APPROVAL SHEET

Monitoring of Moisture Content Behavior of Paddy at Ambient Storage

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Quezon City

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BASIC INFORMATION

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Monitoring of Moisture Content Behavior of Paddy at Ambient Storage[1]

by

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ABSTRACT

Paddy grains stockpiled and stored at the safe moisture level of 13-14% would loss some of its moisture to its microenvironment. The moisture behavior is greatly affected by the relative humidity of the air that surrounds the grains. Mathematical tools have been derived to state the paddy's moisture behavior when stored at long periods. These are:

$$\% MC = 13.162 - 0.004 (SP) \qquad \text{for } SP = 1\text{-}602 \text{ days}$$

$$\% MC = 11.055 - 0.0005 (SP) \qquad \text{for } SP = 603\text{-}1275 \text{ days}$$

$$\% MC = 4.97376 + 0.11859 (\% \text{ Pile } RH) - 0.00115 (SP)$$

The multiple regression given by the third equation needs the following equation before it can be executed:

$$\% \text{ Pile } RH = 66.1 - 0.0107 (SP, \text{ days}).$$

This equation can be used to determine pile RH at a given the storage period or vice versa.

All the MC equations can be used interchangeably and the results would be of no significant difference.

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[1] *Study conducted by the Technical Research Division, Technology Resource Development Department, National Food Authority, Q. C. from Aug. 1999 to Feb. 2003.*

[2] *Statistician III and Research Specialist, respectively.*

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INTRODUCTION

Moisture content has a marked influence on rice quality. Its effect is of primary importance on the keeping properties of rice. It is the factor most responsible for controlling the rate of deterioration. Moisture contents commonly accepted for safe storage of paddy are 13% for less than six months and 12% for long-term storage (Houston, 1972).

The moisture in grain is traditionally considered in terms of the percentage moisture content by weight, usually based upon the wet weight of a sample under test. However, when preservation of grain quality is being studied, it is more meaningful to consider the moisture content of the intergranular environment, or the equilibrium relative humidity (ERH), corresponding to a particular grain moisture content. The susceptibility of stored grain to deterioration is correlated to the ERH and not to the moisture content of the grain (Boxall & Calverley, 1985).

Microorganisms are unable to multiply when the ERH is below 65% although it is generally accepted that to protect stored grain from mold the maximum ERH should be 70%. Insects and mites, however, are most active in the range of 60-80% ERH, although some species survive and multiply at 40-60% ERH, and a few, like the khapra beetle *Trogoderma granarium*, can do so at even lower levels.

Rice is hygroscopic. It gains or loses moisture until it is in equilibrium with the air it contacts. Thus, equilibrium moisture content (EMC) of grains refers to the quantity of moisture in the product when it is in equilibrium with the surrounding environment. The EMC is dependent primarily on the relative humidity, but it varies to a lesser degree with air temperature. Rice losing moisture through exposure to air at any given temperature and relative humidity has a slightly higher EMC than does rice adsorbing moisture by exposure to the same air. Values of EMC are different for paddy, brown rice, milled rice, and bran (Houston, 1972).

The relationship between MC of cereal grains including paddy and their ERH has been studied by many workers. So far, the American Society of Agricultural Engineers has accepted the modified Henderson equation and Chung-Pfost equation. These two equations were recognized as being more accurate than other equations over a wider range of relative humidity. Likewise, several researchers such as Karon and Adams (1949) gave equilibrium moisture contents for rough rice with air at 77 °F (25 °C) and RHs between 11 and 92%. Hogan and Karon (1955) gave them for temperatures of 80 °F (27 °C), 94 °F (34 °C), and 111 °F (44 °C) for relative humidities between 48 and 93%. Wratten and Kendrick (1970) extrapolated their data, combined them with results derived by other researchers, and developed a table of EMC at different temperatures. The table is printed in a book edited by Houston (1972).

The EMC-ERH equations by Henderson, Chung-Pfost, and most grain researchers were generated from results of studies conducted on laboratory scale. The researchers subjected their experimental grains to a controlled environment, just like what Hogan and Karon (1955) did, wherein they subjected the paddy grains at specific temperature and relative humidity. When the paddy grains attained a stable moisture content, they recorded it as the EMC and the controlled relative humidity as ERH.

The experimental procedures of Hogan and Karon and most researchers in coming up with EMC-ERH relationship were definitely different from the operational procedures of handling rice stocks by the NFA. At the NFA, stocks are piled in bags and exposed at ambient conditions.

Although Ramirez et al. (1995) have conducted a research on EMC-ERH relationship on milled rice stored in NFA warehouses, they were not able to establish conclusive findings. Feedback from critics regarding the inconclusive result was that the RH data taken should have been the microenvironment RH of the grain and not the RH inside the warehouse.

Given this feedback, Andres and Bernal (1999) improved their procedure by taking the RH within the pile in their study on MC-RH for corngrains piled inside an NFA warehouse.

They were able to establish a strong correlation, r, of 0.85 between the moisture content of corngrains and RH within the pile.

After obtaining a good correlation between moisture content of corngrains and RH, the NFA was again ready to embark on another study on EMC-ERH relationship, this time with paddy grains.

The NFA'S operating procedure is to store paddy grains with maximum moisture of 14%. It has been adopted because it is supposed to be the "safe" MC level for paddy intended for storage. It is "safe" in the sense that the rate of deterioration of the grain is minimal. However, warehouse records showed that paddy MC decreased when stored at prolonged period to as low as 9%. Several studies made by the Technology Resource Development Department on paddy stocks showed that the MC decreased as storage period is prolonged but not as low as 9%. While the rate of paddy deterioration is slow as the grains had been stored at the safe level of moisture content, the MC, however, decreased significantly with time. There is therefore an indication that the 14% safe level may not be the EMC in relation to the microenvironment RH.

OBJECTIVE

The moisture content of paddy grains stored in bags in NFA warehouses had been documented to decrease as storage period was prolonged. It was therefore important to determine the moisture content behavior of paddy and the level at which it equilibrated with its microenvironment. Results could be used as reference in validating warehouse records.

METHODOLOGY

Materials

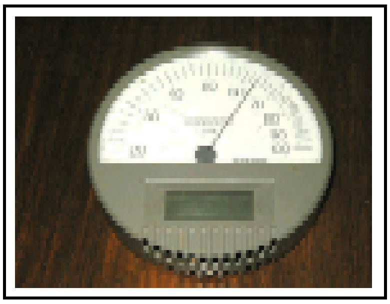
90 bags of newly procured paddy grains

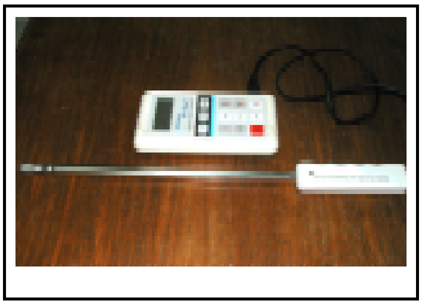
15,000 bags of stored paddy

Hygrometers

Air-oven

Air-oven for moisture determination





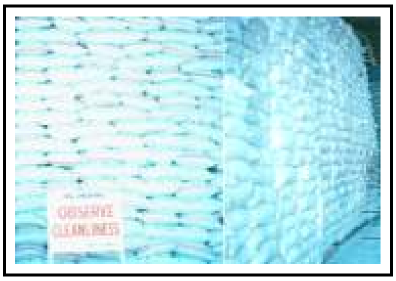
Hygrometers for relative humidity and temperature

Sample Preparation

Ninety bags of paddy were poured on a tarpauline sheet spread on the warehouse floor. The paddy grains were thoroughly mixed using shovel afterwhich they were rebagged, also, into 90. The well-mixed paddy grains were divided into three groups, each group having 30 bags. These would serve as sampling bags of grain. The mixed grains were the samples used for the study. The mixing of the paddy was necessary to minimize sampling error brought about by grain differences thereby assuring uniformity of samples in every monitoring period.

Pile Set-up

Simultaneous with the mixing of the 90 bags of grains was the building up of three piles of paddy at warehouse #7 at NFA-Cabanatuan City grains complex. As a pile was being set-up, 10 bags from one group of the well-mixed paddy had been arranged on one **corner** of a pile which was about five feet from the floor and three feet from the surface going inwards. This was situated on the seventh layer of the pile. PVC pipe was inserted in one of the bags containing the well-mixed grains to serve as access to grain probe for sample withdrawal and for RH and temperature readings.



One of three piles used for the study

The next 10 bags of well-mixed paddy were also laid at the **core** of the pile, also on the seventh layer. Another PVC pipe was also inserted in one bag touching the well-mixed grains.

Along the **periphery** of the pile, on the same seventh layer, the last 10 bags of mixed paddy were placed. The 10 bags were distributed along the four surfaces of the pile.

Monitoring

The paddy moisture content, RH and temperature within the pile (corner, core, and periphery), and RH and temperature inside and outside the warehouse were recorded everyday, at 9:30 in the morning and at 3:00 in the afternoon, for the first three months and every week thereafter.

Monitoring of relative humidity and temperature

Data Analysis

The following statistical analyses were used to treat the data gathered:

- Descriptive Analysis
- Analysis of Variance
- Regression Analysis

DISCUSSIONS OF RESULTS

The 90 bags paddy which was stored for the experiment was newly procured within the province of Nueva Ecija. It was of good quality with only 2.29% discolored and damaged grains. It had an average moisture content of 13.2%. Thirty bags were placed in strategic locations in each pile — at the **corner, center, and periphery**.

Temperature

The temperature profile within the pile, inside and outside the warehouse is shown in Tables 1a and 1b. More than 50% of the temperature data were within the range of 28.1-30°C while at least 25% were within the range of 30.1-32 °C (Table 1a). Tables 1c and 1d also show that the temperatures taken from the corner, center, and periphery of the pile are not significantly different. Likewise, the temperature taken outside the warehouse is similar to the temperature taken inside the warehouse. However, the temperature within the pile was significantly different from the temperature taken inside and outside the warehouse. Since the temperatures from the different points within the pile are the same, their average is taken and, therefore, considered as **pile temperature**. Likewise, the average temperature inside and outside the warehouse are considered **ambient temperature**.

Table 1a. Frequency distribution of temperature data

T Limit, °C	Corner		Center		Periphery		InWhse		OutWhse	
	f	%	f	%	f	%	f	%	f	%
≤26	0	0.00	0	0.00	0	0.00	5	2.40	3	1.44
26.1 - 28.0	20	9.62	2	0.96	19	9.13	36	17.31	27	12.98
28.1 - 30.0	129	62.02	129	62.02	125	60.10	110	52.89	110	52.89
30.1 - 32.0	55	26.44	65	31.25	59	28.37	43	20.67	56	26.92
32.1 - 34.0	3	1.44	10	4.81	4	1.92	10	4.81	9	4.33
34.1 - 36.0	1	0.48	2	0.96	1	0.48	4	1.92	3	1.44
Total	**208**	**100.00**	**208**	**100.00**	**208**	**100.00**	**208**	**100.00**	**208**	**100.00**

Table 1b. Descriptive statistics of temperature

	Pile				Warehouse		
	Corner	**Center**	**Periphery**	**Ave.**	**InWhse**	**OutWhse**	**Ave.**
Average, °C	29.5	29.6	29.5	29.5	29.6	29.8	29.7
Minimum, °C	26.1	27.2	26.3	26.1	25.8	25.7	25.7
Maximum, °C	34.5	35.0	34.1	35.0	35.1	35.0	35.1
Std. Dev.	1.30	1.23	1.37	1.21	1.76	1.73	1.62

Table 1c. ANOVA for temperature

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Treatment	40.0	5.0	8.0	3.9	0.0016 **	2.2
Error	2531.8	1242.0	2.0			
Total	2571.8	1247.0				

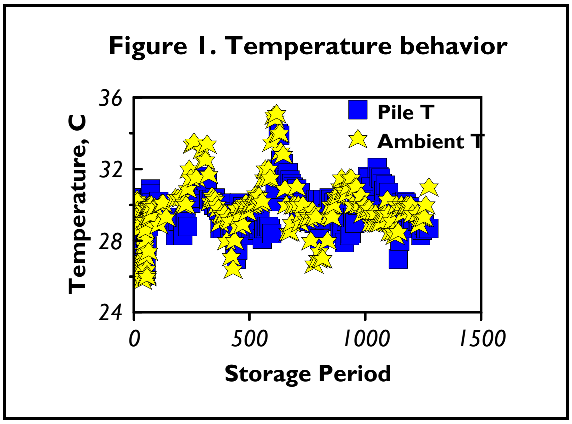
SS - Sum of Squares ***df - degrees of freedom*** ***MS - Mean Square***
F - observed F value ***P-value - Probability*** ***F crit - Critical F Value (from table)***
***** - highly significant***

Table 1d. Multiple comparison of mean temperature

	Meant T*
Corner	29.5 a
Periphery	29.5 a
Center	29.6 a
InWhse	29.6 ab
OutWhse	29.8 b

**** Means with the same letter are not significantly different***

Figure 1 shows a climatological cycle of temperature resembling a sinusoidal curve. The temperature changed to harmonize with the two seasons in the country - the dry and wet seasons. The temperature was low during wet season and high during dry season.



Relative Humidity

The profile of the RH within the piles and inside and outside the warehouse is given in Tables 2a and 2b and Figure 2a. Table 2a shows that the predominant RH range from the various points within the piles is 55.1-60%. Also, the predominant RH inside and outside the warehouse is 60.1-65%. According to Table 2c, there exists significant difference in RH among the reading points within the pile and inside and outside the warehouse. Table 2d confirms that the RH taken from the different points within the piles are similar. Hence, they are lumped together to come up with an average value which is now termed **pile RH**. On the other hand, the RH inside and outside the warehouse were significantly different from the RH taken within the piles. However, the RH inside the warehouse was similar with the RH outside the warehouse. Therefore, their average is now regarded as **ambient RH**.

Table 2a. Frequency distribution of relative humidity

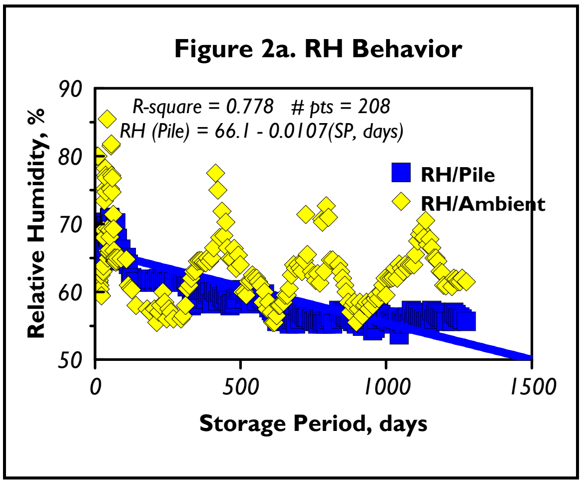
RH Limit, %	Corner		Center		Periphery		InWhse		OutWhse	
	f	%	f	%	f	%	f	%	f	%
≤55	21	10.10	35	16.83	53	25.48	5	2.40	3	1.44
55.1-60	110	52.89	103	49.52	66	31.73	60	28.85	49	23.56
60.1-65	32	15.38	17	8.17	44	21.16	98	47.11	99	47.60
65.1-70	32	15.38	39	18.75	40	19.23	24	11.54	32	15.38
70.1-75	13	6.25	14	6.73	5	2.40	9	4.33	7	3.37
75.1-80	0		0		0		10	4.81	13	6.25
80.1-85	0		0		0		2	0.96	4	1.92
85.1-90	0		0		0		0		1	0.48
Total	**208**	**100.00**	**208**	**100.00**	**208**	**100.00**	**208**	**100.00**	**208**	**100.00**

Table 2b. Descriptive Statistics of Relative Humidity					
	Corner	**Center**	**Periphery**	**In-Whse**	**Out-Whse**
Ave.	60.60	60.30	60.40	63.30	64.20
Min.	53.00	55.00	52.00	55.00	55.00
Max.	74.50	71.70	71.20	82.00	89.00
Std. Dev.	5.00	5.40	5.00	5.60	6.30

Table 2c. ANOVA for Relative Humidity						
Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F-crit**
Treatment	2850.90	4.00	712.74	24.19	4E-19 **	2.38
Error	30496.00	1035.00	29.46			
Total	33347.00	1039.00				
***** - highly significant***						

Table 2d. Multiple comparison of mean relative humidity	
	Mean RH*
Center	60.3 a
Periphery	60.4 a
Corner	60.6 a
InWhse.	63.3 b
OutWhse.	64.2 b
**** Mean RH with the same letter are not significantly different.***	

The ambient RH changed as dry and wet seasons come and go. The experiment started on a rainy season, hence the ambient RH during that time was high at more than 65%. Similar to the temperature sinusoidal curve, ambient RH displayed a climatological cycle as seen in Figure 2a. The ambient RH went to as high as 89% during the rainy season and became low, about 55%, during dry season. RH has been defined as the ratio of the amount of water vapor in the air at a specific temperature to the maximum capacity of the air at that temperature. The higher the amount of water present in the air, the higher the RH. Thus, ambient RH was at its peak of the cycle during the rainy season wherein water vapor is very abundant in the air and was at its lowest peak during dry season.

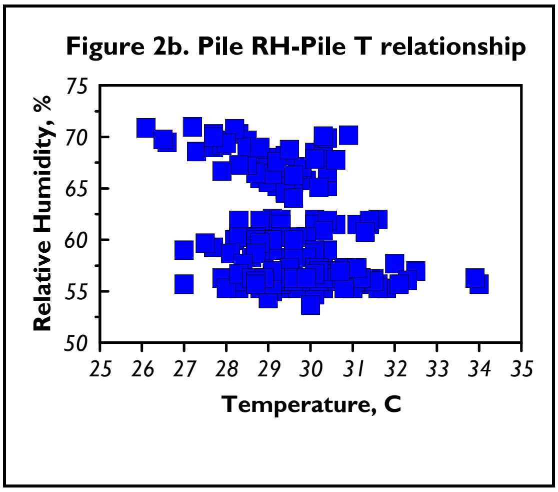


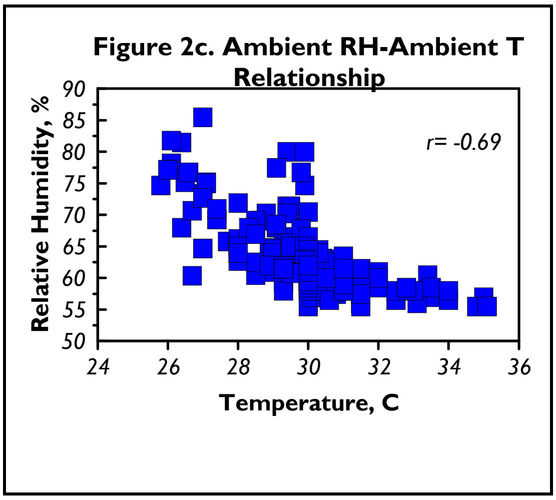
The climatological cycle of the ambient RH did not affect the pile RH, otherwise, there would have also been a cyclical pattern of pile RH. The ambient air had high RH during rainy days but such air did not stay for long because it constantly moved and changed, thus minimizing its effect on pile RH.

The diminishing trend of the pile RH is best expressed by the equation

% Pile RH = 66.1 - 0.00107 (SP, days).

Having a coefficient of determination, r^2, of 0.78, the equation is good enough to associate pile RH with storage period. However, pile RH did not have any correlation with pile temperature as seen in the scatterplot in Figure 2b. While the pile RH was within a wide range of 52-75%, the pile temperature was confined to a very limited range of about 28-32 °C. The limited range of temperature effected to a virtually no correlation between pile RH and pile temperature.





If pile RH and pile temperature did not show any relationship, ambient RH and ambient temperature did. Ambient RH indicated a moderate inverse linear correlation (r = -0.69) with ambient temperature (Figure 2c). If the ambient temperature is low, the ambient RH is high and vice versa. The correlation was made possible by a wide range of ambient temperature of about 26-34 °C and a wide range of RH. A stronger correlation would be possible from data with wider ranges of both RH and temperature variables.

Moisture Content

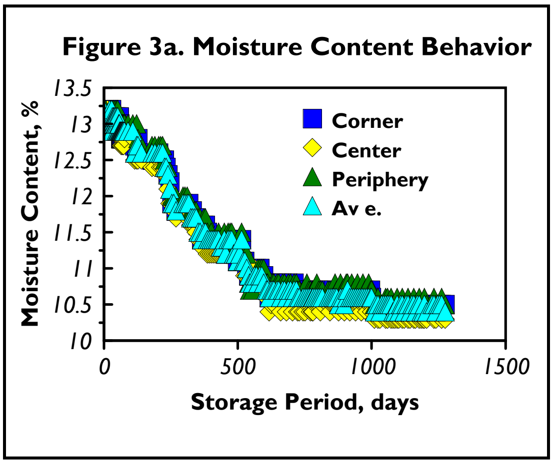


Table 3a and Figure 3a show the MC profile of the stored paddy. The grains' highest MC on all sampling points within the pile was 13.2%. This was registered at the start of stockpiling. The lowest paddy MC which was taken on the last quarter of implementation was 10.5% both at corner and periphery while 10.3% at the center of the pile (Table 3a).

Table 3a. Descriptive Statistics of Moisture Content				
	Corner	Center	Periphery	Ave.
Ave.	11.5	11.4	11.6	11.5
Min.	10.5	10.3	10.5	10.4
Max	13.2	13.2	13.2	13.2
Std. Dev.	1	1.1	1	1.1

Table 3b. ANOVA for Moisture Content.						
Source of Variation	SS	df	MS	F	P	Fcrit
Treatment	3.32	2	1.66	1.49	0.23 ns	3.01
Error	692.31	621	1.12			
Total	695.64	623				
ns - not significant						

All the MCs of the paddy grains taken from the three sampling points were found to have no significant difference (Table 3b), that is, wherever the grains were situated within the piles, their MCs would be similar.

There was an abrupt decrease in MC at about 602 days afterwhich it became practically stable. This indicates that the stored paddy kept on giving off its moisture until such time that it became virtually stable at about 10.7-10.4%. For the first 602 days, the equation that best fit the MC behavior of the grain is

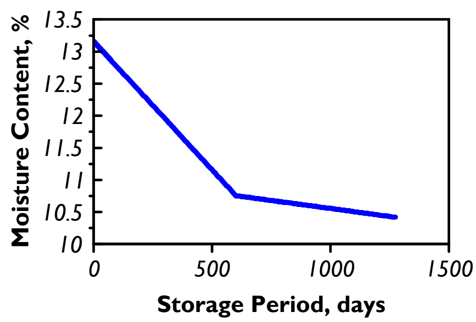
$$\% \text{ MC} = 13.162 - 0.004 \text{ (Storage Period, days)}$$

while the equation that gives the best fit for the MC trend from 603 days and onward up to 1275 days is % MC = 11.055 - 0.0005 (Storage Period, days) Both equations are given in Table 3c and graphically shown in Figure 3b

Table 3c. MC Behavior of Stored Paddy		
Storage Period, days	Regression Equations	r^2
1 - 602	% MC = 13.162 - 0.004 (SP)	0.98
603 - 1275	% MC = 11.055 - 0.0005 (SP)	0.75
MC = Moisture Content* *XP = Storage Period, days* *r^2 = Coefficient of Determination		

The first 602 days gave a faster rate of decrease of grain moisture equivalent to the slope of 0.004%. Then, at 603 days, the rate of decrease of moisture became slower at 0.0005%. At this period, the paddy grain had practically evaporated much of its free moisture - the moisture that is in excess of the equilibrium moisture content (EMC) - to its microenvironment, hence its rate of decrease became very minimal.

Figure 3b. Predicted MC Behavior



Going back to Figure 2a which showed the pile RH behavior as storage of paddy grains was prolonged, the pile RH was highest and reached almost 75% at the first three months of storage. It was during this period that the paddy grains gave off some of its moisture at the fastest rate. RH plays a vital role in the adsorption or desorption of grain moisture. Grains desorb or adsorb moisture depending upon the RH of the grains' environment. The increasing RH at the early part of the storage period was therefore mainly caused by the moisture desorption of paddy.

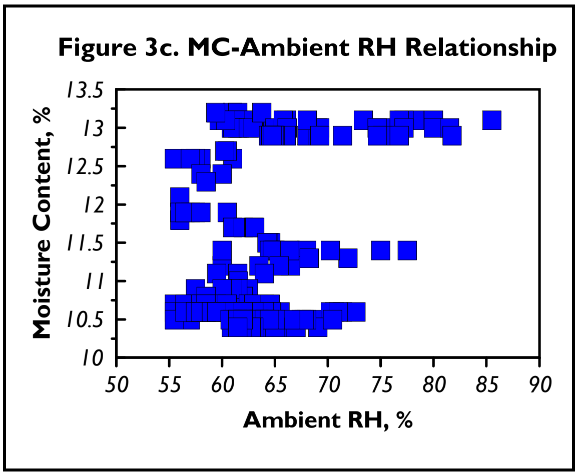
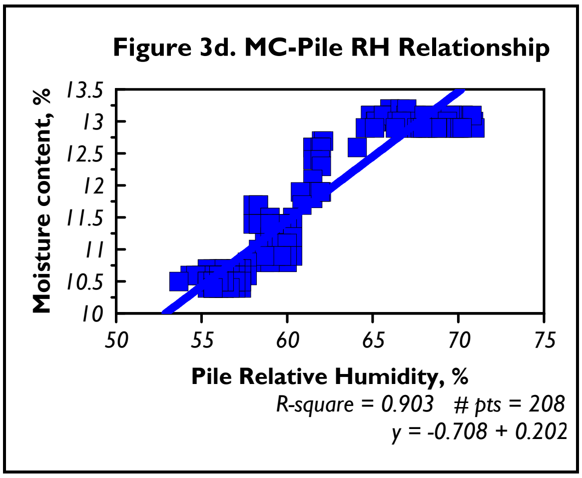


Figure 3c shows the relationship between paddy MC and average ambient RH. The paired data were well-scattered that any type of relationship was impossible. Contrarily, pile RH did give a very strong direct linear relationship with MC as shown in Figure 3d and is best expressed by the linear equation

%MC = -0.708 + 0.202 (% Pile RH)



which is also shown in Table 3d. The pile RH was the microenvironment condition within the pile and it was that RH that the grains reacted to. The grains did not react with the ambient RH. Basing therefore from the MC-RH equation, paddy grains at 60% pile RH would dry to about 11.41%.

So far, the mathematical tools obtained from the study are those between MC vs. SP and MC vs. Pile RH. Another mathematical tool could be derived, a multiple regression among MC, RH, and storage period and is given as

% MC = 4.97376 + 0.11859 (% Pile RH) - 0.00115 (Storage Period, days).

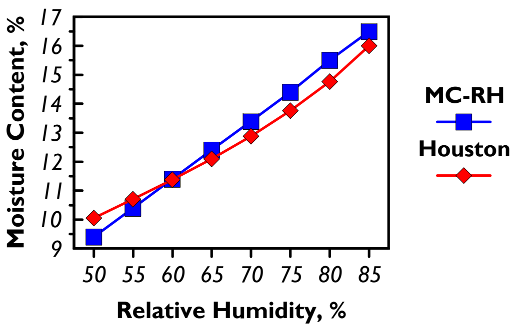
Table 3d. MC-Pile RH-Storage Period Relationship	
Regression Equations	**r^2**
% MC = -0.708 + 0.202 (% Pile RH)	0.90
% MC = 4.97376 + 0.11859 (% Pile RH) - 0.00115 (SP)	0.95
MC = Moisture Content ***RH = Relative Humidity*** ***SP = Storage Period, days***	

In executing the multiple regression equation (MC-Pile RH-SP equation), the RH-SP equation is needed. For example, at 570 days, % Pile RH would be 60%. Thus, at 60% RH and 570 storage days, the MC of the paddy would be 11.43% - an MC result similar to the sample result of 11.41% using the MC-RH equation

Table 4. ANOVA of the derived MC equations						
Source of Variation	SS	df	MS	F	P-value	F crit
Treatment (Equations)	1.06	3	0.35	0.39	0.76	2.62
Error	751.81	828	0.91			
Total	752.87	831				

The MC equations given in Tables 1c and 3d were compared along with the EMC developed by a group of researchers which was presented in Houston's book. All the equations and that contained in Houston's were found to have insignificant differences as shown in Table 4. Therefore, each equation established in this experiment can be used interchangeably in determining the MC of stored paddy grains. Since Houston presented EMC-ERH table at constant temperature, these were plotted together with the MC-RH equation developed from this study. The results are shown in Figure 4 indicating similar results.

Figure 4. Comparison between MC-RH equation and Houston data



CONCLUSION AND RECOMMENDATION

The NFA stores at long periods volume of paddy grains using the Chinese piling system. The temperature recorded within the pile did not significantly changed with time. Contrarily, the RH within the pile decreased with time. The decreasing trend, given by the equation

$$\% \text{ Pile RH} = 66.1 - 0.00107 \text{ (SP, days)}$$

indicates that the pile RH starts at high level at the early stage of storage period if the paddy grains are also stored at MC level of at least 13%. The high pile RH is caused by the desorption of some of the grain moisture.

With NFA's piling system, paddy's moisture behaves in a decreasing trend along with time and is given by the equations

$$\% \text{ MC} = 13.162 - 0.004 \text{ (SP, days)}$$

for the first 602 days and

$$\% \text{ MC} = 11.055 - 0.0005 \text{ (SP, days)}$$

for the succeeding days up to 1275 days. The first equation clearly indicates that the paddy grains have a faster rate of moisture desorption on the first 602 days of storage based from its slope of -0.004%. The rate of desorption slows down after 602 days as given by the slope of -0.0005%. The three variables: MC, RH, and SP, can be pooled together to come up with one multiple regression equation which is

$$\% \text{ MC} = 4.97376 + 0.11859 \text{ (\% Pile RH)} - 0.00115 \text{ (SP)}$$

However, the RH-SP equation is needed to establish the RH at a given storage period before the multiple regression equation can be executed.

Since the MC equations and that of Houston have no significant difference, and since RH instruments are not readily available in NFA warehouses, it is recommended that the MC-SP equation be adopted in determining the behavior of the moisture content of stored paddy. This equation is the simplest among all equations given. It can therefore be easily utilized as reference in validating warehouse records.

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