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Measuring postharvest losses at the farm level in Malawi

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This article measures farm-level postharvest losses for maize, soya and groundnuts among 1,200 households in Malawi. Farmers answered a detailed questionnaire designed to learn about losses during harvest and transport, processing and storage and which measures both complete losses and crop damage. The findings indicate that fewer than half of households report suffering losses conditional on growing each crop. Conditional on losses occurring, the loss averages between 5 and 12 per cent of the farmer's total harvest. Compared to nationally representative data that measure losses using a single survey question, this study documents a far greater percentage of farmers experiencing losses. We find that losses are concentrated in harvest and processing activities for groundnuts and maize; for soya, they are highest during processing. Existing interventions have primarily targeted storage activities; however, these results suggest that targeting other activities may be worthwhile.

Key words: Malawi, postharvest loss, agricultural production.

1. Introduction

Sustainable Development Goal 12 (SDG12), agreed to by the world's governments, aims to 'ensure sustainable consumption and production patterns'. This goal implies an effort to reduce waste and losses in the production and consumption of goods – in particular, in the food system. A specific target of SDG12 is to reduce food losses along production and supply chains. Yet to do so, it is important to know the magnitude and timing of waste or loss within specific supply chains, so that solutions for reducing waste or loss can be applied when it is cost-effective to do so. In this article, working with smallholders in Malawi, we use a specialised survey module designed to estimate postharvest losses and compare these estimates with existing less detailed methods.

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Postharvest losses, and food loss more generally, are an important component of global agricultural policy. From the consumer's perspective, the presence of food loss along the value chain leads to higher food prices. From a macro perspective, for poorer countries dependent on agriculture, lower postharvest losses can reduce the need to import food, freeing scarce foreign exchange. Storage technologies to reduce postharvest losses were prominent in the 1970s and 1980s, when state-run grain marketing boards purchased most of the grain in sub-Saharan Africa. However, after the liberalisation of grain markets in the 1990s, the World Bank (2011) argued that price and quality risks had been passed on to farmers. As a result, incentives to use postharvest technologies may have declined over time and there is little detailed information about how bad such losses are, either in quantity or quality of crops being produced, and where they occur along the value chain.

To meet the SDG12 target, farmers must be provided with the tools they need to limit postharvest losses. However, to properly design these tools more systematic knowledge about both where along agricultural value chains food loss occurs and the severity of these losses is needed, particularly in developing countries.[1] A central challenge is that postharvest losses can occur at one of several different stages. For example, losses may occur during harvesting, the processing phase, while in storage, or after they have been sold by the producer. Moreover, research definitions of postharvest loss are not consistent (Schuster and Torero 2016). Even at the farm level, different surveys may ask about crop losses in different ways, which can result in mistargeted interventions to reduce losses. Given the expense of potential strategies for loss reduction, accurate and consistent measurement is an important input when weighing the cost of solutions against the value of reduced losses (Parfitt *et al.* 2010; Rosegrant *et al.* 2015).

A 2011 FAO report provides estimates of food loss worldwide, separated by region and food type. In general, estimated losses are quite high. In sub-Saharan Africa, total losses for cereals are estimated to be more than 20 per cent, and 8 per cent in the postharvest handling and storage period (FAO 2011). However, these estimates are not based on surveys; rather, they are based on assumptions to extrapolate local measurements into national estimates. Another source of estimates of postharvest losses is the African Postharvest Losses Information System (APHLIS), a multistakeholder monitoring system that dates to 2009. However, like the FAO estimates, estimates from APHLIS may be inaccurate for several reasons. First, when new estimates of postharvest losses are generated, APHLIS largely depends on parameters from the academic literature. Yet, of the 79 references listed on the APHLIS website, only 16 had been published since 2000. Thus, if

[1] When losses are quantified, they have typically been quantified in terms of weight or calories but often neglect nutritional or visual quality (see, e.g., APHLIS 2014; Kummu *et al.* 2012).

postharvest losses have changed in the past two decades, the estimates will be outdated. Second, APHLIS splits loss estimates into seven grain crops but only three climate types (tropical savannah, arid desert, or warm temperate). As such, only 21 grain-climate profiles are used to extrapolate losses when data are not available (APHLIS 2014). Third, when survey data are available, it is not clear what methods are used to estimate postharvest losses, nor is it clear whether the same methods are used across different papers.

A meta-analysis conducted by Affognon *et al.* (2015) echoed the above concerns about the APHLIS system. They found that most estimates in sub-Saharan Africa are unpublished, and the research is generally of poor quality. In addition, the research is perhaps too focused on maize which is represented in 43 per cent of the 213 documents reviewed. Fewer than half of the documents (37 per cent) used household surveys to estimate postharvest losses, they largely focused on West Africa, and they tended to neglect crop quality.

For these reasons, international organisations such as the Food and Agriculture Organization of the United Nations (FAO) and CGIAR have begun to systematise information being collected on postharvest losses (FAO 2011; Aulakh and Regmi 2013; Schuster and Torero 2016). Through a more systematic understanding of these losses, interventions to reduce food loss and waste can be better targeted by both crop and intervention type. For example, if quantity losses are shown to be low prior to food leaving the farm, interventions should target other parts of the value chain if overall losses are high. This article is part of this systematic endeavour; future papers coming from this effort will use similar survey modules to gather information.

The survey modules used in this study are adapted from farmer surveys being used as part of the larger effort to examine postharvest losses among producers and processors (see Delgado *et al.* 2017). The survey specifically asks farmers to self-report whether losses occurred during three particular activities between harvest and sale into the value chain: harvest and transport from the field to home, processing and postprocessing storage. Moreover, the instrument carefully elicits both quantity and quality losses to better understand how losses are occurring. Most prior surveys utilise a one question methodology and focus only on quantity loss. Those few studies that have employed more detailed methods tend to have small samples (Delgado *et al.* 2017).

This article is also related to a recent paper on postharvest losses that focuses on measuring on-farm losses using nationally representative data, including data collected in Malawi. Kaminski and Christiaensen (2014) used the Living Standards Measurement Surveys in Malawi, Tanzania and Uganda to estimate postharvest losses at the farm level for maize. They find losses of only between 1.4 and 5.9 per cent. The estimate of 1.4 per cent is for Malawi, casting doubt on the need for on-farm technologies such as metal silos promoted through the Effective Grain Storage Project (Malira and Kandiwa 2015).

This study measures postharvest losses among smallholder farms in farmer groups in Malawi for three crops: maize; soya; and groundnuts. The postharvest loss survey modules were added to the second follow-up survey for a cluster randomised controlled trial studying the impact of individualised extension services and capital transfers. The detail available in the survey modules helps pinpoint when postharvest losses occur. Moreover, the existence of recently collected nationally representative data allows us to compare the farmers in our sample with both a nationally representative sample of farmers and a representative sample in the intervention districts. Finally, because the nationally representative survey includes a single question on postharvest losses, we can study the differences between asking a single question and the more systematic body of questions included in our survey.

Our results contribute to the existing literature in several ways. First, across crops, fewer than half of households report losses (conditional on growing that crop). Conditional on experiencing a loss, losses vary across crops: 5 per cent for maize, 8 per cent for soya and 12 per cent for groundnuts. Although the maize estimates are small relative to FAO (FAO 2011) estimates, they are comparable to other recent studies examining staple crops in sub-Saharan Africa (Kaminski and Christiaensen 2014; Abdoulaye *et al.* 2016; Minten *et al.* 2016). Losses in our sample are concentrated in harvest and processing activities; for soya, they are highest during processing. Most interventions have targeted storage activities; however, our results suggest that targeting other activities might also be effective. We also find that crop damage and complete crop loss are both important; similar proportions of farmers report damage and complete losses, indicating that only measuring complete losses is not sufficient. Furthermore, the findings indicate that large losses tend to be concentrated on a few farmers.[2]

Second, we compare our results to those from the most recent available data of the nationally representative Integrated Household Survey (IHS), which relies on a single question to measure postharvest losses. Although we find considerably higher incidence of postharvest losses using our detailed approach, we find similar unconditional proportions of lost production estimates.

Finally, we measure postharvest losses for maize, soya bean and groundnuts at the farm level. Although the literature shows other estimates of maize losses, there are only two estimates of groundnut losses from Ghana (Affognon *et al.* 2015), and there appear to be no estimates of soya losses

[2] Groundnuts are the exception – 20 per cent of farmers report losses equivalent to 20 per cent or more of total production.

anywhere in Africa south of the Sahara. Therefore, this article provides new estimates for crops underrepresented in the literature.

Our results can be compared to those using a similar self-reported methodology in Delgado *et al.* (2017). They find similarly low levels of losses. It should be noted that they find somewhat higher estimates when employing alternate methodologies based on commodity damage and commodity attributes not studied in this article. However, their work focuses mostly on Latin America and does not allow for comparisons to the single question method. Both studies clearly emphasise the importance of considering crop damage in addition to complete loss.

The paper proceeds as follows: The next section describes the data. Section 3 describes the incidence of postharvest losses. Section 4 compares postharvest losses measured by the detailed module with those measured by a single question. Section 5 concludes with a discussion of the implications for policy.

2. Data

This article uses data collected for a randomised controlled trial conducted by IFPRI in Malawi. The project evaluates the impact of capital transfers and intensive agricultural extension over the 2014/2015 and 2015/2016 agricultural seasons. All interventions were conducted by the National Smallholder Farmers' Association of Malawi (NASFAM), a smallholder-owned organisation that provides both commercial and development services to member farmers. More details are available in Ambler *et al.* (2017).

The sample comprises farmers in the 120 newest NASFAM farmer clubs in the Dowa and Ntchisi districts in central Malawi. The project focus crops were groundnuts and soya; project services were concentrated on but not completely limited to these two crops. Almost all farmers also grow maize, the primary staple crop in Malawi.

A project baseline was conducted in August and September 2014, and two follow-up surveys were conducted in August/September of 2015 and August/September 2016. These surveys were timed to occur shortly after harvest and crop sales have taken place, and questions referred to the recently completed agricultural season. The second follow-up survey in 2016 included an extensive module on postharvest losses that will form the basis for this article. Therefore, the sample of interest is all 1,118 farmers who completed the second follow-up, including both original sample members and farmers who had joined project clubs since the project began.

The postharvest loss module is designed to measure losses incurred by smallholder producers up to the point at which crops are sold. We adapt the self-reported methodology developed from Delgado *et al.* (2017) for surveys conducted among producers in Guatemala, Honduras, Peru, Ecuador and Ethiopia, and apply it to maize, groundnuts and soya. Prior to the development of this methodology, most surveys measuring postharvest losses employed a single question and did not include reference to reductions in crop quality. The nationally representative IHS in Malawi took this approach, but our method is innovative in that it incorporates both crop damage and complete crop loss. We also differentiate by activity and measure losses at different points in the production process. Such detailed information is important for policy makers designing interventions to mitigate postharvest losses.[3]

Prior to discussing the survey module in detail it is useful to define the terminology used in the rest of the paper. *Postharvest losses* are generally defined as losses that occur during or after harvest, through the value chain until the crop reaches the consumer. Our study measures these losses only while the crop is still with the producer, until it is either consumed by the producer household or sold. Postharvest losses encompass both crop damage and complete losses. Throughout this article, the term *damaged* refers to crops that suffered a reduction in quality but which were still useable in some capacity, and *complete loss* refers to crops that were completely lost. The use of the term *loss* refers generally to either damage or complete loss.

Farmers are first asked to identify the activities they engaged in for each target crop that they had reported growing earlier in the survey. The activities are harvest and transport, processing, and postprocessing storage.[4] For each activity, they are asked to indicate the amount and value of the crop that was damaged but not completely lost and the amount and value that was completely lost. Amounts are reported in kilograms and value is reported in Malawi Kwacha. Farmers are also asked to report the cause of the damage and the cause of the complete loss (separately by crop and activity). For damaged crops, respondents are asked to categorise the damaged quantity into categories (very little damage, some damage and extensive damage). Finally, farmers are asked how they would have used the crop that was not damaged or lost, how they used the damaged crop, and how they would have used the crop that was completely lost. The survey module in presented in Online Appendix A and the relevant section of the Field Officer Manual is in Online Appendix B.[5]

Table 1 presents summary statistics describing the sample and compares the sample to the nationally representative sample from the 2013 round of the IHS. The first column in Table 1 presents statistics for all rural households in

[3] The advantage of the method used here is that a relatively large battery of questions was used to ask about losses in different ways; therefore, farmers' memory could be catalyzed from several different angles. Delgado *et al.* (2017) also employ commodity damage and commodity attribute methods not explored in this paper.

[4] Processing activities were defined as follows: maize – removing husks, drying, shelling, cleaning, chemical application and packaging, storage related to processing; groundnuts – plucking, drying, shelling, cleaning, chemical application and packaging, storage related to processing; and soy – drying, threshing, cleaning, chemical application and packaging, storage related to processing.

[5] The module additionally included a set of questions about storage activities that are not utilized in this paper.

Table 1 Summary statistics and sample comparison

	(1) IHS (All Rural)	(2) IHS (Dowa/ Ntchisi)	(3) NASFAM farmer sample	(4) *P*-value for equality of columns 2 and 3
Demographic characteristics				
Household size	5.1	4.9	5.7	0.000
Age of household head	43.3	41.6	47.0	0.000
Household head is female	0.24	0.17	0.17	0.966
Household head is polygamous	0.07	0.09	0.10	0.683
Education of household head				
No schooling	0.19	0.14	0.19	0.079
Some primary	0.45	0.54	0.59	0.206
Completed primary	0.15	0.16	0.09	0.004
Some secondary	0.13	0.12	0.09	0.238
Completed secondary +	0.08	0.05	0.03	0.073
Agricultural production				
Number of crops	2.1	2.0	4.9	0.000
Land area (Acres)	2.6	2.9	4.1	0.000
Total Sales Revenue (Kwacha)	27,002	52,893	174,310	0.000
Household planted maize	0.97	0.99	0.99	0.365
Land area planted for maize (Acres)	1.5	1.7	1.8	0.870
Production of maize (Kgs)	821	1,394	1,414	0.904
Household planted groundnuts	0.33	0.55	0.81	0.000
Land area planted for groundnuts (Acres)	0.8	1.1	0.9	0.142
Production of groundnuts (Kgs)	292	295	351	0.271
Household planted soya	0.09	0.30	0.78	0.000
Land area planted for soya (Acres)	0.8	1.1	0.9	0.123
Production of soya (Kgs)	268	376	255	0.036
Postharvest losses				
Reports loss: Maize	0.10	0.06	0.36	0.000
Proportion of production lost: Maize	0.03	0.02	0.02	0.217
Reports loss: Groundnuts	0.04	0.04	0.47	0.000
Proportion of production lost: Groundnuts	0.02	0.02	0.05	0.030
Reports loss: Soya	0.02	0.04	0.42	0.000
Proportion of production lost: Soya	0.01	0.04	0.03	0.733

Note: Authors' calculations from the NASFAM farmer surveys and the 2013 round of the Malawi IHS panel survey.

the IHS. The second column limits the sample to Dowa and Ntchisi districts, where our surveys were conducted. The third column presents statistics from our surveys of NASFAM farmers. The fourth column shows the *P*-value for a t-test on the equality of columns 2 and 3. Households in our sample have an average size of 5.7 members. Household heads are 47 years old on average; 17 per cent of household heads are women, and 10 per cent are polygamous. Education levels are low: almost 80 per cent of household heads have not completed primary school. On average, these NASFAM households are larger and household heads are older and somewhat less educated than IHS households in Dowa and Ntchisi. Even though many of these differences are statistically significant, the magnitudes of the differences are small.

Comparison of agricultural measures is also important, as shown in the third panel of Table 1. Farmers in the NASFAM sample grow an average of 4.9 crops on 4.1 acres of land, which is significantly larger than comparable figures for the Dowa and Ntchisi IHS sample (2.0 and 2.9, respectively) and is indicative of the involvement of NASFAM farmers in a higher level of commercial agriculture. Indeed, the sales revenue in our sample is almost three times the average in Dowa and Ntchisi.[6] Maize production, the main staple crop in Malawi, is remarkably similar. Maize is grown by almost all rural households in Malawi, and our sample is no exception. Maize land area and total maize production are also similar and not statistically different from the IHS numbers for Dowa and Ntchisi. Given the project focus on groundnuts and soya, it is unsurprising that NASFAM farmers grow these crops at much higher rates than the population (rates are around 80 per cent for both crops, compared to 55 per cent for groundnuts and 30 per cent for soya in the IHS). However, conditional on growing the crop, production is similar between the IHS and our sample. Overall, although our sample is not representative, these farmers appear to be roughly similar to other farmers in the region, particularly those who grow groundnuts or soya. However, our results should be interpreted with the caveat that the sample was not randomly drawn from the population.

3. Incidence of postharvest losses

This section describes the incidence of postharvest losses in our sample for maize, which the main staple crop in Malawi, and for soya and groundnuts, the two focus crops of the project. In Table 2, we present detailed statistics describing postharvest losses for the 2015/2016 growing season for the three crops of interest. The proportion of households growing maize, groundnuts and soya in 2016 is 99.6 per cent, 80 per cent and 79 per cent, respectively. Panel A shows the percentage of households engaged in each activity considered (harvest and transport, processing and storage) conditional on growing that crop. Across crops, most farmers report participating in all activities, with the lowest percentage being the 85 per cent of households that

[6] These figures are, of course, from different seasons. The IHS numbers refer to the 2011/2012 season, and the numbers for the NASFAM sample refer to the 2015/2016 season. Thus, some of the difference may be due to seasonal variation.

Table 2 Postharvest losses of targeted crops

	Maize			Groundnuts			Soya		
	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*
A. Engaged in activity									
Harvest and transport	1.00	0.06	1,112	0.99	0.07	901	1.00	0.07	873
Processing	0.96	0.19	1,112	0.95	0.21	901	0.95	0.22	873
Storage	0.85	0.36	1,112	0.91	0.29	901	0.89	0.32	873
B. Proportion reporting losses									
Any quality loss	0.28	0.45	1,112	0.37	0.48	901	0.29	0.46	874
Any total loss	0.26	0.44	1,112	0.33	0.47	901	0.34	0.47	874
Any quality or total loss	0.36	0.48	1,110	0.47	0.50	899	0.42	0.49	874
C. Severity of loss (if loss reported)									
Very little damage	0.30	0.38	396	0.31	0.38	420	0.22	0.34	369
Some damage	0.06	0.17	396	0.09	0.21	420	0.05	0.15	369
Extensive damage	0.21	0.27	396	0.20	0.27	420	0.21	0.26	369
Complete loss	0.43	0.37	396	0.40	0.37	420	0.52	0.37	369
D. Timing of losses (% in each activity)									
Harvest and transport	0.43	0.43	396	0.49	0.44	420	0.36	0.42	369
Processing	0.37	0.42	396	0.35	0.42	420	0.58	0.44	369
Storage	0.21	0.37	396	0.16	0.33	420	0.05	0.18	369
E. Mean quantity lost (Kilos)									
Harvest and transport	8.9	35.9	1,110	7.1	21.8	899	3.7	16.8	874
Processing	4.9	35.5	1,110	3.4	11.0	899	4.2	18.2	874
Storage	2.8	15.6	1,110	1.1	6.3	899	0.2	1.1	874
Total	16.6	54.7	1,110	11.7	26.8	899	8.1	25.2	874
F. Mean quantity lost if any loss (Kilos)									
Harvest and transport	24.8	56.7	398	15.2	29.8	421	8.7	24.9	370
Processing	13.7	58.3	398	7.3	15.2	421	9.9	26.9	370
Storage	7.8	25.3	398	2.4	9.0	421	0.5	1.6	370
Total	46.3	83.5	398	24.9	34.7	421	19.1	36.0	370
G. % of total production lost									
Harvest and transport	0.01	0.04	1,109	0.04	0.12	899	0.02	0.07	873

Table 2 (*Continued*)

	Maize			Groundnuts			Soya		
	Mean	SD	*N*	Mean	SD	*N*	Mean	SD	*N*
Processing	0.00	0.02	1,109	0.01	0.05	899	0.02	0.05	873
Storage	0.00	0.02	1,109	0.00	0.02	899	0.00	0.01	873
Total	0.02	0.05	1,109	0.05	0.14	899	0.03	0.09	873
H. % of total production lost if any loss									
Harvest and transport	0.03	0.07	398	0.08	0.17	421	0.04	0.10	370
Processing	0.01	0.03	398	0.03	0.07	421	0.04	0.08	370
Storage	0.01	0.03	398	0.01	0.04	421	0.00	0.01	370
Total	0.05	0.08	398	0.12	0.18	421	0.08	0.12	370
I. Total value of postharvest losses (Kwacha) if any loss									
Total	8,375	15,716	398	8,898	14,722	421	4,886	10,512	370

Notes: Authors' calculations from the second follow-up of the NASFAM farmer study. Base sample by crop in Panel A is all farmers who reported planting that crop.

report storing maize. Panel B shows the percentage of farmers (conditional on growing a certain crop) that report damage or a complete loss: 28 per cent of households report damage for maize; 26 per cent report a complete loss; and 36 per cent report a loss of any kind (damage or complete loss). These numbers are higher for groundnut production (37 per cent report damage, 33 per cent report a complete loss and 47 per cent report a loss of any kind) and for soya (29 per cent, 34 per cent and 42 per cent, respectively). These numbers indicate that the losses are affecting a meaningful number of farmers but are not close to universal.

Panel C examines the percentage of the quantity lost that falls into different quality categories as reported by farmers. These categories are 'very little damage', 'some damage', 'extensive damage' and 'complete loss'. This distribution is similar for maize and groundnuts, with about 30 per cent of the harvest lost in the 'very little damage' category, 6–9 per cent in 'some damage', 20 per cent in 'extensive damage', and 40 per cent in 'completely lost'. The percentage of soya crop completely lost is somewhat higher, at 52 per cent, with only 22 per cent reporting 'very little damage'. These numbers show that both complete loss and crop damage are important components of postharvest losses and should be addressed in any policy solution. For the rest of the paper, we will generally combine damage and complete loss in our analysis.

Panel D reports the percentage of losses (by amount lost) attributable to each production stage. In these data, the harvest and transport stage and the processing stage incur the most losses. For maize, 43 per cent of losses occur at harvest and 37 per cent during processing, while those numbers for groundnuts are 49 per cent and 35 per cent, respectively. Processing is relatively more important for soya, at 58 per cent, compared with 36 per cent for harvest. Storage losses are relatively low: 21 per cent for maize; 16 per cent for groundnuts; and 5 per cent for soya. Storage is often considered one of the most important components of postharvest losses; yet, in our sample, those losses are somewhat low.

Given that our survey is conducted relatively soon after harvest, we may have underestimated the losses due to storage, as they continue to accumulate over time. To better understand how the timing of our survey may have affected the estimation of losses during storage, we analyse losses by week of survey. The survey spanned an eight-week period, and we do not observe differential losses by week of survey in our data. For maize, the survey was conducted approximately four to six months after harvest. Soya and groundnuts were harvested later, and the harvest timing varied more across farmers. Thus while storage losses are likely somewhat underestimated, it does not seem that adjusting survey time would greatly increase those estimates. Indeed, for a crop such as soya, which is grown primarily for sale and may not be stored for long, producers should not have large storage losses.

Panels E and F report the quantity lost in kilograms for the full sample growing that crop (Panel E) and the sample reporting a loss (Panel F). These losses as a proportion of total harvest are reported in Panels G (unconditional) and H (conditional). The unconditional proportions lost across the three activities are 2 per cent for maize, 5 per cent for groundnuts and 3 per cent for soya; the conditional proportions lost are 5 per cent, 12 per cent and 8 per cent, respectively. Similar to Kaminski and Christiaensen (2014), our findings are well below the FAO estimates. However, the number of farmers experiencing loss is significant, and the conditional losses on the order of 5–12 per cent may represent significant amounts for some farmers.

To further understand the distribution of losses, the cumulative distribution function of the conditional proportion lost for each crop is presented in Figure 1. All three distributions are concentrated at low proportions of the crop being lost, with long right tails. In addition, the curve for soya is clearly to the right of maize and groundnuts to the right of soya. Overall, Figure 1 shows that most people who report losses report low levels of loss, with a small minority reporting larger losses. However, this statement is somewhat less true for groundnuts, where 20 per cent of the sample reports losing 20 per cent or more of their groundnut harvest.

To understand the impact of crop loss on farmers, we include questions on how crops are used, separately, for damaged and nondamaged crops. Table 3 presents the percentage of farmers, by crop, who reporting using crops in each of a number of ways. Farmers were permitted to list more than one use. Panel A shows that nondamaged crops are used primarily for consumption and sales, as well as for seed. Panel B shows that, proportionally, damaged crops are much more likely to be consumed by the family, instead of sold or used for seed.

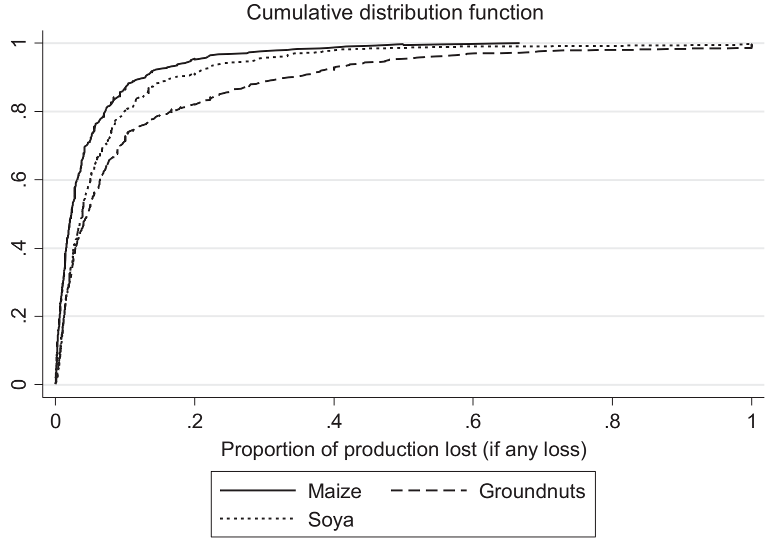

Figure 1 Cumulative distribution function of proportion of production lost. Notes: By crop, sample is all respondents reporting any loss for that crop.

Table 3 Use of crops

Dependent variable: Proportion of farmers reporting each use, conditional on reporting damage for that crop

	Maize	Groundnuts	Soya
Panel A: Use of nondamaged crops			
For sale	0.39	0.72	0.84
Consumption	0.97	0.80	0.74
Donation/gift	0.05	0.02	0.02
Retain for barter	0.01	0.00	0.00
For seed	0.20	0.44	0.38
For animal feed	0.02	0.01	0.00
Ceremonies	0.03	0.00	0.00
Repay Loan	0.00	0.14	0.08
Kept aside	0.01	0.00	0.00
None	0.00	0.00	0.02
Panel B: Use of damaged crops			
For sale	0.14	0.24	0.36
Consumption	0.88	0.83	0.78
Donation/gift	0.01	0.01	0.00
Retain for barter	0.00	0.01	0.01
For seed	0.01	0.02	0.03
For animal feed	0.02	0.03	0.01
Ceremonies	0.01	0.01	0.00
Repay Loan	0.01	0.01	0.01
Kept aside	0.00	0.00	0.00
None	0.00	0.02	0.02

Notes: Authors' calculations from the NASFAM farmer survey. Sample is all farmers who reported damage for each crop.

Beyond careful measurement of crop loss, understanding its root causes is important for any policy aimed at loss reduction. Our survey collected detailed information, by crop and activity, on the causes of damage and total loss. Online Appendix Table A1 shows the per cent of farmers reporting a certain cause of loss for each crop and activity, conditional on growing that crop and participating in that activity. Farmers could list more than one cause. For harvest and transport, the most important causes of loss are loss of product by handlers, weather, mode of transport and timing of activity. During processing, the most important causes are crop blowing away (particularly for soya), crop being spilled, the processing method (for groundnuts) and rodents or other animals. During storage, the main causes are infestation or rodents and animals. While many policy recommendations have focused on storage technologies, these results suggest that technologies or better training that could lead to less waste during harvest and processing may be beneficial.

4. Comparison to other survey methods

Given that our methodology departs from previous self-reported measures through a detailed collection of loss by activity and a differentiation of quality loss and complete loss, it is instructive to compare our estimates to the estimates collected in the IHS through a less detailed methodology. The IHS data were collected with a single question for each crop, asking how much of the harvest was 'lost to rotting, insects, rodents, theft, etc. in the *postharvest period*?' The bottom panel of Table 1 provides comparison of the percentage reporting loss and the proportion of production lost for the three crops of interest between the IHS and our sample. The most striking result is the large discrepancy between the percentage of people reporting loss in the IHS compared to our sample. In the IHS, only 6, 4 and 4 per cent of households report loss for maize, groundnuts and soya, respectively, compared to 36 per cent, 47 per cent and 42 per cent in our sample. The IHS numbers for maize are similar to those reported by Kaminski and Christiaensen (2014), who used the 2010/2011 round of the IHS.

Several things may account for these differences. First, whereas our survey specifically asks about damage and complete loss, the IHS lacks specificity and seems to refer only to complete loss. Given that a significant proportion of damaged crops are rated as having 'extensive damage' and even low levels of damage can affect a crop's suitability for sale and export, collecting this additional information is important. However, the numbers in Panel B of Table 2 show that even when just considering complete losses, the estimates from this survey still far exceed the IHS estimates. It is therefore evident that the detailed questions and differentiation by activity are important to the collection of this information. For example, the IHS question does not specifically refer to harvest and transport or processing activities, which account for the bulk of losses in our analysis. By focusing on causes related to storage, the IHS is missing important information about other activities carried out by producers.[7]

Interestingly, even though the incidence of losses is so much higher in the NASFAM sample, the unconditional proportion of lost production is similar for maize and soya and is only somewhat higher for groundnuts (2 per cent compared to 5 per cent). Indeed, the conditional proportions lost in the IHS data are much higher – above 20 per cent for maize. Beyond measurement differences, the most likely explanation for this discrepancy is the recall period. As noted earlier, our survey will underestimate losses due to storage because it takes place soon after harvest, when crops have not been in storage for long. The IHS, conducted in 2013 over the course of the year, asked the loss question about the 2011/2012 rainy season to fully account for these storage losses. We can assume that any storage losses, although infrequent, are more important when they occur than they seem to be in our data, at least for maize. Because households are less likely to store large amounts of groundnuts and soya for the year, our estimates are more likely to be accurate for those crops. Moreover, the proportion of farmers growing these crops in

[7] It should also be noted that these survey were completed in different years and some differences may be attributable to variations in weather.

the IHS is quite low. Given the low levels of reported losses, there are not sufficient data to reliably compare the two data sources.

Overall, the analysis of the incidence of postharvest losses in our sample suggests that losses at the producer level in our sample are small compared to many previous estimates being used to advocate for policy interventions aimed at loss reduction (FAO 2011). Even using a more detailed methodology that expands beyond maize and carefully accounts for losses by activity and damage level, as well as total loss, our average results are consistent with the estimates for Malawi, Uganda and Tanzania in Kaminski and Christiaensen (2014). Although our methods substantially raise the percentage of farmers who report losses, the proportion of the crop lost remains low overall.

The rich household survey data available in our project and in the IHS also provides the opportunity to examine and compare the correlates of postharvest loss in both settings. Our regression analysis uses ordinary least squares regressions and in regressions using the NASFAM sample, robust standard errors are clustered by farmer club. Regressions include a variety of potential predictor variables. First, we examine variables related to agricultural output, the inverse hyperbolic sine of crop production (in kilograms) and of the gross value of agricultural output. Next, we include a set of variables to proxy for household wealth, the inverse hyperbolic sine of the total value of household assets[8] and of land area owned. We also include a set of demographic variables including household size, age and gender of the household head, and whether the household head is polygamous. Finally, we include control variables for the education level of the household head, although we do not show this variable in the results. All variables are measured contemporaneously, except for a few demographic variables in the NASFAM sample that were measured only at baseline.

Finally, because crop losses are related to climatic factors – specifically, humidity and temperature – we include mean precipitation preharvest (November–March) and during harvest and postharvest (April–September). Rainfall prior to harvest should be indicative of overall production, as well as a proxy for humidity patterns. Excess rainfall during the harvest/postharvest period can directly cause losses, particularly during harvest and processing. The precipitation data come from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data source. The GPS coordinates in our data match 33 unique cells in the CHIRPS data. We additionally control for long-term average precipitation and average maximum temperature[9] but do not show these coefficients in the results.[10] This specification of

[8] We use the total value of assets common to both surveys. Including the full set of assets reported in either survey does not change the results.

[9] We do not have access to the most recent temperature data.

[10] The historical data are monthly averages at approximately 1-km resolution from WorldClim. GPS coordinates in the NASFAM sample are taken at the household level. GPS coordinates in the IHS survey are at the village level and include a random offset.

precipitation and temperature follows the model used by Kaminski and Christiaensen (2014) in their investigation of determinants of losses in Tanzania.

We explore losses aggregated across activities and include both damage and complete loss, to produce comparable analyses in both samples.[11] Table 4 presents the results for the NASFAM sample and Table 5 presents the results for the IHS sample. The results are reported for all crops (columns 1 and 2), maize (columns 3 and 4), groundnuts (columns 5 and 6) and soya (columns 7 and 8). For each category, we examine conditional correlations with two outcome variables: an indicator for any loss occurring and the proportion of harvest lost. For the analysis across crops, we cannot calculate proportion of harvest lost and instead examine the inverse hyperbolic sine of the value of the loss in column 2.[12]

Focusing first on the correlates of losses in the NASFAM survey, across all specifications, the production quantity is an important predictor of crop loss. Increased production of a crop increases the probability of experiencing any loss but decreases the proportion of harvest lost. Wealth measures including the gross value of agricultural production, asset value, and land area are not associated with losses. Household size is positively associated with experiencing any loss and total loss value, a pattern repeated for groundnuts and soya but not maize. The age of the household head is negatively associated with any loss and total value of loss, a pattern also seen for the individual crops, although not for the proportion lost outcome for groundnuts and soya. Finally, the precipitation data show that climate variations are important in determining losses. Preharvest precipitation has a negative effect on losses (statistically significant in columns 1, 2, 3 and 7). Conversely, postharvest rainfall has a positive effect on the incidence of losses (significant in columns 1, 2 and 7). It is also interesting to note that while precipitation in both periods is predictive, the size of the coefficients for postharvest rainfall is much larger than for preharvest rainfall. The patterns in the IHS sample (Table 4) are generally similar, although the coefficients are usually smaller in magnitude and fewer are statistically significant. One explanation for the weaker associations in the IHS is the probable undercounting of losses present in that dataset.

These comparisons between the detailed postharvest loss module and the single question approach in the IHS suggest that both methods recover important information about crop loss, but that the IHS method likely undercounts losses that occur before the storage stage, and fails to take into account crop damage by focusing only on complete loss. It is also important to note that the detailed module likely undercounts storage losses to some

[11] Analysis in the NASFAM sample that disaggregates losses by damage or complete loss or by activity is underpowered, but provides a similar pattern of results.

[12] The inverse hyperbolic sine is similar to the log but is defined at zero. It is defined as $\log(y_i + (y_i^2 + 1)^{1/2})$. As is clear from the formula, the inverse hyperbolic sine collapses to a simple transformation of $\log(y)$ for most values of y.

Table 4 Correlates of postharvest losses: NASFAM survey

	(1) Maize, groundnuts and soya	(2)	(3) Maize	(4)	(5) Groundnuts	(6)	(7) Soya	(8)
	Any loss	Inv hyp sine value of loss	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost
Inv hyp sine production quantity: Maize	0.0292* [0.0161]	0.255 [0.163]	0.0571*** [0.0204]	−0.0102*** [0.00313]				
Inv hyp sine production quantity: Groundnuts	0.0202*** [0.00686]	0.176*** [0.0660]			0.0706*** [0.0194]	−0.0319*** [0.00845]		
Inv hyp sine production quantity: Soya	0.00924 [0.00673]	0.0995 [0.0670]					0.0446** [0.0186]	−0.0147*** [0.00547]
Inv hyp sine of gross value of agricultural output	−0.031 [0.0249]	−0.13 [0.238]	−0.0219 [0.0216]	0.000211 [0.00261]	−0.0392 [0.0252]	0.007 [0.00863]	−0.0431* [0.0255]	−0.00766 [0.00631]
Inv hyp sine of household asset value	0.00296 [0.00364]	0.0268 [0.0343]	0.00451 [0.00349]	0.000252 [0.000344]	0.00427 [0.00413]	−0.00145 [0.00123]	0.00309 [0.00392]	0.000845 [0.000734]
Inv hyp sine of total land area owned	0.00604 [0.0430]	0.266 [0.415]	−0.0491 [0.0415]	−0.000582 [0.00423]	−0.0222 [0.0553]	0.00175 [0.0126]	−0.0269 [0.0467]	0.00719 [0.00782]
Household size	0.0182** [0.00758]	0.166** [0.0703]	0.00188 [0.00763]	0.000296 [0.000731]	0.0201** [0.00849]	0.00551** [0.00270]	0.0158* [0.00847]	0.0000713 [0.00120]
Household head age	−0.00270** [0.00105]	−0.0306*** [0.00983]	−0.00324*** [0.000933]	−0.000172* [0.0000902]	−0.00224* [0.00127]	0.000227 [0.000378]	−0.00210* [0.00115]	−0.0000977 [0.000227]
Household head is female	−0.0234 [0.0447]	––0.14 [0.432]	−0.00511 [0.0421]	−0.00322 [0.00421]	0.0607 [0.0493]	0.0175 [0.0134]	−0.0306 [0.0448]	−0.00635 [0.00867]
Household head is polygamous	0.0238 [0.0582]	0.409 [0.562]	0.0261 [0.0608]	0.0032 [0.00692]	0.0327 [0.0669]	0.0065 [0.0115]	0.0262 [0.0555]	0.0125 [0.0157]
	−0.00658**	−0.0538*	−0.00496*	−0.000108	−0.000968	0.000974	−0.0107***	−0.000173

Table 4 (*Continued*)

	(1) Maize, groundnuts and soya	(2)	(3) Maize	(4)	(5) Groundnuts	(6)	(7) Soya	(8)
	Any loss	Inv hyp sine value of loss	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost
Mean precipitation preharvest	[0.00297]	[0.0279]	[0.00288]	[0.000331]	[0.00383]	[0.00103]	[0.00312]	[0.000622]
Mean precipitation postharvest	0.0428** [0.0209]	0.411** [0.200]	0.0276 [0.0193]	0.000886 [0.00230]	0.0212 [0.0261]	0.00187 [0.00594]	0.0479** [0.0242]	0.00141 [0.00421]
Observations	1,112	1,109	1,107	1,106	896	896	872	871
R-squared	0.056	0.066	0.051	0.043	0.044	0.105	0.053	0.051
Mean of dependent variable	0.614	7981	0.359	0.018	0.468	0.055	0.423	0.032

Notes: Robust standard errors in parentheses are clustered by farmer club. Household asset value includes assets that are common to the IHS and the NASFAM survey. Inclusion in regressions is conditional on growing the crop. Regressions also control for household head education (indicator variables for some primary, completed primary, some secondary and completed secondary plus) and the 1960–1990 average precipitation and temperature. Missing values of independent variables due to missing values are set to zero, and indicator variables are included to control for each missing value. Preharvest precipitation covers November–March and harvest/postharvest precipitation covers April–September. ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

Table 5 Correlates of postharvest losses: IHS

	(1) Maize, groundnuts and soya	(2)	(3) Maize	(4)	(5) Groundnuts	(6)	(7) Soya	(8)
	Any loss	Inv hyp sine value of loss	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost
Inv hyp sine production quantity: Maize	0.0191*** [0.00612]	0.659*** [0.116]	0.0180** [0.00812]	−0.00634 [0.00449]				
Inv hyp sine production Groundnuts	−0.00232 [0.00270]	0.409*** [0.0379]			−0.0155* [0.00904]	−0.0250*** [0.00833]		
Inv hyp sine production quantity: Soya	−0.00711** [0.00352]	0.0556 [0.0564]					0.000141 [0.00285]	−0.00236 [0.00320]
Inv hyp sine of gross value of agricultural output	−0.0052 [0.00505]	0.291*** [0.101]	−0.00825 [0.00550]	−0.00498 [0.00384]	0.0117 [0.00846]	0.0141* [0.00747]	−0.0117 [0.0143]	−0.0169 [0.0124]
Inv hyp sine of household asset value	−0.0016 [0.00156]	0.0104 [0.0227]	−0.00233 [0.00155]	−0.000221 [0.000716]	0.00124 [0.00154]	0.000817 [0.00121]	0.00181 [0.00119]	0.00114 [0.000900]
Inv hyp sine of total land area owned	0.0201 [0.0122]	−0.0961 [0.168]	0.00993 [0.0113]	0.00398 [0.00500]	−0.000935 [0.0118]	−0.00553 [0.00924]	−0.0105 [0.00979]	−0.0101 [0.00989]
Household size	0.00107 [0.00312]	0.0527 [0.0429]	0.000285 [0.00298]	0.00225** [0.00113]	0.00232 [0.00393]	0.000501 [0.00332]	0.00237 [0.00490]	0.0049 [0.00373]
Household head age	−0.000641 [0.000421]	−0.00763 [0.00625]	−0.000532 [0.000405]	0.0000742 [0.000163]	−0.000464 [0.000491]	−0.000383 [0.000401]	0.000165 [0.000609]	0.000521 [0.000456]
Household head is female	−0.00205 [0.0161]	−0.671*** [0.238]	−0.0103 [0.0153]	−0.00206 [0.00694]	0.0232 [0.0190]	0.00177 [0.0101]	−0.0136 [0.0120]	−0.00785 [0.0101]
Household head is polygamous	−0.0231 [0.0242]	0.322 [0.353]	−0.0324 [0.0217]	−0.01 [0.00948]	0.00167 [0.0279]	0.0196 [0.0263]	−0.0216 [0.0143]	−0.0179 [0.0139]
	−0.000164	−0.000402	−0.000365	0.0000569	0.000452*	0.000271*	0.000695	0.000648

Table 5 (*Continued*)

	(1) Maize, groundnuts and soya	(2)	(3) Maize	(4)	(5) Groundnuts	(6)	(7) Soya	(8)
	Any loss	Inv hyp sine value of loss	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost	Any loss	Proportion of harvest lost
Mean precipitation preharvest	[0.000291]	[0.00429]	[0.000283]	[0.000130]	[0.000243]	[0.000162]	[0.000460]	[0.000453]
Mean precipitation postharvest	0.00253*** [0.000903]	0.0395*** [0.0138]	0.00276*** [0.000882]	0.000912** [0.000365]	−0.00112 [0.00103]	−0.000589 [0.000619]	−0.00049 [0.000949]	0.000106 [0.000692]
Observations	2281	2269	2293	2273	767	759	223	220
R-squared	0.016	0.177	0.014	0.024	0.041	0.078	0.278	0.081
Mean of dependent variable	0.11	0.11	0.10	0.03	0.04	0.02	0.02	0.01

Notes: Robust standard errors are in parentheses. Household asset value includes assets that are common to the IHS and the NASFAM survey. Regressions also control for household head education (indicator variables for some primary, completed primary, some secondary and completed secondary plus) and the 1960–1990 average precipitation and temperature. Missing values of independent variables due to missing values are set to zero, and indicator variables are included to control for each missing value. Preharvest precipitation covers November–March and harvest/postharvest precipitation covers April–September. ***$P < 0.01$, **$P < 0.05$, *$P < 0.1$.

extent given the timing of the survey. The fact that the detailed module studied here finds extensive incidence of crop damage and losses across activities is strong evidence that both are important to measure.[13] Further research would be needed to evaluate the efficacy of a single question that incorporated all stages. However, effective policy solutions will rely on information about where losses occur, as strategies addressing transport techniques will be different from those addressing storage. The detailed module is costly to implement, lasting 11.5 minutes on average in the NASFAM sample. Survey implementers must therefore evaluate the importance of collecting detailed, likely more accurate information relative to its cost and the particular goals of each data collection exercise.

5. Conclusion

This research studied the incidence of postharvest losses in Malawi, using a detailed survey module designed to pinpoint where these losses occur on the farm. Losses are, in general, quite low, consistent with findings from a much less detailed survey module described by Kaminski and Christiaensen (2014) and with those from nationally representative data analysed in this article. However, our methodology suggests that losses are spread across a much larger proportion of farmers. The previous work focused on total crop loss during storage; this article, however, uses a more specific questionnaire to document that farmers report both complete loss and crop damage, as well as loss during harvest and transport, processing and storage.

A principal contribution of this article is that it goes beyond maize to study losses in two common smallholder cash crops: groundnuts; and soya. We find slightly higher losses for groundnuts and soya, as compared with maize. However, the estimates are still on the low end of estimates worldwide or publicized through sources such as APHLIS. Our detailed survey instrument allows us to identify which activities are more susceptible to crop losses for the three focus crops. Losses in our sample are concentrated in harvest and processing activities for groundnuts and maize; whereas for soya, they are highest during processing. Most interventions have been targeted towards storage activities, but our results suggest that targeting other activities might also be worth considering. As such, use of a detailed survey module, such as the one presented in this article, is crucial for the development of effective interventions.

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[13] In a parallel to consumption measurement, Beegle *et al*. (2012) find that using more detailed survey modules to measure consumption leads to higher reporting of food consumption (and therefore lower poverty rates) in Tanzania.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Survey module.

Appendix S2. Field officer manual.

Table S1. Causes of loss by activity and crop.