 0.20 hectares going up, this demonstrates an over reliance on synthetic fertilizers. Whilst the increased application of fertilizers is necessary in order to reduce yield gaps, optimum nutrient efficiency can only be achieved when the soil microbiology is functional at its optimum. Over reliance on fertilizers is known to contribute to soil acidity and reduced soil microbial activity (Linnan Wu *et al*., 2020), as such, other organic amendments are necessary in order to optimize yields. The farmer extension program should help farmers understand the complementarity between synthetic fertilizers and added organic materials.

3) Value chain development initiatives should invest in behavioral change curricular targeted to farmers if yield gaps are to be sustainably reduced. The desire of smallholder farmers to obtain another project with the same logic demonstrates a high dependency on external actors. Smallholder farmers should transition to a state of entrepreneurship where at an individual and collective organized manner, should be able to pursue markets where they have a degree of influence on the prices as opposed to the status of always looking towards outward interventions. Whilst the extension training did include farming as a business as one of the core topics, there is need for hands on training of how representative committees can engage markets in a diversity of Geographies as opposed for waiting for buyers to approach them. Generally, all the smallholder farmers indicated disapproval of the smaller& middlemen buyers but did not demonstrate any meaningful effort of pursuing markets of their own.

4) Government should be more closely involved in initiatives that demonstrate significant economic mobility. Both from technical agronomy and program design, government was only invested at the local district level. Considering governments investment in subsidizing various facets of agriculture, this project is an example where government could scale within and scale outwardly through supporting of further mechanization or irrigation equipment. Yield gap reduction initiatives can significantly be sustained if there is multi sectorial layering of investments.

5) Exploration of agroforestry system using such value chain development approaches could be useful in sustainably addressing yield gaps over a long term. Biodiversity not only helps in advancing soil fertility but can also be leveraged for the purposes of integrated pest management. Consideration of nitrogen fixing legumes especially during the winter seasons where flowering is comparatively lower than in warmer summer seasons may be beneficial for the overall yield outcomes of those periods.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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