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Estimating the Reach of Biofortified Crops to Farm Households: The HarvestPlus Model vs. National Sampling and Genotyping in Uganda

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Abstract

This technical note compares two different methods of estimating the reach of biofortified crops – namely, orange-fleshed sweet potato (OSP) and high-iron beans (HIB) – in rural Uganda. This is a topic of significant importance to CGIAR given the millions of dollars invested in developing and disseminating biofortified varieties over the past 15-20 years. One method uses a calibrated model with simplifying assumptions to project the number of rural farm households accessing these crops. The other uses data collected from a nationally-representative sample of rural households in Uganda to estimate consumption, with a sub-sample of households cultivating these crops having samples taken for genotyping, in order to estimate the observed prevalence of these improved biofortified varieties. These two approaches give very different estimates, with the model-based approach indicating far more households reached than the data-driven approach (see Table 1), which align closely with very low levels of OFSP consumption by rural Ugandan households in 2021/22 (Table 2). The purpose of this note is to explore and explain the discrepancies between the results of these two approaches.

Table 1: Reach estimates provided by HarvestPlus and national sampling/genotyping models

	HarvestPlus Model (2022)	National Sampling/Genotyping (2022)	Difference
Orange-fleshed (OF) Sweet Potato (SP)	1,243,023*	3.1% of SP-growing HHs	
	16.7% of rural HHs	1.2% of rural HHs	14x
High-Iron Bean (HIB)	1,094,019*	6.0% of HIB-growing HHs**	
	14.7% of rural HHs	3.6% of rural HHs	4.1x

*The HarvestPlus model projects the absolute number of HHs growing each crop. We use data from UBOS to represent these projections as percentages for comparability with the data-driven estimates in the National Sampling/Genotyping column.

**Of these, 5.4% of bean-growing HHs have mixed bean plots with at least one HIB variety present. Only 0.6% of bean-growing HHs (or 0.36% of rural HHs) cultivate HIB in uniform (pure stand) plots.

Table 2: Consumption of OFSP by rural Ugandan households (UHS data 2021/22, nationally-representative sample of rural households)

	Household level data (UHS 2021/22)	
	N	Mean
Household consumed OFSP in past 7 days	4301	1%
Households with children ages 0-5 consumed OFSP in the past 7 days	2678	1%

1 Background: HarvestPlus and Dissemination Strategies

Established in 2003 as part of the CGIAR, HarvestPlus focuses on enhancing the nutritional quality of staple crops consumed by millions of people in developing countries. HarvestPlus works with national and local government agencies, NGOs, and other partners to tackle hidden hunger brought by micronutrient deficiency on a global scale by developing and promoting biofortified crop varieties. To date, nearly 400 varieties of 12 staple food crops have been released in 40 countries, with hundreds more varieties in testing in these countries and 23 others.

HarvestPlus has established a structured approach to disseminating seeds of biofortified crop varieties. In the research and development stage, HarvestPlus partners with global agricultural research institutions like CGIAR centers to develop biofortified crop varieties for each targeted country. The process begins by looking through data from genebanks and breeding lines for thousands of varieties in CGIAR crop breeding centers around the world. Researchers then identify naturally nutritious varieties that are high in vitamin A, iron and zinc. CGIAR plant breeders then spend up to seven years crossing these promising varieties with others that are adapted to grow in locations where they are most needed.

Before large-scale production, researchers conduct field trials to ensure the quality of the biofortified varieties. After that, local planting material multipliers (in the Ugandan case; in other countries it can be large seed companies) are trained in the agronomic, taste and health characteristics of the different varieties. Those foundation seeds are then used for large-scale production, and the biofortified seeds¹ are distributed to farmers.

The distribution process can be categorized into three main methods. Most countries use a mix of the three methods to maximize reach.

1. **Non-commercial/social distribution:** this includes seed distribution by HarvestPlus and its partners, including NGOs, governments, and international development organizations. The biofortified seeds are usually offered at a subsidized rate to reduce costs for farmers while promoting widespread adoption. In some cases, the arrangement obliges or encourages farmers to return a specified number of seeds or grain after harvesting or provide seed to new farmers through pass-on programs. This method is often used in the initial stage, or for research and evaluation purposes
2. **Commercial sales:** Farmers can acquire seeds through agro-dealer, commercial seed companies or parastatal companies. This is a common and accessible way for any farmer to purchase affordable planting material of biofortified varieties. Even in low-income countries, some farmers purchase new seeds rather than re-using saved seeds.
3. **Farmer-to-farmer diffusion:** This refers to farmers sharing seeds with others after they harvest. Some regions implement obligated pass-on systems, where farmers are required to share seeds with others as a condition for receiving them. Farmers also voluntarily share seeds

¹ We use seed in a broad sense to refer to planting material. For example, in the case of sweet potato, it is vines for clonal propagation that are disseminated.

with other farmers in their communities, significantly expanding seed reach without additional distribution costs.

The farmers then grow and harvest the crops, typically keeping most for home consumption (and therefore for improved nutrition for the family) and selling any surplus in local markets to support their livelihoods. Aggregators purchase surplus harvest from farmers and then aggregate and transport it to processors, wholesalers and retailers. Overall, this model is intended to increase the number of individuals consuming biofortified products.

2 The HarvestPlus Model to Estimate the Reach of Biofortified Crops

In this section, we describe our understanding of the model HarvestPlus uses to project the households (HHs) growing biofortified crops. We do not have access to actual model² and rely instead on documentation shared by the HarvestPlus team about the model. Based on this admittedly limited understanding, HarvestPlus uses the three approaches as listed below. Yearly estimates represent a net figure that includes new households and continuing firms while accounting for double counting and attrition. Ultimately, the estimates are HHs that grow and consume biofortified crops. Table A1 provides a summary of the estimation methods used in different countries.

2.1.1 Data sources

The quantity of seed produced/distributed by surveying producers/suppliers.

- a. Data: Surveyed seed suppliers provide information on the proportion of their seed that is packaged into their most commonly sold seed packs. HarvestPlus tested the method in Zimbabwe and found that it closely matched official government sources, which may or may not be accurate. For example, their Zimbabwe estimate was 29,100 HHs in 2019, compared to the national agriculture ministry's reported number of 31,000.
- b. Frequency: periodically.
- c. Comment: Limited details about this method are available currently.

Non-commercial distribution: HarvestPlus supplies promotional or humanitarian seed.

- a. Data: HarvestPlus registers and tallies recipients at distribution centers. All recipients agree to the "mandatory pass-on," but HarvestPlus and partners register the recipients³. If distributors do not exist, HarvestPlus divides the stock that leaves storage by common seed dissemination units. For example, the average bean pack size is 1.5 kg.
- b. Frequency: Quarterly Monitoring, Learning, and Assessment reporting schedule.

Farmer to farmer (F2F): organic diffusion between farmers – may change seasonally

- a. Data: farmer surveys establish the proportion of farm households who sell or share seed with other farmers. Next, the proportion for the subsequent year is based on making an educated guess that is then updated with their impact surveys, monitoring surveys, or effectiveness surveys.

² Elsewhere, HarvestPlus researchers have published ex ante assessments of the impact of biofortified crops. For example, Lividini and Fiedler (2015) assess the impact of pro-vitamin A maize in Zambia. While that study is "highly contextualized" to Zambia, the reach projections in this analysis are based on the assumption that farmers growing hybrid maize would adopt biofortified maize, which naturally provides no insight into the inner workings of the HarvestPlus model of reach.

³ We are unsure if HarvestPlus registers just the initial recipients or both the initial and secondary recipients.

- b. Frequency: This number is not available in early years.

2.1.2 Forecast model: the Global Households Reached Projections Model (GHRPM)

The GHRPM omits HHs reached through markets for consumption, and this is what HarvestPlus uses to compute estimates of Direct and F2F reaches. The following steps are used for estimation:

- a. HarvestPlus supplies seeds to farmers directly or through distribution centers in specific locations. Let the number of farmers reached be X, which they record, including the names of recipients.
- b. Not all the X recipients will adopt. HarvestPlus bases its adoption rate on the opinion of a local expert, defined as Y, to obtain the proportion. This estimate is later updated (annually) when they run monitoring surveys.
- c. HarvestPlus updates this estimate in the subsequent year by accounting for attrition and newcomers. They base the attrition rate in the first subsequent year on an expert opinion and later update this rate with surveys. Newcomers include new recipients of HarvestPlus seed and those receiving seed through the farmer diffusion channel.
- d. Aggregate to obtain the annual country-by-crop estimates.
- e. HarvestPlus accounts for double counting when computing net adopters by assuming that 1/3 of HHs reached every year are double counted.

2017 Uganda estimation example

- a. The F2F numbers come from HarvestPlus Developing and Delivering Biofortified Crops (DDBC) midterm reports. The DDBC reports that 60% of recipients of HIB seed from HarvestPlus passed on to two additional households, and 80% of OFSP vine recipients passed on to four households. However, for the estimation, HarvestPlus made a conservative assumption of 60% (instead of 80%) of OFSP recipients passing on to an additional two farmers (not four).
- b. HH reached through the market come from asking the agro-dealers for the quantity of bean seed sold and dividing by 1.5 kgs. The implicit assumption here is that there are no issues with intentional (counterfeit) or unintentional mixing up of seed of different varieties. They do the same for multipliers that sell planting material.
- c. Thus, in 2018 HarvestPlus estimated that 217,371 HHs were reached (had adopted) for OFSP, while 294,050 were reached (had adopted) for beans. Detailed numbers and projections are listed in Table 3. By comparison, in the four years from 2018 to 2022 (Table 1), these projections increased four-fold.

Table 3: HarvestPlus estimation by crop and distribution channel for 2018

Crop	Distribution channel	HH reached	Total	Implied share of rural HHs in Uganda ⁴
HIB	Market	200,068	294,050	5.8%
	Direct	42,719		
	F2F	51,263		
OFSP	Market	93,808	217,371	4.3%
	Direct	56,165		
	F2F	67,398		

⁴ UBOS projected the rural population in 2018 to be 24,536,500. Rural household size is 4.8 (2019/20 UNHS report). This implies that there were 5,111,771 rural households in 2018.

2.1.3 Advantages and disadvantages

Advantages of the HarvestPlus model-based approach.

- a. The model takes steps to obtain the correct estimates, which include making assumptions to try to account for attrition and double counting, in addition to using conservative estimates for the farmer-to-farmer OFSP channel.
- b. The model's assumptions are updated based on expert opinions using surveys.
- c. It is an easy and cheap way to produce estimates of reach.
- d. The model records the seed supplied each year.

Disadvantages of the HarvestPlus model-based approach.

- a. While the model assumes a lower diffusion rate for extreme weather conditions, it is unclear how and to what extent the model can account for such conditions. This is especially important for OFSP planting material, where vines can easily die before being planted. This method uses expert opinions to find the proportion of HHs that grow seed that is delivered and only considers consumers that are also growers. The method does not seem to account for HHs that are initially reached but lose planting materials prior to planting them.
- b. The non-commercial distribution channel estimates HHs that grow and HHs that grow and consume but ignores HHs that only consume. It is unclear, however, how the market approach that surveys the agro-dealers and producers about the amount of seed they have sold accounts for HHs that buy either HIB or OFSP to consume.
- c. Given the informality of the Ugandan seed system, the method seems to give insufficient attention to mixed or mis-labeled seed.
- d. Farmers may often receive planting materials when they are not ready to plant them – either the planting materials arrive too early or late in the season. As a result, some of the materials that are delivered to farmers end up unused, and this affects the pass-on rate of the material to another farmer in the subsequent year.
- e. There is no indication if the estimation distinguishes between F2F dissemination within villages versus across villages or districts. F2F dissemination rates are likely higher within treated villages in project areas, but much lower when seeds are shared with villages or districts outside the project's sphere of influence (Arimond et al 2010).
- f. The assumption that all planting materials supplied and distributed to farmers are biofortified may not always be valid, especially for locally-sourced planting materials. For example, some of the biofortified bean varieties, such as NAROBAN 2, closely resemble many non-biofortified varieties. Because many people, including experts, cannot easily distinguish between varieties, the reach of biofortified bean varieties may sometimes be overestimated (Ilukor et al, 2025). Similarly, the orange fleshed varieties are identified by the color of the flesh of the roots, and not the vines, making identification on receipt of planting material difficult.
- g. OFSP has low dry matter content, a characteristic not preferred by Ugandans, particularly in areas where sweet potato is predominantly consumed as a breakfast food (Mwanga et al, 2010, HarvestPlus 2018). Therefore, a proportion of recipients of OFSP vines from HarvestPlus or its development partners may trial the material but be unhappy with these consumption traits. This may lead to slow adoption or disadoption, implying the need for an adjustment factor in the model projections.
- h. It is unclear how HarvestPlus are able to enforce the expectations about passing on of vines to other farmers.⁵ As is the case with many policies/recommendations in Uganda, there is likely

⁵ Based on data from the UHIS, the vast majority of sweet potato farmers acquire vines from another farmer. While the assumption that F2F is a main channel for disseminating planting material is therefore well-justified in general, it is less clear how prevalent F2F is for OFSP in particular.

- to be laxity in this process. This may be an overestimation due to social desirability bias (over-reporting) from recipients who know they are expected to do this.
- i. Although the model considers attrition, no reports have documented this, potentially leading to underestimated attrition rates. The attrition rate could be underestimated. Pass-on households will have less information about the benefits and planting instruction of the seeds, and the purity of passed-on seeds may also be lower. These factors may result in higher attrition for passed-on households in the future.
 - j. From the example of estimates listed in Table A1, it seems that the diffusion rate varies significantly among countries and crops. Also, the source of the diffusion rate may sometimes come from expert estimates instead of surveys. The variation in diffusion rates and household reached per diffusion will likely have robustness issues.
 - k. The model doesn't include households reached through markets for consumption.

3 Nationally-representative Sampling and Genotyping Approach

The Ugandan Household Integrated Survey (UHS) is conducted by the Ugandan Bureau of Statistics (UBOS) in collaboration with the World Bank Living Standards Measurement Survey (LSMS) team. In the 2021-22 UHS round, SPIA joined this collaboration to add detailed questions about CGIAR innovations as part of its inaugural Uganda country study. This expanded data collection effort included crop sampling of OFSP and HIB and subsequent genotyping to estimate the reach of these CGIAR innovations.

3.1.1 Sampling Strategies

The Uganda Harmonized Integrated Survey (UHS) is an integration of the Uganda National Panel Household Survey (UNPS) and the Annual Agricultural Survey (AAS), under the auspices of the 50 X 2030 initiative, and implemented by the Ugandan Bureau of Statistics (UBoS) in partnership with the World Bank Living Standards Measurement Study (LSMS) team. The integration of the two surveys comprises three sets of samples, namely: an annual sample of agricultural and non-agricultural households from a) rural and b) urban areas (together making the annual panel sample – APS), complemented with c) an additional sample of agricultural households every two years (biennial cross-sectional sample (BCS)).

The full UHS sample size is 9,288 households in 774 enumeration areas (EAs). Of these, the APS represents 6,072 agricultural households in 506 rural EAs and 276 non-agricultural households from 23 urban EAs, and is representative of agricultural statistics at the regional level (Ponzini et al, 2022). The BCS contributes an additional 2,940 cross-sectional agricultural households in 245 EAs to make more accurate agricultural statistics, making the combined APS/BCS sample representative at the sub-regional level in those years.

The fieldwork was conducted in three phases. The first phase started with a visit at the end of the planting period for second season 2021. This was followed by a second visit at the start of the first 2022 season post-planting period (and included retrospective questions for second season 2021). Finally, a third visit carried out post-harvest for 2022 first season.

The UHS had four questionnaires, namely: (i) post-planting; (ii) post-harvest; (iii) annual; and (iv) community. The post-planting questionnaire has eight modules: the household's parcel list; agricultural parcels roster; plot and crop rosters; UNOMA leaf sampling (see following section for explanation); UNOMA crop diseases; UNOMA crop-cut; and seed acquisition modules. All UNOMA modules were administered to only the UNOMA sub-samples, and all others were administered to the entire UHS rural

sample.

Uganda National Objective Measurement Survey (UNOMA)

UNOMA is a sub-sample taken from within the UHIS, for variety identification by taking samples of plant tissue from farmers' fields for DNA fingerprinting. UNOMA was Integrated into the 2021 UHIS survey. As part of UHIS visit 1, leaf sampling for sweet potatoes and beans was taken in a single plot per crop (if the farmer has more than one, then the farmer determines which is their main plot) and for at most three varieties per plot in trips 1 and 2 of visit 1 (September and October 2021) in the rural panel EAs.

The UNOMA data collection was designed to be implemented within a subsample of the 506 enumeration areas selected from the agricultural households under the APS. Subsampling took advantage of the logistical organization of the three survey visits covering the two agricultural seasons. Specifically, each survey visit was divided into four trips lasting approximately one month during which the enumeration team covered approximately 144 EAs. The random selection of enumeration areas for each trip means that, by design, one would expect no geographic bias for these samples. However, we do observe imperfect compliance at both the EA level and HH level, and find statistically significant enumerator fixed effects in a model of selection into sampling, suggesting that some enumeration teams shirked their responsibilities.

Despite this imperfect compliance, the impact of a selected UNOMA sub-sample is likely limited, as there is little reason to expect varietal adoption to correlate with enumerator behavior in this instance. Furthermore, we collected data on OFSP consumption from rural households across the entire nationally-representative UHIS sample (shown in table 2), and we observed excellent compliance with those data.

3.1.2 Variety Identification

The UNOMA method uses DNA fingerprinting to identify crop varieties in farmers' fields. This technique compares the genetic makeup of a crop with the closest match in a reference library.

Sweet potato data collection protocol:

1. The enumerator walks with the farmer to their sweet potato plot. If the farmer cultivates more than one sweet potato plot, the farmer should choose what they consider their main plot.
2. The enumerator asks the farmer to show them examples of the different sweet potato varieties cultivated in that plot.
3. For each different variety that the farmer says they have in the plot, the enumerator follows the steps below for up to a maximum of 3 varieties in the plot. If the farmer says there are more than 3, then the enumerator asks them to choose the most important 3 varieties in terms of their share of the plot area).
4. The enumerator asks questions in the SURVEY DNA fingerprinting module for that sweet potato variety.
5. The enumerator untangles the vine of the selected plant (if needed) to be sure they sample a leaf from the desired plant.
6. The enumerator identifies the uppermost healthy young leaves for sampling, takes two of these young leaves, and places them in a silica gel-filled pot.
7. The enumerator tightens the lid and scans the barcode for that sample into the SURVEY application
8. If applicable, the enumerator repeats the steps above for the second and third varieties the farmer identifies.

HIB data collection protocol:

1. The enumerator walks with the farmer to their bean plot. If the farmer cultivates more than one bean plot, the farmer should choose what they consider their main bean plot.

2. The enumerator asks the farmer to identify the number of bean varieties planted in the plot. If more than 1 variety is planted in the plot, the enumerator asks the farmer whether: a) there are specific areas of the plot where each variety grows (i.e. can the farmer indicate specific plants of that variety), or b) if the varieties are mixed (e.g. seed mixed together before planting).

If a) different varieties grow in specific areas of the plot, then:

- i. The enumerator takes a sample of a single young, healthy leaf from each of 5 individual plants of that variety and places them together in a silica gel-filled pot. The enumerator tightens the lid and scans the barcode for that sample into the SURVEY application.
- ii. If applicable, the enumerator repeats the steps above for a maximum of two additional varieties.

If b) the varieties are mixed together, or if the farmer says only 1 variety is planted in the plot, then:

- i. Starting at the northwest corner of the plot, the enumerator takes 10 steps towards the center of the plot
- ii. Using tweezers, the enumerator takes a single young, healthy leaf sample from 5 individual plants, moving 3 paces in a clockwise direction around the plot between each sample, and places the 5 leaf samples together in a silica gel-filled pot. The enumerator then tightens the lid and scans the barcode for that sample into the SURVEY application.

3.1.3 Advantages and disadvantages

Advantages of sample-based approach

- a. Examining genetic information ensures correct identification of biofortified crops. For example, the NAROBEAN 2 distributed in Uganda looks like the local non-biofortified varieties. Even the trained multipliers are unable to distinguish the biofortified variety from the local ones. DNA fingerprinting can help eliminate misidentification when estimating reach.
- b. This method also provides accurate information on the reach of biofortified varieties, establishing a good standard for the survey-based method. The parameters in HarvestPlus' model can be updated using these new estimates of reach. Being grounded in an existing nationally-representative survey and paying marginal costs for integrating DNA fingerprinting leverages a huge existing fixed cost paid by others to CGIAR's advantage.
- c. Additional insights can be gained through this approach. For beans, we can observe the preponderance of admixed fields (only a small minority of samples are uniform biofortified samples). We know from prior work that farmers plant genetically mixed bean seed owing to the informality of the bean seed system with purchases from the grain market, recycling, and passing of material from farmer to farmer being the main mechanisms through which farmers obtain planting. For sweet potato, we can observe a high fraction of unidentified varieties. Uganda's large landrace diversity is evident from the breeding program's collection of 1,300 accessions in the early 2000s, 300 of which were incorporated into the program and now form the basis of our reference library.
- d. We have used advanced bioinformatics to identify admixed bean samples from bulked samples. The bulking from multiple plants reduces the possibility of sample error compared to prior studies that take a single leaf sample to represent a plot.
- e. Data about farmer preferences related to the varieties are collected alongside the DNA fingerprinting, revealing those traits that are, or are not, perceived and valued by farmers.
- f. Data about OFSP consumption could be collected from the entire nationally-representative UHIS sample.

Disadvantages of sample-based approach

- a. Leaf samples were collected for up to three farmer-declared varieties identified in a plot. A variety may be missed if it is not among the top three varieties the farmer grows, or if households cultivate biofortified materials only in a separate location. Note, however, that the consumption estimates (1% of rural households consumed OFSP in the past seven days) refer to the entire sample of rural households and are independent of any plot or variety-level sampling issues.
- b. While survey costs are largely borne by others (UBOS, World Bank) the marginal costs to SPIA are not trivial. DNA fingerprinting costs approximately \$10-12 USD per sample, plus associated costs of compiling the reference library and staff time for bioinformatic analysis and interpretation.
- c. Although the sample started as nationally representative, the selective sub-sampling limits our ability to project point estimates for household reach. Nevertheless, the small sample shares observed are highly informative.

4 Discussion

We conclude this note with some reflections on how the assumptions built into the HarvestPlus model-based approach became so detached from the on-the-ground realities in Uganda. This discussion intends to leverage the discrepancy and the comparison contained in this note as a learning opportunity. Clearly, there is room for improving biofortification reach estimates going forward. While this learning opportunity almost surely extends beyond the Uganda OFSP and HIB context, we continue to focus our discussion here on these specific cases.

During the peak years of NGO-led dissemination efforts in Uganda (2015-2018), the HarvestPlus model likely provided much more accurate estimates of reach. This was when NGO efforts were fully staffed and funded, with widespread dissemination of biofortified planting material. During these years, several factors contributed to the effectiveness of these dissemination activities. HarvestPlus was largely still considered a research activity during this stage, and as such researchers played a more direct role. This provided closer integration of monitoring and research activities, implicitly providing stronger oversight and organizational support. During these active years, access to seeds and planting material (vines) was effectively backstopped by these NGO partners, allowing for ready replacement of material lost due to poor germination or growing conditions (Arimond et. al, 2010). The HarvestPlus model was calibrated during these years of strong institutional support, good integration with research activities, and relatively plentiful planting material. If this same level of support had continued beyond 2018, the HarvestPlus model may have remained more accurate for longer – especially if it leveraged regular ground truthing reports from NGO partners to re-calibrate and update the forecasting model. But without these strong linkages to NGO activity, the model seems to have lost its calibration soon after 2018.

Another calibration detail may have contributed to the model's inaccuracy: if the model was calibrated only for initial intervention areas, it may not represent the many other areas that were targeted later. If these later areas were not quite as suitable for the biofortified crops, or if farmers in these areas were not as open to either growing these new varieties or to sharing planting material F2F as the HarvestPlus model assumes, the HarvestPlus model assumptions may have been overly optimistic and not grounded in the objective realities in these new areas.

Next, and also related to F2F assumptions, it seems that F2F verification was limited, if it occurred at all. While there was some effort to record the reported number of additional farmers reached through F2F sharing, these numbers were either not verified or may not have reflected actual planting of the shared planting material. Moreover, recipients of F2F dissemination may not have received sufficient training in seed maintenance, which may have undermined their ability to successfully cultivate OFSP vines.

Finally, in the absence of an effective seed system for refreshing and renewing planting material for both beans and sweet potato, it may be very challenging for a F2F dissemination system to survive extreme production events from pests or weather shocks. Such shocks can easily destroy much of the planting material in hard-hit areas, either directly in the case of vines or indirectly as people consume their bean stocks as part of their survival strategy. The HarvestPlus model acknowledges this practical challenge to F2F dissemination, but the model seems to only incorporate the effect of extreme weather shocks for biofortified maize. We can see no documentation that the model makes similar adjustments for OFSP and beans, which can be more weather sensitive. Clearly, such shocks do not wipe out all planting material for sweet potato and beans in Uganda; when properly motivated, farmers find a way to either preserve their most cherished varieties or to restock through informal local seed systems. Unfortunately, farmers have apparently not been sufficiently motivated to preserve or replace their planting material for OFSP and HIB. Interestingly, we understand that HarvestPlus had internal proposals early on to invest in a regular (e.g., every 5 years) refreshing of OFSP vines to offset the deterioration or slow disappearance of this critical planting material, but these proposals were neither funded nor implemented.

Other factors may well explain the divergence of the HarvestPlus model from reality. Those we have described here seem plausible, but they mainly serve to initiate discussions that may lead to improvements in ongoing efforts to monitor and estimate reach of these biofortified crops. It is worth noting more generally that any model-based approach is necessarily detached from reality (i.e. all models are wrong, but some are useful (Box, 1976)). The team that built the HarvestPlus model was clearly aware of this fact and attempted to make the model conservative in its assumptions and parameterization. As this note has demonstrated, however, even these attempts at making the model conservative were insufficient. The model structure, which reflects implicit assumptions that are harder to evaluate and interrogate explicitly, may have baked in a degree of over-optimism that even conservative parameter values could not overcome.

What does this comparison of approaches and exploration of the discrepancy of the HarvestPlus model mean for how best to estimate the reach of biofortified crops? This question is largely beyond the scope of this note, but it is worth pointing out that a thoughtful answer would demand careful cost-effectiveness analysis. Annual nationally-represented sampling and DNA fingerprinting is obviously not cost-effective, but the current HarvestPlus model is too wrong to be useful. Somewhere between these two extremes there must exist a more cost-effective option for estimating annual reach. Finding the right combination of ground-truthing and model-based assumptions will demand more work – and implementing such a monitoring process will surely demand more of an investment of resources. But if accurate estimates of reach are important to funders and stakeholders, then it is definitely worth finding a better way to produce reliable estimates within a more acceptable margin of error.

5 Epilogue on OFSP Impacts

This note has focused entirely to this point on divergent estimates of OFSP reach. We close with a more hopeful note on the *impact* of OFSP. A recent study uses the peak OFSP dissemination years and the spatial rollout of the NGO-led dissemination in Uganda to estimate the impact of access to OFSP on child growth outcomes (Macours, Mallia and Okello, 2025). Using a quasi-experimental approach and a long-term panel started in 2011 (Labarta et al, 2012) that includes child anthropometrics, the researchers find significant positive impacts of OFSP on child growth outcomes.

While this is welcome and encouraging evidence of OFSP's potential to positively impact vulnerable rural populations, it also underscores concerns about the low OFSP reach since 2018. Specifically, the pronounced difficulties of reaching rural Ugandan households with OFSP severely limits how much of OFSP's potential impact is realized in practice. Put differently, imagine the aggregate health and human surveyal improvements that would have been generated if the *true* trajectory of individuals reached after 2018 was in the millions as suggested by the HarvestPlus model!

Alternatively, consider a counterfactual that is even more specifically relevant to this note. Imagine the aggregate benefits that could have been generated in the last 7-8 years if (i) the HarvestPlus model detected a rapid decline in households reached shortly after 2018 and (ii) this accurate monitoring information prompted a course correction in HarvestPlus dissemination activities. Under this counterfactual, unrealized child growth benefits from OFSP constitute a massive opportunity cost of misleading monitoring information.

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Appendix

Table A1. A summary of projection method used by HarvestPlus

Country/crop	Projection method used	Diffusion Rate (F2F)	Adjustments and remarks
Rwanda (High Iron Beans)	Non-commercial distribution, F2F, commercial sales	12% sharing with 2 HHs	Conservative F2F diffusion rate
Uganda (Iron Beans & OSP)	Non-commercial distribution, F2F, commercial sales	60% sharing with 2 HHs	Conservative assumptions for F2F diffusion rate and HH reached
India (Zinc Wheat)	Commercial sales, F2F	50% sharing with 3 HHs	
DRC (Iron Beans)	Non-commercial distribution, F2F, commercial sales	49% sharing with 2.4 HHs	Adjusts for overlap (8%) between non-commercial distribution and commercial sales reach.
DRC (Vitamin A Maize)	Non-commercial distribution, F2F, commercial sales	80% sharing with 2 HHs	Reduction in diffusion rate assumptions compared to prior years
Bangladesh (Zinc Rice)	Non-commercial distribution, obligated pass-on, F2F, commercial sales	Obligated sharing with 3 HHs; 30% sharing with 1.755 HHs	Low diffusion rates due to flooding
Pakistan (Zinc Wheat)	Non-commercial distribution, F2F, commercial sales	50% sharing with 2 HHs	
Zimbabwe (Iron Beans)	Non-commercial distribution, F2F, commercial sales	25% sharing with 2 HHs	Low diffusion rates due to drought conditions
Zimbabwe (Vitamin A Maize)	Non-commercial distribution, commercial sales		
Zambia (Vitamin A Maize)	Non-commercial distribution, F2F, commercial sales	0.74% sharing with 1 HH	Very low contribution from F2F sharing
India (Iron Pearl Millet)	Commercial sales		
Nigeria (Vitamin A Cassava)	Non-commercial distribution, F2F, commercial sales	42% sharing with 3 HHs	Adjusted for multiple source acquisitions (17% overlap rate)
Nigeria (Vitamin A Maize)	F2F, commercial sales	30% sharing with 1 HH (OPV)	Diffusion rate is based on expert estimation, and no monitoring survey data is available
DRC (Vitamin A Cassava)	Non-commercial distribution, F2F	51% sharing with 3 HHs	Adjusted for multiple acquisitions (12.88% overlap rate)



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