A Feasibility Study of In-store Corn Drying under Tropical Climates

Pairoj Wongvirojtana, Somchart Soponronnarit
and Adisak Nathakaranakule

King Mongkut's Institute of Technology Thonburi
Suksawat 48 Road, Bangkok 10140, Thailand

ABSTRACT

Aflatoxin is one of the major problems on quality control of shelled corn after harvesting. To avoid aflatoxin produced by fungi, corn has to be dried properly. This paper describes a feasibility study of in-store corn drying under hot and humid climatic conditions. Experimental results indicated that in-store corn drying was technically feasible. The concentration of aflatoxin could be well controlled. Energy consumption index was relatively positive, especially with the strategy of ventilation only during the day time. To achieve this, initial moisture content of corn should be limited to not more than 19% wet-basis, initial concentration of aflatoxin as low as possible, and air flowrate around 2.0-2.5 m^3/min-m^3 of corn. The corresponding drying time was approximately 10 days.

Introduction

Corn is one of the most important exported agricultural products of Thailand. Aflatoxin, produced by fungi named Aspergillus Flavas and Aspergillus Paraciticus, is one of the major problems on corn quality for exportation. This toxin is dangerous to human and animals.

Factors causing aflatoxin production are type of fungi, type of products, and environment i.e. air temperature, relative humidity, and drying time. Among these factors, environment is the most important. The appropriate environment for aflatoxin production is at the temperature about 25-35 °C and relative humidity of more than 85%. In such case, fungi can produce the toxin in 24-48 hours. In order to solve this problem, the growth of fungi has to be decreased by controlling air relative humidity to 65% or less. This value of humidity is correspondent to corn moisture content of 10-15% wet basis.

Normally, corn moisture content after harvesting is about 18-30% wet basis which is too high and has to be reduced to prevent the growth of fungi and aflatoxin production. Usually, direct sun drying is applied by farmers to reduce moisture. Since this method needs a large area and takes a long drying time, corn is easily deteriorated by the growth of fungi and aflatoxin contamination. To avoid this problem, use of a corn dryer which spends less drying time is suggested.

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In-store drying is the technique of drying grain in a storage bin. In this method, there is no grain movement when drying and storage. Moisture gradient between each grain layer in bin must be as low as possible and moisture content in each layer should be low enough for safety storage. Drying temperature is usually low, i.e. close or equal to ambient temperature, and is heated only by fan. The higher drying temperature is used, the more corn weight for selling is lost. This is because of over drying at the bottom layer. As air pressure may drop when the air is passing through a high storage bin, it is necessary to use a low air flowrate.

Many research works on in-store drying of grain were conducted in temperate countries. In Thailand, in-store and batch drying of paddy and batch drying of corn have been studied.

Morey et. al. (1978) studied energy consumption of grain drying. Corn was dried in six dryers of same diameter of 5.5 m, height of 4.5 m and capacity of 106 m^3. Initial and final moisture content were about 28% and 15% wet basis respectively. It was found that the least energy consumption was obtained when corn was dried at the temperature of 120°C and the air flowrate of 120 m^3/min-m^3 of corn and further dried at the temperature of 1-5 °C above the ambient temperature and at the air flowrate of 1.7 m^3/min-m^3 of corn.

Bridges et al. (1980) developed a mathematical model to calculate the least cost drying conditions by studying the effects of the factors such as dryer capacity, initial moisture content, final moisture content, as well as size, number and type of fan. It was found from the simulation model that a dryer with diameter of 10 meters and capacity of 76.7 tons was appropriate to reduce corn moisture content from 23% wet basis to 15.5% wet basis at the drying temperature of 60 °C because of the least drying cost of approximately US$ 4.68 per ton. Increase of initial moisture content and/or decrease of final moisture content made the least drying cost per ton higher. Increase of the drying temperature decreased the drying cost per ton. Different fan sizes and fan combinations did not affect the least drying cost per ton but affected dryer capacity significantly. Using a big fan with high horse power or multiple fan could dry more amount of corn than using only one small fan. The least cost point of drying with centrifugal fan was higher than drying with axial fan while the capacity of dryer was less. The axial fan was appropriate for the dryer with large capacity and low height of corn.

Muhbauer and Kupping (1981) studied the energy consumption for drying with high temperature and with combination of high and low temperatures. The experiment was done by drying corn in a dryer with a diameter of 10 meters and a height of 5 meters. The height of corn in the dryer was 4 meters and its weight was approximately 8500 kg. The initial moisture content of corn was about 30-40% wet basis while the final moisture content was about 14% wet basis. The air flowrate during the experiment was about 20 m^3/min-m^3 of corn. It was found that drying corn with high temperature at the beginning, followed by low temperature, consumed less energy than drying corn with high or low temperature only but used up almost the equal amount of energy to drying with relative humidity control strategy.

Kalchick et al. (1981) reported the result from a 3-year experiment on corn drying at a farm in Michigan State in the north of USA. It was found that in-store drying with ambient temperature and low air flowrate consumed energy about 3.2 MJ/kg (evaporated water), and batch drying with heated air used more energy, about 6.6 MJ/kg (evaporated water).

Brooker and Duggal (1982) used low temperature and low airflow corn drying model of Thompson (1972) to simulate corn storage affected by initial moisture content and initial temperature. The safe storage time was defined such that the dry matter loss was not more than 0.5%. No ventilation while storage and ventilation with an air flowrate of 0.111 m^3/min-ton by using ambient air condition of Misuri State from 1957-1961 were investigated. It was found that initial moisture content affected the safe storage time significantly, especially in the case of no ventilation. It was also found that the safe storage time was about 180 days for an initial corn moisture content of 16 % wet basis and a storage temperature of 15.6 °C. The time decreased to 25 days only for an initial moisture content of 18% wet basis. In case of ventilation, the safe storage time was 60 days for an initial moisture content of 20 % wet basis and an air flowrate of 0.111 m^3/min-ton. If the air flowrate increased to 0.223 m^3/min-ton, the safe storage time would increase to 120 days. Initial temperature affected the safe storage time only in the case of no ventilation. Decreasing initial temperature from 21.1 °C to 15.6 °C would increase the safe storage time from 55 days to 180 days.

Shove (1984) studied the energy consumption of corn drying with unheated air. Corn with an initial moisture content of 22% wet basis was dried to 15% wet basis. It was found that unheated air drying of shelled corn with air flowrate 2 - 4.5 m^3/min-$m^3$of corn was accomplished with an everage energy of about 6.0 kWh per metric ton per percentage point of moisture removed, compared to an everage of about 12.0 kW-h/t-per percentage when using electric heater and air flowrates of 0.8 - 2.2 m^3/min-$m^3$of corn. Experimental results showed that increasing air flowrate was more efficient than increasing drying temperature, in terms of energy saving.

Krongsup and Soponronnarit (1990) investigated appropriate strategies of batch corn drying by conducting experiment and simulation employing a mathematical model. A dryer with a diameter of 0.75 meter and a height of 2.75 meters was used in the experiment. The thickness of corn bed was 0.4 meter. The experiment was carried out with continuous ventilation and intermittent ventilation. Initial corn moisture content was about 15 - 26% wet basis. Air flowrate was about 5.5 - 45 m^3/min-$m^3$of corn and drying temperature was 45 - 90 °C. It was concluded that the appropriate strategy of batch corn drying depended on user's need. Low temperature and low air flowrate technique was suitable for saving energy. But for high drying capacity, high temperature and high air flowrate technique was more suitable. Continuous ventilation should be used in both techniques to prevent the rise of aflatoxin.

Lynch and Morey (1989) also used low temperature, low airflow corn drying model of Thompson (1972) to examine different fan control strategies for finishing ambient air corn drying in the spring. It was found out from the simulation that intermittent fan operation could result in more optimum final moisture contents and slightly reduced energy requirement but at the expense of increased corn deterioration and an extended finishing date. Rewetting control strategies which sougt to rewet the bottom layers of corn after safe moisture contents had been reached and resulted in a more uniform moisture profile through the bin but at the expense of extra fan run time.

In addition to the results of above-mentioned research works, there are other suggestions on in-store drying of corn in temperate region. US Department of Agriculture (1968) suggested that, at the ambient temperature below 10 °C and corn moisture content below 30% wet basis, it was advantageous to use low drying temperature as shown in Figure 1. Midwest Plan Service (1980) also suggested the minimum air flowrate for corn drying temperature of below 10 °C as shown in Table 1.

It can be concluded from the research works above that in-store drying was appropriate to use in temperate countries because the cold weather in this region could prohibit the growth of fungi and aflatoxin producing ability. But in the tropical country such as Thailand, fungi grows very well and aflatoxin problem will be found in case of long drying period. Thus the possible tendency of in-store corn drying in tropical region is to use higher air flowrate and drying temperature than in temperate region so that the drying time is shorter. The initial moisture content of corn should not be too high.

The objective of this research is to investigate the feasibility of in-store drying technique for corn drying in tropical region, such as Bangkok. Quality of corn, energy consumption and drying time will be regarded as criteria for this study.

Materials and Methods

Instruments and Measurement

1. The experimental dryer had a diameter of 0.75 meter, a height of 2.75 meters and a capacity of about 600 kg at the height of corn of 2 meters. It was insulated with fiber glass of 25 millimeters thick. Drying air was blown by a 0.75 kW centrifugal fan and heated by three 0.5 kW electric heaters.

2. Instruments and desired data

2.1 Air flowrate was calculated from the product of mean air velocity in duct and its cross-sectional area. The air velocity was measured by a hot wire anemometer.

2.2 Corn moisture content was measured by the method of Association of Official Agricultural Chemists (AOAC). Samples of corn had been dried in an air oven at a temperature of 103°C for 72 - 96 hours.

2.3 Temperatures in each corn layer in the dryer were measured by thermocouple type K (Chromel-Alumel). In order to measure temperature at the middle of dryer, the thermo-couple was inserted into the stainless-steel tube every 20 cm and connected with a multi-channel digital recorder "Takeda Riken TR 2721" with 12 connected points to read and print out the temperature change in each layer every 2 hours. The accuracy of the data logger is about ± 1 °C.

2.4 The measurement of dry bulb and wet bulb air temperatures followed the same method in 2.3.

2.5 Energy input to the drying system was electricity, which was consumed by the motor and heater and recorded by Watt-hour meters.

2.6 Corn quality before and after drying was measured by sampling about 1500 g of corn before and after drying at each level of dryer (every 40 centimeters). The amount of aflatoxin B1, B2, and G1 was checked by Thin Layer Chromatography method (TLC).

Experiments

The height of corn was set at 1.4 meters. The initial corn moisture content was about 17 - 25 % wet basis while the final moisture content was about 14% wet basis. The experiment was divided in to 3 categories as follows :

1. Continuous ventilation with air flowrates of 1.5 - 4.5 m^3/min-m^3 of corn (Test nos. 1,2, 4 and 6).

2. Continuous ventilation with relative humidity control at not more than 75% and an air flowrate of 2.5 m^3/min-m^3 of corn (Test no.5)

3. Intermittent ventilation by running the fan during the day time (8:00 - 20:00 hrs.) and stopping at night (20:00 - 8:00 hrs.) with air flowrates of 1.5 - 4.0 m^3/min-m^3 of corn (Test nos. 3, 7 and 8).

Results and Discussion

Test nos. 1 to 4 were conducted in the rainy season in 1991. Test nos 5 to 8 were carried out in the rainy season in 1992. The final moisture contents of all tests were about 14% wet basis. The experimental results were shown in Table 2. Figures 2a to 9a showed the relationship between corn moisture content at each level of dryer and drying time. Figures 2b to 9b showed the relationship among ambient temperature, relative humidity and drying time.

Moisture Gradient in Corn Bed

From figures 2a to 9a, it was found that the moisture gradient after drying was not so high. The mean moisture difference between the top and bottom layers was less than 4% wet basis. Experimental results of batch drying of corn conducted by Krongsup and Soponronnarit (1990) showed that the difference was more than 5% wet basis. This was resulted from the higher drying temperature used in the latter case.

It was found that moisture gradient of corn after drying in test no. 5 was highest. This was due to the control of relative humidity of drying air by an electric heater. As a result, the moisture content at the bottom was relatively low.

In view of figures 2a to 9a, it was found that the evolution of moisture at each layer in the grain bed could be divided into 2 types i.e. normal and specific types. In the normal type, corn was slowly dried from the bottom to the top layer (test nos. 1, 4, 5, 6, 7 and 8). In the specific type, corn at the top and bottom layers was dried simultaneously but with a slower rate at the top (test no.2). This was due to heat deliberated from respiration. In some tests there was rewetting, caused by condensation (test nos. 2 and 3) due to high air temperature, high humidity and low corn temperature.

Energy Consumption of Drying

There were 2 parts of drying energy, mechanical energy and heat. In this research, conversion factor from mechanical energy to heat was 2.6. The results in Table 2 showed that continuous ventilation consumed more energy than intermittent ventilation because continuous ventilation with high relative humidity air at night made the total drying efficiency decreased. Continuous ventilation with heated air at night showed highest energy consumption.

Aflatoxin

In all tests, it was found that the amount of aflatoxin increased with the height of corn, that was, with corn moisture gradient. The largest amount of increasing aflatoxin was in the test no. 8 because of long drying time resulted from low air flowrate and a large initial amount of aflatoxin.

In the test no. 2, the initial moisture content was very high, about 25.5% wet basis, and the drying time was long, which caused a rapid growth of fungi and a large amount of aflatoxin. The initial amount of aflatoxin, which meant initial contamination of fungi in corn, affected the final amount of aflatoxin significantly (test nos. 4, 5, and 6) because of the growth of fungi while drying. Final amount of aflatoxin was not found in test no.1 as there was no initial amount of aflatoxin. For intermittent ventilation (test nos. 3 and 7), the amount of aflatoxin was not increased, although it should be, because of low initial moisture content and short drying time (see Table 2).

Different initial moisture contents, air flowrates, and initial amount of aflatoxin were compared. It was found that, for continuous ventilation (test nos. 1, 2, 4, 5 and 6), initial moisture content of more than 19% wet basis was not appropriate for in-store drying because the final amount of aflatoxin was too high although a high air flowrate was used (test no.2). For intermittent ventilation (test nos. 3, 7 and 8), it was found that the amount of aflatoxin was not increased when the initial moisture contents were 17.4% and 18.0% wet basis (test nos. 3 and 5 respectively). But in the test no. 8, the initial moisture content was about 18.7% wet basis and air flowrate was rather low, about 1.5 m^3/min-m^3 of corn. It was necessary to dry for a long time. As a result, a large amount of aflatoxin was detected.

From the above discussion, it can be concluded that the initial moisture content of corn should be limited to not higher than 19% wet basis, air flowrate of about 2.0 - 2.5 m^3/min-m^3 of corn and initial concentration of aflatoxin as low as possible. With these conditions, the corresponding drying time was approximately 10 days and the final moisture content was about 14% wet basis.

Conclusion

1. In-store corn drying under hot and humid climatic conditions was technically feasible.

2. Initial moisture content, initial concentration of aflatoxin and corresponding drying time affected increase of aflatoxin concentration significantly.

3. The factors to achieve the lowest final concentration of aflatoxin were :
   - Initial moisture content of not more than 19% wet basis,
   - Air flowrate of about 2.0 - 2.5 $m^3/min\text{-}m^3$ of corn (drying time of about 10 days),
   - Initial concentration of aflatoxin as low as possible.

4. Intermittent ventilation with the strategy of ventilation only during the day time consumed less energy compared with continuous ventilation.

Recommendation

A mathematical model for predicting the concentration of aflatoxin should be developed and combined with a grain drying model in order to investigate the most appropriate operating parameters.

Acknowledgement

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Table 1 The least possible air flowrate for low temperature corn drying, air temperature = 10 °C or less (Midwest Plan Service, 1980)

Initial moisture content (% wet basis)	The least possible air flowrate ($m^3/min\text{-}m^3$ of corn)
20	1.1
22	1.4
24	2.2
26	3.3
28	5.6

Table 2 Results of corn drying (Final moisture cotent of about 14% wb)

Description	test no.							
	1	2	3*	4	5**	6	7*	8*
moisture content, %wb								
initial	19.1	25.5	17.3	20.3	20.0	20.8	18.0	18.7
final, top	17.7	13.0	17.0	16.6	16.9	13.3	15.1	15.5
bottom	10.9	15.4	12.5	12.8	12.8	11.5	14.9	11.7
average	13.6	14.0	14.2	14.3	14.2	13.1	14.5	14.2
air flowrate (m^3/min-m^3)	3.0	4.5	4.0	1.5	2.5	2.5	2.5	1.5
depth of corn (m)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
ambient air								
temperature (C)	28.0	28.0	27.0	25.9	27.6	27.0	26.7	26.7
relative humidity (%)	85.0	83.0	76.0	75.8	86.2	87.7	82.9	80.1
temperature rise (C)	5.0	1.0	2.0	1.5	3.4	0.6	1.4	1.3
total time (h)	144	216	132	360	240	264	244	432
energy consumption (MJ/kg water evap.)								
shaft energy	NA	2.96	2.67	3.28	2.71	2.27	1.95	2.38
heat	-	-	-	-	3.29	-	-	-
total	NA	2.96	2.67	3.28	6.00	2.27	1.95	2.38
primary energy consumption (MJ/kg water evap.)	NA	7.70	6.94	8.53	10.34	5.90	5.07	6.19
condensation in grain bulk	no	yes	yes	no	no	no	no	no
average aflatoxin before drying	0	16	119	51	605	48	274	314
average aflatoxin after drying	0	666	69	61	1200	282	187	1166

NA = NOT AVAILABLE
* = INTERMITTENT VENTILATION (ON 12 hrs. OFF 12 hrs.)
** = RELATIVE HUMIDITY CONTROL (75% RH)

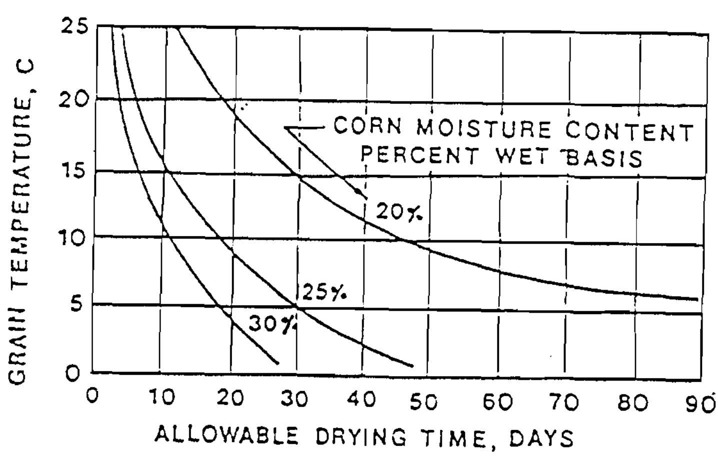


Figure 1 Allowable drying time for corn
(US Department of Agriculture, 1968)

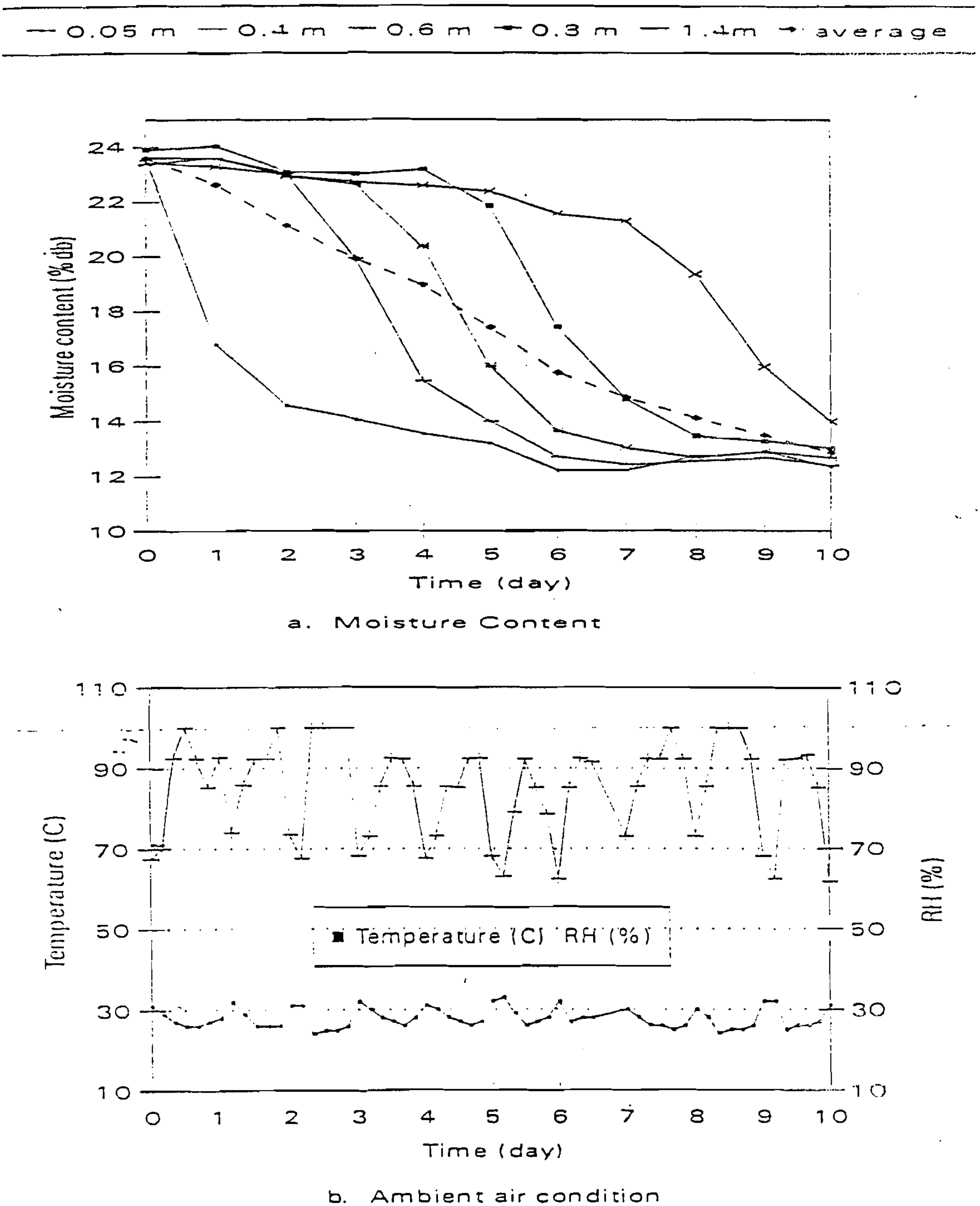
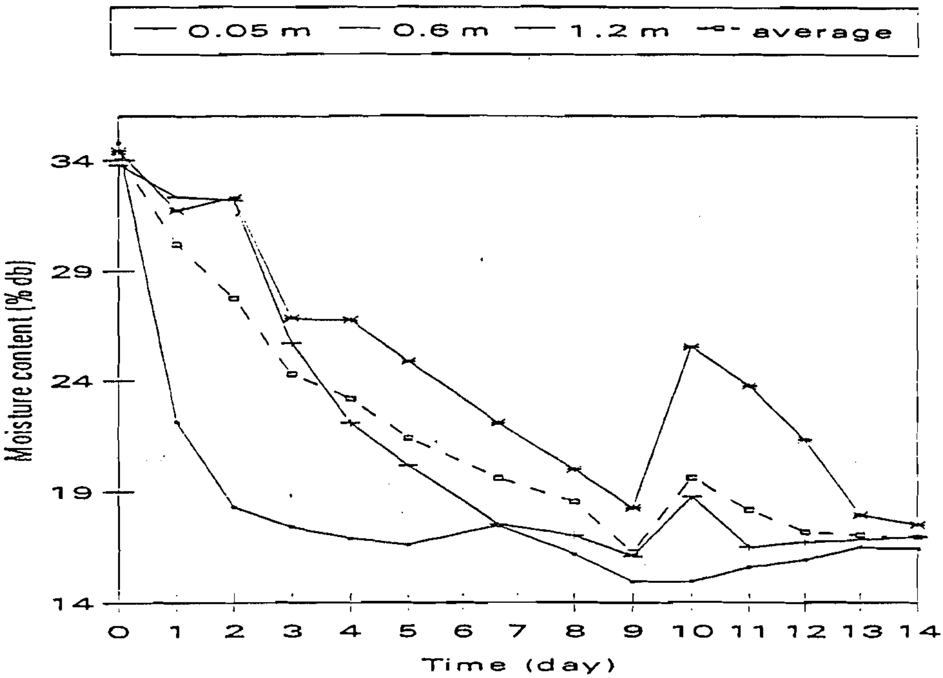
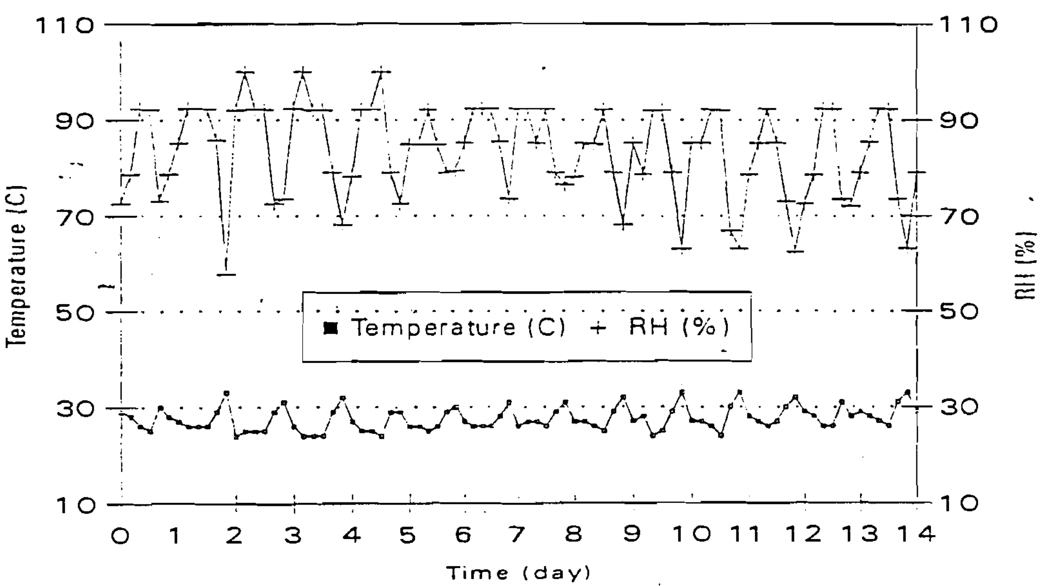


Figure 2 Evolution of moisture content and ambient air condition (Test no.1)

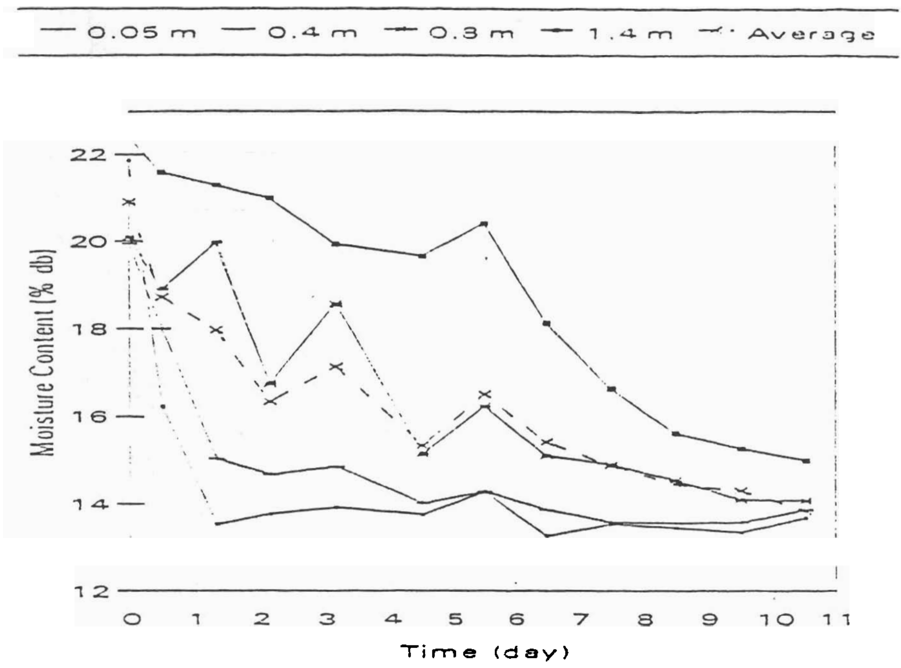


a. Moisture content



b. Ambient air condition

Figure 3 Evolution of moisture content and ambient air condition (Test no. 2)



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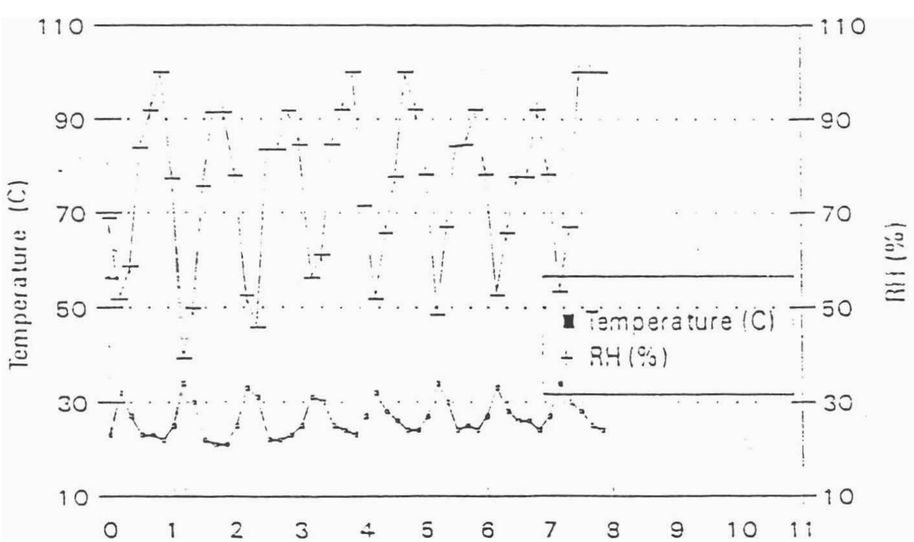
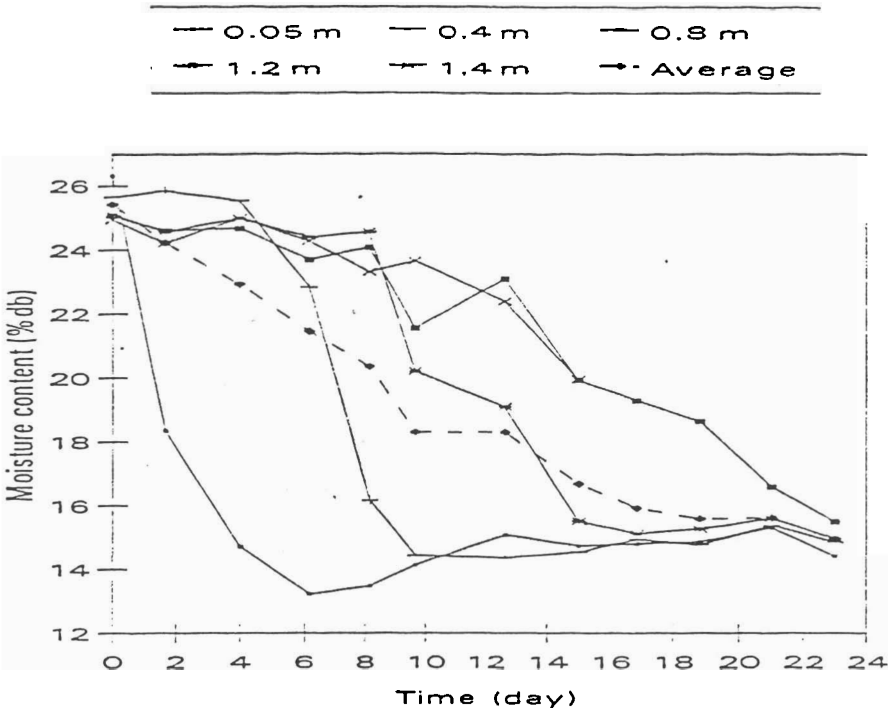


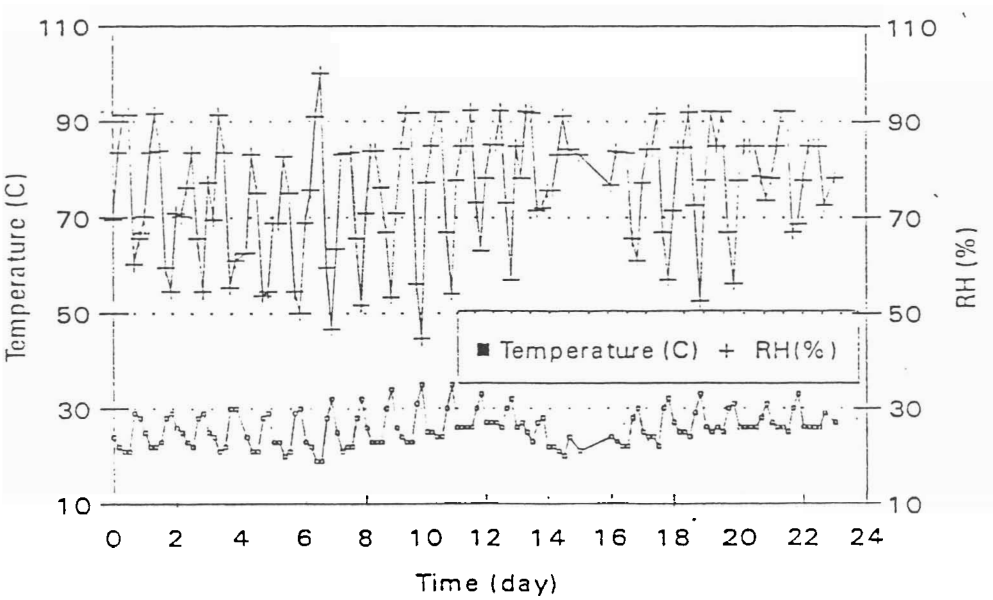
Time (day)

b. Ambient air condition

Figure 4 Evolution of moisture content and ambient air condition (Test no. 3)

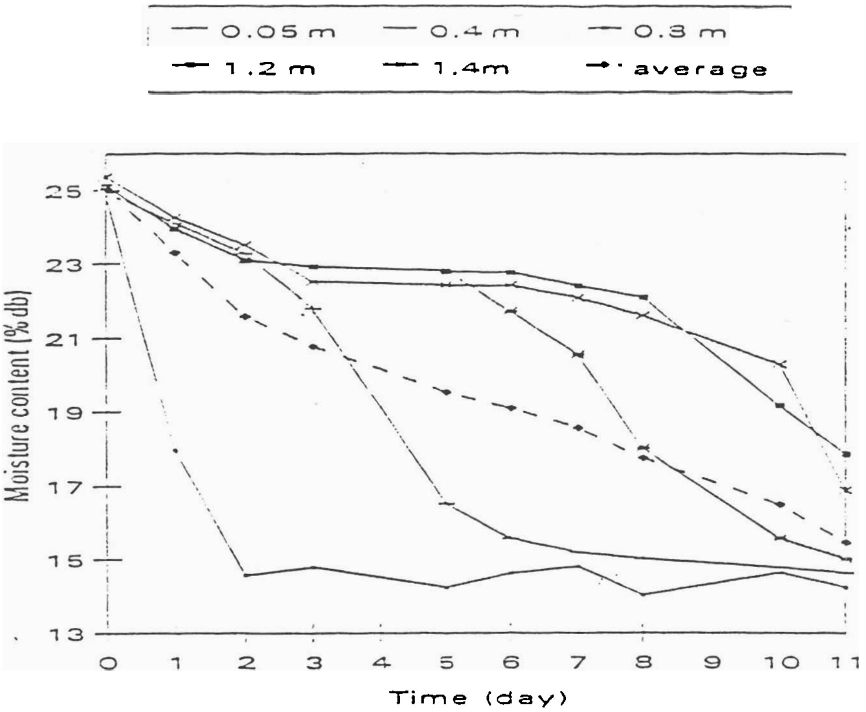


a. Moisture content

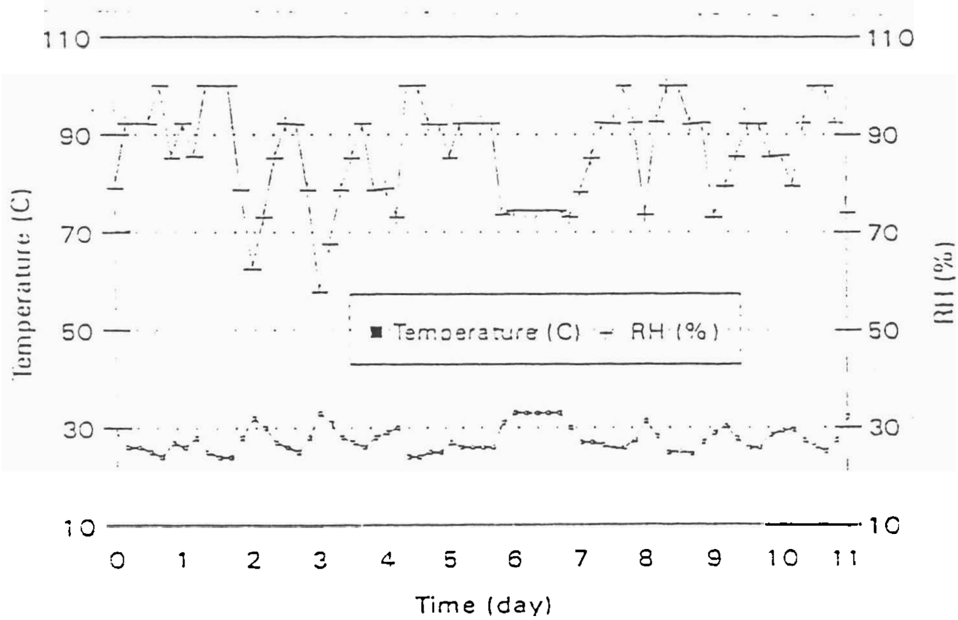


b. Ambient air condition

Figure 5 Evolution of moisture content and ambient air condition (Test no. 4)

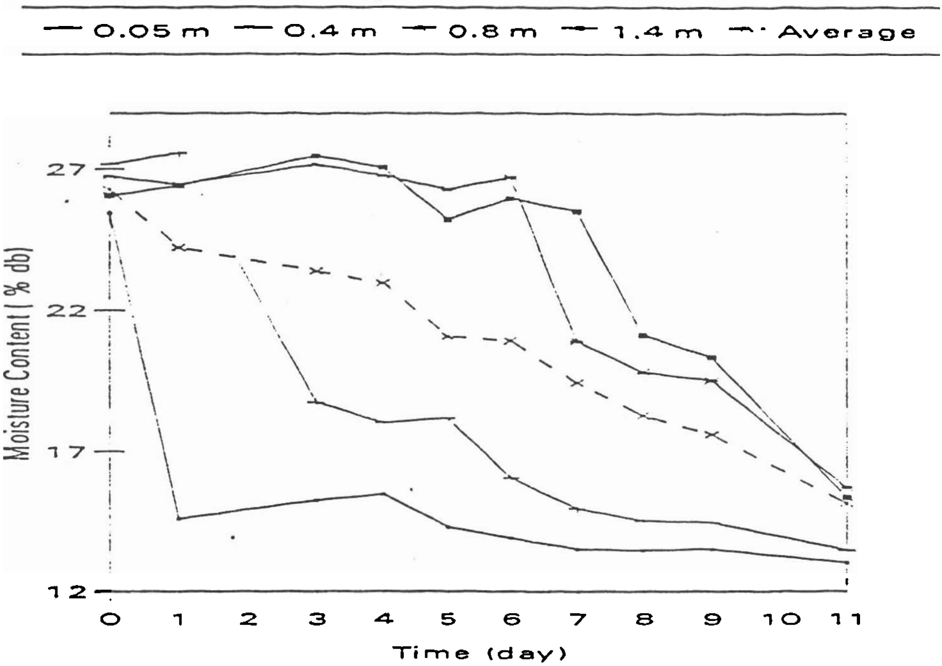


a. Moisture content

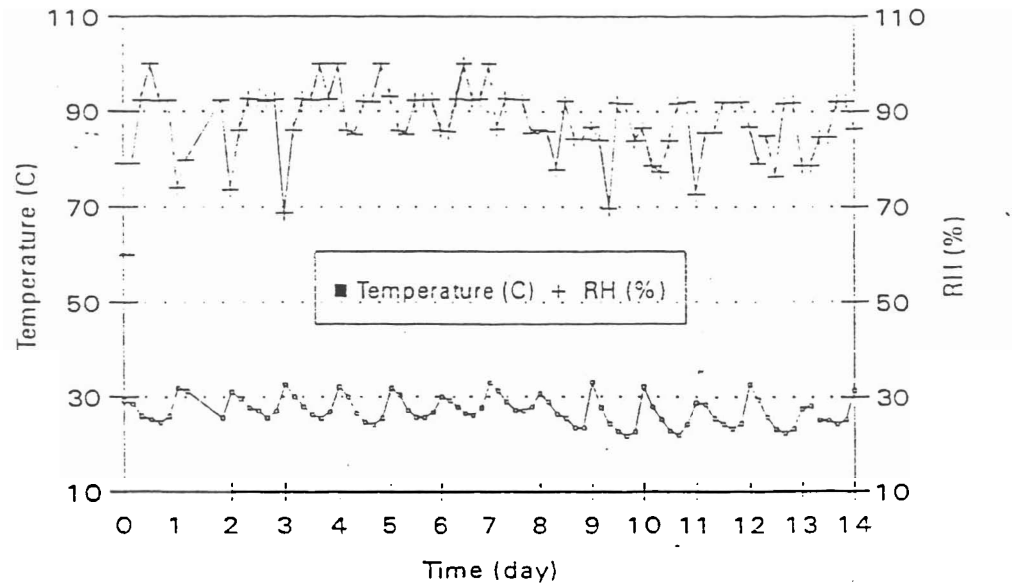


b. Ambient air condition

Figure 6 Evolution of moisture content and ambient air condition (Test no.5)

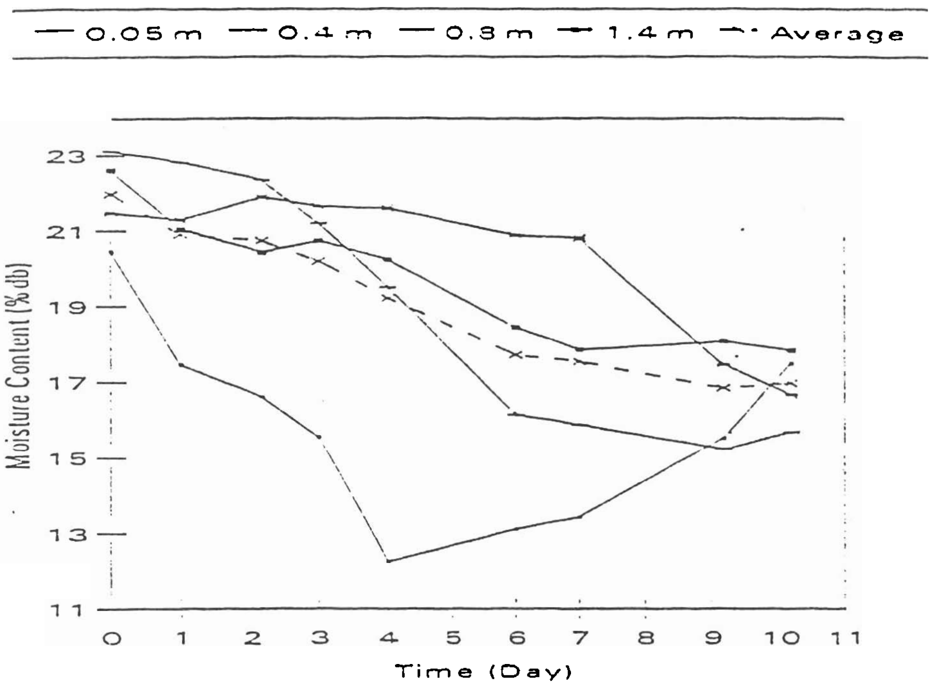


a. Moisture content

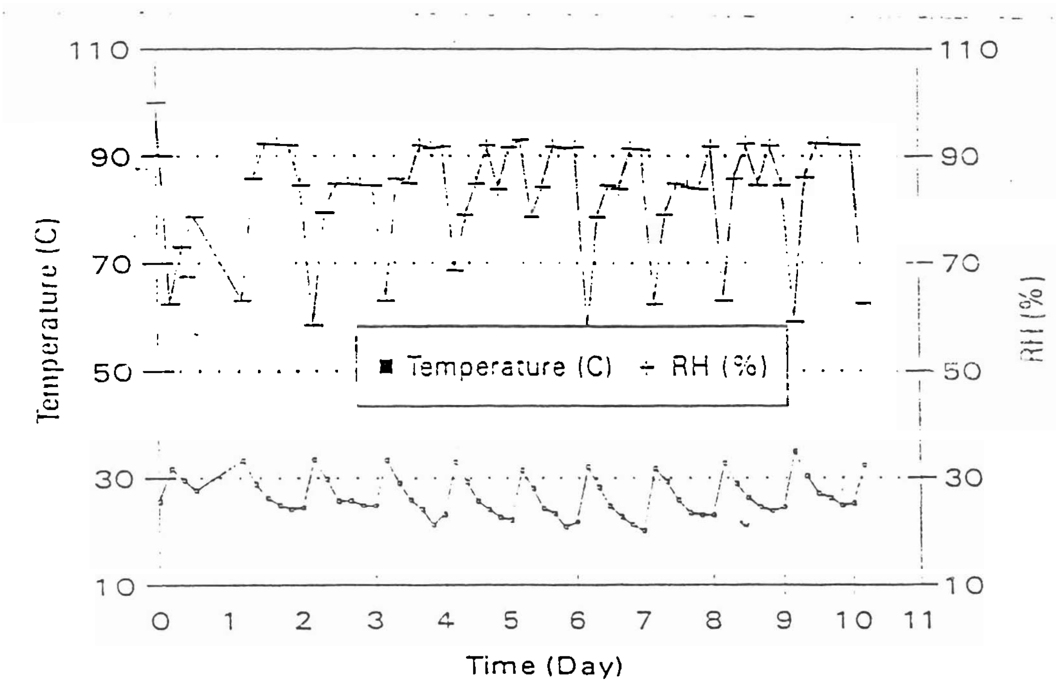


b. Ambient air condition

Figure 7 Evolution of moisture content and ambient air condition (Test no.6)



a. Moisture content



b. Ambient air condition

Figure 8 Evolution of moisture content and ambient air condition (Test no.7)

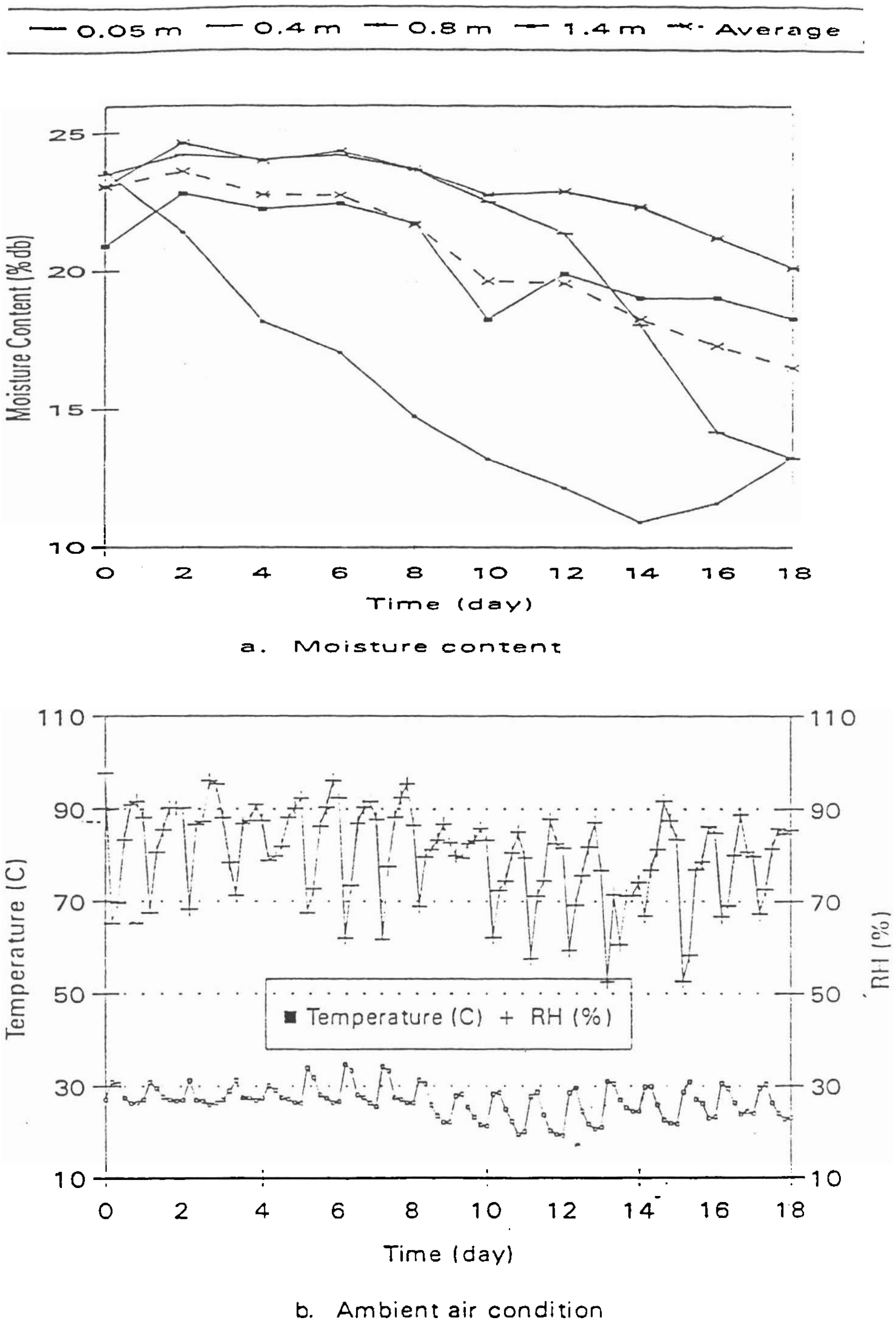


Figure 9 Evolution of moisture content and ambient air condition (Test no.8)