# An experimental approach to determining the value of grain moisture information to farmers in Bangladesh

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**Abstract**

In the developing world grain storage losses are high and in humid areas inadequate grain drying is often a source of storage problems. Farmers and traders depend on traditional grain moisture estimation methods which are subject to a wide error margin. Grain storage decisions could be improved if farmers and traders had a low cost grain moisture meter that fit their needs. The goal of this study was to determine the desired grain moisture meter functionality and to estimate the value of grain moisture measurement for small holder farmers and for small-scale grain traders, using Bangladesh as a case study. This study was based on interviews with 140 randomly selected Bangladeshi rice farmers in 2016 and 2017, discussions with millers at 30 rice mills and a voucher based moisture meter sales program. It shows that except for rice kept for seed and home consumption, most Bangladeshi farmers sell their rice shortly after harvest to satisfy cash needs and to eliminate storage risks. They say that they would store more rice on-farm if they had better storage methods including cost-effective grain moisture testing. Survey results show that the average farm storage loss was 52 kg or 563 Taka (US$6.78) annually. Using experimental economics methods, farmers were given the opportunity to purchase a probe type grain moisture meter through vouchers with a range of prices. Twenty three of the 140 of the participants (i.e. 16%) purchased at an average of price of 374 Taka (i.e. US$4.67). No farmer purchased a voucher price over 800 Taka (US$10.00). Those who purchased moisture meters had larger farms and produced more rice than those who did not exercise the voucher. They were also younger on average, have more education and more off farm income than non-purchasers.



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| **Keywords** | grain moisture; rice; Bangladesh; information value; on-farm storage |



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Highlights:

- Average farm storage loss was 52 kg with a value of 563 Taka (US$6.78) annually.
- The average purchase price of the moisture meter was 374 Taka (i.e. US$4.67).
- No farmer purchased at a voucher price over 800 Taka (US$10.00).
- Those who purchased moisture meters had larger farms and produced more rice.
- Purchasers were also younger, more educated and had more off farm income.

# An Experimental Approach to Estimating the Value of Grain Moisture Information to Farmers in Bangladesh

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# An Experimental Approach to Estimating the Value of Grain Moisture Information to Farmers in Bangladesh


## Abstract

In the developing world grain storage losses are high and in humid areas inadequate grain drying is often a source of storage problems. Farmers and traders depend on traditional grain moisture estimation methods which are subject to a wide error margin. Grain storage decisions could be improved if farmers and traders had a low cost grain moisture meter that fit their needs. The goal of this study was to determine the desired grain moisture meter functionality and to estimate the value of grain moisture measurement for small holder farmers and for small-scale grain traders, using Bangladesh as a case study. This study was based on interviews with 140 randomly selected Bangladeshi rice farmers in 2016 and 2017, discussions with millers at 30 rice mills and a voucher based moisture meter sales program. It shows that except for rice kept for seed and home consumption, most Bangladeshi farmers sell their rice shortly after harvest to satisfy cash needs and to eliminate storage risks. They say that they would store more rice on-farm if they had better storage methods including cost-effective grain moisture testing. Survey results show that the average farm storage loss was 52 kg or 563 Taka (US$6.78) annually. Using experimental economics methods, farmers were given the opportunity to purchase a probe type grain moisture meter through vouchers with a range of prices. Twenty three of the 140 of the participants (i.e. 16%) purchased at an average of price of 374 Taka (i.e. US$4.67). No farmer purchased a voucher price over 800 Taka (US$10.00). Those who purchased moisture meters had larger farms and produced more rice than those who did not exercise the voucher. They were also younger on average, have more education and more off farm income than non-purchasers.



**Keywords:** grain moisture, rice, Bangladesh, information value, on-farm storage

# The Value of Grain Moisture Information to Farmers in Bangladesh

## 1.0 INTRODUCTION

Estimates indicate that 20% to 30% of grain in developing countries is lost before it reaches consumers. In humid areas, one of the key problems is inadequate drying before storage and one of the constraints to proper drying is measuring grain moisture content. Grain drying is a costly process. It takes time, energy and money. While traditional solar drying uses free energy, it requires substantial labor. The traditional grain moisture measurement methods used by farmers and small scale traders in the developing world have a wide margin of error. Grain moisture is often misjudged and consequently grain is stored at higher than optimal moisture leading to mold and other damage. There are several grain moisture meters commercially available, but the price of this equipment is not within the purchasing power of developing country farmers and traders. Several research teams around the world are developing low cost moisture testing technology, but they lack information on the functionality that farmers need and the value of such technology for farmers and traders. Consequently, those researchers lack key design criteria needed to create technology that meets the needs of their stakeholders. The problem is that farmers, researchers and extension personnel in developing countries lack the economic information needed to develop low cost moisture meters and use them in grain marketing and storage decision making.

The focus of this study is on design criteria because appropriate design criteria are essential to engineering solutions to solve international development problems (ASME, 2009). Business, engineering and development experience indicates that in most cases developing country problems cannot be solved by cheaper versions of “First World” solutions (Prahalad, 2005; Polak and Warwick, 2013). In most cases it is essential to understand the needs of the developing country stakeholders and their priorities, and redesign the solutions for them.

Grain drying has long been a key concern for grain storage in the tropics, especially the humid tropics. For example, Hall (1970) focuses on grain drying as a key component of good grain management in the tropics. The recent World Bank (2011) report entitled "Missing Food: The Case of Post-Harvest Grain Losses in Sub-Saharan Africa" emphasized the need for improved grain drying to enhance food security. The World Food Program action research trials in Burkina Faso and Uganda (Costa, 2014) identified good grain drying as key to reducing fungal problems.

The lack of a cost effective means for smallholder farmers to identify when grain is dry enough to store is frequently cited as a key constraint (Robbins et al, 2004). Commercially available grain moisture measurement includes counter top models used by many American farmers which are often priced at US$300 to US$400 and the handheld Chinese made probe or cup devices which are priced at under US$100. Several research teams are focusing on lower cost grain moisture measurement (e.g. Rai et al, 2004; Ileleji et al, 2012; Tubb et al, 2017).

The rice sector contributes one-half of the agricultural GDP and one-sixth of the national income in Bangladesh. Almost all of the 13 million farm families of the country grow rice. Rice is grown on about 10.5 million hectares which has remained almost stable over the past three decades. About 75% of the total cropped area and about 80% of the total irrigated area is planted to rice. Thus, rice plays a vital role in the livelihood of the people of Bangladesh. The population of Bangladesh is still growing by about two million every year and may increase by another 30 million over the next 20 years. Reducing post harvest losses is a key method to maintain food security in the face of rising population and shrinking crop land area.

Bangladesh produces three rice crops per year in the Aus, Aman and Boro seasons. Aman is generally cultivated in December to January whereas Boro is in March to May and that of Aus from July to August. In recent years, generally in most regions of Bangladesh, the rice farmers mainly produce Boro and Aman. With multiple harvests annually, the rice supply and consequently the price in Bangladesh is not strongly seasonal (Figure 1 & 2).

After harvest, rice is typically sun dried before storage or marketing. A moisture level of 12%-13% is recommended for safe storage in the temperature range of 20-40º C, but farmers have many traditional ways of determining grain moisture (Ileleji et al., 2011). Some bite on the kernels and claim to know when the grain can be safely stored. Others shake a handful of grain and say that a rattling sound indicates that it is dry enough to store. Yet others will thrust their hand into a sack of grain and say that if the hand goes in easily, the grain is dry enough. Comparisons between farmer methods and measured grain moisture in Africa indicate that there is a 4% to 5% of error around the farmer moisture assessment (Robbins et al., 2004). A farmer might think that grain is ready to store, but in reality it is 18% moisture and will deteriorate rapidly.

The so called “Salt Jar Method” is quite accurate, but may not help farmers when removing the last few percentage points of moisture. The salt jar method involves shaking grain in a jar with non-idodized salt. If the salt sticks to the side of the jar, the grain is above 15% moisture (Robbins et al., 2004). The salt jar does not help the farmer determine if grain has reached the 12% moisture often recommended for storage in the tropics.

In Bangladesh grain is retained on-farm for consumption either in the form of parboiled rice or raw paddy. The commonly used storage structures are made of bamboo, earthenware and jute. Other small storage containers are earthen pitchers, drums, tins and wooden chests. The size of these storage structures varies considerably from house to house depending on the economic condition of the family, amount of rice produced and stored.

The need for farm level grain moisture measurements also depends on the structure and technology used for commercial rice milling. In the past, paddy rice was parboiled and dried on farm or by small scale traders. This rice was processed into finished rice by entrepreneurs with husking machines located in the village bazaar or mobile units that would come to the farmyard or trader's shop. More recently, semi-automatic mills were established to buy paddy rice from farmers or small scale traders, parboil, dry and husk that rice at the same location. The semi-automatic mills typically use open sun drying after parboiling. However, the rice milling sector in Bangladesh is undergoing another change (Ali, 2011). New automatic rice mills are being set up at a growing rate (Table 1). Automatic rice mills use a continuous flow process. Paddy rice goes in and finished rice ready for consumer markets comes out. With on-farm processing, husking mills and semi-automatic mills, rice grain moisture information is important for the farmer or trader who stores the intermediate product until consumption or sale. Automatic rice mills are less sensitive to the moisture level of incoming paddy. The processing cost and management are similar for high moisture and well dried paddy. However, automatic rice mills can not process all paddy immediately and consequently even they must be concerned about the grain moisture for paddy going into storage until processing capacity is available.

Table 1- Number of rice mills in Bangladesh by division and type of mill, 2014-15

| | Division | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Mill Type | Barisal | Chittagong | Dhaka | Khulna | Rajshahi | Rangpur | Sylhet | Total |
| Husking | 2771 | 2503 | 5198 | 4381 | 4829 | 5712 | 1256 | 26650 |
| Semi-Auto | 117 | 1082 | 1376 | 399 | 225 | 264 | 187 | 3650 |
| Automatic | 1 | 715 | 489 | 262 | 77 | 201 | 371 | 2116 |
| All | 2889 | 4300 | 7063 | 5042 | 5131 | 6177 | 1814 | 32416 |

Source: BBS, 2014.

The goal of this study was to determine the desired grain moisture meter functionality and estimate the value of grain moisture measurement for small holder farmers and for small-scale grain traders, using Bangladesh as a case study. The specific objectives were to: 1) determine the functionality desired by farmers for grain moisture measurement devices, 2) estimate the economic value of improved grain moisture information for smallholder famers and small scale grain traders, and 3) identify the grain moisture meter price threshold for a target market of smallholder farmers and small scale traders.

The hypotheses are:

i. All other things beings equal, Bangladeshi rice farmers would prefer a moisture meter with a digital read out.
ii. There is relatively little price seasonality of paddy rice in Bangladesh and consequently little motivation to store rice for marketing.
iii. Farmers are willing to pay up to US$10 (i.e. 800 Taka) for a grain moisture meter.

This article provides a summary of the methodology and results. Additional details are reported by Akter et al. (2018).

## 2.0 MATERIALS and METHODS

The methodology of this study should be understood in the context of experimental economics which goes beyond asking respondents about their "willingness to pay" (WTF) to more realistic situations (see for instance Cardenas and Carpenter, 2008; Lusk and Schroeder, 2004, Duflo et al., 2008). One of the lessons from experimental economics is that the closer researchers approach real transactions, the more likely respondents will express their true preferences. Previous studies of the value of grain moisture information and measurement devices have demonstrated devices and elicited preferences (Shinamoto et al., 2017; Channa et al., 2018). This study goes beyond previous studies in that grain moisture measurement devices were sold to farmers who pay with their own funds. The voucher sale methodology differs from a commercial transaction mainly because farmers buy from the researchers and not from a retailer. The researchers attempted to arrange for farmers to buy through local agricultural input shops, but shopkeepers were reluctant to handle a small consignment of a new product that would not be part of their long term retail strategy.

The voucher sales were combined with farmer interviews focused on rice production, storage and marketing practices. The interview data helped researchers understand why some farmers purchased moisture meters and not others. The interviews were done during the period Feb. to Sept. 2016. Seven villages were randomly selected from the major rice production districts of Barisal, Comilla, Tangail, Jessore, Bogra, Dinajpur and Habigonj. In each village 20 farmers were randomly selected (Table 2). Akter et al. (2018) provides the questionnaire used. In the January to March, 2017 period, farmer data were complemented by key informant interviews focused on the grain drying and moisture measurement practices of grain traders and millers.

Table 2. Number of rice farmers randomly selected per village. District, Upazila and Village selected randomly.

| Divisions | Districts selected | Upazilas selected | Villages selected | Number of rice farmers selected | Number of rice farmers in each villages |
|---|---|---|---|---|---|
| Barisal | Barisal | Barisal Sadar | Raipura | 20 | 450 |
| Chittagong | Comilla | Chandina | Chikot | 20 | 600 |
| Dhaka | Tangail | Ghatail | Atharodana | 20 | 250 |
| Khulna | Jessore | Monirampur | Bhojgati | 20 | 1100 |
| Rajshahi | Bogra | Shibgonj | Rainagar | 20 | 420 |
| Rangpur | Dinajpur | Biral | Boropukur | 20 | 350 |
| Sylhet | Hobigonj | Madhabpur | Ratanpur | 20 | 400 |
| **Total** | | | | **140** | **2580** |

Source: Field survey, 2016

A voucher sales process was used to measure the value placed on grain moisture information by approximating an actual commercial sale. At the end of the interview, each farmer (respondent) had the opportunity to draw from a container a voucher for purchasing a Post Harvest Loss (PHL) Equilibrium Moisture Content (EMC) meter (Armstrong, 2015). This device was used as representative of the lower cost grain moisture measurement tools being developed. The device was demonstrated as part of the interview process. The voucher was in a sealed envelope with a numerical code on the exterior. The numerical code allowed researchers to track who had chosen which voucher. That voucher allowed the farmer to purchase a grain moisture meter from the research team at a given price. To test the threshold price at which farmers were willing to buy, the voucher prices varied from farmer to farmer.

Based on the meager literature, the voucher prices had a mean of US$20 (about 1600 Taka) and a range of $2.50 to $70 (200-5,600 Taka). The $70 upper end was set at the estimated manufacturing cost of the PHL EMC meters. Throughout this study the exchange rate of 80 Taka per US$ was used.

The PHL EMC meter was designed to provide a digital readout of moisture content of various agricultural commodities (hard wheat, soft wheat, yellow maize, soybeans, paddy rice, and grain sorghum) while in bulk storage based on measurements of relative humidity and temperature (Armstrong, 2015). The PHL EMC Meter makes use of relative humidity (RH) and temperature data to determine the equilibrium moisture content of various agricultural commodities. This meter uses a capacitive polymer-sensing element for an integrated RH and temperature measurement with outputs internally coupled to a 14-bit analog to digital converter and a serial interface circuit on a singular chip. Due to the sensitivity of sensor to grain dust and free moisture, it is protected by a metal tube with openings covered by wire mesh.

The voucher data were analyzed using a probit model to estimate which factors influenced the farmer decision to purchase and use a grain moisture meter. Probit was used because the cumulative normal distribution curve is like the “S” shaped curve often used in analyzing adoption. Greene (2012) provides an overview of probability models including logit, probit, and tobit. Feder and Umali (1993) review the early uses of probability models in agricultural technology adoption studies. Mercer (2004) reviews more recent use of these models in forestry and agriculture. Factors such as age, gender, education, farm area, off farm income and production levels are often are statistically significant in these models. The dependent variable was 1 if the farmer purchased a grain moisture meter and zero if not. The independent variables included in the moisture meter analysis were the purchase price, farm area, annual grain production, and reported off-farm income.

## 3.0 RESULTS

Bangladeshi farmers are aware of the importance of grain moisture in safe storage, but they continue to use traditional methods to measure moisture content of rice. Table 3 shows that out of 140 sampled farmers, 56% preferred to use a probe (like the EMC PHL demonstrated) meter and that 44% preferred a moisture meter that would fit into a pocket like cell phone. It is important to note that farmers usually gave preference to small size and cheaper moisture meters. None of the sampled farmers preferred a table top moisture meter.

To reduce the manufacturing cost of the moisture meter, one option is to eliminate the digital read out and only provide a green light when grain is dry enough storage. Another cost cutting option is building in algorithms only for rice, not for other crops. Out of 140 selected rice farmers in all locations, 76% of farmers preferred the digital read out (like EMC PHL meter) and only 24% preferred a meter with a green light when the grain was dry enough to store. All the sample farmers (100%) preferred multigrain moisture meters which could measure moisture in rice, maize, wheat and other crops.

Bangladesh is a developing country with increasing population density and decreasing farmland area. Most farmers only have one or two hectares of land. As farmers do not have enough cash in hand to meet daily needs, they are accustomed to selling paddy rice beyond household consumption needs immediately after harvest. Forty eight percent say that the main reason for selling at harvest is to eliminate risk. Another 34% indicate that the lower price of wet rice is more than offset by the additional kilograms of moisture being sold. The remaining 19% say that family needs are urgent and they must sell at harvest.

Simple calculation suggests that if they could tolerate the risk and delay family cash needs, farmers could gain by drying grain before sale. In the survey the average price for dry rice at about 14% moisture is 14.6 Taka/kg (~US$0.18/kg), while the average for high moisture rice at 16% to 18% moisture is 10.7 Takas/kg (~US$0.13/kg). This indicates that on average there is a 3.9 Taka/kg (~US$0.05/kg or 27%) discount for a 2% to 4% difference in grain moisture.

Many farmers store rice on the farm for family consumption and seed. Average annual loss of rice farmers due to high moisture during storage was 52 kg and varied from 41 kg to 65 kg in different study villages. The average monetary value of rice lost in storage was 563 Taka (~US$7.04) and ranged from 424 Taka (~US$5.30) to 650 Taka (~US$8.13) per household.

Sample farmers said that if they could purchase an affordable grain moisture meter, 56.4 percent would store 50 percent of their rice, 35 percent would store 75 percent of their rice and 12 percent of farmers would store all the rice they produce. Among all the rice farmers, 63.6 percent reported that they would receive a higher price at the time of selling and 36.4 percent would feed family members in off season if they could have stored more rice at home.

When presented with the opportunity to purchase a grain moisture meter, 23% of the participants did so at an average price of 374 Taka (i.e. $4.67). The prices that they acted on were 200 to 800 Taka (i.e. US$2.50 to US$10.00). No farmer acted on a price over 800 Taka (US$10.00). In demographic terms the major differences between the farmers who purchased a moisture meter and those who did not is that the purchasers tend to have larger farms, more rice area and greater rice production (Table 3). The average farm area of purchasers is about 1.2 ha, while for non-purchasers about 0.6 ha. Similarly, the rice area for purchasers averages 1.1 ha, while for non-purchasers  0.5 ha. The average rice production for purchasers is over 9 tons, while for non-purchasers  about 3.5 tons.

Given a farmer with enough rice production to use a moisture meter, the voucher price seems to be the key factor in determining the purchase decision. Among the 14 farmers that were offered a moisture meter at the 200 Taka (~US$2.50) price, 10 purchased (71%) including all the farmers with over 1.2 ha of land. Among the 16 farmers that were offered the 400 Taka price (~US$5), 50% purchased. Among the 15 offered the 600 Taka (~US$7.50) price, only 20% purchased and among the 13 offered the 800 Taka (~US$10) price only 15% purchased. At the 200 Taka (~US$2.50) price most farmers with larger farms and greater surplus rice production purchased, but at the 800 Taka (~US$10) price even some farmers with over 1.2 hectares of rice did not purchase, probably because they felt the price was too high.

The data were analyzed using a model to estimate which factors influenced the farmer decision to purchase a grain moisture meter. The dependent variable was 1 if the farmer purchased a grain moisture meter and zero if not. Based on the variable typically used in new technology adoption analyses, the independent variables used include the voucher price, farm area, rice area, annual rice production, age, education and reported off-farm income. The means of these variables are given in Table 3. For analysis the data was scaled with rice production in terms of tons, voucher prices in 100 Taka units and off farm income in 10,000 Taka units.

317 Table 3. Demographics for moisture meter purchasers and non-purchasers by voucher price

| Voucher price, Taka (US$) | No. of farmers at that price | Average age | Average years of education | Average area (ha) | Average rice area (ha) | Average rice prod.(kg) | Average off farm income, US$ |
|---|---|---|---|---|---|---|---|
| Purchasers | | | | | | | |
| 200 ($2.50) | 10 | 42 | 7 | 1.3 | 1.2 | 9164 | 1348 |
| 400 ($5.00) | 8 | 51 | 8 | 1.3 | 1.2 | 11300 | 1392 |
| 600 ($7.50) | 3 | 54 | 3 | 0.6 | 0.4 | 3320 | 10250 |
| 800 ($10.00) | 2 | 51.5 | 8 | 1.1 | 0.9 | 10720 | 875 |
| Sub-Total | 23 | 47 | 7 | 1.2 | 1.1 | 9280 | 1280 |
| Non-Purchasers | | | | | | | |
| 200 ($2.50) | 4 | 64 | 2 | 0.5 | 0.4 | 3180 | 797 |
| 400 ($5.00) | 8 | 44 | 8 | 0.7 | 0.5 | 3210 | 1311 |
| 600 ($7.50) | 12 | 54 | 6 | 0.5 | 0.4 | 3190 | 574 |
| 800 ($10.00) | 11 | 52 | 7 | 0.6 | 0.6 | 3992 | 1118 |
| All <=800 ($10.00) | 82 | 52 | 6 | 0.6 | 0.5 | 3445 | 939 |
| Sub-Total | 117 | 48 | 5 | 0.6 | 0.5 | 3310 | 1051 |
| **Total** | **140** | **48** | **6** | **0.7** | **0.6** | **4291** | **1089** |

Table 4. Probit estimates identifying key factors in moisture meter purchase decisions

| Variable | Coef. | Std. Err. | z | P > \|z\| |
|---|---|---|---|---|
| Age | -0.0185 | 0.0155 | -1.20 | 0.232 |
| Education | -0.0027 | 0.0545 | -0.05 | 0.961 |
| Farm area | -0.2584 | 0.5342 | -0.48 | 0.629 |
| Rice Area | 0.1756 | 0.5703 | 0.31 | 0.758 |
| Production | 0.1860 | 0.0892 | 2.08 | 0.037 |
| Voucher | -0.3458 | 0.0821 | -4.21 | 0.000 |
| Off Farm Income | 0.0119 | 0.0222 | 0.54 | 0.591 |
| Constant | 1.5541 | 0.9584 | 1.62 | 0.105 |

Number of obs = 140

LR $chi^2(7)$ = 67.41

Prob > $chi^2$ = 0.0000

Pseudo $R^2$ = 0.5389

Gender was not included in the probit analysis because only five women heads of households were interviewed and none of them decided to purchase the moisture meter. Their non-purchase decision was probably made because of the relatively high voucher prices that they drew, not because of any gender related factor. For the estimation, gender was a perfect predictor for non-purchase and created a statistical estimation problem.

The coefficients of the probit regression equation and related statistics explaining probability of purchasing a grain moisture meter are shown in Table 4. The Chi Square test is highly significant and the Pseudo $R^2$ is a substantial 54%. The voucher price was the most significant factor in the estimate. Annual rice production was also significant at the 5% level.

Table 5. Probit margins effects estimates for moisture meter purchase decisions

| | dy/dx | Std. Err. | z | P > \|z\| |
|---|---|---|---|---|
| Age | -0.0021 | 0.0017 | -1.23 | 0.219 |
| Education | -0.0003 | 0.0063 | -0.05 | 0.961 |
| Farm area | -0.0297 | 0.0616 | -0.48 | 0.630 |
| Rice area | 0.0202 | 0.0657 | 0.31 | 0.759 |
| Production | 0.0214 | 0.0094 | 2.28 | 0.022 |
| Voucher | -0.0397 | 0.0055 | -7.23 | 0.000 |
| Off Farm income | 0.0014 | 0.0025 | 0.54 | 0.590 |

The marginal effects estimates in Table 5 show that a 100 Taka increase in the voucher price results in a 4% reduction in the probability of purchase. A one ton increase in annual rice production results in a 2% increase in the probability of purchase. Other factors are not statistically significant different from zero.

In the July to September 2017 period, farmers who purchased grain moisture meters were revisited and asked about their experience in using the instruments. That visit also allowed researchers to verify that the farmer was using the moisture meter and did not just use the voucher to buy it for someone else (e.g. a grain trader relative) or resell it. The follow up study revealed that out of the 23 farmers who purchased moisture meters, 18 used the devices. Seven farmers bought a moisture meter, but did not use it. Ten of the 18 farmers used it in all seasons, four used the meters in the Boro season only, one used it for the Aus season and three for the Aman season. Twelve farmers used the meter for rice only and six other farmers used it for three crops such as rice, maize and wheat. Regarding usefulness, five, seven and six farmers reported that the moisture meter was very useful, useful and not so useful respectively. The results indicate that about two thirds of those who bought a moisture meter said that it was useful or very useful. It can be noted here that after using the moisture meter the farmers stored 20-100% of their paddy production. In terms of benefiting from stored paddy, the farmers stated that they were able to feed the family in off season and they received a slightly higher price when sold. Out of 18 farmers who used the moisture meter that they purchased, ten farmers expressed that they could avoid their loss of stored paddy from insect and pests after using the moisture meter.

Finally, the farmers who used moisture meters were asked regarding problems faced when using the meter. The farmers responded with two problems: 1) the battery became quickly exhausted and had to be replaced, and 2) the shape and size of the probe was not user friendly. Their suggestions were that the battery should be rechargeable and the size should be small like a cell phone.

Key informant interviews were done with 30 rice millers. The husking mills and semi-automatic mills all reported using open sun drying, while the automatic mills used mechanical drying. The husking mills reported losing 10% to 15% of their rice every year to mold and spoilage in storage. The semi-automatic mills reported losing 5% to 10% annually. Among those millers, all of the husking mills and semi-automatic mills used traditional grain moisture measurement methods. A few of the automatic mills had counter top grain moisture testers. They reported paying 22,000 Taka (~US275) to 35,000 Taka (~US$438) for their grain moisture testers. Many of the millers expressed interest in the PHL probe meter and estimated that they would pay 3000 Taka (~US$37.50) to 5000 Taka (~US$62.50) for this type of meter.

## 4.0 DISCUSSION

Bangladeshi farmers interviewed in this study say that on-farm rice storage is mainly for the purpose of household consumption and seed. Michler and Balagtas (2013) also found that for low income Bangladeshi farmers, grain storage is mainly for consumption and seed. They find storage for marketing increases with higher income and for less risk averse producers. Because of multiple harvests each year, price charts show relatively little rice price seasonality in Bangladesh and consequently little motivation to store rice for marketing. However, grain moisture information is still important for marketing because farmers can improve returns by selling dry grain shortly after harvest, instead of wet grain direct from the field..

The 52 kg average rice storage loss reported in this study is 1.2% of the average total production of 4291 kg. This estimated storage loss is in the range of loss levels reported by other researchers. Calverley (1994) reported 0.9% loss in storage for Bangladesh. Begum et al. (2012) reported 0.8% storage loss for the Aman harvest and 0.6% loss for the Boro harvest in the Rangpur district. Abedin et al. (2012) reported an average of 3.92% loss based on a survey in 96 villages representing all the divisions of Bangladesh.

The voucher sales showed that Bangladeshi farmers are willing to pay up to US$10 (i.e. 800 Taka) for a grain moisture meter. Moisture meter sales were mostly to farmers with over 1.2 hectares of land and several tons of rice production annually. Channa et al. (2018) reported a willingness to pay by Kenyan farmers of an average of US$1.20 for a hygrometer that can measure the temperature (T) and relative humidity (RH) of the air around the grain. The RH measurement with the hygrometer requires 15 to 20 minutes in contrast with the PHL EMC grain moisture reading which can take up to 6 minutes. With temperature and EMC table lookup this RH can provide an indirect grain moisture estimate. Alternatively, T and RH data can be input into a new spreadsheet tool that calculates and displays the EMC of 11 different grains using the same equation programmed into the PHL meter (McNeill, 2018). In contrast, IRRI researchers conclude that their electrical resistance moisture tester is too expensive for most rice farmers in South Asia (IRRI, 2013). IRRI researchers estimated that their tester would sell for US$35 with mass production. Over the last decade, the IRRI grain moisture meter has been provided to farmers in some research and development projects in south Asia, but it has struggled to find a commercial market.

Among the Bangladeshi farmers interviewed, the stated preference for the size and shape of the moisture measurement device was slightly in favor of a probe type, but in discussion respondents favored a pocket sized device (like a cell phone). One limitation of this study was that only a probe type device was demonstrated and sold. It would have been better to demonstrate and sell several different grain moisture measurement devices.

The Bangladeshi farmers interviewed preferred a digital readout and ability to test moisture for a range of grains. The IRRI grain moisture meter, which has struggled to find a commercial market, is for rice only and does not have a digital readout. It offers a green light when grain was dry enough to store as grain and a yellow light when it is dry enough to store as seed (IRRI, 2013). In comparison, the DryCard (UC Davis, 2017) essentially provides the same information at the IRRI meter, but at a very low cost (~$US 0.1).

## 5.0 CONCLUSION

For research teams focusing on the development of low cost grain moisture measurement tools for use in the developing world, this study suggests that the design criteria should include:

- Retail sales price under US$10
- Digital grain moisture readout
- Usable for a wide range of grains

Teams should consider the shape and size of the device. Farmers who purchased and used the PHL EMC device said they would have preferred a pocket sized device like a cell phone.

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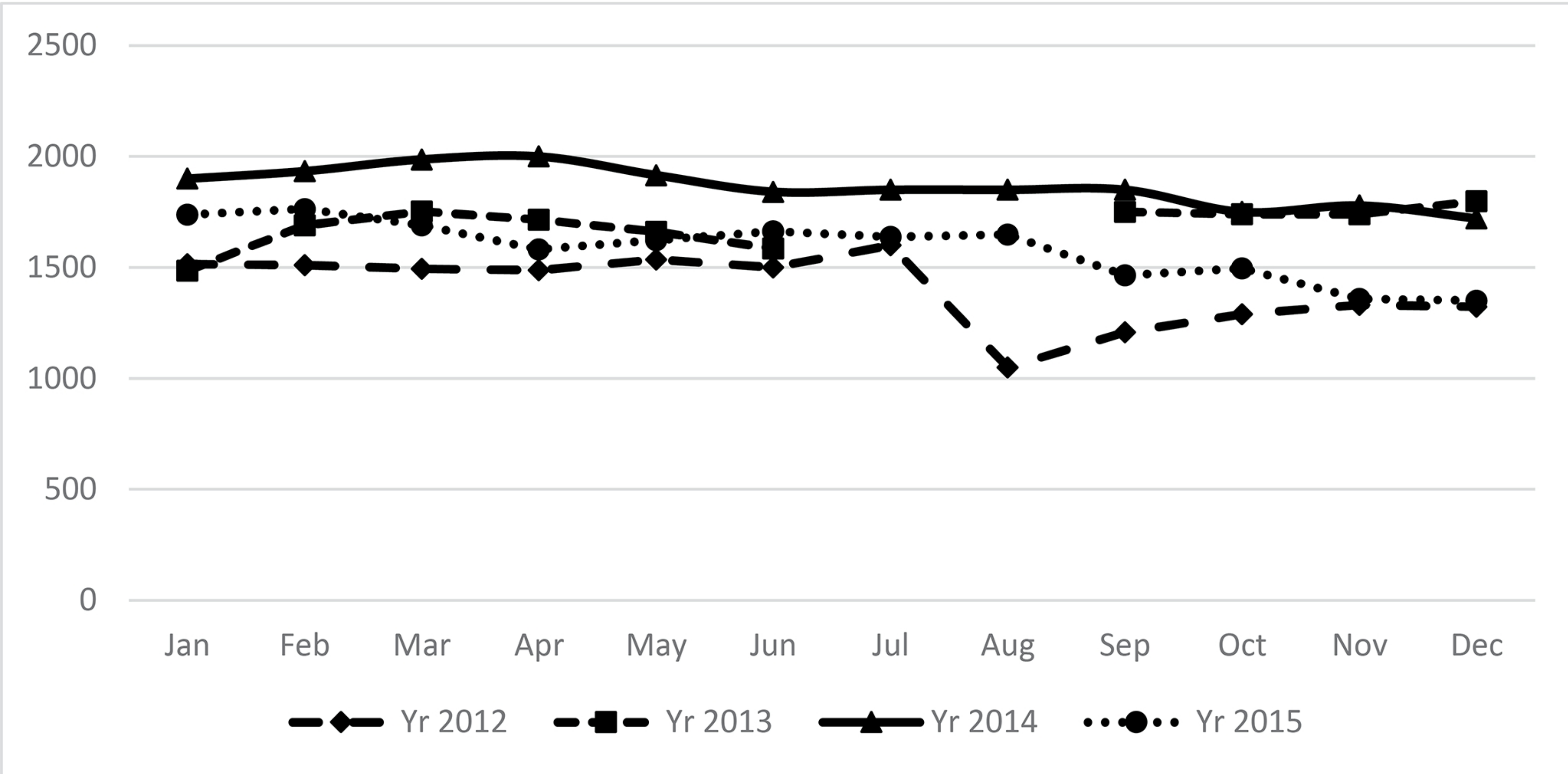
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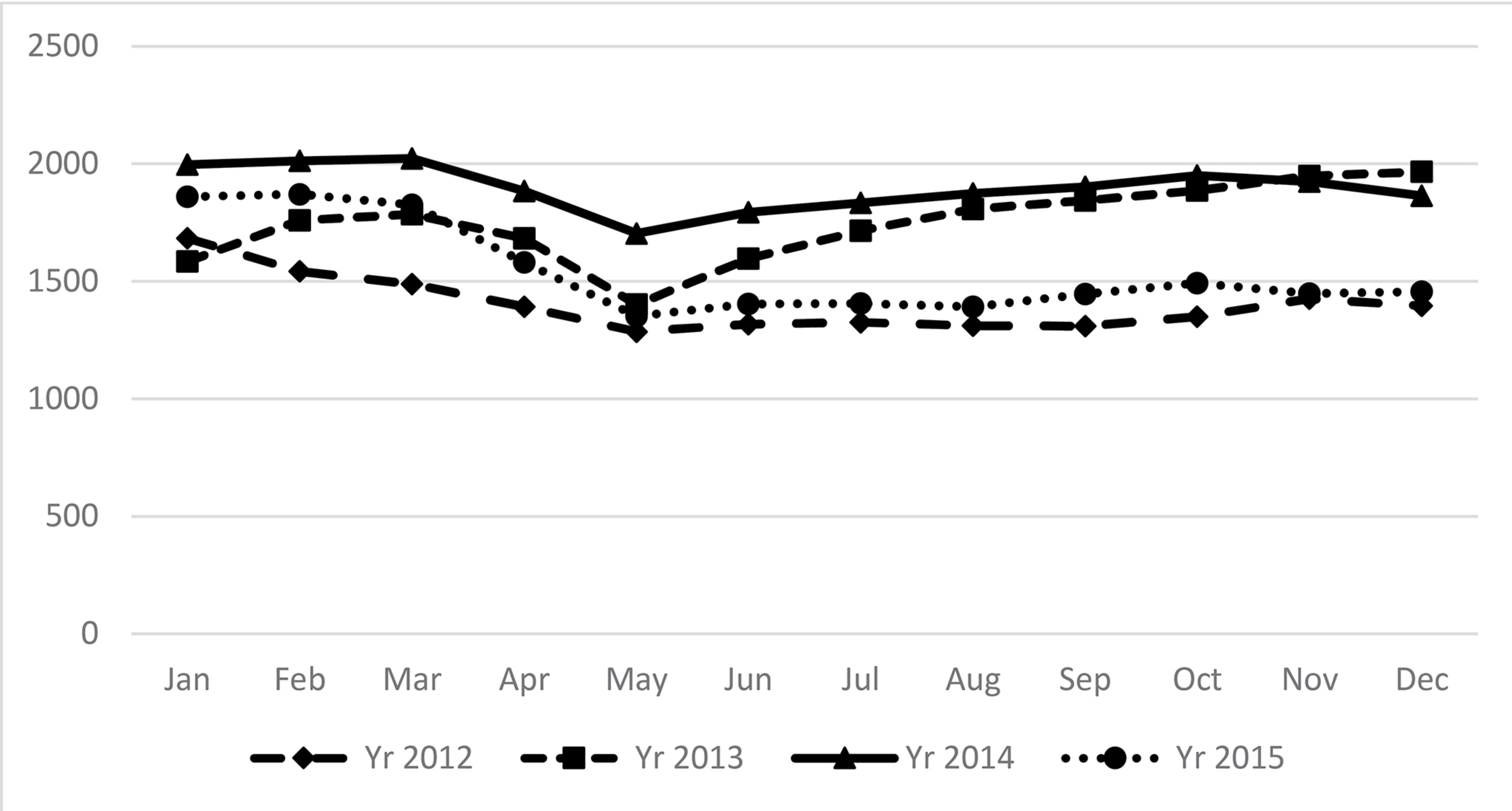
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**Figure captions**

Fig 1: Bangladesh average whole price of Aman season paddy during 2012-2015. Aman season rice is usually harvested in December and January.

Source: BBS (2014-2016)

Fig 2: Bangladesh average wholesale price of Boro seasons paddy rice during 2012-2015. The Boro season harvest is typically in April and May.

Source: BBS (2014-2016)