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EVALUATION AND ADAPTIVE MODIFICATION OF A LOW COST PADDY DRYING TECHNOLOGY

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ABSTRACT

A low cost paddy drying technology originating from Vietnam was evaluated and modified to suit the local grain drying requirement. The original design can dry one ton of wet paddy in 2 to 3 days depending on the moisture content and relative humidity of the drying air. Modification of the blower assembly and bin material significantly reduced the drying time compared to the original design. The modified low cost dryer (LCD) can dry wet paddy with more than 24% moisture content, down to a safe level of 18% moisture content wet basis (MCwb) in ten hours. The LCD was pilot tested with prospective end-users to solicit feedback and gauge its acceptability. The respondents compared the LCD with sun drying and suggested that if the dryer cannot dry paddy as fast as sun drying, it is not acceptable to them. It takes 6 to 8 hours to sundry paddy during sunny days compared with 15 to 30 hours in the LCD. But sundrying is not possible during the wet season when it is needed most. Farmers realized that the LCD would be very useful in saving the wet season harvest from deterioration. LCD-dried paddy when milled has higher amount of headrice, comparable milling recovery and whiteness. Testing and evaluation for lower capacities resulted in shorter drying time and lesser energy consumption. Economic analysis showed that using the LCD during the wet season can be economically profitable, depending on the volume of grain dried.

Keywords: farm-level drying, low cost dryer, low temperature drying

I. Introduction

Postharvest losses and labor shortage during peak harvest season are the two major problems of the Southeast Asian rice postproduction system (Gummert, 1998). In the Philippines postproduction losses were estimated at 10% - 37% of the total harvest (De Padua, 1978). In Vietnam, 10 to 25% of the total harvest is being lost due to improper and delayed drying. The introduction of drying technologies at the farm level in the Philippines has always been a difficult challenge. Various drying technologies have been developed and introduced but none were accepted on a wide scale. Low volume of harvest, high investment cost, and market conditions are some of the reasons. Traders in the Philippines accept both dry and wet paddy. Delay in drying result in qualitative and quantitative losses such as reduction in milling and headrice recovery, and grain quality deterioration. In the wet season 4 to 6 attempts are needed to dry paddy down to 14% MCwb. Without drying facilities farmers have no choice but to sell their produce at very low prices dictated by traders. The price of wet paddy is half that of dry paddy resulting in economic loss. Given this constraint, the development of rice postproduction technolo-

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gies was undertaken by the International Rice Research Institute (IRRI) in collaboration with Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) with its project "Postproduction Technologies for Rice in the Humid Tropics". The National Agricultural Research Systems (NARS) of Vietnam, Indonesia, Thailand, and the Philippines participated. Drying principles and concepts were provided to the NARS as basis for developing actual prototypes. Research engineers at the University of Agriculture and Forestry in Vietnam developed the SRR dryer, based on the low temperature in-bin drying and storage principle provided by the GTZ project, which can dry paddy within 3 to 4 days in Mekong Delta conditions (Hien, 1994). The SRR can dry other crops such as coffee, peanut, corn and others boosting the acceptability of the technology to the small farmers. In contrast to the Philippines, farmers in Vietnam have limited market for wet paddy. Realizing the potential of SRR as a farm-level drying technology, the Agricultural Engineering Division of IRRI looked into its possible adaptation and application to other Asian countries particularly in the Philippines. The study specifically aimed to: 1) apply the SRR technology to the need of the small farmers in Asia, 2) adapt its construction with locally available materials, 3) improve its technical design and performance, and 4) determine its acceptability to the end users. The study was done in collaboration with the Philippine Rice Research Institute (Philrice), the Bureau of Postharvest Research and Extension (BPRE), and the Social Science Division of IRRI.

II. Review of literature

Drying is the most important and critical operation after harvesting. It provides initial product stabilization and preliminary control against insect infestation. The drying process significantly determines the milling, cooking, and eating quality of rice (Yamashita, 1993). Some rice varieties develop poignant odor four hours after harvest. Pathogenic microorganisms that cause plant diseases and mycotoxin contamination are normally present in harvested crops (Cogburn, 1985) including spores of fungi. The most abundant pathogenic species include Helminthosporium oryzae (causal agent of brown spot), Alternaria padwickii (which causes stack burn), Curvularia spp., and Fusariun spp. which causes grain discoloration. With enough moisture and heat present, dormant spores become vegetative and resume metabolic and reproductive activities. In the process they produce heat, pigments, waste, and mycotoxins causing grain quality deterioration. Heat in the pile can cause the grain to become yellow to tan (translucent grain that is not completely gelatinized). Therefore fresh paddy must be dried immediately to a safe level of 18% MC_{wb} to prevent quality deterioration. In countries where sundrying is not favorable the lack of appropiate mechanical drying facilities is a severe impediment in maximizing the benefits of increased production (Hien, 1994). This problem exists in China with an annual harvest of 425-450 million metric tons, where approximately 30 million metric tons of high moisture paddy (>24%) are received in depots each year (Yonglin and Graver, 1995).

In developing countries sun drying is the popular practice. It has several advantages including free energy, low investment and operating cost, and low technical skill requirement. The cost of sundrying is five pesos per bag in the dry season and 20 peso average during wet season. Nothing is wrong with sun drying if done properly. Frequent stirring is essential to attain uniform moisture content. Hourly stirring increases drying rate by 67% on the average (Gayanilo, 1980). The intensity of solar radiation, air velocity over the grain, and grain thickness affect the drying rate. However in sun drying, the temperature cannot be controlled resulting in overdrying. The risk of rewetting is high during unpredictable weather condition. Rewetting result in fissured grains. Overdrying and grain fissuring cause poor milled rice quality. Aside from weight loss, overdried grains become brittle and break during milling (van Ruiten, 1985) resulting in low milling recovery. Twenty five percent of the broken grains can be lost during milling due to polishing of the edges (Bautista, 1998). Overdried grains also have poor cooking, and eating quality although they have better storability. A two-stage drying technique for paddy has been developed and is recommended to reduce drying cost and produce grains with good milling quality. It enables safe storage of wet grain for longer periods (Soponrannarit, 1984). The first stage employs high temperature (100 – 150^{0} C) drying of wet grains rapidly down to 18% MC_{wb}, followed by low temperature in-store drying to 14% MC_{wb}. Results showed higher head rice recovery but the milled rice exhibited "accelerated aging." Contrary to this process low temperature drying of high moisture paddy was recommended to preserve good milling, cooking, and eating qualities (Yamashita, 1993)..

III. Methodology

The original SRR unit (Fig. 1) from Vietnam was evaluated for its drying performance using paddy with various moisture contents. Pertinent data were gathered including initial and final moisture content of the paddy, ambient temperature, drying air temperature, relative humidity, plenum pressure, heater settings, energy consumption, instantaneous moisture content of the paddy at predetermined time, and total drying time. A tubular grain sampler was used in getting samples from the sampling points. Moisture contents of the samples were determined by destructive sampling using a resistance-type moisture meter. A digital power meter was used to record energy consumption. Thermocouples and pressure sensors were used to record drying air temperature at different sampling points in the grain bulk and plenum pressure (Fig. 1). Thermocouples were attached to the computer via a data logger. Other relevant observations were recorded. Two hundred fifty gram dried grain samples were subjected to milling analysis using IRRI standard procedures. Recorded data were analyzed and interpreted with respect to the dryer performance. The performance of the fan in the original SRR unit and several locally available fan blades were tested using the Japanese Industrial Standard for testing and evaluation of fan and blowers (JIS B 8330 - 1962). The testing apparatus was equipped with static and dynamic pressure sensors. Important fan features were recorded including the number of blades, blade angle, wheel diameter, hub diameter, static and dynamic pressures. Data gathered were analyzed and used as basis for fan selection. Local availability and suitability to current application were considered. The design and assembly of the blower were examined with respect to airflow (turbulence), structural strength and reliability.

Alternative bin materials were studied including welded wire, plastic mesh, and "sawali"(a local bamboo mat). The criteria in selecting the bin material include the strength, labor cost, stability under loaded condition, ease of handling, assembly and disassembly, effect on dryer performance (resistance to airflow), and local availability. Based on the testing and evaluation results and analysis of the SRR design, a modified SRR called the low cost dryer (LCD) was fabricated. Two units of LCD with modified blower assemblies were provided to Philrice for their pilot testing activities.

The LCD was pilot tested with prospective end users in collaboration with the Social Science Division of IRRI. Cooperators included farmers in Central Luzon, Laguna, and Quezon provinces who were asked for their feedback. Actual field performance observations were recorded and integrated into the final LCD design. The LCD was tested for different capacities. For each batch, samples were taken and subjected to shade drying, sundrying, and laboratory drying with controlled drying rate. The dried samples were subjected to standard milling analysis. The milled rice characteristics of each sample including milling recovery, headrice, whiteness, and broken were compared.

An economic analysis was done to determine profitability with sun drying as reference. The following assumptions were applied: purchase value =US $350 (not the commercial value of the LCD. Can be lower if produced on a larger scale), salvage value = 10% of purchase cost, economic life = 5 years, depreciation based on straight-line method, and interest rate = 18%. Eight batches for the farmer's rainy season harvest and 4 batches contract drying per year were assumed in calculating the economic indicators including payback period, break even batch per year, benefit cost ratio (BC), net present value (NPV), and internal rate of return. A sensitivity analysis was done to assess how the economic indicators vary with the utilization rate (i.e. volume of grain dried).

IV. Results and Discussion

The original SRR dryer consists of three major components: 1) blower assembly composed of electric motor, two fan blades in series, and electric resistor made integral to the blower assembly, 2) central air duct with steel reinforcement wrapped with knitted bamboo slots, and 3) the drying bin also made of knitted bamboo slots supported with concentric round bars. Test results by the Vietnamese engineers showed that it could dry paddy in 3 to 4 days in Mekong Delta, Vietnam conditions. Laboratory testing and evaluation of the SRR show that it could dry wet paddy in 2 to 3 days under local conditions (Table 1). The moisture content of the paddy, drying air temperature and the existing relative humidity affected the performance of SRR. When the relative humidity of the drying air exceeded the equilibrium relative humidity of the grain being dried, rewetting occurred as depicted in Figure 2. Hence, paddy drying needs to be managed relative to the existing relative humidity to avoid rewetting of the grains. Because of the relatively long drying time the SRR was modified. The original blower design consists of two fan blades in series. The possibility of using only one fan blade that could maintain sufficient airflow and static pressure was considered. Several fan blades were tested, including the original fan blade from Vietnam. The Toyota Porsche radiator fan was chosen based on its ability to maintain the required static pressure, and local availability. One fan blade was enough to meet the operational requirement, thus simplifying the blower assembly. For the bin material the welded wire mesh was chosen being cheap, available in hardware stores and has less resistance to airflow (Table) 2.

The LCD was pilot tested with different end users (farmers, traders, & millers) to 1), evaluate its actual field performance 2) gauge its acceptability, and 3) solicit comments/suggestions for further technology development to ensure its suitability. It should be emphasized that the pilot testing was done to gather feedback from the target users as basis for further improvement of the technology rather than as basis for analyzing its socio-cultural aspects. Table 3 is the summary of the comments and suggestions of pilot testing cooperators. Four of the five pilot testing participants commented on the long drying time. Some said that they should be able to dry paddy and mill it within the day for immediate consumption. Only the trader-miller commented on the dryer's low capacity and labor requirements for loading and unloading. He owned a batch re-circulating dryer with bucket elevators for loading/unloading equipped with automatic moisture sensors. The drying performance of LCD at farm level conditions showed that it can reduce the moisture content of wet paddy down to a safe level of 18%MCwb in about 10 hours (Fig. 2). Pilot testing results confirmed the effect of grain moisture content and relative humidity of the ambient air on the drying performance. The latest generation LCD (Figure 3) was designed and fabricated integrating the comments and suggestions of the end users and the observations of the researcher. Table 4 exhibit the comparative features of LCD and the original SRR.

A test for various capacities and heater settings was conducted. For 500-kg paddy with 25.60% initial MCwb the total drying time was 15.80 hours down to 14% MCwb. Performance data showed that 36% or 5.70 hours was actually spent in rewetting the grain. Thus the effective drying time was 10.10 hours. The average drying rate was 0.734%/hr. The 792-kg paddy at 27.0% initial MCwb used 18.28 hours to dry down to 15.65% MCwb. Effective drying time was 13.77 hours or 75% of the total drying time. A ton of paddy with 25% initial moisture took 29 hours to reach 13.90% MCwb (Table 5). Testing and evaluation of Philrice had similar result where a 945-kg paddy with 25.40% initial moisture took 30 hours to reach 13.50% MCwb (Gagelonia, et. al., 1999). Milled rice analysis of paddy samples subjected to different drying systems resulted in 7.85% more headrice from LCD dried paddy samples and 7.95% less broken than the milled rice from sundried paddy (Table 6). Milling recovery was 68.04% and 68.32% respectively (Figure 4). Whiteness was not significantly different.

Using the LCD is economically profitable particularly in the wet season. For the given assumptions (Table 7) the payback period was 2.09 years, B/C ratio=1.16, average break even point=1.65, net present value=U$ 187.74, and internal rate of return=39.42%. A sensitivity analysis (Table 8) showed how the economic indicators vary with the number of batches dried per year. As expected the payback period was inversely proportional to the dryer utilization while the benefit cost ratio, net present value, and internal rate of return increased with increasing dryer utilization. The economic threshold of LCD utilization was 4 batches per year corresponding to 4 tons of wet season harvest without contract drying. At three batches per year the BC ratio was less than one, NPV negative, payback period = 4.0 years, and the internal rate of return was 10.53%.

V. Conclusions and Recommendations

The LCD can be used in preventing quality deterioration of wet season harvest when sundrying is not possible. It can dry wet paddy (>24%) down to a safe level of 18%MCwb in ten hours. It requires longer drying time compared to sundrying. For one ton paddy with 25.6% initial MCwb the average drying time was 30 hours. Lower capacities required less drying time. For 500 kg paddy with 25.6% initial MCwb the drying time was 15 hours. The modifications made on the dryer significantly reduced the drying time of one ton paddy from 48 -72 to 15-30 hours due to reduced turbulence, increased airflow, and lower air resistance of the welded wire mesh. Lower capacity required shorter drying time. Milled rice from paddy dried in the LCD has higher headrice yield and less broken grains compared to milled rice from sun dried paddy. A minimum of 4 batches per year was the lower limit of economic profitability. Payback period decreased with increased utilization, while NPV, BC ratio, and internal rate of return increased proportionally with the dryer utilization.

After 10 hours of operation the upper 1/4 layer of the grain bulk must be exchanged with the next quarter layer to minimize moisture content variability. In drying very wet paddy it is highly recommended that a one-inch layer of rich hull be placed under the canvass before loading the wet paddy. This will prevent the bottom layer of very wet paddy from germinating.

The drying rate can still improved by increasing the drying air temperature and airflow rate. A 2kW heater can be used instead of the two one-kilowatt resistors. Managing the drying operation with respect to the existing relative humidity can shorten the drying time. Other sources of energy must be explored including the liquefied petroleum gas, rice hull, and kerosene.

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Table 1

Test results of the SRR in Mekong Delta, Vietnam (adapted from: ....reference).

	Evaluation in Vietnam *		Evaluation at BPRE			
Basic information	Trial 1	Trial 2	Trial	Trial 1	Trial 2	Trial 3
Initial weight (kg)	963	1004	1004	983	950	1000
Final weight (kg)	867	835	835	870	824	925
Water removed (kg)	96	169	169	112	126	125
Average moisture						
Initial (% w.b.)	20.0	29.0	28.6	21.7	23.5	22.8
Final (% w.b.)	13.6	14.5	14.5	12.3	12.8	13.5
Drying time (hr)	60	98	84	72	72	48
Energy used (kWh)	102.1	90.1	118.9	98	98	65.9

Table 2

Criteria for the selection of bin material.

Alternative materials	Local availability	Structural strength	Flexibility in assembly	Material and labor cost	Resistance to airflow
Welded wire mesh	High	strong	good	low	low
Plastic mesh	Medium	weak	good	low	low
Sawali (local bamboo mat)	High	strong	poor	low	high
Knitted bamboo slots	High	strong	good	high	high

Table 3

End user's comments and suggestions on the LCD.

Pilot testing cooperator	Classification	Comments/suggestions
E. Pestañas Polilio Island Quezon	farmer	"LCD is very useful. Will no longer wait for my turn to use basketball court. No need to haul the paddy. I can now dry the paddy during rainy days".
Women farmers Guimba, N. Ecija	cooperative	"Good and simple design. But long drying time. Can't dry as fast as sun drying. Capacity must be adjustable for lower paddy quantity".
Barangay captain (Pila, Laguna)	farmer	" Simple, low cost dryer, easy to fabricate. But long drying time. Cannot compete with sun drying. Quite noisy especially at night".
Mang Beth (Pila, Laguna)	farmer	"Long drying time. Not as fast as sun drying. We must be able to dry some paddy for milling immediately and for home consumption".
Johny Sangcal	trader/miller	"Low capacity and long drying time. Requires much labor for loading and unloading the paddy. Noisy especially at night".

Table 4

Comparative features of the original SRR and LCD (modified SRR)

Components	*Features of the SRR*	*Features of the LCD*
Fan blade	Double fan assembly	Single fan assembly
Central duct	Same height as the drying bin	Shorter than the drying bin
Cover canvass and weights	Necessary to minimize excessive airflow on top of the grain bulk	Not needed anymore. Canvass cover replaced with the grain itself.
Bin materials	Knitted bamboo slots	Industrial wire mesh and plastic net
Heating elements	Fixed setting (low only)	Variable setting (low, medium, high)
Capacity	One ton	Adjustable (one ton or less)
Airflow (m^3/min)	80.70	90.40
Temperature rise	2°C	4°C
Air vane curve	Opposite the fan rotation	Curved with the fan rotation
Blower assembly	Mounted on top of central duct	Slide fit into the top of central duct
Switch design and safety	The heater can be turned on with the blower off	The heater can only be switched on if the blower is running
Transportability	Unit can be packed into two pieces	Unit can be packed into one piece

Table 5
Summary of LCD test results of different capacities (Nov 1999 to Jan 2000).

Parameters	*Load No. 1*	*Load No. 2*	*Load No. 3*	*Load No. 4*	*Load No. 5*	*Load No. 6*	*Load No. 7*	*Load No. 8*
Int'l wt. (kg)	491	500	500	994	884.5	1001.8	792.3	730.9
Initial %MC	23.13	25.61	20.71	25.56	19.24	29.78	27.04	25.42
Dry wt. (kg)	442.0	431.4	457.7	852.7	837.7	806.8	673.2	627.3
Final %MC	15.04	14.34	13.90	14.65	15.05	13.90	15.65	13.90
Drying t(h) (h)	10.42	15.35	6.23	32	21.63	29.17	18.28	12.07
Effective drying time(h)	7.25	9.64	5.23	15.17	14.19	17.29	13.77	12.07
Re-wetting Time h (%)	3.17 (25)	5.71 (37)	1.0 (16)	16.83 (53)	7.44 (34)	11.88 (41)	4.51 (25)	0.00 (0)
Total energy used (kWh)	32.4	43.4	16.0	81.7	64.4	94.8	57.1	59.4
Ave. plenum pressure (Pa)	289.82	280.62	276.00	329.54	300.38	309.6	282.2	286.6
Ave. %RH	75.03	76.72	65.00	78.12	80.7	83.32	72.46	69.71
Heater setting	4 hrs M rest H	4 hrs M rest H	4 hrs M rest H	H throughout	5 hrs M rest H	2 hrs Aa 3.25 M rest H	4 hrs M rest H	H through-out

M = medium H = High Aa = ambient air (heater off). * Predicted values

Table 6
Milling analysis results of samples subjected to different drying systems.

Drying systems	MC (%)	Purity (%)	Brown rice (g)	Milled rice Weight (g)	Milled rice MR (%)	Headrice (g)	Headrice (%)	Brokens (g)	Brokens (%)	Whiteness
Laboratory dryer	14.10	86.97	198.12	174.35	69.74	161.04	92.37	13.31	7.63	38
	12.55	90.96	194.42	175.39	70.16	163.23	93.06	12.17	6.94	37
	13.48	89.79	195.46	173.40	69.36	160.66	92.66	12.74	7.34	40
	14.58	88.87	188.40	165.79	152.9	152.88	92.21	12.91	7.79	40
	10.45	87.99	183.20	155.72	62.29	134.01	86.06	21.71	13.94	39
	14.65	93.83	186.16	162.30	64.92	152.36	93.88	9.94	6.12	36
	14.12	98.86	193.40	169.00	67.60	150.25	88.90	18.76	11.10	36
Average	*13.42*	*91.04*	*191.40*	*167.99*	*67.20*	*153.49*	*91.31*	*14.50*	*8.69*	*38*
Shade drying	13.95	86.97	195.13	170.96	68.38	154.60	90.43	16.36	9.57	39
	13.75	90.96	192.26	172.81	69.12	160.98	93.15	11.83	6.85	39
	13.77	89.79	195.94	174.30	69.72	162.63	93.30	11.68	6.70	39
	14.30	88.87	195.31	175.02	70.01	163.28	93.29	11.74	6.71	40
	13.94	87.99	194.17	165.48	66.19	147.69	89.25	17.79	10.75	40
	12.17	93.83	189.19	168.52	67.41	160.83	95.43	7.70	4.57	37
	14.43	98.86	185.78	164.34	65.74	147.99	90.05	16.36	9.95	38
Average	*13.76*	*91.04*	*192.54*	*170.20*	*68.06*	*156.85*	*92.13*	*13.35*	*7.87*	*38.9*
Low Cost Dryer		14.20	192.88	174.16	69.66	163.11	93.64	11.06	6.35	32.5
	13.68	90.96	191.94	169.60	67.84	158.83	93.65	10.77	6.35	37
	13.72	89.79	193.88	171.96	68.78	160.10	93.10	11.86	6.89	39
	14.05	88.87	197.35	177.74	71.10	166.69	93.78	11.06	6.22	38
	13.95	87.99	184.40	160.87	64.35	146.65	91.17	14.22	8.84	38
	13.80	93.83	190.41	167.41	66.96	157.20	93.90	10.21	6.10	38.5
	13.35	98.86	189.96	168.89	67.56	154.70	91.60	14.19	8.40	35
Average	*13.82*	*91.04*	*191.5*	*170.09*	*68.04*	*158.2*	*92.98*	*11.91*	*7.02*	*36.9*
Sun drying	13.40	86.97	193.16	170.40	68.16	152.26	89.35	18.14	10.65	33
	12.10	90.96	192.26	172.81	69.12	160.98	93.15	11.83	6.85	39
	12.52	89.79	194.90	173.79	69.52	150.08	86.36	23.71	13.64	38
	13.90	88.87	196.59	175.92	70.37	160.78	91.39	15.14	8.61	37
	12.70	87.99	198.36	168.47	67.39	129.89	77.10	38.58	22.90	40.5
	13.20	93.83	192.28	166.66	66.66	115.17	69.11	51.49	30.89	38
	14.10	98.86	188.44	167.44	66.97	152.19	90.89	15.25	9.11	38
Average	*13.11*	*91.04*	*193.75*	*170.81*	*68.32*	*145.42*	*85.03*	*25.39*	*14.97*	*38*

Note: Each figure presented is the average of two data. Overall average for each drying system based on the averages of 14 sets of raw data

Table 7
Summary of the LCD economic analysis.

Basic assumptions and pertinent LCD data	Economic parameters	Economic Indicators
LCD Purchase cost (Pc) = U$ 350 Max. capacity = one ton/batch	Fixed cost: U$ 136.50/yr Depreciation = U$63/yr	*Internal rate of return = 39.42%*
Interest on investment = 18% R and M cost = 10% of Pc Tax, insurance, etc.= 2% of Pc Depreciation: straight line method	Interest = U$31.5/yr R and M = U$35/yr Tax, etc. = U$ 7/yr Variable cost: U$ 116.24/yr	*NPV = U$ 187.84* *Payback = 2.09 yrs.*
Economic life = 5 yrs. Salvage value = 10% of Pc With family labor = U$ 2.33/ton Contract drying = U$ 9.3/ton	Total cost: U$ 252.74/yr Total benefits: U$ 496.72/yr Drying = U$ 413/yr Labor = U$ 83.72/yr	*B/C ratio = 1.16* *Break even point =0.54 batches/yr*

NPV = Net present value R and M = Repair and maintenance

Table 8

Sensitivity analysis of the LCD for different drying utilization rates.

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6(base)	Case 7	Case 8
Own farm, wet season	3	4	4	4	4	4	4	4
Own farm, dry season	0	0	2	4	4	4	4	4
Contract drying (CD)	0	0	0	0	2	4	6	8
Batches/yr	2	4	6	8	10	12	14	16
Fixed cost, US $	136.50	136.50	136.50	136.50	136.50	136.50	136.50	136.50
Variable cost, US $	39.13	52.17	67.39	82.61	108.70	134.78	160.87	186.96
CD benefits, US $	0	0	0	0	26.09	52.17	78.26	104.35
Family labor opportunity cost, US $	8.70	17.39	26.09	34.78	43.48	52.17	60.87	69.57
Total cost/yr, US $	175.63	188.67	203.89	219.11	245.20	271.28	297.37	323.46
Price difference, US $	250.50	334	334	334	334	334	334	334
Benefits/yr, US $	259.20	351.39	360.09	368.78	403.57	438.35	473.13	507.91
Payback period, yr	3.98	2.15	2.24	2.34	2.21	2.09	1.99	1.90
Break even points (batches/yr)	1.50	1.86	1.77	1.68	1.65	1.62	1.59	1.57
NPV, US $	-60	174.14	153.75	133.22	160.55	187.74	214.93	242.13
Benefit cost ratio	0.93	1.19	1.16	1.13	1.14	1.16	1.17	1.18
Internal rate of return	10.53	37.95	35.7	33.46	36.45	39.42	42.35	45.25

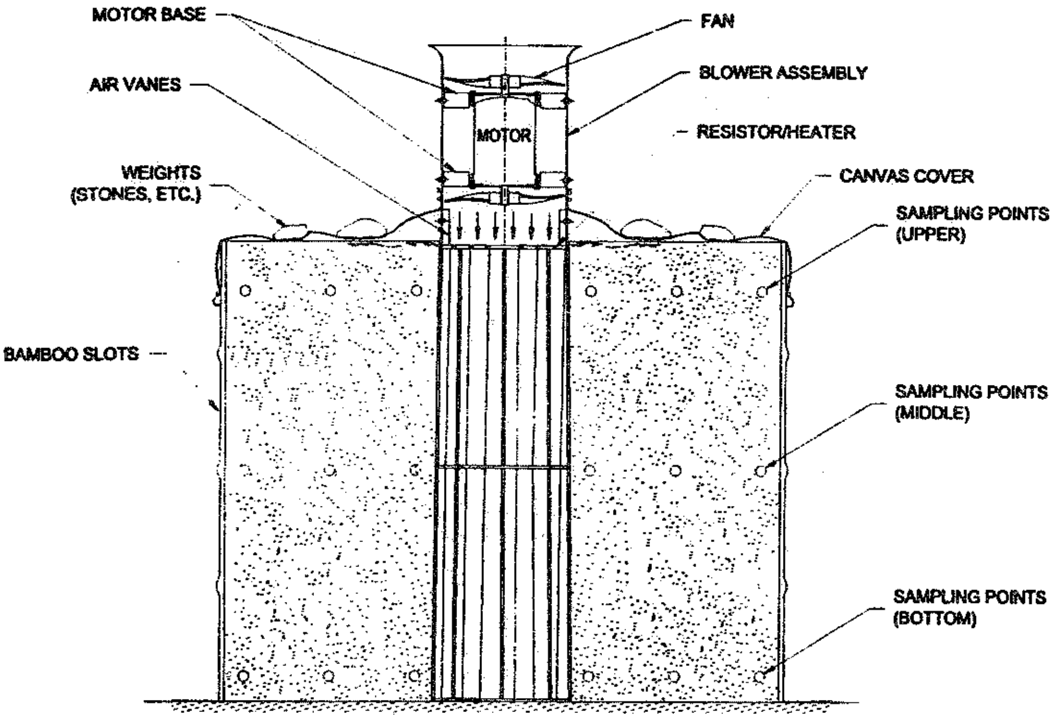

Figure 1. Schematic assembly of the original SRR design from Vietnam

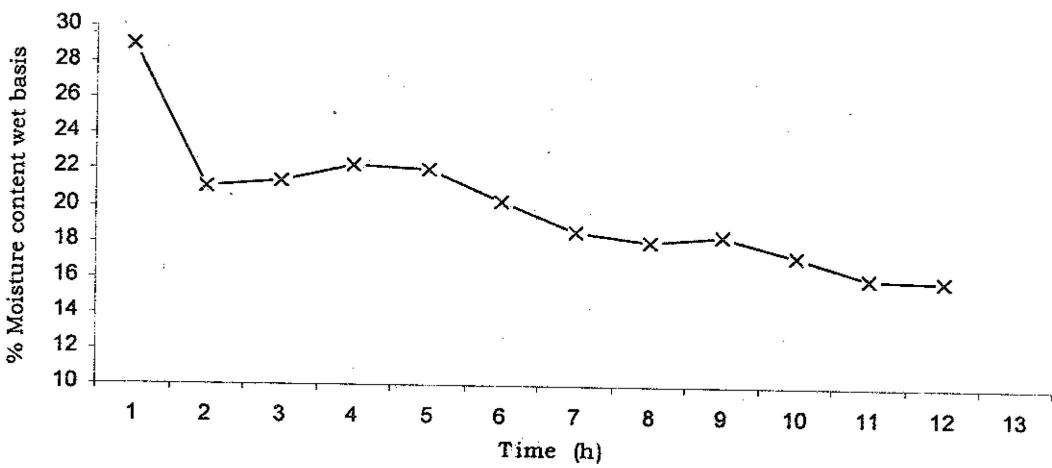

Figure 2. Drying curve of the LCD in Pila, Laguna

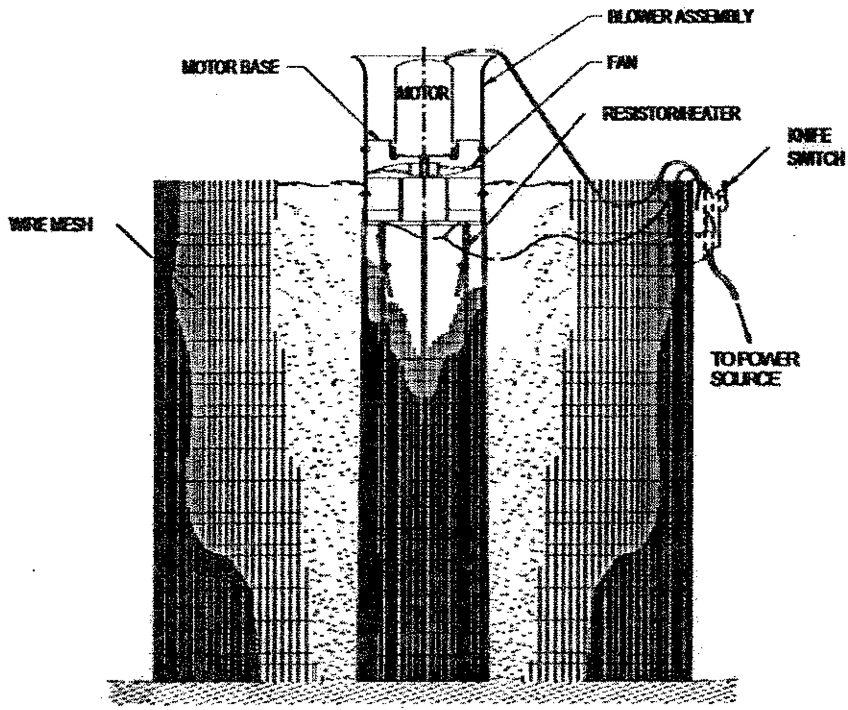

Figure 3. Schematic operating assembly of the low cost dryer (LCD final design)

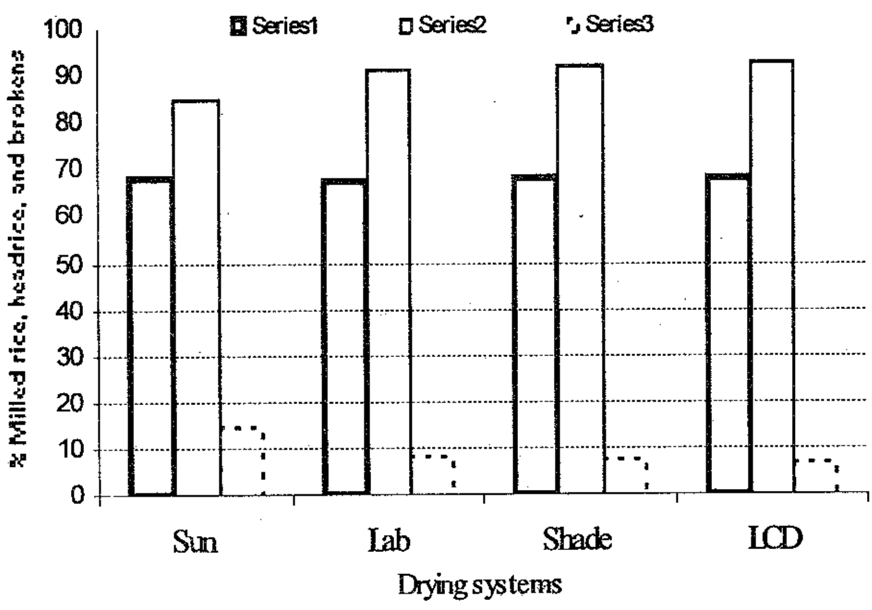

Figure 4. Comparative %milled rice (series 1), %headrice (series 2) and %brokens (series 3) from four drying methods