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ORIGINAL PAPER

The economics of post-harvest loss: a case study of the new large soybean - maize producers in tropical Brazil

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Abstract Reducing post-harvest loss (PHL) allows farmers to keep more of their crop and increases grain supplies, which are critical in a world where resources are scarce and rural developing economies struggle. While the policy goal is well understood, the micro-economics of loss are not. Little research focuses on the role managers play in reducing loss. Using economic theory and field research, we built and tested a conceptual model of farmers' loss problem. We modelled a tradeoff where the opportunity costs of loss mitigation were sufficiently high to motivate managers to increase rather than reduce PHL. The setting was the fast growing tropical maize and soybean region of Mato Grosso, Brazil. Results showed that harvest losses of 6 % and short-haul losses of 2 % in soybean, as an opportunity cost, might be insufficient to cause farmers to be as aggressive in reducing loss as policy makers would expect. This is because delay in harvesting soybean may delay the planting of maize as a second crop (safrinha) on the same land, causing risk of loss of this valuable crop owing to drought and inhibition of pollination. Hastening of the harvest of soybean (and consequent loss) can be achieved by desiccation and increased harvesting speeds. The results provide insights, which may be applicable elsewhere, into the complexities of tropical grain production where high moisture environments, large spatial contexts and poor infrastructure promote tactics, such as those described, in order maximize the benefits of double cropping.

Keywords Post-harvest loss · Economics · Brazil · Mato Grosso · Soybean · Maize · Safrinha

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Introduction

Reducing post-harvest loss (PHL) of grains and oilseeds allows farmers to keep more of their crop and increases grain supplies, two factors which are critical in a world where resources are scarce and rural developing economies struggle. We define PHL as a loss problem involving three components; harvest loss, short haul loss, and storage loss. Harvest loss reflects the difference between the volume of standing grain in the field and the quantity harvested. Short haul loss occurs moving grain from the field to the storage or commercial sale location. Finally, our research focuses on farmer managerial decision making. Storage loss only reflects private storage, although we acknowledge that public and commercial storage, as well as long haul movements, may involve significant levels of loss but these are beyond our focus, which is on managerial decision making at the farm.

The micro-economics of loss reduction are not well understood, even though the policy goals are well documented. Little research focuses on the role the farm manager plays in reducing loss. More specifically, why would a rational farmer accept loss? Using economic theory and field research, we built and tested a conceptual model of the farmers' loss problem. The research setting was the fast growing tropical maize and soybean region of Mato Grosso, Brazil, the largest agricultural state in the world. We focused on a new cultural practice in the tropics where farmers, using adapted soybean varieties plant and harvest early, allowing the planting and harvesting of a maize succession crop. This new system, is called “safrinha”, the Portuguese word for little or secondary crop. The safrinha system is unique to tropical farmers and allows significant improvements in land factor productivity (Goldsmith and Montesdeoca 2015). The results also provide insights into the complexities of tropical grain production where high moisture environments and poor infrastructure cause losses of grains and oilseeds at harvest and during transport and storage

Harvest loss is a function of several causes: bad weather conditions, uneven soil, bad seed quality, combine adjustment, carelessness, and high harvesting speed (Vaccaro 1981; Embrapa 1999; and Pinheiro Neto 1999). Reducing harvest loss increases yield and profitability (Shay et al. 1993; Vagts 2003; Kulkarni 2008; Staton and Harrigan 2011). The impact of harvest speed on grain losses is unidirectional: higher combine speed increases losses, consequently, farmers have to be more careful and maintain a harvesting speed no higher than 7 km/h in order to avoid loss of soybean at harvest (Mesquita et al. 2001; and Campos et al. 2005). However, no previous research on harvest loss addresses the motivation as to why producers continue to operate equipment that results in post-harvest loss. If farmers are rational profit maximizers, (Schultz 1964; Norton and Scheifer 1980; Wallace and Moss 2002), why would producers accept losses, or even intentionally increase harvest and post-harvest losses in their operations? Answers to this question are essential for policymakers as they think of efficient and effective policies to reduce losses and establish policy targets for loss levels. Similarly, equipment manufacturers looking at loss reduction technologies need to understand the farm manager’s problems and their willingness to pay for components of loss mitigation.

Previous work indicates that tropical growers increase soybean harvest speed and may accept a certain amount of loss in order to plant maize earlier in the season as a second or double crop (Martins et al. 2014). Specifically in this research we explored the general hypothesis that farmers willingly tradeoff higher soybean PHL in order to plant the succession maize crop earlier. Testing this hypothesis allows for an understanding that PHL levels may include a significant component that is a function of opportunity costs. That is, managers may rationally elevate the level of PHL. The implication for policy makers and equipment manufacturers is that managers may not only face loss due to uncontrollable events, say weather, or technical inadequacies, which could be due to under development, but that there exists a third component, high opportunity costs, whereby managers explicitly allow PHL levels to rise.

The double-cropping (safrinha) of soybean-to-maize is unique to the low latitude regions of the world, and allows producers the ability to dramatically increase grain output per hectare compared with temperate regions (Goldsmith 2011). But there are significant PHL implications when double cropping as farmers only have a short planting window for maize after advancing the traditional soybean growing season (Goldsmith and Montesdeoca 2015). The rise of world maize prices and expanded poultry production have increased the profitability of the soybean-maize double cropping system (IMEA 2012). As a consequence, farmers might rationally accept soybean harvest loss to reach higher farm profitability when jointly producing soybeans and maize.

To date there is little literature analyzing the economics of the safrinha model, and no literature addressing the implications for PHL. Additionally, tropical commercial producers, the world’s fastest growing producer segment, are rarely studied because of their inaccessibility. Thus our case study reports unique findings that are extremely relevant to global food production, especially in low-latitude regions of the world. The implications of our research extend beyond the narrow context of double cropping systems in Mato Grosso. The farmers of Mato Grosso are the technological and production leaders of the world’s broad hectare tropical farms, which lie in the zone between latitudes 15° north and 15° south, an area that has long lagged behind the rest of the world in terms of agricultural productivity. These farmers have changed that, and now serve as thought and practice leaders for agricultural expansion in low latitude regions. Thus understanding PHL among Mato Grossean farmers will have broad implications for loss management and storage as well as stakeholders, such as policymakers and private sector firms that operate in this fast growing farming region of the world.

Research context: safrinha production

The development of the agricultural sector in the Brazilian savannah began in the 1970s as a consequence of federal government programs. These programs included financial incentives and the construction of the first highway crossing the state of Mato Grosso from south to north, the BR-163. Migrants from the densely populated south and southeast of Brazil were encouraged to buy land, expand crop areas and raise cattle in areas surrounding the BR-163. Land prices were fairly low in Mato Grosso compared to the states of Goias and Mato Grosso do Sul (also in the Brazilian savannah), because of its remoteness and difficulty of access. As a consequence, farmers sold smaller plots of land in the south and southeast and bought larger properties in Mato Grosso. This exchange of land laid the foundation for the dominant large-scale agricultural model in Mato Grosso. Typical crop farms in Mato Grosso average 2000 hectares (IMEA 2013) compared with a typical farm in Southeast Brazil of 308 hectares (Cepea 2012).

However, it was only at the beginning of the 21st century that the production system was really established in Mato

Grosso. The rise in international demand for soybean, in addition to the depreciation of the Brazilian Real, increased the profitability of soybeans in a monoculture cropping system. Mato Grosso quickly became Brazil's leading soybean producing state. Tropical soybean production in Mato Grosso increased from 0.12 million metric tons in 1980, to 2.9 million metric tons in 1990, to 9.8 million metric tons in 2000, and to 18.76 million metric tons in 2010 (CONAB 2013) — an 18 % compound annual growth rate. In 2010, Mato Grosso was responsible for 27 % of the national soybean production, followed by the semi-tropical states state of Paraná, with 20 %, and Rio Grande do Sul, with 15 %.

The year-round monoculture of tropical soybean, unique to Mato Grosso, unfortunately led to a dramatic increase in soybean rust, a severe fungal disease (Goldsmith 2008). Presence of the disease initiated a policy limiting farmers to only one crop per year in order to break the rust cycle. This limit dramatically reduced farmer income, forcing farmers to expand their area cropped to soybean or find another crop: hence the rise of the double cropping system whereby farmers harvest two consecutive commercial crops in the same season i.e. soybean and maize. Double cropping maintains soil moisture during the winter (dry period), breaks pest and disease cycles, and improves soil quality (Arvor et al. 2011). This is advantageous with tropical soils, like those found in Mato Grosso, that are nutrient poor, contain very low levels of organic matter, hold moisture poorly, are high in aluminum, and are very acidic (Broch and Ranno 2011). There are economic benefits as well. Double cropping improves cash flow, reduces the cost of pest control, spreads fixed costs over two productive activities, and utilizes labor more efficiently (Tsunechiro et al. 2006; Silva Neto 2011). Moreover, nitrogen fixation from the soybean crop improves the fertility of the soil.

Agricultural intensification using double cropping is a recent phenomenon driven, in part, by the rise in maize prices. In 2009, only 10 % of the soybean area in Mato Grosso was double-cropped with maize, but the area had rapidly jumped to 38 % by 2011. Net profit from safrinha production reached $672 R ($305 USD) per hectare in 2010/11 while soybean, the main crop, had net profits of $631 R ($287 USD) per hectare in the same year (IMEA 2013).

The safrinha planting season begins in late January, after the soybean harvest and has a window lasting 30 days. Farmers must plant maize no later than February 15th—25th, depending on location, in Mato Grosso (Fundação 2013). Planting later than March 1 significantly increases the risk that the onset of the dry season will negatively affect maize pollination, which will reduce yield. The earlier farmers harvest soybean, the earlier the maize crop can be planted. In 2012/2013 two million hectares, or 69 % of the soybean crop, was harvested before February 25 (Table 1). This allowed 1.3 million hectares of maize or 92 % of the safrinha to be planted within the window.

Desiccation of soybean is a practice for advancing the date of harvest but reduces yield and quality. This involves stripping the plant of its leaves, and can advance harvest by 3 to 7 days. This time interval can be very important for maize yield as it increases the probability that pollination will occur before the onset of the dry season (Silva Neto 2011). Desiccation is practised more frequently when rainfall is excessive but reduces threshing performance because the grain is tougher to handle and increases storage losses because of higher moisture levels resulting in quality discounts from commercial buyers (Lelis et al. 2012). Additionally, the tight harvest/planting window and adverse weather conditions cause farmers to increase combine and transport speeds in order to complete the soybean harvest as quickly as possible These too increase PHL.

Double-cropping has become more attractive recently because of the continual rise in both world and local prices. Increase in local utilization and the development of the agro-industrial complex in Mato Grosso has led to a strengthening of the maize price basis (Goldsmith 2011). Consequently, the shortening of the harvesting window for soybean places Mato Grosso in a unique position to initiate an analysis of post-harvest loss where there exists an "acceptable" amount of loss in order to increase the total production (soybean and maize) and maximize profit.

Conceptual model: farmer behavior and PHL

There are significant harvest and postharvest soybean losses in Mato Grosso, Brazil. The average stated harvest loss in Mato Grosso is 5.68 % and the short-haul loss is 2.24 %, but the standard deviations are high, 12.6 and 5.1 %, respectively (Martins et al. 2014).

Each day's delay in planting maize after the 25th of February decreases yield by 210 kg per ha, or 3.5 % or 2.1 % assuming harvests of six and ten metric tons per hectare, respectively (Fundação 2013). Suppose a farmer is faced with a choice of harvesting soybeans and planting maize on February 28 or on February 24 (Table 2). The farmer could risk a decrease in maize yield of 810 kg per hectare because of drought stress when planting maize at the later date. Or the farmer could advance the soybean harvest date by, for example, desiccating green soybeans, operating equipment more quickly, and/or harvesting in excessively moist environments. Harvesting early could incur soybean losses of 10 % or $98/ha but the cost of delaying planting maize until February 28 could be $117 USD. The rational farmer would advance the harvest and incur 10 % PHL. This stylized example provides the conceptual framework whereby low latitude farmers may rationally incur moderate levels of PHL because of climatic conditions, weather uncertainty, and an optimization problem across two successive crops.

Table 1 Crop progress on february 25 in mato grosso

Season	Soybean harvest progress		Maize planting progress	
	Million hectares	% of total area	Million hectares	% of total area
2008/2009	1.096	48 %	0.498	78 %
2009/2010	1.542	63 %	0.738	88 %
2010/2011	0.732	28 %	0.412	48 %
2011/2012	1.681	62 %	0.980	86 %
2012/2013	2.074	69 %	1.322	92 %

Source: IMEA, 2012

Farmers will minimize post-harvest losses when they have financial motivations to do so, just as food companies have an incentive to reduce waste because they must pay disposal costs (Hodges et al. 2011). Clearly ceteris paribus, reducing loss increases the grain for sale and gross revenue on the farm. Thus, the quantity of grain farmers capture by reducing losses plays an important role on farmers' decisions (Mwebaze and Mugisha 2011). Farmers from Uganda prefer local post-harvest reduction methods instead of government improved post-harvest technologies because producers do not know whether the benefits of the latter will surpass the likely cost (Mwebaze and Mugisha 2011).

We model the safrinha farmer's problem using a standard microeconomics structure (see Varian 1990) to focus on soybean PHL. First assume soybean output is Y_s, and there are only two inputs, X_1 and $\overline{X}_2$. X_1 is the level of soybean PHL mitigation, and $\overline{X}_2$ are all inputs to produce soybean, and for simplicity $\overline{X}_2$ is fixed. So $\overline{X}_2$ are positive inputs directly producing Y_s, and X_1. PHL mitigation is an indirect input affecting Y_s. The production function is defined as:

$$Y = f\left(X_1, \overline{X}_2\right) \quad (1)$$

The manager then maximizes profit in the following manner:

$$Max_{X_1} \; P_s Y_s - (W_1 * X_1) - \left(W_2 * \overline{X}_2\right) \quad (2)$$

where P_s reflects the soybean price. W_1 is the cost to reduce soybean PHL measured in maize opportunity costs, which is a function of maize revenue (yield and price). W_2 are the costs associated with all the other inputs. W_1 captures a variety of activities associated with PHL, for example; desiccating soybean, reducing combine reel or running speed, increasing combine maintenance and adjustment, using truck bed liners, employing on-farm storage, or training employees. So ceteris paribus, when W_1 rises, the opportunity costs measured in maize incent managers to increase soybean PHL, and when W_1 falls, say due to a fall in maize prices, smaller levels of soybean PHL occur. Solving the profit function for Y_s as a function of X_1 results in the following:

$$Y_s = \left({}^{\pi}/_{P_s}\right) + \left({}^{W_2}/_{P_s} * \overline{X}_2\right) + \left({}^{W_1}/_{P_s} * X_1\right) \quad (3)$$

Table 2 Opportunity cost of soybean loss reduction when planting maize after window closure

Days	Harvest/Planting Date Soybean/ Maize Day/Month	kg/ha	Yield sacrificed maize @6mt/ha @10mt/ha		US$/ha[b]	PHL[a] soybean US$/ha	
1	25-Feb	210	3.5 %	2.1 %	29	98	
2	26-Feb	420	7.0 %	4.2 %	59	98	
3	27-Feb	630	10.5 %	6.3 %	88	98	Between
4	28-Feb	840	14.0 %	8.4 %	117	98	
5	1-Mar	1050	17.5 %	10.5 %	147	98	
6	2-Mar	1260	21.0 %	12.6 %	176	98	
7	3-Mar	1470	24.5 %	14.7 %	206	98	
8	4-Mar	1680	28.0 %	16.8 %	235	98	
9	5-Mar	1890	31.5 %	18.9 %	264	98	
10	6-Mar	2100	35.0 %	21.0 %	294	98	
11	7-Mar	2310	38.5 %	23.1 %	323	98	
12	8-Mar	2520	42.0 %	25.2 %	352	98	
13	9-Mar	2730	45.5 %	27.3 %	382	98	
14	10-Mar	2940	49.0 %	29.4 %	411	98	
15	11-Mar	3150	52.5 %	31.5 %	440	98	

[a] Assume harvest+Short Haul+Storage Loss=PHL=10 %

[b] Assume $140/mt for maize in Sinop, Mato Grosso

Where $\left({}^{\pi}/_{P_s}\right) + \left({}^{W_2}/_{P_s} * \overline{X}_2\right)$ depicts the Y_s intercept. ${}^{W_1}/_{P_s}$ reflects the slope of profit line (π), which is the marginal product of PHL mitigation in terms of Y_s and the tangency point with the production function $f\left(X_1, \overline{X}_2\right)$. The base level of PHL mitigation, X_1^a (point a), falls within the range of 0 and 100 % (Fig. 1).

No effort in PHL mitigation results in no loss reduction, 0 on the X axis, and extreme levels of X_1 produce complete mitigation of losses, 100 % on the X axis. The rational farmer may mitigate all or a part of the loss. (Realistically there is always some loss, as EMBRAPA, the national agricultural research institute of Brazil, sets the maximum harvest loss at 2.51 % (EMBRAPA 1999).) The left vertical axis reflects the benefits a farmer receives from reducing loss, measured in units of soybean (Y_s).

Focusing simply on P_s,farmers receive greater benefits from loss mitigation when soybean prices rise, and lower benefits when prices fall. Point b reflects a rise in soybean prices, so producers mitigate more loss, and the optimal PHL mitigation level is X_1^b and soybean supply rises from Y_s^a to Y_s^b. Alternatively, rising maize prices increasing the opportunity costs of reducing soybean PHL (W_1^c) or rising mitigation costs due to say, rising labor costs, would shift the optimal level of mitigation back to point X_1^c.

Labor costs have dramatically risen in Brazil (IMEA 2013), and agricultural production in Mato Grosso is a labor-intensive business (IMEA 2013). Labor scarcity in the short run leads to the employment of less skilled workers, employees working longer hours, and potentially paying less attention to lower priority activities, such as PHL reduction. Unless there is an effective substitution of PHL mitigation labor with PHL mitigation capital, ceteris paribus, PHL might rise and grain supply will fall (Y_s^c). Thus the level of PHL mitigation may fall under conditions of labor scarcity as the labor cost per unit of mitigation rises.

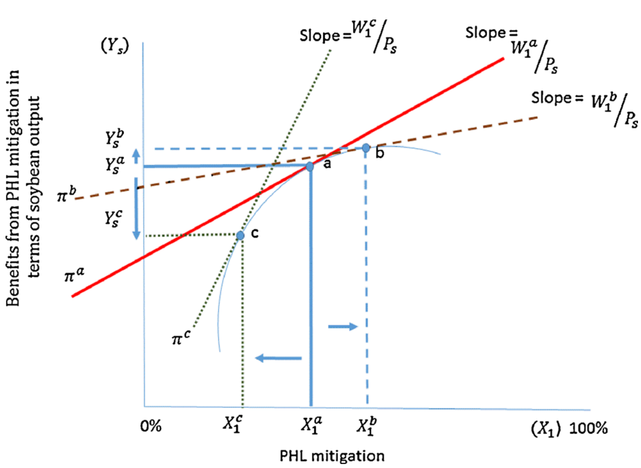

Fig. 1 A model of farmer behavior and PHL mitigation tradeoffs

Consistent with the model presented in Fig. 1, we stylize two safrinha scenarios to reflect loss mitigation management in action. Scenario b, reflects the base case where managers encounter spring rains that fall on time allowing soybean planting on October 16, and harvest on February 3, well before the maize window closure date of February 24. Harvest is unhurried as there are 21 days of the window for planting maize remaining, so the opportunity cost in terms of maize is low. Loss mitigation is simple and low cost (W_1^b), percent loss mitigated rises (X_1^b), as does the soybean yield (Y_s).

Scenario c though reflects a common and difficult situation facing managers. In scenario c spring rains fall late, or equipment rationing on large farms causes soybean planting to occur later, for example on November 7. Late planting delays harvest until February 25. Closure of the maize planting window now approaches and maize yield losses are likely. The farmer now trades off soybean losses for maize yield by accelerating harvest speed and desiccating green soybean, for example. Avoiding high moisture harvest environments becomes less critical when the opportunity costs of a foregone maize crop are high. Soybean harvest and maize planting compete for the fixed resource of time. The net marginal benefit of loss mitigation is the tradeoff of soybean PHL with maize (W_1^c). Soybean PHL mitigation falls to X_1^c and grain output falls to Y_s^c .

The loss of soybean and maize though are not deterministic. There is some uncertainty as to how much soybean is lost through a hurried harvest, and there is significant uncertainty as to when the rainy season will end, and the resulting effects on maize yield. A late end to the rainy season, May 15 for example, allows sufficient moisture for pollination and good yields for a maize crop planted on February 25. Significant maize losses would occur though if the rainy season were to end prematurely. Thus producers have an incentive to get the maize crop planted, even if it means incurring soybean post-harvest losses.

Thus, we explore the following two general hypotheses:

Hypothesis 1 Farmers accept soybean harvest loss because the costs to mitigate loss are greater than the benefits.

Hypothesis 2 Farmers accept soybean harvest loss because the opportunity cost (maize) is higher than the revenue.

Data and method

The research method involves five important steps in order to establish the validity of the case study of large producers operating in the tropics. First, in depth interviews were conducted with a focus group of seven farmers in Mato Grosso in June of 2012. All interviews were recorded and involved two researchers at all times. The focus group helped the researchers test key questions, explore theoretical concepts, and refine language and terminology. Second, a survey instrument was developed with the aid of the results of the focus group, and then individually administered to the focus group farmers. The results provided an initial assessment of the functionality and likely performance of the survey. Third, researchers followed up the survey seeking comments about the survey from the focus group farmers. Fourth, these comments help produce version two of the survey, which was then pre-tested with a sub-sample of our population. Lastly, with the results of the pre-test, a final online survey was administered in December 2012 to 1902 producers of the soybean and maize association of Mato Grosso (Aprosoya).

The survey queried producers across a number of relevant topics relevant to PHL. Specific to the subject of this manuscript, the survey followed the above conceptual model and sought farmer views on costs and benefits with regard to reducing soybean losses and the importance of the safrinha. The section on the trading of soybean for maize contains both quantitative (level of postharvest losses) and qualitative answers, and consists of a set of 19 statements. Respondents were asked to identify the degree to which they agreed or disagreed with each statement, (1=strongly agree, 5=strongly disagree).

We employed descriptive analysis procedures, specifically Chronbach's Alpha, to group our data. All factors with an eigenvalue value greater than 1 were constructed using principal components. Then, groups of individual items that loaded with factors of 0.60 or greater were tested for reliability. There were four factors based upon Chronbach's alpha coefficients. Individual items that loaded into those four factors with a factor loading score greater than 0.50 were examined for common themes and assigned descriptive names. The computed value for all 19 items combined was 0.58. According to Nunnally (1978) Hair et al. (1998) and George and Mallery (2003) a coefficient of 0.70 indicates acceptable reliability for the alpha value. Bowling (2002), however, argues that an alpha value greater than 0.50 is acceptable in the case of exploratory research, such as our focus on PHL among modern low-latitude farmers. Nevertheless, eight statements presented an alpha value lower than the combined alpha of .58, thus were dropped. The remaining eleven had a new combined alpha of 0.70, which indicates an acceptable level of reliability. .

The analysis then employed factor analysis on the remaining eleven statements in order to construct the factors' coefficients. All eigenvalues greater than one were extracted using principal component analysis and Varimax Rotation with Kaiser normalization to generate the rotated matrix. The four factors were subsequently used to create four independent variables for a binary logistic regression analysis. The Cronbach's alpha for 3 out of 4 factors did not indicate good reliability based upon the commonly used cutoff value of 0.7. Factors 3 and 4, however, achieved an acceptable level of reliability, 0.6. Factor 2 presented a Chronbach's alpha of 0.52, which, following Bowling (2002) is low, except in the case of exploratory research.

We specifically tested a farmer's decision to accept soybean harvest losses in order to increase total grain production. The maximum likelihood procedures employed two models for validation purposes. Model A regressed the dependent variable against four factors plus management and demographic characteristics. Model B differed in that the highest loading items for each factor replaced the four factors. The logistic model explores factors that influence a farmer's decision to accept soybean harvest loss to increase total production across the two crops. Estimates of the parameters result from the use of maximum likelihood (ML) procedures. We produced summary statistics, β coefficients, p-values, and marginal effects using Stata (Stata 2013).

The dependent variable ACCEPT_PHL is a binary variable where 1 represents farmers that are willing to accept 3 %, 5 %, or a greater loss of the soybean harvest in order to plant maize earlier in the season and reduce the risk to maize yield. Farmers, who responded that they were not willing to accept additional soybean harvest loss, received a value of zero.

The following model estimates when farmers were more or less likely to accept soybean harvest losses in order to produce more maize:

$$\begin{aligned} \text{ACCEPT\_PHL} = {} & \beta_0 + \beta_1 Factor1 + \beta_2 Factor2 \\ & + \beta_3 Factor3 + \beta_4 Factor4 \\ & + \beta_5 On\_Farm\_Storage + \beta_6 Combine \\ & + \beta_7 Maize\_price + \beta_8 Risk\_lover \\ & + \beta_9 PHL + \beta_{10} Age + \beta_{11} Education \\ & + \beta_{12} Double\_crop + \varepsilon \end{aligned}$$

Where:

1. *On_farm_storage* is a dummy variable taking the value of 1 when there is storage on farm. There is a lack of literature as to the relationship between storage and soybean PHL under safrinha production systems. This variable is hypothesized to be positively related to the dependent variable. The positive relationship is derived from the conceptual model in three ways as producers incur soybean PHL in order to produce a maize crop. Maize production, as a second crop, creates opportunities to use storage capital more efficiently in terms of higher grain volumes and a longer storage season because maize yields per hectare generally range from 50 to 300 % higher than

soybean yields per hectare. The greater volume of the maize crop more readily fills grain silos, and as a result more efficiently uses this fixed asset so storage scale-up is quicker than with soybean production alone. Finally, the maize basis, the difference between the local price and the national pricing point in Paranagua, Paraná, or the global pricing point in Chicago, is weaker in Mato Grosso as relevant markets are less developed, transport costs relative to the value of maize are high, and distances to markets are great. As a result the buyers' market at harvest allows for relatively greater returns to storage for maize compared with soybean (Goldsmith 2011).

2. *Combine* is the soybean area divided by the number of combines. The smaller the combine variable the better capitalized is the farmer. Drawing insights from the conceptual model has the manager having a significant equipment need in order to produce both a soybean and maize crop. Thus better capitalized producers will engage in the challenges of safrinha production yet assume higher soybean PHL. Thus we expect a negative sign on the coefficient.
3. *Maize_price* is the price received from the 2011/12 season in Reals per bag of maize (60 kg). Following Eq. 3 above, we hypothesized a positive coefficient, as the greater the price received for maize, the more the farmer will be willing to tradeoff soybean post-harvest losses for maize yield.
4. *Risk_lover* is a dummy variable equal to 1 if the producer marks a three or four when answering the following question: 1) I am extremely averse to risk; 2) I avoid risk; 3) I take risks after some research; 4) I am a risk lover. The conceptual model reflects the calculus whereby the manager makes a series of decisions throughout the soybean planning, growing, and harvest period under the uncertainty of the impact on future maize yield. It is hypothesized that farmers who are more risk loving will be willing to accept certain short term losses (soybean PHL) for the possible potential of a high yielding maize crop in the future.
5. *PHL* is the level of post-harvest losses farmers perceive they have as a percentage of total production. The conceptual model portrays a tradeoff whereby the dependent variable reflects a purposeful acceptance of PHL. Therefore the sign of the PHL variable is hypothesized to be positive and reflects that producers do implicitly manage for soybean losses when engaging in safrinha production.
6. *Age* is the age of the respondent (<40 years old, 41 to 60 years old, >61 years old). We do not assume any hypothesis for this variable.
7. *Education* is the level education: high school, college and graduate. We do not assume any hypothesis for this variable.
8. *Double-cropping* is the coefficient on maize/soybean area (hectares) planted by the farmer in the 2011/12 season. We hypothesize that the more producers double crop the more willing they are to accept loss.

Results and discussion

Descriptive statistics

From an email list of 1902 farmers, 158 accessed the survey, but responses to some questions were missing and therefore excluded, leaving a total of 94 completed surveys. The response rate was low, 8.3 %. Farmers in Mato Grosso have never been surveyed online before our effort. They are also sporadic users of email and do not use the Internet as their main source of information (Aprosoja, 2013). The sample is not representative as the farm size of the respondents was twice as large as the average in the state, 2247 hectares planted to soybean (Table 3). The area double-cropped with maize (safrinha) in the 2011/12 season averaged 1097 hectares, nearly 50 % of the soybean land. The average level in Mato Grosso was 30 % safrinha in 2011/12 (IMEA 2012). Average perceived soybean post-harvest losses were 5.68 % at harvest, 2.24 % for short-haul, and 2.45 % with on-farm storage, i.e., greater than 10 %, or approximately two million metric tons (Martins et al. 2014).

The survey results should still be of great interest, though the response rate is low and the sample does not represent the entire farmer population of Mato Grosso. We argue that the sample bias is advantageous as the respondents are some of

Table 3 Sample descriptive statistics

Total number of farmers Item	94 Average
Acreage	
2012 Crop year Soybeans Acreage	2247
2012 Crop year Maize Acreage	1097
% of area double-cropped	49 %
Age (% of farmers with age of)	
<40 years old	50 %
41 to 60 years old	48 %
>61 years old	2 %
Education (% of farmers with education)	
High School	34 %
College graduate	72 %
Graduate school	1 %
Risk Propensity	
Risk averse	49 %
Risk neutral or loving	51 %

the largest and most dynamic farmers in the world, and their perceptions about PHL and the new double crop ("safrinha") system are unknown. They are the thought leaders for the industry. The respondents operate in the largest and fastest growing maize and soybean state (Mato Grosso) in the world, produce a significant portion of total grain PHL worldwide, and up until now have not been surveyed about their production practices. The survey results have application to other high growth tropical regions such as Africa, other parts of Brazil and Latin America, and Southeast Asia because respondents operate in comparable environments.

The majority of the respondents were young as 50 % were less than 40 years old, and well educated. Furthermore, 51 % of the producers considered themselves as risk neutral or risk loving. A slight majority of the respondents (51 %) said they would not increase harvest speed and accept soybean loss to produce more maize (Table 4). But a considerable number of producers (43 %) would accept 3 %, 5 % or greater soybean losses.

Farmers stated that they cared about soybean loss. They averaged 4.29 (0.68 standard deviation) on a 5 point Likert scale in response to the question; "*I care about soybean loss during harvest on my farm*" (Table 5). However, they score lower (3.85 with a standard deviation of 0.90) to the question, "*The manager and the employees from my farm are able to make good decisions and to efficiently manage harvest.*" A validation question, "*The operators on my farm take care to avoid soybean harvest loss*," supports the concern that human resource management has a role in PHL reduction. The average response score was 3.68 with a standard deviation of 0.89. These results concerning labor management may explain farmers' perceptions as to the source of the 5.68 % average harvest loss estimates. A third validation question, asked if a "*lack of training of equipment operators is one important factor affecting PHL?*" Responses were in strong agreement—an average of 4.14 with a standard deviation of 0.76. Thus employees may not be well trained or motivated to reduce harvest loss.

Table 4 Responses to a question about accepting soybean harvest loss

Question: What statement would better represent your management decision in a scenario with good prices for soybeans and maize and soybean harvesting is delayed due to weather?	% of respondents
I would increase soybean harvesting speed to plant maize as soon as possible.	6
I would increase speed and take a maximum of 3 % soybean losses during harvest.	18
I would increase speed and take a maximum of 5 % soybean losses during harvest.	25
I would not increase speed and would take the maize yield risk	51

Farmers were near neutral on average to the following questions: "*the cost to reduce harvesting speed and post-harvest losses affects my decision to not prioritize this issue* (2.78 with a standard deviation of 0.99); and "*the financial benefits to reduce losses during harvest and post-harvest on my farm are small* (2.37 with a standard deviation of 0.93.) The results make sense as producers were split 51 % to 49 % in terms of their wiliness to tradeoff soybean losses for maize yield gains.

Factor analysis

Eight items were individually tested and dropped because they presented alpha values lower than the combined alpha (Table 5): 1) *Farmers from my region care about soybean losses during harvest on their farms;* 2) *Large scale-farms have larger losses due to a lack of control by the manager*; 3) *Farmers who have on-farm storage can better manage their time and as a result have less loss*; 4*) Farmers who have on-farm storage can better manage harvest timing, including machinery speed;* 5) *The difficulty of accessing loans to finance the construction of storage is the main reason for why most farmers don't have on-farm storage;* 6) *Planting maize after the optimum planting window (February 20th) introduces high yield risk.;* 7) *Soybean yields are greater on areas previously planted with safrinha*; 8*) Post-harvest loss reduction is an efficient way to increase food availability.*

The eleven remaining statements generated four factors (Table 6). Coefficients on factor loading represent the correlation between the statement (variable) and the factor.

(1) Factor 1 includes three statements relating to the timing of planting the safrinha and is named: "*The safrinha has affected the management of soybean harvesting.*" The expected sign on the coefficient estimate is positive, meaning that those managers willing to accept additional PHL explicitly do so by integrating soybean harvesting and maize planting activities.
(2) The second factor loads two positive statements relating the costs and benefits of reducing soybean losses with increasing safrinha production. A negative statement stipulates the lack of training as a cause of harvest loss. This last statement presents a negative sign, meaning it affects the factor loading in an opposite direction from the two other statements. Its value is low, indicating that this statement does not affect the factor as strongly as the two positive statements. Thus, a good representation of this factor is: "*the cost to reduce loss is high and the financial benefit of reducing loss is low.*" We name the factor; "*My demand to reduce loss is weak.*" The expected sign on the coefficient estimate is positive. Thus when managers willingly accept addition PHL they do so in

Table 5 PHL Attitudes and Perceptions

Variable	Description of variable	Average	STD
PHL_1	The manager and the employees from my farm are able to make good decisions and to efficiently manage harvest.	3.85	0.90
PHL_2	I care about soybean losses during harvest on my farm.	4.29	0.68
PHL_3	Farmers from my region care about soybean losses during harvest on their farms.	3.59	0.85
PHL_4	The operators on my farm take care to avoid soybean harvest losses.	3.68	0.89
PHL_5	Large scale-farms have larger losses due to a lack of control by the manager.	3.71	1.13
PHL_6	Lack of training for operators is one important factor affecting PHL.	4.14	0.76
PHL_7	Farmers who have on-farm storage can better manage harvest timing, including machinery speed.	4.23	0.89
PHL_8	Farmers who have on-farm storage are able to start harvesting earlier and have more time to plant the safrinha.	3.46	1.19
PHL_9	The difficulty of accessing loans to finance the construction of storage is the main reason for why most farmers don't have on-farm storage.	3.83	1.15
Double-Cropping statements			
DC_1	My concern about planting maize at the end of February affects the combine speed during the soybean harvesting.	3.35	1.22
DC_2	I employ soybean desiccation on my farm to advance harvest in order to plant maize before the end of February on my farm.	3.19	1.26
DC_3	Farmers from my region employ soybean desiccation to advance harvest in order to plant maize before the end of February.	4.09	0.79
DC_4	Planting maize after the optimum planting window (February 20th) introduces high yield risk.	4.09	0.86
DC_5	The cost to reduce harvest and post-harvest losses affects my decision to not prioritize this issue.	2.78	0.99
DC_6	The financial benefits to reduce losses during harvest and post-harvest on my farm are small.	2.37	0.93
DC_7	Soybean yields are greater on areas previously planted with safrinha.	3.58	1.10
DC_8	The economic benefits of double-cropping compensate for the costs of soybean harvest losses.	3.13	1.00
DC_9	Post-harvest loss reduction is an efficient way to increase food availability.	3.53	1.01
DC_10	I have increased harvest speed on my farm since I increased the safrinha acreage.	3.22	1.08

Scale 1 through 5, where 1 is "Strongly Disagree" and 5 is "Strongly Agree"

part because the benefits of reducing loss are relatively low.

(3) The third factor includes statements relating only to harvest loss. The central understanding is that farmers care about harvest loss and they try to prevent it. The factor is named "*My employees and I care about harvest loss and we avoid it*". The expected sign on the coefficient estimate is negative.

Table 6 Factor Loading and Individual Cronbach's alpha

	Factor Loading	Cronbach's alpha
Factor 1: *The safrinha has affected the management of soybean harvesting*		0.6954
My concern about planting maize at the end of February affects the combine speed during soybean harvesting.	0.6560	
I use soybean desiccation on my farm to advance harvest and allow maize planting before the end of February.	0.7722	
Farmers from my region use soybean desiccation to advance harvest and allow maize planting before the end of February.	0.6737	
Factor 2: *My demand to reduce loss is weak*		0.5213
The cost to reduce harvest and post-harvest losses affects my decision to not prioritize this issue.	0.5206	
The financial benefits to reduce losses during harvesting and post-harvesting on my farm are small.	0.7165	
Lack of training for operators is one important factor affecting PHL.	−0.4495	
Factor 3: *My employees and I care about losses and we avoid it*		0.5866
The manager and the employees from my farm are able to make good decisions and to efficiently manage harvest.	0.4806	
I care about soybean losses during harvest on my farm.	0.5940	
The operators on my farm take care to avoid soybean harvest losses.	0.6631	
Factor 4: *The benefits of reducing loss are lower than the benefits of the safrinha*		0.5855
The economic benefits of double-cropping compensate the costs of soybean harvesting losses.	0.6265	
I have increased the harvesting speed in my farm since I increased the safrinha acreage.	0.5245	

(4) The fourth factor loads two statements and denotes a preference for producing more maize relative to preventing greater soybean harvest loss. Thus, it is named "*The benefits of reducing soybean loss are lower than the benefits of the safrinha*". The expected sign on the coefficient estimate is positive. This factor most directly tries to capture the logic that a tension exists between PHL mitigation and the opportunity costs measured in units of the output of the second crop (maize).

Logistic regression

The conceptual and empirical models attempt to explain why PHL levels, in part, remain more than double the technical minimum and higher than societal expectations. Specifically, the dependent variable reflects a manager's stated willingness or lack of willingness to accept higher levels of soybean PHL in order to plant a succession maize crop at an appropriate time. The model (A) has moderately good fit as measured by a Hosmer and Lemeshow Chi-Square P-Value test far from zero and the coefficient results are consistent with theoretical expectations (Table 7). For a robustness check, we tested a second model (B) using the highest loading item from each of the four factors (Table 8). The results were quite similar indicating robustness. We present below results from both Model A and B, but focus our discussion primarily on Model A.

Factor 1, "*The safrinha has affected the management of soybean harvesting*" does not help to explain a willingness to tradeoff soybean PHL for maize yield. The coefficient estimate was positive as expected, but was not statistically significant. The coefficient estimate for Factor 3, "*My employees and I care about losses and we avoid it*" was negative as expected, but was also statistically not significant.

Producers that hold weak (strong) demand to reduce loss, Factor 2, are significantly (.10 level) and positively willing to accept greater (lower) levels of loss. This coefficient suggests that higher scores for "My demand to reduce loss is weak" increases the probability of accepting soybean harvest loss. Factor 2 entails a lack of recognition of the role of employee training on loss reduction, a sense that loss mitigation is expensive, and the benefits of PHL reduction are low. Thus those willing to elevate soybean PHL for a maize crop hold weak demand to reduce loss. In terms of marginal effects, any point increase in Factor 2 increases the incentive to accept loss by 20 %. The positive and significant relationship between the factor and the dependent variable makes sense as producers appear to differentially value loss, though they face the same grain prices. This result is consistent with the conceptual model's logic that a relatively high opportunity cost when valuing soybean mitigation, in terms of maize revenue, reduces PHL mitigation efforts.

Table 7 Model A: results from binary logistic regression with weighted factor scores

	Regression	Marginal effects
Factor 1	0.207	0.051
	(0.542)	(0.542)
Factor 2	0.832[a]	0.207[a]
	(0.091)	(0.091)
Factor 3	−0.593	−0.148
	(0.232)	(0.231)
Factor 4	1.335[c]	0.333[c]
	(0.008)	(0.009)
On-farm storage (dummy)	1.833[b]	0.426[c]
	(0.012)	(0.004)
Combine coefficient	−0.002	−0.0006
	(0.119)	(0.119)
Maize price	0.239	0.059
	(0.105)	(0.105)
Risk-lover (dummy)	2.082[c]	0.476[c]
	(0.005)	(0.001)
Postharvest-Losses	0.065[c]	0.016[b]
	(0.054)	(0.053)
Age	0.1547	0.038
	(0.589)	(0.589)
Education	0.0234	0.006
	(0.953)	(0.953)
Double-cropped area	−1.227	−0.306
	(0.363)	(0.363)
Constant	−8.17[a]	
	(0.08)	
Prob chi2	0.0002[c]	
Chi-square[a]	36.83	
	(0.300)	

[a] significant at the .10 level

[b] significant at the .05 level

[c] significant at the .01 level

Standard errors in parentheses

The negative sign on the item, *Lack of training for operators is one important factor affecting PHL*, may suggest that managers do not link operator training with loss reduction. This line of inquiry attempts to better understand managers' thoughts as to the role of employees and loss. Previous research indicates managers do understand the role of combine operating speed and maintenance on harvest losses (Martins et al. 2014). The result is consistent with the weak results from Factor 3, but the factor loading on the item is admittedly low. At issue is a possible disconnect between weak private incentives to train employees about PHL mitigation and a policy imperative seeking lower levels of loss. Thus there might be

Table 8 Model B: results from binary logistic regression with the highest loading item from each of the four factors

	Regression	Marginal effects
DC_2: I employ soybean desiccation on my farm to advance harvest in order to plant maize before the end of February on my farm.	0.189	0.047
	(0.464)	(0.464)
DC_6: The financial benefits to reduce losses during harvest and post-harvest on my farm are small.	0.792[b]	0.197[b]
	(0.043)	(0.043)
PHL_4: The operators on my farm take care to avoid soybean harvest losses.	0.122	0.03
	(0.725)	(0.726)
DC_8: The economic benefits of double-cropping compensate for the costs of soybean harvest losses.	0.852[c]	0.212[c]
	(0.007)	(0.007)
On-farm storage (dummy)	1.523[b]	0.363[b]
	(0.026)	(0.014)
Combine coefficient	−0.001	−0.0004
	(0.307)	(0.306)
Maize price	0.266[a]	0.066[a]
	(0.062)	(0.063)
Risk-lover (dummy)	1.581[b]	0.3734[c]
	(0.019)	(0.009)
Postharvest-Loss	0.084[b]	0.0209[b]
	(0.018)	(0.017)
Age	0.347	0.086
	(0.22)	(0.219)
Education	0.147	0.0367
	(0.719)	(0.719)
Double-cropped area	−1.232	−0.306
	(0.357)	(0.356)
Constant	−12.868[c]	
	(0.004)	
Prob chi2	0.0003[c]	
Pseudo R2	0.3196	
Chi-square[a]	36.27	
	(0.413)	

[a] significant at the .10 level

[b] significant at the .05 level

[c] significant at the .01 level

Standard errors in parentheses

benefits to public policies supporting curricula that include courses or modules on PHL mitigation, as the private sector appears to have weak incentives to do so.

Factor 4 builds on the weak valuation of loss explored with Factor 2, by having respondents directly state if the benefits of reducing loss are lower than the benefits of maize production. The expected sign is positive and the results are significant at the .01 level. Higher scores for "*The benefits of reducing loss are lower than the benefits of the safrinha*" increase the probability of accepting soybean harvest losses. Any point increase in Factor 4 increases the chance to accept loss by 33 %. The result provides evidence that producers are incented to produce positive losses, and these losses are rational. The finding also supports the proposition that positive loss is not only a function of uncontrollable events and technical inadequacies, which previous research shows, but opportunity costs as well.

Having on farm storage serves as the second largest driver to increase PHL in terms of marginal effects. The positive coefficient estimate on on-farm storage is positive, as expected, and significant at the .05 level. Farmers are more likely to accept PHL when producing a safrinha if they have on-farm storage. In terms of marginal effects, farmers who have on-farm storage are 42 % more likely to accept an increment of soybean harvest loss. The results provide nuance to the PHL mitigation question as intuitively on-farm storage reduces short haul distances, and thus indirectly short haul post-harvest losses, allows for grain conditioning, and may reduce harvest urgency by providing buffer holding capacity. So ceteris paribus, storage may be very useful for producers harvesting soybean during the challenging compressed summer harvest-planting season. But at the same time storage allows managers to better manage a large maize crop. In this way on-farm storage indirectly elevates soybean PHL because it supports not only the safrinha system but managers aggressive use of maximizing a maize crop which in tonnage may exceed the soybean crop. In this sense, storage's positive effect on PHL may appear to be counter-intuitive, but loss levels may be quite reasonable when measuring PHL across both soybean and maize production. Thus PHL measurement, or PHL reduction policy in low-latitude environments might best employ a tropical systems approach as the unit of analysis and not simply measure loss at the individual crop level.

The Combine variable is defined as the soybean area divided by the number of combines. The smaller the combine variable, the better capitalized is the farmer, and the lower is the expected PHL level. The coefficient estimate is negative, as expected, but not significant.

Maize price reflects the incentive to incur higher soybean loss levels and has a positive sign, as expected, but it is not significant. In model B maize price is significant at the .10 level, and the marginal effect is small, about 1/6th the effect of on-farm storage. The result supports the hypothesis that higher maize prices elevate the opportunity costs of PHL, and thus indirectly leads to higher soybean losses.

Risk loving is the largest driver of the willingness to incur higher levels of PHL. The sign on the coefficient is positive, as expected, and significant at the .01 level. The higher a manager's perception of their level of the loss, the more willing the manager will incur higher levels of loss to produce a second crop. Farmers who consider themselves as risk lovers are 47 % more likely to accept greater loss compared to those who consider themselves as risk averse. The coefficient for the estimated level of PHL was also positive and significant at the .10 level, and was consistent with the expected sign. Thus farmers who perceive they have a greater level of post-harvest loss are more likely to accept additional loss. Therefore farmers might be very rational about their post-harvest loss. Those that have higher levels of loss, explicitly do so, as they attempt to achieve higher total two-crop gross revenue per hectare.

The demographic variables of age and education are not significant. The expected sign on the safrinha cropped area is positive. The results are negative but not statistically significant. Thus there is no effect on the likelihood to accept soybean PHL when producing more safrinha maize. Previous research (Martins et al. 2014) shows that large-scale farmers perceive loss no differently from smaller-scale farmers. The level of the safrinha maize variable may be a proxy for farm size but not safrinha intensity, and thus should have little explanatory power with respect to the willingness to accept higher levels of PHL. A better variable to test the propensity to accept PHL might be the percentage of soybean hectares that undergo safrinha production.

Conclusion

Preventing loss and increasing food production are two feasible alternatives for meeting the future worldwide demand for food. It is commonly thought that increased food production results from loss prevention. Our results present a counter factual setting, where the relationship does not hold. Farmers are rational profit maximizers and increasing PHL can be optimal in the case of double-crop systems in low latitude countries, where "time" is a critical variable and weather is uncertain. The results help to explain the conundrum why a manager accepts controllable loss.

Safrinha production in Mato Grosso, latitude between 10^{o} and 15° south, causes harvest to occur directly in the middle of the rainy season. Doing so allows sufficient moisture both for the planting of the second crop, maize, and critically its pollination. Employing the safrinha system means that significant rain events are a daily concern, harvest is often interrupted, and farmers must be very adept at having equipment in the right place at the right time in order to get the soybean crop out of the ground within a small time window. Soybean post-harvest loss is in part a casualty of trying to get a maize crop planted before February 25. Thus we may see increasing post-harvest losses as farmers increase their safrinha area. Farmers accept soybean harvest loss in Brazil because "*The financial benefits to reduce losses during harvest and post-harvest on their farms are small*" and "*The economic benefits of double-cropping compensate for the costs of soybean harvesting losses*".

The limitation of this study is that we are not able to measure the costs and benefits in numerical terms. Though clearly indicated, we cannot definitely prove that farmers who accept soybean loss to produce more maize generate more protein, energy, and oil per hectare of land per year. Such a measure is essential for important research on the factor productivity of land, especially as agricultural output between 15° North and South shows great potential for expansion in the next 25 years. Thus, future studies should measure the amount of protein, starch, and oil produced on a hectare of land and the monetary cost and benefits when trading off loss for expanded grain production. The present study provides evidence that farmers are rational profit maximizers and trade PHL for grain production but the study cannot specify the levels of the tradeoff.

There are several implications for policymakers, farmer organizations, and agricultural industries. First, policy makers might rethink the net social welfare impacts of loss and be very methodical when assessing the causes of loss. The opportunity costs of mitigating loss appear to be a third critical component to causes, in addition to uncontrollable events, and technical inadequacies. Second, policy goals of fixed levels of loss may be unrealistic without a proper understanding of the management context facing farmers, such as a system of production that includes multiple crops. Managers may employ complementarities within a system such that positive losses may enhance societal welfare. In the case of tropical producers in Brazil, increasing soybean PHL increases total grain output per hectare. Policymakers might best focus on public drivers of PHL such as infrastructure (road construction and quality) and regulation (grain standards and vehicle inspection). Losses are higher when roads are poor, traffic moves slowly and aged vehicles remain part of the transport fleet. Such environments elevate the cost of PHL mitigation and limit managers' ability to affect loss levels. Finally, tropical grain production is expanding. Thus the findings apply to the new growth of grain regions in Latin America, Asia and Africa. Producers in these regions face similar PHL reduction challenges. Training of farm operators, the integration of passive loss management technologies on equipment, and improving public infrastructure would help reduce losses among the next generation of producers who are so important to meeting the global challenges of assuring an ample and affordable food supply in the decades ahead.

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