The Economics of On-Farm Rice Drying in Arkansas

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Abstract

Globally, rice producers are faced with the temporal problem of deciding the optimal time to being rice harvest. When harvested, paddy rice is typically at a moisture content (HMC) between 15 and 22%. Upon delivery, the rice is subsequently dried by the mill to a moisture content (MC) of 12.5%. Riceland Foods Inc., the largest miller of rice in the world, uses a stair step pricing model to charge farmers to dry in price/unit as the MC of grain decreases from a range of +22% to 13.5%. This study estimates an alternative linear relationship in the stair step model to determine MC that incur a cost penalty/savings for commercial drying. Using current building, operating, insurance, and financing costs, we will then estimate the total fixed and operating costs to establish and run an on-farm rice drying and storage facility with capacities between 50,000 and 200,000 bushels over the lifetime of the drier at varying rates of farm size and rice yield, while drying from a range of 16 and 23% HMC. A cost/benefit analysis compares on-farm operating to the current Riceland drying costs. The main deliverable from this study will be a payback-matrix rice producers can use to determine how many years a specific size farm with a specific yield will take to payback the cost of building an on-farm drier. The results will help farmers determine the feasibility of on-drying on their operation and potential savings associated with that operation.

Introduction

Globally, rice producers are faced with the temporal problem of deciding the optimal time to begin rice harvest. Rice is unique in that producers are paid both on the quantity (paddy yield) of rice produced as well as the quality (head rice yield) of the rice, which is not determined until after the milling process. Rice requires a relatively large amount of post-harvest processing, including drying to an acceptable moisture content (MC) for storage and milling to remove the hull and bran layer. Rice is typically harvested between a MC of 20 to 25%, which is higher than the MC required for storage or 12.5% (Rice Knowledge Bank, 2018). Because of this, rice must be dried for storage, which commercial mills charge the rice producers for. It has been found that head rice yield (HRY), which for the purposes of this study is the "quality" of the rice, is directly affected by the moisture content (MC) that the rice is harvested at (HMC) (Dilday, 1989). Rice that has a higher HRY receives a higher premium from buyers, while a lower HRY results in a discounted price. This puts farmers in the predicament of deciding when to harvest, based on HMC. The issue that producers face is that the higher the HMC the higher the quality but the higher the associated drying costs. Conversely, producers can harvest with a lower HMC and face lower drying costs but often-times this results in lower HRY (quality) reducing potential profits. Farmers must decide when to harvest in relation to HMC by determining which is less costly: drying charges or quality discounts.

Empirical studies have found that long-grain rice varieties in Arkansas experience losses in milling quality (HRY) when HMC is above or below the optimal range of 15-22% (Siebenmorgen, Counce, Lu & Kocher, 1992). Compounding the problem is that it has also been found that there is a different optimum HRY for each rice cultivar and type (long, medium, and short grain), and a respective HMC that maximizes HRY (Siebenmorgen et al, 1992). In their research Siebenmorgen et al. (1992) found a convex relationship between HRY and HMC, with a different response curve for each rice cultivar. This compounds a farmer's decision of when to harvest their rice (with regards to MC) by increasing the variation of the optimal HMC to harvest at. Another issue is that the HMC which maximizes HRY often-times does not maximize profits as it does not account for drying costs. Finding the optimal point which maximizes profit is both a difficult and moving target.

Rice must be dried to a MC of 12.5% to be stored, which is below the optimum range of HMC to maximize HRY. Drying costs are deducted from the unit-price that a farmer receives for their rice and vary with HMC. Because of this, the HMC that maximizes HRY (quality) may not be the most profitable due to drying costs. Nalley et al. (2016) found that the optimal HMC for maximizing HRY in the nine most commonly produced cultivars in Arkansas and Mississippi ranges from 17 to 22%, and the optimal HMC to maximize net present value (NV) ranges from 16 to 20% (Nalley et al, 2016). With this information the decision of when to harvest is further complicated by deciding between harvesting at an HMC that could increase HRY while incurring higher drying costs and harvesting at a lower HMC that could lower drying costs and HRY. This means the producer must decide to maximize NV or HRY, which often times diverge.

Riceland Foods, headquartered in Stuttgart, Arkansas, is the largest rice-mill in the world, processing and marketing 25% of the United States rice crop (Riceland 'Business Lines', 2018). Riceland, which dries rice for its co-op members, uses a stair-step model to price drying-costs within ranges of varying HMCs, so a unit of rice with an HMC within a certain range would incur the same drying cost as a unit of rice at any other HMC in that range. The 2019 drying cost schedule used by Riceland Foods is presented in Table 1 (Riceland 'Marketing Programs', 2019). This stair step pricing method can either lead to large costs savings/additions if you are on the margin of a decrease/increase. This compounds uncertainty for rice producers because the drying cost schedule is not linear and can lead to large increases in drying costs depending on what side of the MC step they happen to fall.

Table 1

Riceland Foods 2019 Rice Drying Fee Schedule

Harvest Moisture Content %	**Drying Costs** cents/bu
Less than 13.5%	30.0
13.6 thru 18.9%	36.5
19 thru 21.9%	43.0
Greater than 22.0%	60.0

One potential way that rice producers can attempt to mitigate drying cost uncertainties associated with the Riceland stair step pricing method is to dry their rice on-farm. Young and Wailes (2002) estimated the cost/bushel (bu) for four types of rice storage and drying systems, ranging in investment cost from $3.00 to $4.00 per bu, with capacities ranging from 15,000 to 200,000 bu. The Young and Wailes study utilized the on-farm drying and storage computer model (OFDRY), using data from 1999 and 2000 for their initial 2001 study and updating that information with 2001 cost data for their 2002 study. In the 2002 study, in a comparison of on-farm drying facilities versus commercial facilities, at an HMC of 19%, commercial drying rates were $0.35/bu, while on-farm drying costs when only being used for rice ranged from $0.37 to $0.48/bu (Young & Wailes, 2002). At the time of the Young and Wailes study, 2002, it was not profitable for farmers to dry on-farm unless using the facility to dry well over 200% of its storage capacity of rice where costs for a 60,000-bu facility were as low as $0.30/bu or using the facility to dry rice, corn, wheat, and soybeans where rice drying costs range as low as $0.21/bu

(Young & Wailes, 2002). The study by Young and Wailes (2002) does not factor in higher HRY associated with drying on-farm that some producers had reported. The increase in HRY could possibly also help retain the NV lost when deviating from the optimal HMC that maximizes NV. The Young and Wailes study was conducted in 2001 and since then pricing factors that have changed, such as updated technologies for drying grain, the higher cost of building storage facilities, higher propane costs, and higher labor costs. Further, the Riceland drying fees have also changed altering the relative cost comparison. For these reasons, on-farm drying costs necessitate a reevaluation with regards to profitability.

There are several emerging technologies and techniques in rice drying, which could increase the profitability over the methods used in Young and Wailes (2002) evaluations. One such technique is the use of crossflow dryers to rapidly dry rice. Crossflow dryers are commonly used in corn, but recent research has evaluated the use of these dryers for rice. Billiris, Siebenmorgen, and Baltz (2014) found that the energy costs to dry rice with MCs ranging from 16.6 to 21.7% to below 13%, ranged from 7.7 to 12 cents/kg water removed. This study was based on measurements taken from a crossflow dryer system in Pocahontas, AR and comprised of five tests in September-October 2011 and July-October 2012 (Billiris et al, 2014).

Previous studies have analyzed the impact of HMC on NV through HRY, to costs of commercial drying systems. To date there is a void in the literature on the impact of on-farm drying on NV at varying HMC using on-farm drying costs. As such, the objectives of this study are to:

1. Simulate 1000 random HMC's and estimate if the stair-step drying method put forth by Riceland foods is more profitable (in terms of lower costs) compared to a hypothetical (but more intuitive) linear drying schedule.

2. Estimate the cost ($/bu) to build, maintain and dry rice using an on-farm drying and storage facility over the useful life of the facility.
3. Estimate the number of years it would take to breakeven from the construction and utilization of on on-farm drying assuming varying, dryer capacities, farm sizes and yields.

This study is pertinent given the thin margins rice producers are currently experiencing. The results from this study should give rice producers an idea of payback time, profitability and feasibility of building an on-farm drying facility given farm size and expected yields.

Literature Review

As described by Nalley et al. (2016), rice producers are faced with the dilemma of selecting the optimal HMC level to begin harvesting. This is because producers are faced with: harvesting at a higher HMC that could increase drying costs at the mill while improving HRY or harvesting at a lower HMC to save drying costs but possibly decreasing HRY due to fissuring (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016). These findings implied that when farmers only focus on maximizing HRY, they diminish their potential NV by harvesting at sub-optimal HMCs (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016).

Dilday (1989) found a significant, inverse relationship between HMC and the percentage of broken kernels among the eleven cultivars they tested at the Rice Research and Extension Center in Stuttgart, AR. The cultivars tested by Dilday (1989) were Bond, Leah, Lebonnet, Lemont, L202, Mars, Newbonnet, Newrex, Nortai, Starbonnet, and Tebonnet. In a study by Siebenmorgen et al. (1992) the HRY in rice harvested on the last harvest date (2 October 1989, day of year [DOY] 275) and a generally lower HMC was lower than those on earlier harvest dates with a generally higher HMC (up to 22%). This relates to the earlier study by Dilday

(1989) which found the significant inverse relationship between HMC and HRY. Siebenmorgen, et al., (2008) also found that quadratic relationships characterize changes in HRY and NV across HMCs. Rice is priced on paddy yield and milling quality, as the price of brokens increases, the harvest moisture content that optimizes net value ($HMC_{opt\text{-}NV}$) at which NV was maximized decreases (Siebenmorgen, et al., 2008).

In the long grain cultivars tested by Siebenmorgen, Counce, Lu and Kocher (1992), ‘Newbonnet’, ‘Lemont’, and ‘Tebonnet’, they found no significant change in HRY at HMCs ranging between 15-22%. For 'Newbonnet' no significant change in HRY was noted at HMCs between 15-22%. The harvest moisture content that maximized head rice yield ($HMC_{opt\text{-}HRY}$) for 'Lemont' ranged between 18-22%, although HRY variation was generally not large when the rice was harvested between 15-22% MC. 'Tebonnet' rice also did not have a significant change in HRY when harvested with average MC's between 14% and 22% (Siebenmorgen et al., 1992). Among the nine most-commonly produced cultivars in Arkansas and Mississippi in 2013, the optimal HMC to maximize HRY ranged from 17-22% while the optimal HMC to maximize NV ranged from 16-20% (Nalley et al. 2016). These cultivars were Rex, Taggart, XL753, CL 111, CL 151, CL XL745, Roy J, CL152 and CL XL729. Studies have shown that when HMC, NV, and HRY were plotted regardless of cultivar, location, or harvest year, the HMC at which HRY was maximized was 21.7%. The HMC that maximizes NV was 18.5%. This represents a 3.2% difference between $HMC_{opt\text{-}HRY}$ and $HMC_{opt\text{-}NV}$ (Siebenmorgen, et al., 2008).

Because of its impact on NV per bu and per acre, producers are interested in the response function of deviating from the optimal HMC that maximizes NV (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016). Once again, because of the economies of scale in rice production that limit the pace of harvest farmers must consider multiple factors to maximize profitability through the selection of harvest time: paddy yield (quantity), HMC to maximize HRY (quality), and the rate at which quality diminishes as it moves away from the HMC level (Nalley et al., 2016). Another confounding issue is that as farm size increases so does the variability of HMC. That is, often large rice producers start harvesting when HMC is too high and finish when the HMC is too low in the hopes of averaging the optimal HMC.

The study by Nalley, Dixon, Tack, Barkley, and Jagadish (2016) found that overall, hybrid cultivars in the study had a greater NV than all conventional cultivars because of higher yield potentials and less punishment for deviating from $HMC_{opt\text{-}HRY}$. Conventional cultivars, on average, were more susceptible to the economic penalties associated with harvesting at sub-optimal HMCs than hybrid cultivars on a per hectare basis (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016). In other words, hybrid cultivars were more lenient (in terms of deviation from maximum profitability) when deviating from the optimal HMC. The analysis suggests that as acreage increases past harvest capacity, hybrids have a distinct advantage over conventionals because the economic penalties associated with deviating from $HMC_{opt\text{-}HRY}$ are less in hybrids than conventionals (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016). This can be seen in further analysis, that found that hybrids maintained a greater NV than all of the conventional varieties in the study that were harvested at their optimum HMC, even when the hybrids were harvested at 5% above or below their $HMC_{opt\text{-}HRY}$ (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016). Hybrids have a greater NV because of their inherent large paddy yield in comparison to conventional cultivars (Nalley, Dixon, Tack, Barkley, & Jagadish, 2016).

While hybrid technology can potentially benefit a farmer’s profits, conventional cultivars are typically preferred by commercial mills due to less variation in HRY. On their website, Riceland lists eight different rice cultivars as “Preferred Varieties”: CL 153, CL 172, CL XL745, Diamond, LaKast, XL753, Jupiter, and Titan (Riceland 'Marketing Programs', 2018). Of these eight varieties, six are conventional cultivars. This is because of a higher quality associated with conventional varieties, as seen in the Arkansas Rice Cultivar Testing, 2016-2018 (Hardke et al., 2018). Interestingly, over 40% of the state of Arkansas was sown to hybrid cultivars in 2018. While Nalley et al., (2016) found that varietal selection is a larger factor in determining the profitability of a rice crop than HMC, once the seed is sown, HMC selection influences the overall profitability.

Table 2

Riceland Foods 2015 Rice Drying Fee Schedule

Harvest Moisture Content %	**Drying Fee** Cents/bu
Thru 13.5	25
13.6-18.9	30
19.0-21.9	35
22 or more	50

When harvested, rice typically has an HMC ranging from 15-20%, but to prevent mildew and rot it must be dried down to a MC of 12.5% (Rice Knowledge Bank, 2018). Because of this, farmers are charged a drying fee based on MC when delivering to a commercial mill. That is, the mill will sample each load a producer brings to the mill for MC and then will charge drying fees based on the MC. One study quantified the total cost to dry rice to 12.5% to range from 2.4-3.3 cents/kg water removed in 2011 and 3.1-3.5 cents/kg water removed in 2012 using varying drying air temperatures from 30*C-70*C, electricity costs of 4.6 cents/kWh, and the natural gas prices of 2011 and 2012 (Billiris & Siebenmorgen, Energy Use and Efficiency of Rice Drying Systems II. Commercial, Cross-Flow Dryer Measurements, 2013). The equations given in this article can be used to estimate the commercial drying costs for varying HMCs down to 12.5%.

In the study by Nalley et al. (2016), the drying costs used to determine NV across HMCs were based on Riceland Foods’ 2015 drying schedule, presented in Table 2. The drying schedule is set up so that within a given range, any MC in that range is subject to the same price. For example: a bu of rice brought in at 14% and a bu of rice brought in at 18.5% would both be charged $0.30/bu for drying costs because they are in the same drying bracket. Riceland Foods has since updated their rice drying schedule with the 2019 schedule is shown on Table 1 (Riceland Foods ‘Marketing Programs’, 2019).

Theoretically, the rise in the price of rice drying would cause the $HMC_{opt\text{-}NV}$ to shift to a lower HMC and the drying costs to increase at each level of MC. This could negatively affect the NV of rice and hurt the overall profitability of rice producers.

An accompanying work to Billiris’ (2014) work on commercial rice drying by Billiris, Siebenmorgen, and Baltz (2014) quantified the costs of on-farm drying using cross-flow drying systems. Billiris, Siebenmorgen and Baltz (2014) found that in 2011 and 2012, the total cost to dry rice was 2.3-3.3 cents/kg water removed. This was found using the long-grain cultivar XL745, thermal energy ranging from 6,900-9,760 kJ/kg water removed for seven tests, thermal energy efficiency ranging from 26% to 36%, drying air temperature ranging from 30*C-70*C and ambient temperatures varying from 10*C-25*C. The study found that drying air T, ambient T, and MC were relevant factors affecting energy use and efficiency, and therefore affect the cost of on-farm drying (Billiris, Siebenmorgen, & Baltz, Energy Use and Efficiency of Rice-Drying Systems I. On-Farm Cross-Flow Dryer Measurements, 2014).

Using the OFDRY model, a PC executable file that allows the user to specify specific facility size, type, alternative commodities for use, volume, and other design and cost items, Young & Wailes (2002) updated and quantified the costs for rice drying as well as associated costs and benefits with on-farm drying in 2001. The investment cost per bu for drying and storage systems at full retail price for all system components ranged from \$3.00-\$4.00 for the largest systems at a capacity of 200,000 bu where inline leg and circle leg systems had higher investment costs per bu than the inline auger and circle auger systems (Young & Wailes, 2002). When used at 200% capacity for 100% usage for drying and storing rice for 6 months, the cost is as low \$0.45/bu for a 130,000 to 200,000 bu capacity system (Young & Wailes, 2002).

In Young and Wailes' study (2002) commercial drying costs were \$0.35/bu at an HMC of 19% and on-farm drying costs for inline auger facilities of varying sizes at 100% utilization ranged from \$0.37 to \$0.48/bu. While this rate is not competitive to the commercial drying costs at the time, utilization rates above 100% have costs/bu that are competitive with commercial drying rates with a 60,000-bu facility ranging as low as \$0.30/bu at a 200% utilization rate (Young & Wailes, 2002). Combining usage with other commodities also reduces the on-farm drying cost for rice, where it ranges as low as \$0.21/bu when used for rice, wheat, corn and soybeans (Young & Wailes, 2002). Logistical advantages can also play a large factor in the decision for a producer to invest in on-farm drying. Between the travel cost advantage of on-farm systems (associated with lower distance to off-loading points and less time used to deliver grain and return to the field), high capacity and high utilization, on-farm systems can compete strongly with commercial rice drying and storage rates used in the study (Young & Wailes, 2002). While there is a risk of rice damage associated with mismanagement of drying and storage, some producers have reported increased rice milling yields (HRY) when using on-farm drying compared to commercial drying (Young and Wailes, 2002).

Table 3

Average Energy Usages and Drying Duration at a Given Moisture Content

Moisture Content (%)	Energy Usage (kWh)	Days
16	18,443.7	24.8
18	22,864.2	30.1
20	27,602.8	35.5
22	32,830.4	41.1

A model created by Atungulu and Zhong (2016) simulated in-bin drying using the software program Post-Harvest Aeration Simulation Tool (PHAST), based on the Thompson EMC model and modified to simulate and assess five different fan control strategies for natural air drying of rice at four Arkansas locations (Jonesboro, AR, West Memphis, AR, Stuttgart, AR, and Monticello, AR using weather data gathered at Greenville, MS). The simulation used a bin of 14.63 m (48 ft) diameter and a drying depth of 6.10 m (20 ft) (Atungulu & Zhong, 2016). This is equivalent to 29,068.46 bu. The study used the fan controls of running the drying fans continuously (CNA), night only (NO), day only (DO), at a set window of the Equilibrium Moisture Content (EMC) of natural air (EMC-NA), and at that EMC window with supplemental heating of ambient air (EMC-H) (Atungulu & Zhong, 2016). This simulation also used rice at HMCs of 16, 18, 20, and 22% down to 13% MC, drying start dates of August, September, and October 15th for the years 1995-2014, and airflow rates (m^3 min-t^{-1})

of 0.69, 1.39, 2.08, and 2.77 (Atungulu & Zhong, 2016). Over all of the different trials and variables, there was a range in drying duration of 15.0 to 66.7 days and a range in total energy consumption from 12,989.6-38,931.9 kWh (Atungulu & Zhong, 2016). The average energy usage and drying duration in days across all other variables for HMCs is shown in Table 3 (Atungulu & Zhong, 2016).

The National Agricultural Statistics Service reported the 2019 the 5-year averages of rice harvest progress in Arkansas for weeks #31-45 of the calendar year. Arkansas has a 5-year average of 98 days to harvest the crop statewide (National Agricultural Statistics Survey, 2019).

Methods

This study utilizes secondary data to determine if on-farm drying is competitive or possibly advantageous, with regards to profitability, compared to commercial drying. First, current commercial costs will be analyzed to determine a linear relationship within the stair step nature of the commercial pricing schedule used by Riceland in 2019. Using historical rice HMC data we will simulate 1,000 HMCs which will need then to be dried to 12.5%. Given that producers harvest rice at varying HMCs, it is imperative to estimate how variability in HMC effects relative profitability between on-farm and commercial driers. From this simulated data we will first estimate the cost of drying each iteration using the 2019 Riceland stair step drying costs (Table 1). Second, because there is no scientific/intuitive merit for the stair step nature of Riceland's drying costs (Table 1) we will run a linear regression to get linear per unit drying costs using the drying costs on Table 1. By comparing these two costs we can see if the stair step method is on average advantageous or punishes rice producers who dry using Riceland's drying scheme.

Next, the fixed cost of building an on-farm drying and storage facility will be determined using quotes from in-state contractors and debt-financing information from in-state lenders while insurance rates are assumed at a fixed rate. The operating costs for the facility will be calculated using energy usage (kWh), energy cost ($/kWh) and labor. Total cost will be derived from fixed costs and the total operating costs used over the life of the system. From there, a payback matrix will be compiled based off the average annual savings/additional costs per bu using the variables of yield and farm size. Assumptions were made for the following factors: HMC, energy usage and costs, labor costs, insurance costs, maintenance costs, building costs, lending, useful life, and yield. @Risk was used in the simulation of the following variables: HMC (from historical HMC percentages in Arkansas), and energy costs (from U.S. Energy Information Administration industrial rates January 2008-September 2018) .

Commercial Costs Comparison

To evaluate the possible benefits of drying using Riceland's 2019 cost schedule (Table 1), we will use the stair step model of commercial drying costs where commercial costs per bu (DC_C) are regressed against HMC. The linear estimation of Riceland's commercial drying costs (DC_{CL}) is shown in Equation 1.

$$DC_{CL} = \alpha + \beta_1 HMC + e \qquad (1)$$

Next, the DC_{CL} for each of the simulated HMC is subtracted from DC_C to find the difference in the two drying costs (DC_{CD}), shown in Equation 2. HMCs where DC_{CD} is greater than or equal to zero will be considered advantageous (positive relative net gains) to farmers. HMCs where DC_{CD} is less than or equal to zero will be considered advantageous to Riceland Foods, Inc.

$$DC_{CD} = DC_{CL} - DC_C \qquad (2)$$

Fixed Costs

This study assumes storage systems with 48' diameter bins and a capacity of approximately 50,000 bu. The systems have an approximate total capacity ranging from 50,000 to 200,000 bu, consisting of 1, 2, 3 or 4 bins, a dump, 10" loop system, sweep augers, concrete necessary for the pad and new ramps, fan systems as deemed appropriate by the contractor, and other electrical hardware required. K&K Construction Incorporated (S. Sheets, Personal Communication, January 21, 2019) and Valley View Agri-Systems (D. Halijan, Personal Communication, January 23, 2019) provided estimates for this project. The quotes provided do not include extra concrete, electrician work, scales, or “smart” technology such as bin management systems. The quoted prices range from \$239,273 to \$617,570 with a cost per bu ranging from \$2.93/bu to \$4.87/bu. To establish a “true” building cost, representative of using an in-state contractor, the quoted prices by size were regressed against price to get a marginal cost/bu of capacity. This is used to determine the building costs of systems ranging from 50,000 to 200,000 bu of capacity, as shown in Equation 3, where building cost (B_C) is estimated as a function of capacity (C_S) in bu. The assumption that building costs are linear is naïve but given the lack of potential builders (and therefore financial quotes) for this project it had to be assumed.

$$B_C = \alpha + \beta_1 C + e \qquad (3)$$

Lending information was provided by AgHeritage (G. Golleher, Personal Communication, August 12, 2019), a branch of Farm Credit Services. AgHeritage provided an interest rate range of 5.5-7.5% to finance grain storage bins over a 10-year amortization period. They project the depreciation of grain storage systems, like the ones quoted, over a 30-40 year useful life. For this study, an estimated interest rate of 5.5% and expected useful life of 35 years were used. The principal amount used will be the building costs in Equation 3. Interest (I) will be equal to the sum of compounding interest payments found using the 2018 Microsoft Excel® Payment (PMT) function over a 10-year amortization period

A static repair factor of 10% is assumed and is used to determine the total value of repairs that will be required by the drying system. Equation 4 where TM is equal to the total maintenance, in dollars, for the entire life of the drying facility, where BC_t is equal to the building cost for a capacity of storage and RF is equal to the repair factor. Annual maintenance (AM in equation 5) is estimated to be TM as estimated in Equation 4 divided by expected useful life (EUL). Annual maintenance per bu (AM_B, equation 6) is estimated to be annual maintenance divided by the fixed storage capacity of a facility.

$$TM = BC_t * RF \tag{4}$$

$$AM = TM/EUL \tag{5}$$

$$AM_B = AM/C_S \tag{6}$$

Insurance rates are assumed to be a static rate of 0.55% of the book value of the asset. A salvage value of $0.00 after a 35-year useful life is used to determine the average book value of the asset. The average book value (ABV) of the asset is equal to the difference of B_C from Equation 3 and the salvage value (S) divided by 2, shown in Equation 7.

$$ABV = (B_C - S)/2 \tag{7}$$

Annual insurance costs (IC_{Annual}) are calculated by multiplying the ABV from Equation 7 by the static insurance rate (R_{Ins}), shown in Equation 8. Total insurance costs (IC_{Total}) are equal to annual insurance costs (IC_{Annual}) multiplied by expected useful life (EUL), shown in Equation 9.

$$IC_{Annual} = ABV * R_{Ins} \tag{8}$$

$$IC_{Total} = IC_{Annual} * EUL \tag{9}$$

Total fixed cost (TFC) is estimated to be the sum of total maintenance (TM), building costs (B_C), total interest cost (I_{Total}) and total insurance costs (IC_{Total}), shown in Equation 10.

$$TFC = B_C + I + TM \tag{10}$$

Operating Costs

HMC was simulated 1,000 times using @Risk with a range of 16-23%, representative of 1,000 potential loads brought into Riceland for drying and comparing that to an on-farm drying facility. The simulated HMCs were used to determine energy usage.

Energy usage data gathered in Atungulu and Zhong (2016) was used to determine energy used for each of the 1,000 HMC simulations. Total energy consumption in kWh (E_T) is estimated using initial moisture content data (HMC_i) which then is linearly regressed based on the relationship of HMC and energy usage from Atungulu and Zhong (2016) to obtain energy usage for each of the 1,000 simulated HMC_i (Equation 11). kWh used per bu (E_{Bi}) for the 1,000 iterations estimated as E_T from Equation 11 is then divided by a volume of 29,068.46 bu (C_D), the capacity for a single 48' diameter bin used in Atungulu and Zhong (2016), as represented in Equation 12.

$$E_{Ti}= \alpha_i+HMC_i+e \quad (11)$$

$$E_{Bi}= E_{Ti}/C_D \quad (12)$$

Agriculture is categorized into industrial usage under the U.S. Energy Information Administration (EIA). The EIA Electric Power Monthly with Data for September 2018 lists an average national industrial energy cost for the years 2008-2017 as well as January to September of 2018, at a range of \$0.0667 to \$0.071 per kWh (EIA, 2018). Using @Risk, the energy costs is simulated 1,000 times ranging from \$0.0663 to \$0.071 per kWh (EC_{HMC}). This represents the uncertainty in power costs a producer would face running their own on-farm drier. These simulated energy costs are then associated with the 1,000 simulated HMCs. Equation 13 represents Energy cost/bu (EC_B) where EC_B is a function of E_B and EC_{HMC}.

$$EC_{Bi}= E_{Bi}*EC_{HMCi} \quad (13)$$

Labor costs are subject to multiple assumptions within this study. Labor cost evaluated is only tied to the loading and unloading of grain into the system and not a function of HMC. Transportation labor is not included in these assumptions. A “truck” in this instance is assumed to be a tractor-trailer with a payload capacity of 55,000 lbs. A bu of rice weighs 45 lbs., so it is assumed that a truck can carry 1,222.22 bu. Equation 14 is representative of the total trucks used to meet the capacity of the grain storage system (T_T) as a function of capacity divided by the capacity of a truck (C_T).

$$T_T = C_S/C_T \qquad (14)$$

Hourly wages are assumed to be $10/hour. It is assumed that:

1. Unloaded: Using a 10” loop system and dump a single worker can unload a truck in 15 minutes (0.25 hrs.) and 100% of trucks are unloaded this way.
2. Loaded: Using a 10” loop system a single worker can load a truck in 15 minutes (0.25 hrs.) and 80% of trucks are loaded this way.
3. Swept: Using a 10” loop system and a 10” sweep auger two workers can load a truck in 30 minutes (0.5 hrs.) and 20% of trucks are loaded this way.

Trucks that are considered loaded, as in Activity 2, are loaded using the 10” loop system and grain is gravity-fed from the bin into the loop system. Trucks that are considered swept, as in Activity 3, are loaded using the 10” loop system and the grain that could not be gravity-fed is fed into the system using an auger in the floor of the bin.

Trucks per activity (T_A) is estimated as a function of T_T and the percentage of trucks needed for that activity ($\%_{Activity}$), represented in Equation 15. Labor per truck for each activity (L_A) is estimated to be a function of the number of workers (*w*) multiplied by the time (*t*) used for each activity, represented in Equation 16. Labor cost for each activity (LC_A) is estimated to be a function of labor per truck (L_A) found in Equation 16, multiplied by T_A found in Equation 15, and then multiplied by the hourly wage (*h*), represented by Equation 17. Total labor cost (TLC) is estimated to be the summation of LC_A found in Equation 17, this is represented by Equation 18. Equation 19 estimates labor cost per bu (LC_B), whereas LC_B is equal to TLC divided by C_T.

$$T_A = T_T * \%_A \quad (15)$$

$$L_A = w * t \quad (16)$$

$$LC_A = T_A * L_A * h \quad (17)$$

$$TLC = LC_{Unloaded} + LC_{Loaded} + LC_{Swept} \quad (18)$$

$$LC_B = TLC / C_T \quad (19)$$

The total operating cost/bu for each of the 1,000 HMC simulations (TOC_{Bi}) is estimated to be the summation of EC_{Bi} and LC_B, shown in Equation 20.

$$TOC_{Bi} = EC_{Bi} + LC_B \quad (20)$$

Total Costs, Savings, and Cost Benefit Analysis

Yield and acreage are integral factors in this study as they determine the throughput on a drier. That is, the larger the farm and larger the yield the higher the throughput lowering payback time, assuming you do not go over capacity. Acreage will be analyzed at 250-acre increments, ranging from 250-2,000 acres. Yield will vary from 150-250 bu/acre at 10 bu increments. This range was determined from the highest and lowest observed observations in the 2018 Arkansas Rice Performance Trials (ARPT) as reported by the Arkansas Division of Agriculture. The amount of on-farm production is estimated to be a function of the amount of area used for rice production (in acres) multiplied by the simulated yield (bu per acre), whereas on-farm production is equal to P_F, area *i* is equal to a_i (area ranges from 20-2000 at 250 acre intervals), and yield for farm *i* is equal to y_i (where yields range from 150 to 250 bu/ac at 10 bu intervals), shown in Equation 21.

$$P_{Fi}=a_i*y_i \qquad (21)$$

For a comparison to be made between on-farm drying costs and commercial drying costs, total drying cost per bu and total savings per bu must be determined. For each simulated iteration of HMC, the appropriate commercial drying costs according to Table 1 are incurred. Difference in drying costs per bu (D_{Bi}) is the difference between the associated commercial drying cost (DC_{Ci}) and the total on-farm operating costs (TOC_B), shown as Equation 22.

$$D_{Bi}=DC_{Ci}-TOC_{Bi} \qquad (22)$$

Annual cost savings (S_{Ai}) are representative of the amount of money saved by a producer at a given acreage and average yield, where it is equal to P_{Fi} multiplied by D_{Bi}, shown by Equation 23. The total benefit over the lifetime of the facility (B_T) is estimated to be equal to EUL multiplied by S_A/1000 (which finds the average annual cost savings for all 1,000 HMC iterations), this is shown in Equation 24.

$$S_{Ai}= P_{Fi}*D_{Bi} \qquad (23)$$

$$B_T= EUL*(S_A/1000) \qquad (24)$$

The drying capacity of each drier will be determined by the amount of cycles each grain bin can run through in a harvest season. The drying durations listed by Atungulu and Zhong (2016) in Table 3 were regressed against HMC. This is used to estimate the drying duration ($D_{Durationi}$) for each iteration (*i*) of the 1,000 simulated HMCs used between 16-23%, shown in Equation 25. The average drying duration (D_{Avg}) will be equal to the sum of the estimated drying durations found in Equation 25 divided by 1,000, shown in Equation 26. The amount of cycles (D_{Cycles}) that a grain bin can handle will be equal to the average harvest duration ($H_{Duration}$)

divided by D_{Avg}, shown in Equation 27. The total drying capacity (C_{Total}) of the system is a function of D_{Cycles}, number of bins in the system (n), and C_D, shown in Equation 28. The proportion of storage capacity that can be dried ($\%_C$) is equal to C_{Total} divided by C_S, shown in Equation 29.

$$D_{Duration(i)} = \alpha_i + \beta_1 HMC_i + e \quad (25)$$

$$D_{Avg} = \sum D_{Duration}/1000 \quad (26)$$

$$D_{Cycles} = H_{Duration}/D_{Avg} \quad (27)$$

$$C_{Total} = D_{Cycles} * n * C_D \quad (28)$$

$$\%_C = C_{Total}/C_S \quad (29)$$

Results and Discussion

Figure 1 illustrates the relationship between Riceland Foods cost schedule (Table 1) and the DC_{CL}, the regressed commercial drying costs, across a range of 12.5-23% HMC. The HMCs where DC_{CL} is greater than or equal to the corresponding commercial rate are considered advantageous to farmers that use commercial drying. This is because the farmers are utilizing commercial drying at a discounted rate compared to what Riceland Foods 2019 charges for those HMCs. The HMCs considered advantageous to farmers are 12.93-13.5%, 16.01-18.89%, and 19.08-21.9%. The HMC where DC_{CL} is less than the corresponding commercial rate are considered advantageous to Riceland Foods, Inc. This is because Riceland is drying at a lower cost compared to the rate charged for those HMCs. The HMCs considered advantageous to Riceland Foods, Inc. are 12.5-12.93%, 13.51-16.0%, 18.9-19.07%, and 21.9-23.0%. The average of DC_{CD} is zero, meaning that Riceland Foods, Inc. 2019 cost schedule (Table 1) is net neutral to producers with respect to a hypothetical linear drying scheme. This simple exercise does not take into consideration of farm size or yield though, both of which can alter preference for on-farm vs commercial drying.

Table 4 shows the regressed building costs and weighted costs/bu of the on-farm drying and storage facilities using the quotes provided by in-state contractors. It was found that building costs increased as capacity increases, with building costs ranging from \$239,466.50 to \$596,789.32 for capacities ranging from 50,000 to 200,000 bu. The weighted costs/bu have an inverse relationship with capacity, as they decrease as capacity increases. The weighted costs/bu range from \$4.79 for 50,000-bu capacity to \$2.98 for 200,000-bu capacity. It was shown that capacity is statistically significant at $P<0.01$, showing a strong correlation between the capacity of the system and the total cost of the system.

Figure 1

Relationship of Linear Commercial Costs and Riceland Foods 2019 Cost Schedule

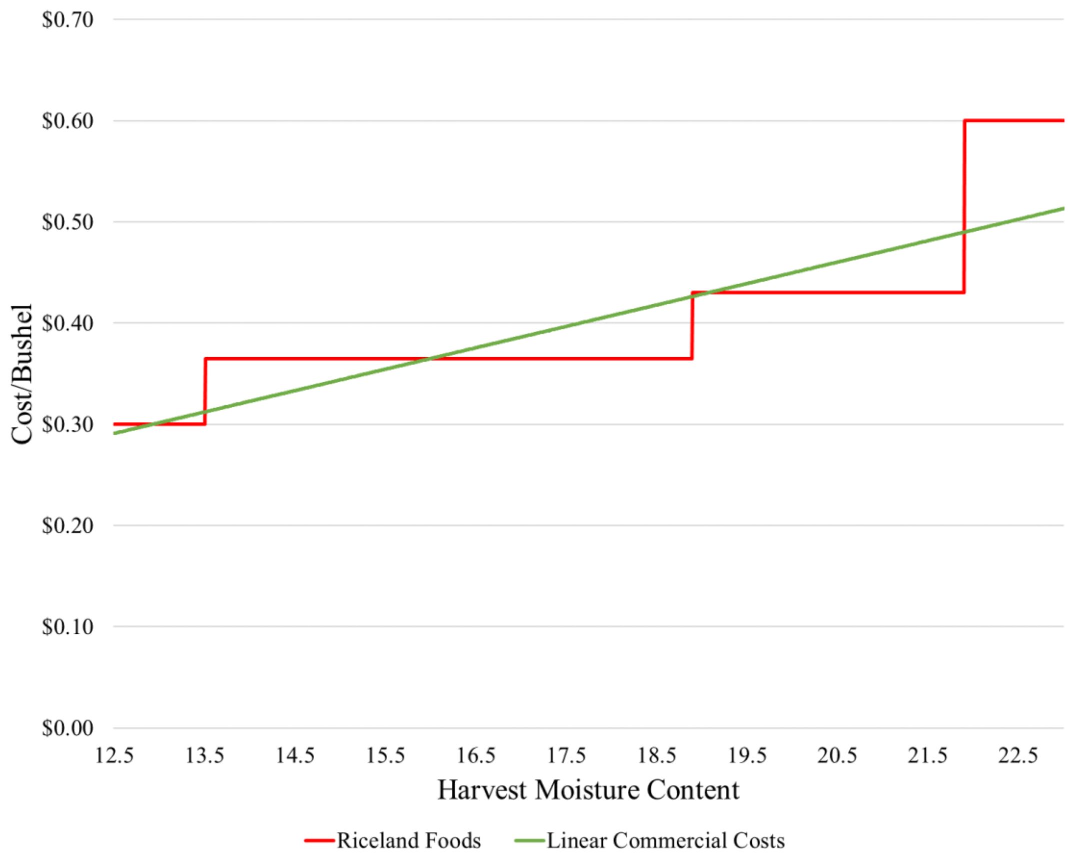


Table 4

Regressed Building Costs and Weighted Cost/Bushel of On-Farm Drying Facilities

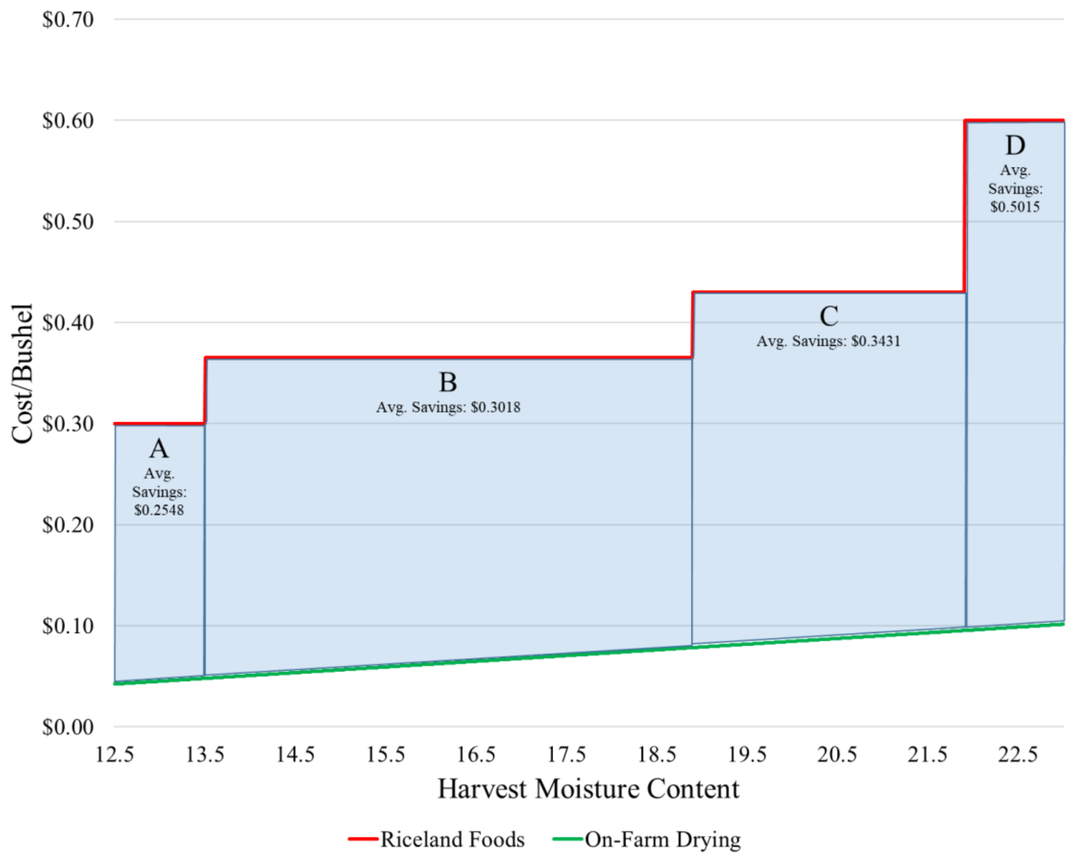
Capacity	Building Cost	Weighted Cost/Bu
50,000	$239,466.59	$4.79
100,000	$358,567.50	$3.59
150,000	$477,668.41	$3.18
200,000	$596,769.32	$2.98

Figure 2 shows the differences in the Riceland Foods 2019 cost schedule and the on-farm operating expenses. When comparing the commercial drying costs to on-farm operating expenses, it was found that there is a savings associated with on-farm drying across all HMCs from 12.5-23%. Table 5 shows the average savings associated with each bracket in the Riceland Foods 2019 cost schedule and the simulated HMCs in the study. The smallest average savings per bu of $0.2548 was for the bracket where HMC is less than 13.5% (A). The highest average savings per bu of $0.5015 was for the bracket where HMC is greater than 21.9% (D). In the 1,000 simulated HMCs ranging from 16.0-23.0% there was an average savings of $0.3341/bu. This is equal to D_B. It is important to note that these "savings" are only incurred once the drier has been paid back. Thus, the payback period is of importance to producers.

Figure 3 shows the payback periods of each capacity system. The payback period is equal to the amount of years needed to payback the total fixed cost of the facility using the annual savings (S_A) at varying production rates. Each system is limited to drying 166.43% of its storage capacity, from Equation 29, in a 98-day harvest season, assuming 100% of the drying capacity is used to dry rice. This harvest season is taken from the 5-year average of Arkansas rice harvest progress from the National Agriculture Statistics Service (2019). When drying at full capacity, the payback periods range from 7.52-12.26 years. The smallest capacity of 50,000 had a payback period of 12.26 years, while the largest capacity of 200,000 had the fastest payback period of 7.52 years. This seems counter intuitive (larger investment is paid back quicker) but the larger throughput of the larger drier helps pay back the initial investment quicker. The 100,000-bu system had a payback period of 9.08 years and the 150,000-bu system had a payback period of 8.04 years when drying at full capacity.

Figure 2

Commercial vs. On-Farm Drying Operating Costs with Average Savings



[a]The graph above shows the difference in on-farm drying operating costs and Riceland Foods, Inc.'s 2019 rice drying fee schedule, [b]Shaded portions are representative of the total savings throughout the range of HMC between its on-farm operating costs and its respective Riceland price. [c]The average savings is listed for each bracket. [d]Brackets: A- HMC<13.5%, B-13.5%< HMC<18.9%, C- 19.0%<HMC<21.9%, D- HMC>22%

Figure 3

Payback Periods for Different Size Farms and Rice Yield for Appropriate Capacities of Drying Systems

Acreage	Yield (Bushels/Acre) 150	160	170	180	190	200	210	220	230	240	250	Capacity
250	27.20	25.50	24.00	22.66	21.47	20.40	19.43	18.54	17.74	17.00	16.32	50,000
500	13.60	12.75	17.78	16.79	15.91	15.12	14.40	13.74	13.14	12.60	12.09	100,000
750	13.44	12.60	11.86	11.20	10.61	10.08	9.60	9.16	11.63	11.15	10.70	150,000
1,000	10.08	9.45	11.80	11.15	10.56	10.03	9.56	9.12	8.73	8.36	8.03	
1,250	10.70	10.03	9.44	8.92	8.45	8.03	9.53	9.10	8.71	8.34	8.01	200,000
1,500	8.92	8.36	9.82	9.27	8.78	8.34	7.95	7.58	na	na	na	
1,750	9.53	8.94	8.41	7.95	7.53	na	na	na	na	na	na	
2,000	8.34	7.82	na	na	na	na	na	na	na	na	na	

[a]Payback periods that are greater than 10 years are highlighted in red. Payback periods that are less than or equal to 10 years are highlighted in green. [b]Arkansas Rice Yield Averages in Bushels for 2018 are labeled to highlight impact of yield and variety selection on payback periods: State-163 (Green Line), Conventional-181 (Red Line), and Hybrid-214 (Blue Line). [c]Black lines in-between cells segment production rates within 166.43% of fixed storage capacity. All production rates above a segment are feasible but may not be optimum for that system capacity. [d]Production rates that are outside the drying capacity of any dryer in the study are labeled as “na”.

Limitations

Limitations to this study could have an impact on the application of this study for producers. Many pricing factors for building costs are variable, in the fact that individual preference could add or subtract certain features that impact initial building costs. Since these are highly specific based on preferences, locations, and logistics, it is impossible to receive quotes for every possible configuration. The inability to secure estimates for electrical, scales, or “smart” bin technology means that building costs were most likely understated and therefore payback periods were also understated. More current quotes for building costs could also affect the payback periods if prices were to change. Because the 98-day harvest season is an average of the entire state’s crop, it is not necessarily representative an individual farm. This would mean that the drying capacities of the systems are overstated and therefor the payback periods at maximum capacity are understated. It should also be acknowledged that this study assumes the farmer commits at least a given amount of production to rice each year. This means that farmers must take crop rotation into account when considering payback periods for each system. A farmer that drops rice acreage without compensating with a yield increase would see a drop in production and would then increase their payback period. The converse is also true, as a farmer that increases production would experience a shorter payback period. The relationship between total production and payback periods can be seen in the 150,000-bu system. At 1,250 acres and 200 bu/acre yields, the system has a payback period of 8.03 years. To drop acreage to 1,000 acres of rice and maintain a payback period of 8.03 years, the farmer must increase yield to 250 bu/acre. This maintains the total production of the farm therefor maintaining its payback period. The system could potentially be used for other crops but is not accounted for in this study.

Conclusion

While the high initial costs of constructing a grain drying and storage system are a significant barrier to entry for many rice producers, on-farm drying could prove to be an effective long-term solution to high commercial drying costs. Farmers that do not wish to construct an on-farm drying facility must carefully time harvest to hit the narrow windows of HMC where commercial drying costs are advantageous to them. While the Riceland Foods, Inc. 2019 drying cost schedule could be considered net neutral to farmers, compared to a hypothetically linear cost curve, on-farm drying seems to be beneficial once payback has occurred.

This study found that on-farm drying facilities require large initial investments and may limit the number of producers who could afford them. Economics of scale seem to hold as increased capacity resulted in lower building cost per bu of storage capacity. Farmers who build on-farm drying and storage facilities must consider the high capital costs and the production capacity of their farm. While a small farmer may believe a smaller facility would be more practical, the high weighted building cost/bu indicates it may not be economically advantageous .

A farmer in the growth stage may decide to purchase a facility larger than their current production to meet future needs, where they could see a discount in weighted building costs/bu when comparing a smaller capacity system to a larger capacity system.

Farmers who build and utilize on-farm drying facilities can see an average savings per bu of $0.3341 across an HMC range of 16-23% when comparing on-farm drying operating costs to Riceland, only however; when they have completed their payback period (which is a function of throughput). Another advantage for on-farm driers found in this study was that producers were estimated to experience higher savings when drying at higher HMCs. This could allow farmers to begin harvest at higher HMCs, or earlier in the year, without incurring high commercial drying costs and maintaining higher HRY percentages.

This study saw that farmers with higher rates of production and systems with larger capacities have lower payback periods. When considering payback periods equal to or less than the amortization period of 10-years as advantageous to farmers, the 50,000-bu capacity system was never estimated to be advantageous. The Arkansas state average rice yield in 2018 was 163 bu/acre (Hardke et al., 2018), and at this level of production a farmer would need at least 1,000 acres of rice for the facility to be feasible within 10 years. Hybrid varieties yield higher than conventional varieties in Arkansas, yielding 214 bu/acre and 181 bu/acre, respectively (Hardke et al., 2018). The higher yields mean that hybrid producers would need a larger capacity than conventional producers. When holding acreage constant hybrid producers would see lower payback periods compared to conventional producers, as long as the production of the hybrid producer does not surpass the 166.43% of the storage capacity.

To further assess the economic benefits of on-farm rice drying, there are several factors that should be studied. When waiting to unload trucks at the buying point, farmers may have to wait hours to unload. This can significantly hamper harvest progress, as many farmers are forced to shut down production until those trucks return. On-farm drying can lead to earlier harvest dates and higher HMCs, which can translate into higher HRY. This would lower the economic penalties to farmers who deviate from harvesting at $HMC_{Opt\text{-}NV}$. On-farm rice storage could also be used to target seasonal pricing highs for rice, increasing the cash price received by farmers.

The results of this study show that on-farm rice drying could be a realistic long-term solution to commercial drying charges. Riceland Foods Inc., drying cost schedule could be considered net neutral to farmers, with the most advantageous to farmers bracket being the most common HMC range of 16-18.9%. This also coincides with the range of $HMC_{Opt\text{-}NV}$ of 16-20% (Nalley et al, 2016). Farmers with access to large amounts of capital are at an advantage when building on-farm storage because of the high initial building costs associated with construction. Larger capacity systems would be considered more cost-effective because of the lower payback periods typically needed. Farmers with higher rates of production would see more benefit from on-farm storage, as shown by lower payback periods for larger capacities and production rates.

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Appendix A

Item A-1

Regression of Riceland Foods, Inc. 2019 rice drying fee schedule

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.826539758
R Square	0.683167972
Adjusted R	0.68286594
Standard E	0.043749458
Observatio	1051

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.329315848	4.329316	2261.90265	4.5587E-264
Residual	1049	2.007801849	0.001914		
Total	1050	6.337117697			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.02647794	0.008009606	3.305773	0.000979231	0.010761267	0.042195	0.010761267	0.042194613
HMC	0.021154189	0.000444795	47.55946	4.5587E-264	0.020281401	0.022027	0.020281401	0.022026977

Item A-2

Regression of Building Costs

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.99685267
R Square	0.99371525
Adjusted R Square	0.99245829
Standard Error	11630.6294
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.06942E+11	1.0694E+11	790.576016	1.0656E-06
Residual	5	676357700.4	135271540		
Total	6	1.07619E+11			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	120365.675	12317.69168	9.77177201	0.00019094	88702.0404	152029.31	88702.04	152029.31
Total Capacity	2.38201824	0.084717526	28.1171836	1.0656E-06	2.1642449	2.5997916	2.1642449	2.5997916

Item A-3

Regression of Electrical Usage

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999379415
R Square	0.998759215
Adjusted R Square	0.998511058
Standard Error	199.6568252
Observations	7

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	160436306.3	160436306	4024.70759	1.8421E-08
Residual	5	199314.2393	39862.8479		
Total	6	160635620.5			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-20074.12143	720.861079	-27.8474203	1.1179E-06	-21927.1538	-18221.089	-21927.1538	-18221.089
HMC	2393.714286	37.73159336	63.4405831	1.8421E-08	2296.72214	2490.70643	2296.72214	2490.70643

Item A-4

Regression of Drying Duration

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.999922
R Square	0.999844
Adjusted R Square	0.999766
Standard Error	0.107238
Observations	4

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	147.4245	147.4245	12819.52174	7.79969E-05
Residual	2	0.023	0.0115		
Total	3	147.4475			

	Coefficients	*tandard Errc*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*.ower 95.0%*	*Jpper 95.0%*
Intercept	-18.71	0.458748	-40.78489	0.000600634	-20.68383461	-16.73617	-20.68383	-16.73617
HMC	2.715	0.023979	113.2233	7.79969E-05	2.611826012	2.818174	2.611826	2.818174