Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth

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Abstract

In this paper, we assess the levels of infrastructure investment and rates for return on investments to reduce postharvest losses (PHL). Food security impacts and rates of return to reducing PHL are compared to rates of return to productivity-increasing research and development (R&D) investment. First we undertake of review of the literature on the magnitude of PHL. Next we undertake an econometric analysis of the impact of infrastructure investments on PHL using a panel data set. Third, we quantify the investments required for any given level of PHL reduction by combining marginal effect analysis based on the econometric estimation with data on unit costs for specific infrastructural variables. Fourth, we undertake a cost-benefit analysis of the required infrastructural investments to assess whether or not significant efforts in PHL reduction are economically feasible; and compare these to the rates of return to investments in R&D.

These scenarios show that investment in infrastructure for PHL reduction contributes to lower food prices, higher food availability, and improved food security, and has positive economic rates of return. However, improvements in food security and marginal returns to investment in agricultural research are considerably higher for investment in agricultural research than for investment in PHL reduction. Reductions in PHL are not a low-cost alternative to productivity growth for achieving food security. Rather, reduction in PHL through improved infrastructure requires large public investments and is complementary to investments in long-term productivity growth to achieve food security.

The 2008-2011 food price spikes brought the issue of postharvest losses (PHL) back to the forefront of policy debate, and observers are again calling for a reduction in PHL as a tool to feed the expanding global population. Food losses due to improper postharvest handling, lack of appropriate infrastructure, and poor management techniques, have once again become a matter of serious concern. Food losses, defined as "any decrease in food mass throughout the edible food supply chain," can occur in any point of the marketing stages–from production (e.g., crop damage, spillage), postharvest and processing stages (e.g., attacks from insect or microorganisms during storage), distribution, and retail sale until home consumption (e.g., spoilage, table waste) (Rosegrant et al. 2013). Kummu et al. (2012) suggest an additional 1 billion people could be fed if food crop losses were halved, which could potentially relieve some of the pressure on the significant increase in production that would be required. Achieving lower levels of food losses, however requires both investments in technologies that help prevent losses as well as in overall infrastructure. Understanding the magnitude of these investments and their impact is key to establish that a reduction in PHL has in fact an impact on food security.

In this article, we seek to better understand the levels of investment required to effectively reduce PHL.   Doing so requires a series of steps. First, it is necessary to understand how infrastructure impacts losses. This is done via econometric analysis (see subsequent section for details). The second step is to quantify the levels of investments required, which is done by combining marginal effect analysis (based on the econometric estimation) with data on unit costs for specific infrastructural variables. Third, a cost-benefit analysis of the required infrastructural investments is done to assess economic returns to PHL reduction. Results are subsequently compared to investments in agricultural research and development. This last step is done using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute.

This work begins by reviewing the evidence to date focusing not only on the magnitude of PHL but also on the suggested solutions to reduce it. The review presented in the two subsequent sections paves the way to the analytical work that follows. In particular, the review provides the rationale for analyzing the role of infrastructural variables on PHL after considering the issues that surround PHL and the technologies available to address these issues. The remainder of this paper is organized as follows. The next section describes the landscape of the research done on PHL and the diverging magnitudes of losses. It also provides a brief review of the impact of PHL-related technologies as well as the importance of infrastructure in addressing PHL and ensuring that technologies are adopted. The third section presents the methodological approach used in the econometric analysis as well as for the IMPACT model. The fourth section discusses the data and results. The paper ends with a brief conclusion and recommendations.

Overview of the Postharvest Loss Debate

A large number of papers have been published focusing on four aspects of PHL: 1) estimates of the magnitudes of losses; 2) the economic impacts of losses in general but also on the poor and the hungry in particular (Gómez et al. 2011); 3) alternatives to decrease losses through the use of both new and traditional technologies; and 4) the economic costs of losses as well as their remedies.

The various papers published on PHL show widely varying estimates. For instance, estimates of rice losses in Southeast Asia in one publication range from 37-60 percent, while extreme cases in Vietnam are estimated to result in 80 percent of production being lost (Institution of Mechanical Engineers 2013). But a more comprehensive estimate for rice losses in Asia are at 13-15 percent, based on several studies reported in Parfitt, Barthel and Macnaughton (2010). Using self-reported measures from household surveys, Kaminski and Christiaensen (2014) estimated that on average between 1.4, 2.9-4.4, and 5.9 percent of the national maize harvest is lost in Malawi, Tanzania and Uganda respectively. These estimates are lower than the Food and Agriculture Organization (FAO's) estimate of 8 percent PHL in cereals in Sub-Saharan Africa (FAO 2011). In the section below we present a summary of PHL from a literature review.

Estimates of economic losses caused by PHL vary dramatically in both developing and developed world. For instance, in the United States (US), Buzby and Hyman (2012) estimate the economic value of food loss at the retail and consumer levels to be at US$ 165.5 billion in 2008 and point out that achieving a 1 percent reduction in food loss in the US would save US$ 1.66 billion. Hodges, Buzby and Bennett (2011) estimate annual weight losses in Sub-Saharan Africa to be valued at around US$ 4 billion a year out of an estimated cereal production value of US$ 27 billion. They do, however, acknowledge that most PHL estimates in developing countries are based on questionnaires rather than actual measurements and explain that these estimates are calculated based on data from

16 countries in East and South Africa assuming rates would be similar in the rest of Sub-Saharan Africa. The African Postharvest Losses Information System (APHLIS) estimates the value of PHL to be US$ 1.6 billion/year in eastern and southern Africa alone. This large variation is in part caused by multiple stages from farm to retail in which PHL can occur and the nature of the loss, whether avoidable or not.

One important factor to take into consideration in PHL discussion is how much of a reduction is actually feasible or realistic and at what cost these goals can be achieved. As part of the UN "Zero Hunger Challenge" announced in 2012, one of the five pillars to achieving this goal was to attain zero food waste. De Gorter (2014) points out that not only is this target unrealistic and impossible to achieve in practice, but in terms of economic efficiency, the resources used to reach this level of PHL might better be used to eradicate hunger in other ways. Kader (2005) argues that a cost-benefit analysis is needed to evaluate the return to investment to find an acceptable level of loss for different commodities and environments rather than assuming that everyone should aim for 0 percent loss.

Technology and infrastructure

Reduction in PHL is inherently linked to availability and profitability of technologies that can eliminate or reduce losses. Various technologies exist to help abate losses in the various stages of postharvest. The potential gains from adopting technologies need to be measured against the costs in adopting these technologies. Studies that look at the cost effectiveness of specific technologies to reduce PHL are not abundant, but provide insights into the questions that surround technology adoption.

For example, Kitinoja (2010) find that on-farm technologies, adopting curing on roots, tubers and bulbs lead to a return to a profit that is 2.5 times larger than the returns on non-adoption. Cooling practices used for vegetables can provide gains up to 7.5 higher than the initial costs. Other technologies such as shading have more limited gains, even though the adopter recoups the investment quickly. Gains for technologies at the value chain stage also vary in magnitude and in the time-span to recoup the investment. Two important factors have to be considered, however, in analyzing these gains. First, some of the technologies do require a substantial amount of production (as well as increases in related inputs, such as labor) in order to be applied, thus limiting the availability to small farmers. Technologies like metal silos may not require additional labor but are expensive to adopt, though the returns are high (Gitonga et al. 2013). Second, technologies such as improved packaging require additional costs in labor and in capacity building, which may reduce the overall profitability.

Perhaps though the most telling reason for slow adoption or scaling up of potential PHL is found in Minten et al. (2014) and echoed in a number of other papers (Swaminathan 2006 as cited in Lundqvist, de Fraiture and Molden 2008; Kaminski and Christiaensen 2014). Minten et al. (2014) looks at cold storage practices in Bihar, India. They find that over recent years, the adoption of storage practices has increased significantly. Increases totaled 64 percent between 2000 and 2009, or 5.7 percent per year. The reasons for increased adoption, however, are the improvement of the physical and social infrastructure, which paves the way for producers to have access to profitable technologies. Not only have recent governments in the region put in place better public provision services and policy reforms, they have also invested in roads and infrastructure, thereby increasing the ability of farmers in remote areas to have access to markets. At the same time, the rule of law has improved in recent years, as have general governance practices. Kaminski and Christiaensen (2014) also point to the importance of education in reducing PHL. They argue that education combined with economic incentives such as easier access to markets via better infrastructure can significantly reduce losses. One study about the use of metal silos in Kenya points to significant improvements in the adoption of silos with improved infrastructure (Tefera et al. 2011).

Methods

This section presents the econometric analysis implemented as well the application of the IMPACT model to generate long-term projections of food supply, demand, trade and prices that influences global food security between 2010 and 2050.

Grouped logistic regression

The relationship between PHL and infrastructural variables can be modeled using an Ordinary Least Squares (OLS) approach as issues of endogeneity are not present in a country level. The absence of endogeneity arises because the data on losses are collected or estimated at the producer level. For small farmers, particularly in developing countries, the infrastructure that surrounds the farm is therefore taken as a given and thus can be seen as exogenous. Even at the value chain level, firms in a given country also have to tap from the infrastructure that is provided.

The problem that arises from a standard OLS approach is the fact that the dependent variable is expressed as a rate (a percentage). This means that the variable is bounded between 0 and 1. As a result, fitted values obtained from the regression need to fall within this range, but the OLS provides no assurances that this will happen. Following an approach based on Wooldridge and Papke (1996), we have applied a weighted grouped logistic approach in which the logit transformation is applied to the dependent variable, as defined in equation (1).

$$\log\left(\frac{y_i}{1-y_i}\right) = \beta_0 + \beta_1 x_i + \varepsilon_i \qquad (1)$$

Where y corresponds to the percentage of loss of in country i, β_0 is a constant, β_1 is a vector of coefficients for infrastructural, geographical, type of loss and crop variables in x in country i and ε is an error term. The transformation applied to the dependent variable ensures that fitted values fall between the specified 0 and 1. As specified the model becomes a logistic one, hence implying that the coefficients on the right-hand side are to be interpreted as odds ratios. The model is estimated using weighted least squares.

A subsequent step after the estimation of equation 1 is to obtain the marginal effects of the significant variables in order to compute the required levels of investments needed for a reduction in PHL. Predicted marginal effects were estimated by treating sequential points along the distribution of each of the significant variables as fixed while keeping all other variables at their means. This provided a number of points which could be mapped to show the relationship between losses and increases in selected infrastructural activities. By combining these results with unit cost data for each of the relevant infrastructures, we derived the required levels of investments needed to reduce losses by 5, 10 and 25 percentage points.

The IMPACT Model

The International Model for Policy Analysis of Agricultural Commodity and Trade (IMPACT) is a partial equilibrium, multi–commodity, multi-country model which covers 56 crops and livestock commodities. The model generates long-term projections of food supply, demand, trade, and prices that enable us to estimate the trends in global food security between 2010 and 2050. It also provides measures to important indicators such as the number of malnourished children under the age of five and the number of people at risk of hunger (Rosegrant and the IMPACT team 2012; Hoddinott, Rosegrant, and Torero 2013; Robinson et al. 2015).

The food security and economic impacts of investments to reduce PHL—and increased investments in agricultural research—are modeled here in IMPACT Version 3, updated in 2014 (Robinson et al. 2015). PHL reductions are represented in the model by equivalent increases in commodity yields. Four PHL scenarios were run to simulate the effects of potential improvements in harvest technologies, and transportation infrastructure that would allow for a larger percentage of what it planned actually reaching the markets. The results for these PHL scenarios were compared to the impact of increased agricultural research investments. All scenarios were run using the Intergovernmental Panel on Climate Change (IPCC) medium projection on socioeconomics (SSP2), and assuming a constant 2005 climate. Table 1 summarizes the assumptions on socioeconomics for SSP2.

The following scenarios (table 2) were then implemented to test the effects of potential decreases in PHL. Scenarios 1-2 follow the same specifications as the Baseline, except where described below. Note that a 10 percent reduction in PHL is defined as a reduction by 10 percentage points, for example from 20 percent PHL to 10 percent PHL. Additionally, a scenario with an increase of agricultural research and development (R&D) investment from US$ 5 billion/year to US$ 13 billion/year was included to allow for comparability of the benefits of investments decreasing PHL to the benefits of increasing agricultural R&D. For this 3rd scenario, we follow the assumptions made by Hoddinott, Rosegrant, and Torero (2013), where the effects of agricultural R&D would increase the yield growth for crops by 0.4 percent/year and livestock by 0.2 percent/year. Three scenarios are presented in table 2 namely, scenarios PL1, PL2 and AR1. These first two scenarios provide insights about the impact of a reduction in PHL on a global scale and in the developing world. AR1 offers the alternative investment option, i.e. to invest in agricultural research instead of PHL reduction.

Data and results

Data on PHL and infrastructural variables used in the econometric analysis are summarize here, followed by the results from the econometric analysis and IMPACT model projections are presented below.

Losses

Data on PHL were drawn for a wide range of sources including APHLIS and a variety of published work on the subject (appendix table 1). In total, data for 40 countries and four aggregates were compiled. The data were collected for four types of losses: on-farm, value chain, consumption, and total losses. Losses were also further classified by region and by type of crop. In particular, the data contain information for the following regions:

Developed countries, Africa, Middle East and North Africa (MENA), Latin America and the Caribbean (LAC), and Asia. Six commodity groups were identified: cereals, roots, oilseeds, fruits and vegetables, meat and dairy (henceforth referred as animal), and others. The dataset contains 253 observations.

Figure 1 illustrates the mean losses by type and by region. Mean losses vary by region depending on the type of loss. For instance, while consumption and on-farm losses are higher in developed countries, value chain losses are higher in developing countries. Africa displays the highest average losses for value chain and the lowest for consumption, which is expected given the continent’s lower incomes. For consumption and value chain PHL, Asia, LAC and MENA show fairly similar averages. MENA’s on-farm losses are considerably lower than the other developing regions, all of which observe average losses of around 10 percent. Total losses presented in the figure were obtained directly from sources and are not a result of our calculations (the same applies to the developed country averages). The developed world displays a lower overall loss average compared to developing regions, but the differences across regions are surprisingly small. The data show also that the various estimates for different parts of the food chain are not consistent with the estimates for total PHL. In each case estimated total losses are lower than would be expected from the individual component losses. None of the studies reviewed did an integrated estimate of food losses at each part of the value chain to derive a consistent total loss figure.

The mean values are illustrative but mask considerable variation in the distribution of losses across regions. Figure 2 shows box plots with bars that represent different moments in the distribution. The box in the middle is bounded by the 25th and 75th percentile and has the median displayed as a horizontal line inside of it. The whiskers show the end points of the distribution. The range of estimated consumption losses in the developed countries is considerably higher than in developing regions, as would be expected. A large range is also observed for on-farm losses in the developed world. However, regions like Africa, Asia and LAC are not too distant from the median loss in the rich world. This scenario of higher losses in the developed world is reversed when value chain losses are considered.

Figure 3 shows mean PHL by the type of crop. Fruits and vegetables have the highest on-farm losses. Cereals, roots and oils seeds observed similar percentages. Losses are also large on value chain for fruits and for roots and tubers. On-farm losses do not show much variation across commodity groups with the exception of losses originated from animal products, which have significantly lower averages (figure 3). Estimated total losses are lower for cereals than for other commodities.

Infrastructural variables

The main principle guiding the selection of choice variables was the importance these variables play in explaining not only PHL but also economic development in a broader sense as discussed in previous sections.

Below we outline the infrastructure and governance variables selected, the reason for selecting them, and the expected direction of the coefficients in the regression analysis.

All variables were obtained from the World Bank, via its World Development Indicators (WDI) interface. Table 3 presents the selected variables.

Unit cost data to estimate required levels of investments were drawn from a variety of sources. For road infrastructure (both development and maintenance), information was taken from the World Bank's Road Cost Knowledge System. Costs for electricity were obtained from US Energy Information Administration (http://www.eia.gov/). We also obtained costs of tons per kilometer of rail transportation. This information came from a technical report about the costing of railroads in Canada (DAMF et al. 2007).

Econometric specification and results

Two specifications are presented in table 4 below. Specification number 1 regresses the transformed rate of PHL losses against infrastructural variables and the appropriate dummies. Number 2 adds a governance variable which accounts for the stability of government, a key indicator of governance.

Right-hand side variables were regressed in their natural log form when appropriate. This was done to reduce issues of non-linearity, heteroskedasticity and other minor deviations from normality. Since the natural log is a monotonic transformation, the scaling in the data has been preserved.

The coefficients of the results presented in table 4 are expressed in odds ratios, meaning that coefficients measure the impact of changes in the right hand-side variables on the ratio of PHL over the rate of no PHL (see method section). Thus, coefficients greater than one increase the odds of PHL, while coefficients less than one decrease it.

The results provide support to the importance of roads, particularly paved roads, which reduce the odds of PHL by half. Higher usage of railroads expressed by the amount of goods transported, which also measures to some degree the intensity of market transactions, also helps decrease PHL. Higher consumption of electricity also helps decrease the odds of PHL, perhaps signaling that more consumption leads to increased use of technologies that require power. Not all infrastructural coefficients showed the expected signs. Higher capacity of ports seems to increase the odds of PHL, perhaps reflecting significant issues related to the transportation of good to ports, particularly in developing countries. Similarly, increased numbers of landlines per 100 people also seem to increase PHL. We would have expected availability of cell phones to be an important factor in decreasing PHL, as it has been shown to play an important role in speeding up development in general (Aker and Mbiti 2010).

No significant effects were found for the governance variable.

Dummy variables indicating the region, crop and type of loss all report results that are in line with the descriptive section. For instance, roots and oilseeds increase the odds of PHL relative to cereals. At the same time, regional dummies for developed countries and MENA show that these regions are less likely than Africa to incur in PHL.

Based on these estimated coefficients and the unit costs we estimated the infrastructure investments costs for achieving PHL reductions. The results include simulations for various levels of decreases in PHL. Table 5 illustrates the required investments in four types of infrastructure for a 5 percent decrease in PHL.

Estimates derived from global regression. Estimates for MENA not available due to lack of enough observations to calculate marginal effects.

We don't have a unit cost for millions of tons per km as we do for rail. Cost for road maintenance was used instead.

The estimation of the investments costs for PHL scenarios described in table 2 are based on the results shown in table 5. For Scenario 1, we assumed that the 10 percent decrease in PHL would be generated with 2.5 percent in PHL reduction from each of the investment categories presented in table 5, resulting in a total investment of US$ 415 billion. The estimated regression coefficients for the investment impacts are conditioned on the underlying values of all of the investments in the data set, so a balanced increase in infrastructure is the most plausible approach. For Scenario 2, we assumed that reducing PHL in developed countries would be less expensive in terms of infrastructure investment given that the physical infrastructure is already in place and therefore most of the effort in the developed countries has to focus on behavioral changes. The recognition of the challenges behind changing behavior has led us to add 25 percent of the developing country investments to achieve the same percentage reductions in developed countries. This results in a global total of US$ 515 billion in investments under Scenario 2.

IFPRI IMPACT Model Results

The decrease in PHL, represented in IMPACT as the equivalent increase in effective crop and animal yields, leads in almost all cases to lower commodity prices by 2050. The price decreases are in the 10-20 percent range with only a few exceptions. World prices decrease more in the scenarios where the PHL assumptions were applied globally (e.g.

PL2). The effects of expanding PHL reduction to developed countries contributes an additional 4-5 percentage points to the projected price declines observed under PL1.

Under the scenario of increased investment in agricultural research, price reductions for crops are larger than for PHL reduction scenarios, with prices for most crops declining by more than 20 percent in 2050 relative to the baseline. The livestock price effects are not as great as for crops, because of the lower projected yield enhancements for livestock compared to crops (see table 2), but are nevertheless comparable to the first PHL scenario (PL1).

As already mentioned above the changes in prices can have profound effects on both consumer and producer behavior. The decreases in agricultural commodity prices seen in table 6 are significant in leading to the increased availability of affordable food globally. Tables 7 and 8 summarize the projected effects that these lower prices would have on food security regionally and globally by 2050.

Increased food availability due to these scenarios are projected to significantly improve food security, as shown in the tables. For developing countries as a group, the population at risk of hunger is projected to decline by 11-15 percent relative to the baseline in 2050. Malnourished children decline by 3.7-5.5 percent. Under both of these metrics AR1 followed by the PL2 scenarios show the largest declines in food insecurity with a decline of over 70 million at risk of hunger (table 7), and around 5 million children (table 8). Both of these metrics are closely tied to changes in per capita calorie consumption, which explains why PL2 shows the largest effects among the PHL scenarios, as this scenario has the largest reduction in losses of high calorie grains like rice and wheat. The regions where most of the biggest improvements in food security are observed are South Asia and Sub-Saharan Africa.

Reductions in commodity prices under these scenarios have a straightforward effect on consumers, where this serves as a relative increase in income, as they are able to purchase more food with the same resources. Most farmers globally are net consumers of food and would benefit from lower prices. Nevertheless, prices decline can have a negative effect for producers if they are not compensated by increased productivity. To determine if the price declines are beneficial to society as a whole, we do a welfare analysis and quantify the benefits and losses accrued by different segments of society. This is done by estimating the producer and consumer surplus and net welfare changes induced by each scenario compared to the baseline. The following tables will highlight the results of this welfare analysis under a 5 percent discount rate. We have also ran the analysis using 3 and 10 percent but the results were similar in magnitude. These results are not reported.

The global results of the welfare analysis can be seen in table 9, which shows the percentage changes and economic returns relative to the baseline. The economic value of the percentage changes in consumer surpluses are estimated with respect to projected total world agriculture gross production value through 2050, starting from the 2010 value of US$ 2.3 trillion (FAOSTAT database, accessed on December 18, 2014). The projected lower food prices have a negative effect on producers in all three scenarios because lower prices are only partially offset due to increased productivity. The losses for all scenarios are in the range of US$ 2,097-2,867 billion, extending between 3.7-4.7

percent declines in producer surpluses, with the largest declines occurring in the global scenarios (PL2) where we see the largest price decreases among PHL scenarios. Although producers are losing, consumers are benefitting, and the benefits accruing to consumers is larger than the losses observed for producers. This difference is both true in terms of magnitude (gains are US$ 4,140-5,796 billion), and in terms of percentage gains. Subsequently, society as a whole benefits, as the benefits received by consumers can compensate for the losses observed by producers. Total welfare is projected to increase by 2.8 percent to over 3.9 percent compared to the baseline. As was observed for price effects, the additional gains from expanding the PHL investments to developed countries has a smaller relative effect (0.8 for PL2) on welfare change than the effects on welfare from improvements in just the developing world (3.1 for PL1). One potentially counterintuitive result is that the agricultural research scenario shows the smallest change despite having the largest price changes by 2050. This result is due to the larger upfront gains in the PL1-PL2 scenarios, compared to the smaller but growing benefits through 2050 in AR1 (table 9).

Benefit-Cost Analysis

Each of the scenarios is driven by increased investment, with total infrastructure and research investment costs summarized above. In addition to assessing the economic rates of return to PHL reductions under the full investment costs, the rates of return are examined at lower cost allocations.   The rates of return to investment for infrastructure and technologies that would lead to PHL reductions would likely have large benefits in other sectors of the economy, as expansion of roads, electricity, and railways benefit the economy more broadly beyond the agricultural sector, whereas the scenario focusing on agricultural research investments targets primarily this sector, and would have relatively small spill-over effects on other sectors of the economy. Therefore infrastructure investment cost allocations to PHL reduction of 50 percent and 25 percent are also assessed for the PHL scenarios. Table 10 summarizes the distribution of incremental investment costs over time and the cost for each of the scenarios as the increased investments are phased in.

Table 11 summarizes the benefit-cost analysis for three scenarios with 100 percent attribution of the PHL investment costs to PHL reduction. All of the scenarios generate benefits that are substantially higher than investment costs. The PHL scenarios have benefit-cost ratios (BCR) of 11 to 12 percent. The importance of the growing benefit streams generated by productivity growth and lower costs of investment under the AR1 scenario are clear. The BCR for the AR1 scenario is more than twice to more than three times higher than for the PHL scenarios, depending on the discount rate.

Even when the BCR for the PHL scenarios doubles when only 50 percent of the costs of infrastructure development are allocated to PHL reduction, the BCR for AR1 remains substantially higher than the BCR for the PHL scenarios. The BCR for the PHL scenarios become greater than the AR1 only under the 25 percent cost allocation for PHL.

Conclusions

In this paper we provided a comprehensive review of the state of PHL in various regions of the world as well as across types of losses and commodities. Moreover, we have conducted econometric work to link losses with infrastructural and governance variables. The premise of our work is that infrastructure is of primary importance to explaining PHL as well as to providing the enabling conditions for adoption of PHL-reducing technologies.

Our literature review discussed a number of issues pertaining to PHL. First, it highlighted the reasons for the renewed interest in reduction in PHL as a contributor to improved food security, particularly after the 2008-2011 hikes in food prices. Second, it showed that estimates of losses vary dramatically across studies and types of losses. The measurement of losses is also found to be problematic by a number of papers. To derive better estimates of the potential benefits from the reduction of PHL, the conditions for improvement in PHL, and the appropriate policies and investments, it is critical to develop better measurements of loss along the value chain for key commodities. Third, the impact of PHL on food security has not been clearly established in the literature. While a number of studies point to the financial costs from PHL, the magnitude of the costs associated with remedying losses is also estimated to be high in many cases. Fourth, we have reviewed the existing literature that assesses the gains from adopting selected technologies and found that PHL technologies can lead to significant reduction in losses if properly applied, but may in some require a scale of production that excludes smallholders. Of critical importance, poor infrastructure is a barrier to PHL reduction, and adoption of PHL-reducing technologies is facilitated by the development of improved infrastructure.

Based on the findings of the review, we conducted empirical analysis to seek to explain levels and potential reductions in PHL due to infrastructural variables. To do so, we applied a weighted grouped logistic approach in order to ensure that fitted values of losses remain within the range of 0-1. Results show the important roles of electricity, roads, particularly paved roads, and railways in reducing PHL. Dummy variables also revealed significant differences across commodities and regions. For instance, roots and tubers, oilseeds and fruits all increase the probability of higher of PHL relative to cereals. At the same time, regional dummies indicate that relative to Africa the probability of PHL is lower for all other regions. Infrastructure development is an essential enabling condition for achieving lower PHL.

Next, we utilized the estimates of impact of infrastructure on PHL together with the unit costs of infrastructure development to estimate a number of scenarios for the investment costs required to reduce PHL. These investment scenarios were then implemented in the IMPACT global food supply and demand model to simulate the impacts of reductions in postharvest food losses on food prices, food security measures, producer and consumer surpluses, net welfare gains, and benefit cost rations to the investments. These scenarios show that investment in infrastructure for PHL reduction contributes to lower food prices, higher food availability, and improved food security, and has positive economic rates of return. However, comparison with a scenario of increased investments in agricultural research shows that improvements in food security and BCRs and marginal returns to investment in agricultural research are considerably higher for investment in agricultural research than for investment in PHL reduction.

Reductions in PHL are not a low-cost alternative to productivity growth for achieving food security. Rather, large-scale reduction in PHL requires large public investments and is complementary to investments in long-term productivity growth to achieve food security.

References

Aker, J.C. and I.M Mbiti. 2010. Mobile Phones and Economic Development in Africa. *Journal of Economic Perspectives* 24:207-232.

Buzby, J.C. and J. Hyman. 2012. Total and Per Capita Value of Food Loss in the United States. *Food Policy* 37: 561–570.

DAMF, Joseph Schulman Consulting and CANARAIL Consultants Inc. 2007. Estimation of Unit Costs of Rail Transportation in Canada. Final Report http://www.bv.transports.gouv.qc.ca/mono/0965332.pdf

de Gorter, H. 2014. Evaluating the Zero Loss or Waste of Food Challenge and its Practical Implications. Background draft paper prepared for the Food and Agriculture Organization of the United Nations.

FAO (Food and Agriculture Organization of the United Nations) 2011. *Global Food Losses and Food Waste: Extent, Causes, and Prevention*. Rome

FAOSTAT database, accessed on December 18, 2014

Gitonga, Z.M., H. De Groote, M. Kassie, and T. Tefera. 2013. Impact of Metal Silos on Households' Maize Storage, Storage Losses and Food Security: An Application of a Propensity Score Matching. *Food Policy* 43: 44–55.

Gómez, M.I., C.B. Barrett, L.E. Buck, H. De Groote, S. Ferris, H.O. Gao, E. McCullough, D.D. Miller, H. Outhred, A.N. Pell, T. Reardon, M. Retnanestri, R. Ruben, P. Struebi, J. Swinnen, M.A. Touesnard, K. Weinberger, J.D.H. Keatinge, M.B. Milstein, and R.Y. Yang. 2011. Research Principles for Developing Country Food Value Chains. *Science* 332: 1154-1155.

Hoddinott, J. F., M.W. Rosegrant, and M. Torero. 2013. Hunger and Malnutrition, Chapter 6. In *Global Problems, Smart Solutions: Costs and Benefits*, edited by B. Lomborg. New York, NY, USA: Cambridge University Press

Hodges, R.J., J.C. Buzby, and B. Bennett. 2011. Postharvest Losses and Waste in Developed and Less Developed Countries: Opportunities to Improve Resource Use. *Journal of Agricultural Science* 149: 37-45.

Institution of Mechanical Engineers. 2013. Global Food: Waste Not, Want Not. Retrieved from http://www.imeche.org/knowledge/themes/environment/global-food

Kader, A.A. 2005. Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce. *Proceedings of the 5th International Postharvest Symposium*, edited by F. Mencarelli and P. Tonutti. Leuven, Belgium.

Kaminski, J. and L. Christiaensen. 2014. *Post-Harvest Loss in Sub-Saharan Africa – What Do Farmers Say?* Policy Research Working Paper 6831. The World Bank http://elibrary.worldbank.org/doi/pdf/10.1596/1813-9450-6831

Kitinoja, L. 2010. *Identification of Appropriate Postharvest Technologies for Improving Market Access and Incomes for Small Horticultural Farmers in Sub-Saharan Africa and South Asia*. WFLO Grant Final Report to the Bill & Melinda Gates Foundation, March 2010. 318 pp.

Kummu, M., H. de Moel, M. Porkka, S. Siebert, O. Varis, and P.J. Ward. 2012. Lost Food, Wasted Resources: Global Food Supply Chain Losses and Their Impacts on Freshwater, Cropland, and Fertiliser Use. *Science of the Total Environment* 438: 477-489.

Lundqvist, J., C. de Fraiture and D. Molden. 2008. *Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain*. SIWI Policy Brief. SIWI.

Minten, B., T. Reardon, K.M. Singh, and R. Sutradhar. 2014. The New and Changing Roles of Cold Storages in the Potato Supply Chain in Bihar. *Economic and Political Weekly* 49 (52): 98-108

Parfitt, J., M. Barthel and S. Macnaughton. 2010. Food Waste within Food Supply Chains: Quantification and Potential for Change to 2050. *Philosophical Transactions of the Royal Society, Biological Sciences*, 365.

Robinson, S, D. Mason d'Croz, S. Islam, T. Sulser, R. Robertson, T. Zhu, A. Gueneau, G. Pitois, and M.W. Rosegrant. 2015. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description for version 3.* IFPRI Discussion Paper 1483. Washington, D.C.: International Food Policy Research Institute (IFPRI). http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825

Rosegrant, M.W., S. Tokgoz, P. Bhandary, and S. Msangi. 2013. Looking ahead: Scenarios for the future of food. In *2012 Global Food Policy Report* Chapter 8. Pp. 88-101. Washington, D.C.: International Food Policy Research Institute.

Rosegrant, M.W. and the IMPACT Development Team. 2012. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description*. International Food Policy Research Institute (IFPRI), Washington, D.C. http://www.ifpri.org/book-751/ourwork/program/impact-model

Swaminathan, M.S. 2006. 2006-07: Year of agricultural renewal. 93 Indian Science Congress in Hyderabad, Public Lecture, January 4.

Tefera, T., F. Kanampiu, H. De Groote, J. Hellin, S. Mugo, S. Kimenju, Y. Beyene, P.M. Boddupalli, B. Shiferaw, and M. Banziger. 2011. The Metal Silo: An Effective Grain Storage Technology for Reducing Post-Harvest Insect and Pathogen Losses in Maize while Improving Smallholder Farmers' Food Security in Developing Countries. *Crop Protection* 30: 240-245.

World Bank 2011. *Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa.* Report 60371-AFR, 2011 http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10_web.pdf

Table 1. Average annual growth rates (%) to 2050 for GDP, population, and per capita GDP by region under SSP2

Region	GDP[a]	Population[b]	Per capita GDP[c]
East Asia and Pacific	2.9	0.1	2.8
Europe and Central Asia	1.9	0.1	1.8
Latin America and Caribbean (LAC)	2.4	0.5	1.9
Middle East and North Africa (MENA)	3.6	1.1	2.4
North America	1.5	0.5	0.9
South Asia	4.1	0.7	3.3
Sub-Saharan Africa (SSA)	5.4	1.8	3.5
World	2.5	0.6	1.9

Source: SSP Database (https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about)

Notes: [a] OECD GDP projections; [b] IIASA Population projections; [c] Calculated in the IMPACT model

Table 2. Scenario summary

Scenario	Region	Postharvest Loss Assumptions
Baseline (BSL)	Global	Standard IMPACT 3 yield projections
Scenario1 (PL1)	Developing Countries[c]	By 2020: postharvest losses decline by 3% By 2025: postharvest losses decline by 6% By 2030: postharvest losses decline by 10%
Scenario2 (PL2)	Global	
		Yield Assumptions from Investments in Agricultural R&D
Scenario3 (AR1)	Global	Starting in 2015 All crops: exogenous yield growth increases by 0.4 percent per year All livestock products: exogenous yield growth increases by 0.2 percent per year

Source: Authors

Notes: [a]Cereals, Pulses, Roots and Tubers, Oilseeds, and Other Crops; [b]Fruits, Vegetables, and Livestock products; [c]Excludes High Income countries: Australia, Canada, EU27, Israel, Japan, New Zealand, South Korea, Singapore, Switzerland, USA, and High Income Persian Gulf States

Table 3. Selected infrastructural variables and rationale

Variable	Rationale	Expected direction
Electric power consumption (kWh per capita)	Access to technology	Reduce PHL directly
Port infrastructure	Access to markets by sea	Reduce PHL indirectly
Air transport, freight (million ton-km)	Access to markets by air	Reduce PHL indirectly
Road density (km of road per 100 sq. km of land area)	Ability to transport goods	Reduce PHL directly
Roads, goods transported (million ton-km)	Intensity of transport capability	Reduce PHL directly
Roads, paved (% of total roads)	Quality of transport capability	Reduce PHL directly
Railways, goods transported (million ton-km)	Access to markets by train	Reduce PHL indirectly
Mobile cellular subscriptions (per 100 people)	Modern access to information	Reduce PHL indirectly
Telephone lines (per 100 people)	Access to information	Ambiguous
Government stability	Provision of an enabling environment	Reduce PHL indirectly

Variable	Rationale	Expected direction
Rural population density	Rural markets	Reduce PHL indirectly

Source: WB WDI 2013

Table 4. Econometric results

Variables	**-1**	**-2**
Dependent variable: proportion of PHL (between 0 and 1)		
Dummy for port quality (1=high, 0=low)	1.481	1.25
	(0.447)	-0.403
Electric power consumption (kWh per capita)	0.672**	0.688**
	(0.106)	-0.11
Air transport, freight (million ton-km)	1.048	1.073
	(0.0413)	-0.0516
Road density (km of road per 100 sq. km of land area)	1.028	1.121
	(0.106)	-0.148
Roads, goods transported (million ton-km)	0.940	0.876**
	(0.0446)	-0.0485
Roads, paved (% of total roads)	0.648*	0.573**
	(0.153)	-0.145
Railways, goods transported (million ton-km)	0.936**	0.921***
	(0.0241)	-0.0262
Mobile cellular subscriptions (per 100 people)	0.959	0.941
	(0.0897)	-0.0914
Telephone lines (per 100 people)	2.270***	2.288***
	(0.457)	-0.512

Variables	-1	-2
Port capacity (Container port traffic; TEU: 20 foot equivalent units)	1.092	1.327**
	(0.0790)	-0.151
Government stability		1.377
		-0.41
Rural population density	1.222	1.384
	(0.354)	-0.418
Dummy for roots	1.568*	2.994***
	(0.403)	-0.869
Dummy for oilseeds	2.200**	2.549**
	(0.839)	-0.979
Dummy for fruits and vegetables	1.266	1.426
	(0.255)	-0.315
Dummy for animal	0.596	0.862
	(0.188)	-0.321
Dummy for other	1.707**	1.904**
	(0.409)	-0.48
Dummy for on-farm losses	1.204	1.125
	(0.312)	-0.359
Dummy for total losses	2.960***	2.088**
	(0.712)	-0.221

Variables	**-1**	**-2**
Dummy for value chain losses	0.895	0.546*
	(0.221)	-0.168
Dummy for Asia	0.485**	0.535
	(0.172)	-0.203
Dummy for LAC	0.576	0.935
	(0.250)	-0.511
Dummy for MENA	0.216***	0.292**
	(0.106)	-0.156
Dummy for developed countries	0.311**	0.142***
	(0.162)	-0.104
Constant	0.214	0.0216
	(0.456)	-0.0537
Observations	250	208
R-squared	0.383	0.452

Notes: Standard errors in parenthesis; *** p<0.01, ** p<0.05, * p<0.1

Table 5. Investment (US$) requirements in infrastructure to reduce PHL by 5 percentage points

Region	Electricity[a]	Paved Roads[b]	Rail Capacity[c]	Road Capacity[d]
Africa	10,493,751,296	7,027,633,152	57,907,712	6,256,584,192
Asia	80,715,096,064	209,079,418,880	35,974,656,000	403,101,483,008
LAC	32,002,551,808	14,760,436,736	3,956,525,824	22,900,320,256

Notes: [a] Investments for electricity are for a 69 percent increase in per capita consumption. An average of coal and natural gas source was used as basis. [b] Investments for paved roads are for a 45 percent increase in maintenance and construction (average costs of the two) of paved roads. [c] Rail capacity refers to investments required to increase the millions of tons per kilometer capacity of goods transported by rail by 98 percent. [d] Road capacity refers to investments required to increase the millions of tons per kilometer capacity of goods transported by road by 95 percent

Table 6. World prices in 2050 (% change from baseline)

Commodity	PL1	PL2	AR1
Beef	-11.5	-15.1	-11.0
Lamb	-13.9	-16.6	-11.3
Pork	-9.3	-14.9	-10.9
Poultry	-11.8	-17.0	-13.0
Dairy	-6.9	-9.8	-7.0
Eggs	-13.8	-17.2	-12.8
Rice	-19.8	-21.6	-26.3
Wheat	-12.5	-16.6	-20.4
Maize	-0.0	-2.7	-3.0
Groundnuts	-18.5	-21.0	-25.5
Rapeseed	-8.4	-15.4	-19.3
Soybeans	-11.4	-16.9	-21.0
Fruits and Vegetables	-14.0	-16.9	-20.7
Pulses	-14.5	-17.4	-21.5
Roots and Tubers	-14.3	-16.2	-20.1
Processed Oils	-3.4	-4.1	-4.7
Oil meals	0.1	1.7	0.4

Source: Author calculations from IFPRI IMPACT Model version 3 (2014)

Table 7. Population at risk of hunger in 2050

Region	million				% change from baseline		
	BSL	PL1	PL2	AR1	PL1	PL2	AR1
East Asia and Pacific	126	118	116	115	-6.3	-7.5	-8.6
Europe and Central Asia	38	37	37	37	-2.9	-3.7	-4.1
LAC	48	45	44	44	-6.0	-7.7	-8.6
MENA	38	37	36	36	-3.9	-4.9	-5.8
South Asia	162	138	134	131	-15.3	-17.6	-19.2
SS Africa	137	116	112	108	-15.8	-18.6	-21.2
Developing	509	452	442	434	-11.2	-13.1	-14.7
Developed	59	56	55	55	-4.7	-6.1	-6.9
World	568	508	497	489	-10.5	-12.4	-13.9

Source: Author calculations from IFPRI IMPACT Model version 3 (2014)

Table 8. Number of malnourished children in 2050

Region					% change from baseline		
	BSL	**PL1**	**PL2**	**AR1**	**PL1**	**PL2**	**AR1**
East Asia and Pacific	8.3	7.9	7.8	8	-4.1	-4.9	-6.0
Europe and Central Asia	1.6	1.5	1.5	1	-4.9	-6.6	-7.6
LAC	2.0	1.8	1.7	2	-10.1	-13.5	-14.8
MENA	2.0	1.8	1.7	2	-8.9	-11.6	-13.8
South Asia	52.6	51.3	50.9	51	-2.5	-3.2	-3.8
SS Africa	36.8	35.1	34.7	34	-4.7	-5.7	-6.9
Developing	103.0	99.2	98.3	97	-3.7	-4.6	-5.5
Developed	0.2	0.2	0.2	0	-2.2	-3.0	-3.4
World	103.2	99.4	98.5	98	-3.7	-4.6	-5.5

Source: Author calculations from IFPRI IMPACT Model version 3 (2014)

Table 9. Global change in producer surplus, consumer surplus and welfare by 2050 between baseline and investment scenarios, using a discount rate of 5 percent

				% change from baseline		
	PL1	**PL2**	**AR1**	**PL1**	**PL2**	**AR1**
Producer Surplus	-2,288	-2,867	-2,043	-3.7	-4.7	-3.3
Consumer Surplus	4,508	5,796	4,140	4.9	6.3	4.5
Welfare	2,220	2,929	2,097	3.1	3.9	2.8

Source: Author calculations from IFPRI IMPACT Model version 3 (2014)

Table 10. Investment scenarios

Scenario	Years	Annual Investment/Cost Allocation Scenarios (US$ billion per year)		
		100 percent	**50 percent**	**25 percent**
PL1	From 2014 to 2029	27.67	13.84	6.92
PL2	From 2014 to 2029	34.33	17.17	8.58
AR1	From 2014 to 2025	Starts at 0.67 growing to 8	NA	NA
	From 2026 to 2050	Held constant at 8		

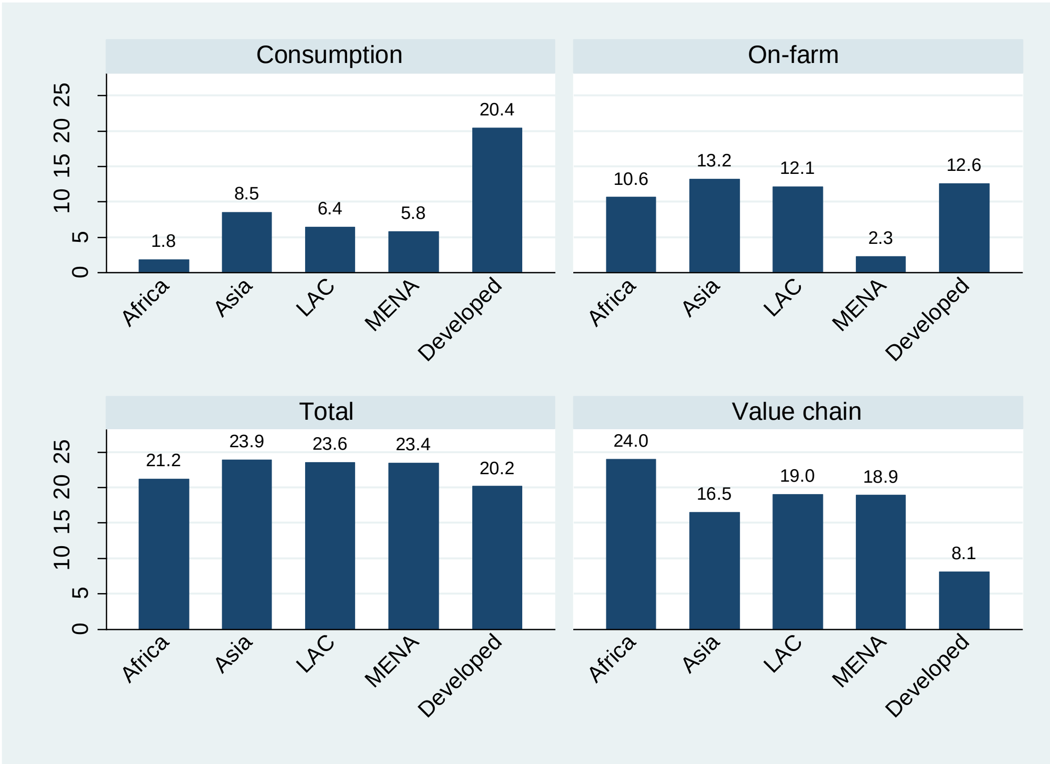
Source: Authors

Table 11. Benefit-cost analysis under 100 percent cost allocation and a five percent discount rate.

	PL1	PL2	AR1
Benefits derived from investments (US$ billion)	2,220	2,929	2,097
Costs (US$ billion)	203	254	66
BCR	11	12	32

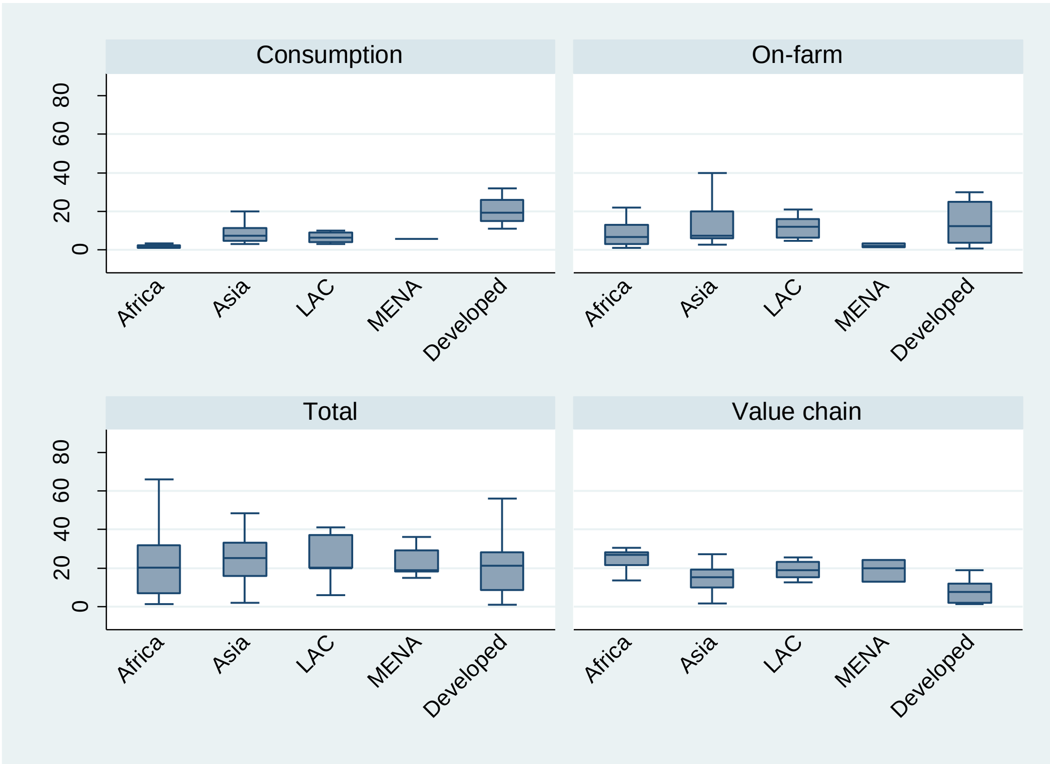
Source: Author calculations from IFPRI IMPACT Model version 3 (2014)

Figure 1. Mean losses by region and type of loss



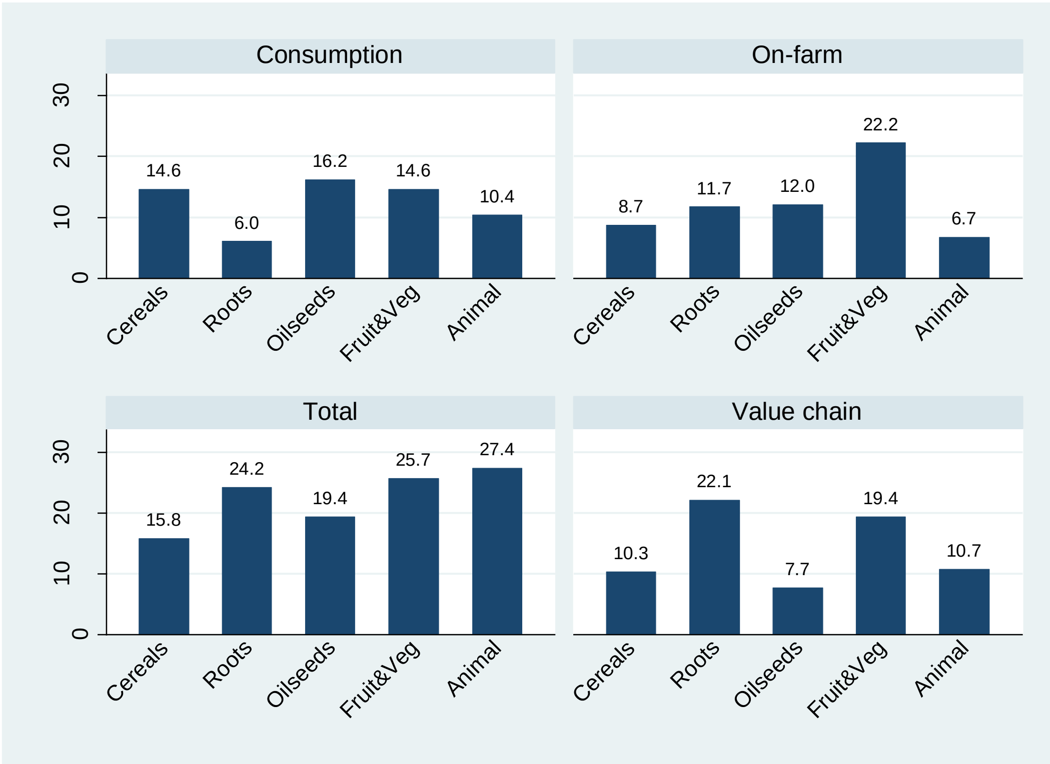
Source: Author's calculations using various sources

Figure 2. Box plots of postharvest losses by type of loss and region



Source: Author's calculations using various sources

Figure 2. Mean losses by type of loss and commodity



Source: Author's calculations using various sources

Appendix Table 1. Sources of postharvest data

Adhikari, S. 2006. Nepal (2), Part III. Country Papers. . In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 200-208. Asian Productivity Organization, Rome, Italy

Agravante et al. 1996 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Ahsan, H. 2006. India (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 131-142. Asian Productivity Organization, Rome, Italy

Akande, G. and Y. Diei-Ouadi. 2010. Post-harvest losses in small-scale fisheries: Case studies in five sub-Saharan African countries. FAO Fisheries and Aquaculture Technical Paper 550

Amuttiratana, D. and W. Passornsiri. 1992. In *Postharvest losses of vegetables* ed by M.H. Bhatti, Ch. Hafeez, A. Jaggar, Ch. M. Farooq.A report on workshop held on October 17-22, Pakistan Agricultural Research Council, Islamabad, Pakistan. FAO Regional Co-operation for vegetable research and development RAS/89/41.

Anjum, M.I. and I.A. Awan. 2006. Pakistan, Part III. Country Papers.,. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 209-215. Asian Productivity Organization, Rome, Italy

APHLIS (African Post Harvest Losses Information Systems) Database http://www.aphlis.net/

Asian Productivity Organization http://www.apo-tokyo.org/

Baghkhandan, M.S. 2006. Islamic Republic of Iran (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 169-174. Asian Productivity Organization, Rome, Italy

Bajracharya, A. 2000. An Overview of Post-harvest Handling Activities in MARD Project Areas cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 191-199 Asian Productivity Organization, Rome, Italy

Bantoc et al. 1983 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244 Asian Productivity Organization, Rome, Italy

Barile and Esguerra unpublished cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rapusas, pp 227-244. Asian Productivity Organization, Rome, Italy

Bautista et al. unpublished cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Beretta, C. A. Stoessel, U. Baier and S. Hellweg. 2013. Quantifying Food Losses and the Potential for Reduction in Switzerland. *Waste Management* 33: 764–773

Bhalla, S.K. 1982. Post-harvest Technology and Its Impact on the Rural Poor in Nepal. Rural Technology, Rural Institutions and the Rural Poorest: Proceedings of a

Workshop organised by the Center on Integrated Rural Development for Asia and the Pacific, February 2-5, 1981

Blond, R.D. (ed) 1984. The Accomplishments of a California-Egypt Research Collaboration: The Agricultural Development Systems-Egypt Project, 1979- 83, University of California Davis.

Bond, M., T. Meacham, R. Bhunnoo, and T.G. Benton. 2013. Food waste within global food systems. A Global Food Security report. http://www.foodsecurity.ac.uk

Boxall, R.A., M. Greeley, D.S. Tyagi, M. Lipton, and J. Neelakanta. 1978. The Prevention of Farm level Food Grain Losses in India: A Social Cost-Benefit Analysis. IDS Research Report, Institute of Development Studies, University of Sussex, Brighton, UK

Boxall, R.A. 2001. Post-harvest Losses to Insects—A World Overview. *International Deterioration and Biodegradation* 48: 137-152.

Brena 1985 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244,. Asian Productivity Organization, Rome, Italy

Buzby, J.C., and J. Hyman. 2012. Total and Per Capita Value of Food Loss in the United States. *Food Policy* 37: 561-570

Buzby, J.C., J. Hyman, H. Stewart, and H.F. Wells. 2011. The Value of Retail- and Consumer-Level Fruit and Vegetable Losses in the United States. *The Journal of Consumer Affairs* Fall: 492-515.

Chung, G.S. and M.H. Heu. 1980. Status of Japonica-indica Hybridization in Korea. Selected paper for the 1979 Innovative Approaches to Rice Breeding Conference organized by the International Rice Research Institute, pp. 135-152

Clarke, J. 1989. Drying Rate and Harvest Losses of Windrowed Versus Direct Combined Barley. *Canadian Journal of Plant Science* 69: 713-729.

Cyril, S.D.P. 2006. Sri Lanka (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 253-263. Asian Productivity Organization, Rome, Italy

de Gorter, H. 2014. Evaluating the Zero Loss or Waste of Food Challenge and its Practical Implications Background draft paper prepared for the Food and Agriculture Organization of the United Nations.

Esguerra et al. 2002 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers, In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244.. Asian Productivity Organization, Rome, Italy

Farm Income Diversification and Market Development Project 2003 cited in Rapusas R.S. 2006. Philippines (2), Part III. Country Papers, In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244.. Asian Productivity Organization, Rome, Italy

Fernando, M.D. 2006. Sri Lanka (2), Part III. Country Papers,. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 264-275. Asian Productivity Organization, Rome, Italy

FAO (Food and Agriculture Organization of the United Nations (Gustavsson, Jenny, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, and Alexandre Meybeck) 2011. Global Food Losses and Food Waste: Extent, Causes, and Prevention. Rome

FAO. 2007 Post-harvest loss compendium—database of information on PHL for different crop types.www.fao.org/inpho

Fuentes et al. nd cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers,. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Gaiser, D. 1981. A brief summary of paddy loss in Indonesian Rice Post-Harvest System. Proceedings of the 4th Annual Workshop on Grains Post-Harvest Technology. Laguna, Philippines: South-East Asian Co-operative Post-Harvest Research and Development Programme, pp. 133-138.

Garnett, T. 2006 Fruit and vegetables and UK greenhouse gas emissions: exploring the relationship. UK: Food and Climate Research Network, University of Surrey.

Ghana Business News. 2003. Bolton firm's system will boost economy of Ghana. http://www.ghanaweb.com/GhanaHomePage/economy/artikel.php?ID=45751

Greeley, M. 1982. *Farm-level Post-harvest Food Losses: the Myth of the Soft Third Option*. IDS Bulletin 13: 51-60

Greeley M. 1987. *Postharvest losses, technology, and employment: the case of rice in Bangladesh.* Westview Press

Grolleaud, M. 2002. Post-Harvest Losses: Discovering the Full Story. Overview of the Phenomenon of Losses during the Post-harvest System. Agricultural Support Systems Division, Food and Agriculture Organisation, Rome

Hanley, M. L. 1991. After the Harvest. *World Development* 4 (1): 25-27.

Haryanto, B., S. Rayaningsih and H. Henanto. 2006. Indonesia (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 152-157. Asian Productivity Organization, Rome, Italy

Hazarika, C. 2006. Post-harvest Loss and Food Security — A Study on Fruits and Vegetables in Assam. *Indian Journal of Agricultural Economics* 61(3): 418-419

Hill Agriculture Research Project (HARP) 2002 In Adhikari, S. 2006. Nepal (2), Part III. Country Papers.,. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 200-208. Asian Productivity Organization, Rome, Italy

Hodges, R.J., J.C. Buzby and B. Bennett. 2011. Postharvest Losses and Waste in Developed and Less Developed Countries: Opportunities to Improve Resource Use. *Journal of Agricultural Science* 149: 37-45

Hossain, M.A. and M.A.M. Miah, 2009. *Post-Harvest Losses and Technical Efficiency of Potato Storage Systems in Bangladesh*. National Food Policy Capacity Strengthening Programme. Final Report CF # 2/08

International Development Research Centre (IDRC). 1992. *Post-harvest Technology for Bananas*. Project Report

Institution of Mechanical Engineers. 2013. Global Food: Waste Not, Want Not. Retrieved from http://www.imeche.org/knowledge/themes/environment/global-food

Ilag and Borromeo 1983 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Kader, A.A. 2005. Increasing Food Availability by Reducing Postharvest Losses of Fresh Produce. *Acta Horticulturae* 682: 2169-2176.

Kaini, B.R. 2002. Country Paper on Post-harvest Techniques for Horticultural Crops in Nepal. In Report of the Asia Productivity Organization Seminar on Appropriate Technologies for Horticultural Crops, Bangkok, Thailand, July 5-9, 1999, cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 191-199. Asian Productivity Organization, Rome, Italy

Kaminski, J. and L. Christiaensen. 2014. *Post-Harvest Loss in Sub-Saharan Africa – What Do Farmers Say?* Policy Research Working Paper 6831. The World Bank http://elibrary.worldbank.org/doi/pdf/10.1596/1813-9450-6831

Kantor, L.S., K. Lipton, A. Manchester, and V. Oliveira. 1997. *Estimating and Addressing America's Food Losses*. Food Review, Economic Research Service, U.S. Dept. of Agriculture.

Kumar, V. 2006. Fiji, Part III. Country Papers. In. *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 123-130. Asian Productivity Organization, Rome, Italy

Labios 1984 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers.. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Lantican et al. 1983 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Lian Gracia, G.S. 2006. Singapore, Part III. Country Papers. *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region*, ed by R.S. Rolle, pp 245-252. Asian Productivity Organization, Rome, Italy

Liang, L. et. al. 1993. China's Post-harvest Grain Losses and the Means of Their Production and Elimination. *Economic Geography* 1: 92-96.

Lipinski, B., C. Hanson, J. Lomaw, L. Kitinoja, R. Waite, and T. Searchinger. 2013. *Reducing Food Loss and Waste*. Working Paper, Installment 2 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute

Liu, G. 2013. *Food Losses and Waste in China: A First Estimate*. Retrieved from 4th OECD Food Chain Analysis Network Meeting: http://www.oecd.org/site/agrfcn/4thmeeting20-21june2013.htm

Liu, M.S. and P.C. Ma. 1984. *Postharvest Problems of Vegetables and Fruit in the Tropics and Subtropics*. Workshop on Postharvest Technology of Food Industry Research and Development Institute Agricultural Produce Taipei, Taiwan, pp. 26–35

Mangaoang, C.C. 1982. Losses of selected fruits and vegetables. Report: Research Division, Technical Research and Extension Directorate, National Food Authority, Quezon City, Philippines, cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Manto, J.M. 1980. Product Loss in Marketing Selected Green Vegetables, Benguet to Metro Manila. Special Studies Division, Planning Service, Ministry of Agriculture, Diliman, Quezon City, Philippines cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Manto and Darrah 1979 cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Marketing Development Division 1999/2000. Marketing System including Packaging of Apple from Jumla, Marketing Development Division, Haribar Bhawan, Lalitpur cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 191-199. Asian Productivity Organization, Rome, Italy

Marketing Development Division. 2000. Study of High Value Commodities (selected vegetables and fruits) Marketing in Indian Market Centers, Marketing Development Division, Haribar Bhawan, Lalitpur cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers In *Postharvest Management of Fruit and Vegetables in the Asia-*

Pacific Region ed by R.S. Rolle, pp. 191-199. Asian Productivity Organization, Rome, Italy

McKinsey & Co & Confederation of Indian Industry cited in Ahsan, H. 2006. India (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 131-142. Asian Productivity Organization, Rome, Italy

Moghaddasi, R., M. Elaheh and S. Shariati. 2006. Islamic Republic of Iran (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rosse, pp. 164-168. Asian Productivity Organization, Rome, Italy

Murthy, D.S., T.M. Gajanana, M. Sudha and V. Dakshinamoorthy. 2009. Marketing and Post-Harvest Losses in Fruits: its Implications on Availability and Economy. *Indian Journal of Agricultural Economics* 64 (2): 259-275

Navarro, S. and R. Noyes. 2001. The Mechanics and Physics of Modern Grain Aeration Management. CRC Press, Boca Raton, FL. USA.

National Academy of Sciences (NAS). 1978. Post-harvest Food Losses in Developing Countries. Washington, DC: National Academy of Sciences.

Pantastico, 1979. Postharvest losses of fruits and vegetables in developing countries—An Action Program. SEARCA Professional Chair Lecture, PHTRC, Los Banos, Philippines.

Parfitt, J.P., M. Barthel, and S. Macnaughton. 2010. “Food Waste within Food Supply Chains: Quantification and Potential for Change to 2050.” *Philosophical Transactions of the Royal Society Biological Sciences* 365: 3065-3081.

Paudel, K.B. and J.N. Chaudahray. 2004. Study on Low Temperature Inducing Chilling Injury on Mandarin Orange. Paper presented during the Fourth National Conference on Science and Technology, Kathmandu, Nepal, March 23-26, 2004. In Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 191-199. Asian Productivity Organization, Rome, Italy

Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 191-199. Asian Productivity Organization, Rome, Italy Paull, R.E., W. Nishijima, M. Reye and C. Cavaletto. 1997. Postharvest handling and losses during marketing of papaya (Carica papaya L.). *Postharvest Biology and Technology* 11: 165-179

Phan, H. H. and L.H. Nguyen. 1995. Drying research and application in the Mekong Delta of Vietnam. In Proc. Of the 17th ASEAN Technical Seminar on Grain Postharvest Technology, July 1995. Lumut, Malaysia

Postharvest Loss Reduction Division, Department of Agriculture, Ministry of Agriculture and Cooperatives. 2001/2002. Progress Report. In Paudel, K.B. 2006. Nepal (1), Part III. Country Papers, pp 191-199. In Rolle, R.S. (ed) 2006. Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization, Rome, Italy

Prakash, V., J. Ambuko, W. Belik, J. Huang and T. Timmermans. 2013. Food Losses and Waste in the Context of Sustainable Food Systems. Project Report submitted to High Level Panel of Experts on Food Security and Nutrition (HLPE)

Quintana and Esguerra unpublished In Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers, pp 227-244. In Rolle, R.S. (ed) 2006. Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization, Rome, Italy

Ramos, M.E.V., H.G. Malanon, C.L. Maranan and F.B. Lanuza. 2003. Socioeconomic assessment and technical feasibility of a cold chain system for vegetables in the Cordillera. A Preliminary Report, Bureau of Post-harvest Research and Extension, Munoz, Nueva Ecija. In Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers, pp 227-244. In Rolle, R.S. (ed) 2006. Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization, Rome, Italy

Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. ,. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 227-244. Asian Productivity Organization, Rome, Italy

Rolle, R.S. (ed) 2006. Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization, Rome, Italy

Ruiz, L.F. and C. Ringler. Undated. Crop Post Harvest Losses: Myth or Reality. Unpublished paper

Salda, V.B., S. Santiago, H. Caoili, N. Bantog, B. Ladilad and L.T. Tandang. 2004. Actual post-harvest loss assessment of selected vegetables at various handling points.

Horticulture Institute, Benguet State University, La Trinidad, Benguet cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 227-244. Asian Productivity Organization, Rome, Italy

Serrano, E.P. 2006. Philippines (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 216-225. Asian Productivity Organization, Rome, Italy

Serrano 1996 In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle. Asian Productivity Organization, Rome, Italy

Sharma, N.K. 2001/2002. Vegetable and Fruit Post-harvest Technology: Some Information cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 191-199. Asian Productivity Organization, Rome, Italy

Singer, D. D. 1980. Post-Harvest Food Losses: World Overview. *Food and Nutrition Science* 4 (3): 3-9.

Smil, V. 2000. Feeding the World: Challenge for the 21st century. Cambridge, MA: The MIT Press.

Stuart, T. 2009. Waste – uncovering the global food scandal. Penguin Books: London

Techawongstien, S. 2006. Thailand (1), Part III. Country Papers, pp 276-283. In Rolle, R.S. (ed) 2006. Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region. Asian Productivity Organization, Rome, Italy

Tefera, T. 2012. Post-harvest Losses in African Maize in the Face of Increasing Food Shortage. *Food Sec* 4: 267–277

Thapa, M.J. and M.B. Shrestha. 2001/2002. Study on Grading, Packaging and Transportation of Orange. In Annual Report, Food Research Unit, Post-harvest Research Programme, Nepal Agriculture Research Council, Lalitpur, Nepal cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 191-199. Asian Productivity Organization, Rome, Italy

Thuy Hai, T. 2006. Vietnam (1), Part III. Country Papers. ,. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 293-297. Asian Productivity Organization, Rome, Italy

Tyler, P.S. 1982. Misconception of Food Losses. *Food and Nutrition Bulletin* 4: 2.

Tyler, P.S. and R.A. Boxall. 1984. Post-harvest Loss Reduction: A Decade of Activities: What Consequences? *Tropical Stored Products Information* 50: 4-13

US Department of Agriculture, Economic Research Service (USDA/ERS). 2010. Food CPI and Expenditures. Washington, DC: USDA

Vinh Yeh, T. 2006. Vietnam (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp 298-302 Asian Productivity Organization, Rome, Italy

Vizmonte, E.V. 1982. Farm level storage of yellow granex onion using sawdust and rice hull. BS Thesis, University of the Philippines Los Baños, College, Laguna. 25 leaves. (unpublished)

Werner, R.A. and D.K. Subedi. 1991. Post-Harvest Losses Assessment in Selected Vegetablesin Nepal: Tomato, Cabbage and Cauliflower. FAO-VDD/DOH-GCP/NEP/046/SW1 cited in Paudel, K.B. 2006. Nepal (1), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 191-199. Asian Productivity Organization, Rome, Italy

World Bank 2011. Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa. Report 60371-AFR, 2011 http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10_web.pdf

Yaptenco, K.F., J.U. Agravante, E.B. Esguerra and E.P. Serrano. 2001. A case study on refrigerated and non-refrigerated transport of highland vegetables from Benguet to Manila. In Quality Assurance in Marketing of Horticultural Produce. PHTRC-FRLDM PICC, Pasay City cited in Rapusas, R.S. 2006. Philippines (2), Part III. Country Papers. In *Postharvest Management of Fruit and Vegetables in the Asia-Pacific Region* ed by R.S. Rolle, pp. 227-244. Asian Productivity Organization, Rome, Italy

Yong, H., Y. Bao, X. Liu and A.H. Algader. 1997. Grain Post-production Practices and Loss Estimates in South China. *Agric. Mechanisation Asia Africa Latin Am*. 28: 37-40