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MOISTURE ADSORPTION OF BULK STORED GRAIN UNDER TROPICAL CONDITIONS

By

AXEL CARO GREIFFENSTEIN

B. S., Universidad de America, Bogota, Colombia 1969

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Harry B. Pfost
Major Professor

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INTRODUCTION

It is more difficult to maintain quality of bulk stored grain in tropical areas than in any other areas. The high temperature and high relative humidity, usually above 70% in tropical areas, contribute to an environment which damages grain as a consequence of insect infestation, fungi and bacteria.

Over the years, it has been observed that there is an increase of moisture content in grain which has been stored for relatively short periods of time, although care has been taken to preserve its quality. Quite often, grain has to be dried again after a period of storage, due to the increase in the moisture above the "safe" limits. Convection currents caused by temperature gradients within the mass of grain have been identified as the main cause of moisture migration.

However, taking into account the hygroscopic nature of grain kernels, it is believed that the increase of moisture content of stored grain is related to the high humidity and temperature of the surroundings. From this point of view, grain would adsorb moisture from the air above the free surface of the grain, or through the concrete walls of a bin, in a way similar to that in which grain attains equilibrium with the surrounding atmosphere, in laboratory type experiments.

Although a great deal of research has been conducted to study the kinetics of moisture adsorption in grains, virtually nothing has been reported with respect to the practical conditions of large masses of bulk stored grain. Again most of the research has been done with respect to non-tropical areas, where weather conditions are not so troublesome for storing grain. Therefore, these investigations are directed toward various other factors that can change or influence the equilibrium moisture content of stored grains.

Since many of the developing countries, which have significant grain production, are in tropical areas, storage losses contribute to the increase of existing economical and social problems. Thus a better understaning of moisture adsorption by stored grains could lead to better methods for grain processing and storage, and hence improve the quality and value of cereal and grain products.

The present research was planned to investigate the behavior of bulk stored grain subject to high temperature and humidity levels on the top free surface of a bin. The very common case of recently dried grain put in storage with moist surroundings was simulated. A hypothesis that explains this phenomenon is presented. Three experiments were conducted, the last of which was with low level aeration in order to test the hypothesis.

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REVIEW OF LITERATURE

The two main phenomena that influence in the behavior of stored grain are the equilibrium relative humidity at a given temperature, and, the air flow that occurs naturally or artificially within the mass of grain. Convection currents due to temperature gradients and mechanical aeration are such types of air flow.

Several researchers have investigated the hygroscopic properties and equilibrium moisture content of grains. Pixton and Warburton (16) presented the equilibrium moisture content of soft wheat, barley and yellow dent corn. Their work established the relationship between the vapor pressures in the air and in the grain, and the dew point temperature for different moisture concentrations. Hygroscopic equilibria of rough rice at elevated temperatures have been calculated by Hogan and Karon (10). Chung and Pfost (5) investigated the moisture equilibria of corn and corn products, and the effect of hysteresis in the adsorption rates.

The speed of adsorption has been investigated by Pixton and Warburton (15) for two different types of wheat, and the sorption isotherms for grain sorghum have been found by Hodges, Chung and Dustan (9). From the above examples of research efforts, it is evident that the subject of hygroscopic properties and equilibrium moisture content of grains has been analyzed extensively for a wide variety of products.

Aeration is used in several ways to preserve the quality of grain. It is used to maintain the soundness of dry grain, to keep large quantities of wet grain in safe conditions, and to equilibrate the natural differences in temperature that occur in large bulk storage.

The influence of aeration in stored grain has been analized by several investigators: Foster (7) states that: " When grain is cooled by aeration, its moisture content is reduced. When grain is warmed by aeration, moisture is added". Valencia and Teter (19) experimented with aeration with air almost at the saturation point. Their findings show that the relationship between vapor pressures in the air and in the grain is what regulates moisture transfer, rather than the simple difference between relative humidities. Calderwood (2,3) investigated the convenience of aeration in the drying process of rice, and the prolonged storage of undried rice in aerated bins.

Convection currents due to differences in temperature may relocate moisture within the grain. It has been shown (8) that moisture goes from zones with higher temperature to zones with lower temperature. There, the moist air may reach the dew point and deposit water in the liquid state over the surface of kernels. This phenomenon is typical of seasonal weather differences, and can occur due to temperature changes between day and night in tropical areas. It has been reported by Carter and Farrar (4) that strong concentrations of moisture occured in soybeans stored with uniform moisture content between 11 and 12% . Within a few weeks the concentration reached 16% to 20% in the upper part of the bins. They state that:

> "... Experiments with watertight converings have shown that the condition is due to moisture movement within the grain rather than that of wetting from rain or snow".

For the present case, the "rain or snow" element could be any kind of external moisture that may have been in contact with the grain.

The transfer of moisture due to diffusion has been investigated by Pixton and Griffits (14). Their experiment is the only one that has analyzed the behavior of grain stored in bulk, subject to highly moist air, and the transfer of moisture due to diffusion. They found that:

> "... calculated moisture changes in a large bulk storage exposed at the surface to a high relative humidity indicate that moisture changes due to diffusion under practical conditions are extremely slow".

In their work, these investigators state that:

> "The rate at which grain will absorb or lose moisture depends on the amount by which its equilibrium humidity differs from that of the surroundings atmosphere and on the extent to which the individual grains are exposed. Generally the rate of moisture exchange with the atmosphere is slower than is usually expected, especially when a considerable quantity of grain is stored in bulk. If the grain is exposed in a layer only a few kernels thick, the time to reach equilibrium may be a week or more and small further increases in the thickness of the layer will greatly extend the period required for equilibration".

They also say that air currents can be expected to contribute to the transfer of moisture, but they identify wind as the main contributor to that phenomenon.

The investigations which have been sumarized above provide the motivation for the present research. The hypothesis pertaining to the proposed research is that there is no adsorption of moisture of practical significance from the sorrounding atmosphere in stored grain, unless the moisture reaches beyond the first layers of kernels in the surface of the grain, as a consequence of some kind of air flow through the grain.

EQUIPMENT

The equipment used for the present research is a modified version of that developed and used by Breton (1). Although a detailed description of the original apparatus is available in his paper, a brief description of the same with related modifications is given, in order to better understand its performance.

Four simulated plastic bins, 6" diameter and 72" high were originally insulated with $2\frac{1}{2}$" of fiberglass. Later on, this insulation was increased to $3\frac{1}{2}$". Several small plastic pipes 1" diameter were attached perpendicular to the axis of the bins, in order to take samples and record the temperature of the grain.

The four bins were connected at the top to a wooden box where the temperature and relative humidity were controlled by means of two thermostats. The heat was suplied by three electric bulbs, 60 watts each, and the relative humidity was attained by heating approximately two gallons of water using three additional bulbs. Therefore, the control of the relative humidity was indirect, and not always easy to maintain within the proper limits. (The use of humidistat, or a switch controlled by relative humidity instead of temperature is recommended to improve the performance of the system).

The entire apparatus was located in a wooden platform, 8" above the floor level, in order to minimize the heat transfer between the bottom of the bins and the floor. A wooden structure held all the components in place. Figure 1 is a photograph of the equipment.

The temperature of the grain was taken by means of thermocouples located through the plastic pipes, 4", 1', 2', 3', 4', 5', and 6' below the grain surface. The 28 thermocouples, and two others used for recording both the water and box temperatures were attached to a master switch. This switch was connected to a galvanometer set up to read temperatures within the range 32-212° F.

A dial hygrometer for direct reading was located inside the box and the values checked through a plastic window on the box.

The aeration system in the third experiment, consisted of a small diaphragm pump, that delivered 200 cu. in./min. (.116 cfm). The pump was located inside the chamber and connected with the bins by means of plastic tubing and fittings. Airtight plastic covers were attached at the top of bins 1, 2 and 3, and the tubings from the pump were securely fastened to the covers in order to insure that the system was hermetically sealed. The closed circuit was completed using standard rubber hoses, that were connected to the lowest plastic pipes on the bins and to the wooden chamber. The three hoses were attached to the box near the water source.

The above details are shown in figure 2.

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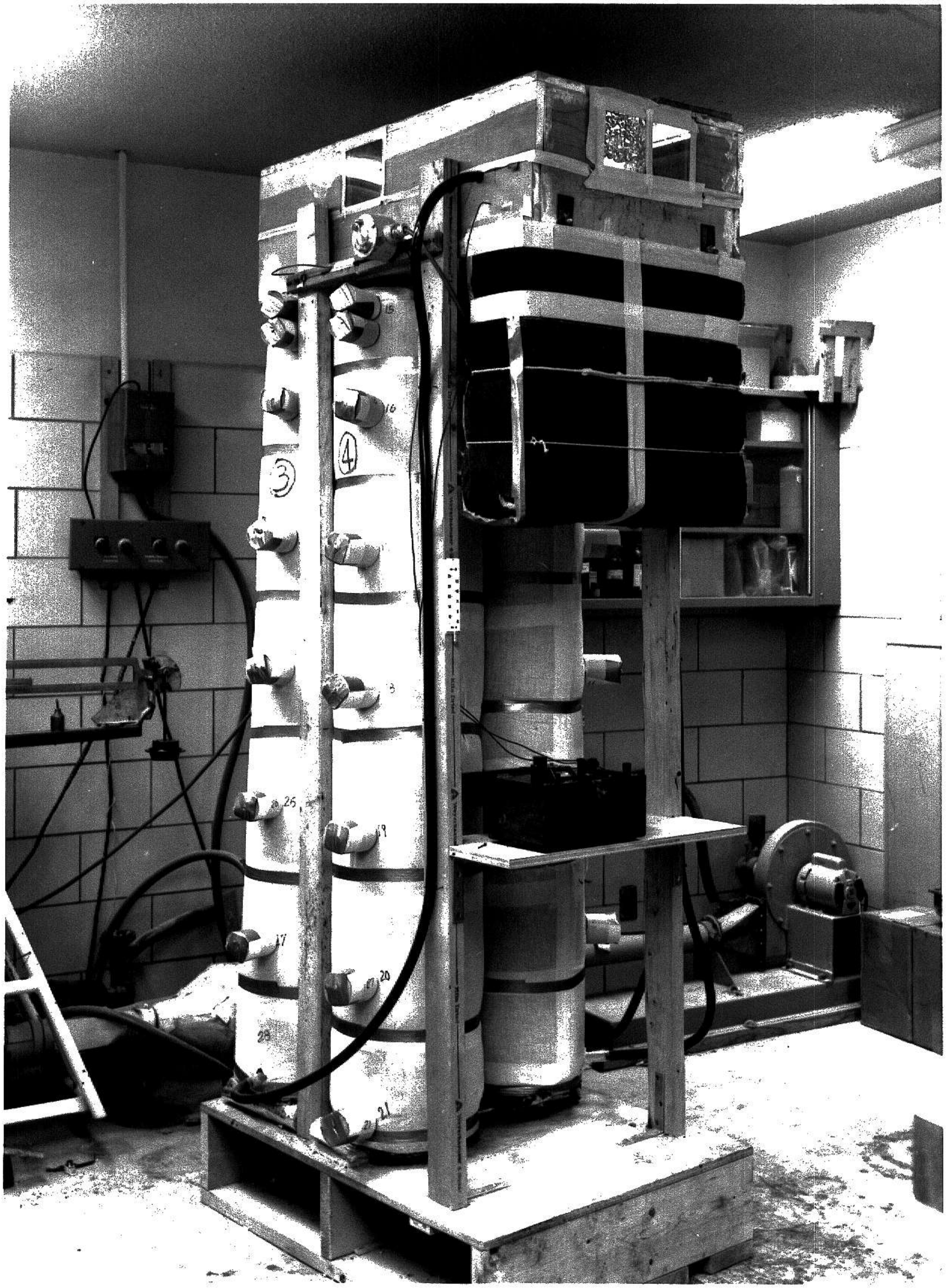

Figure 1. Photograph of the equipment.

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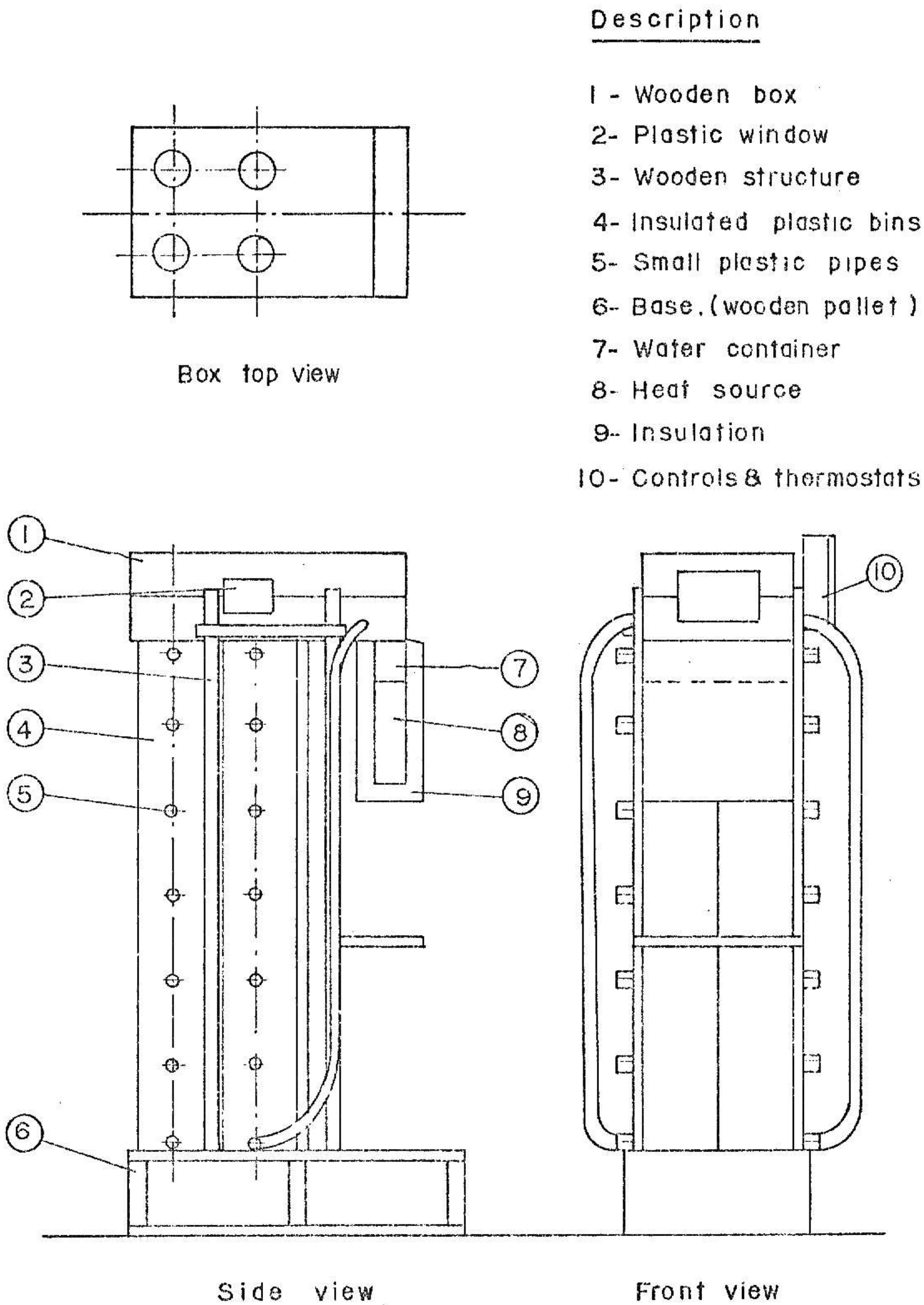

Figure 2. Schematic view of the equipment.

PROCEDURE

The objective of the present research was to record and analyze moisture variations of bulk stored grain, subjected to tropical conditions; i.e. high relative humidity and high temperature on the free surface of a bin.

The grain was kept without aeration during the first and second experiments in order to observe the behavior of the diffusion forces. The third experiment used aeration at low levels for the purpose of comparing the adsorption of moisture attained in both instances.

First Test.

This experiment was conducted using the original equipment developed by Breton (1), before any modifications were made.

Four different grains, rough rice, yellow dent corn, hard red winter wheat and grain sorghum were placed in the bins at low moisture content levels.

Rice had a moisture content of 9.8%, while those of corn, wheat, and sorghum were 10.2%, 10.0% and 10.6% respectively.

The temperature of the chamber was set at 90° F. (± 1°.F.), and the relative humidity, measured approximately 75%.

Samples of grain were taken every 12 hours during the first $3\frac{1}{2}$ days, and again every 12 hours, from the 11th day to the 14th day. The moisture content was recorded from samples taken from the surface of grain, and from levels located 2", 4", 6" and 1' below the surface.

The grain temperature, as well as the room and chamber temperatures were recorded at least every 12 hours during the first four and the last four days.

The experiment was discontinued after 336 hours for the following reasons. The first and more important was the wide variation of room temperature which had a strong influence on the grain temperature. The second was that it was impossible to maintain the level of grain in the bins due to the large number of samples taken, and the relatively small amount of grain held in each bin.

Second Test.

Prior to the second experiment the equipment was revised and modified as explained previously and was moved to a room with a relatively constant temperature.

An initial test of the equipment was conducted in order to check the reliability of the controls. Temperature and relative humidity were recorded for two days at intervals of four hours or less.

It was found that the bulb thermostat had a very slow reponse to temperature changes in the box, allowing differences up to 6^{o}F. between the high and low limits.

To improve that situation, the thermostat bulb was located very near to the heat source, instead of protecting it from the radiant heat. A remarkable improvement followed due to the fact that the radiant heat increased the temperature of the bulb much more rapidly than the temperature of air in the rest of the box. By setting the lower limit on 89.5^{o}F., the bulb put off the lights any time the temperature on the box was 90.4-90.5^{o}F. The variation was reduced to $\pm .5^{o}$F.

The relative humidity of the air was set between 75 and 80%. Care was taken not to surpass the 80% limit to avoid mold growth. The above relative humidity was maintained by keeping the water temperature at 106°F. (± 2°).

Small samples of grain were taken from the 4", 1' and 2' levels every 12 hours during the first four days; once a day from the fifth to the 13th day, and then on the 17th, 22th, and 40th day. Samples from the 4' and 6' levels were taken several times during the test, as a control measure.

Special samples were taken on the last day of the test from the surface of the grain, and from layers ½", 1" and 1½" below the surface. Individual kernels were picked by hand, selecting a representative sample of each of the above mentioned layers.

The moisture content of the samples was taken using the standard air-oven method. The A.O.A.C. standards for the air oven method are as follows:

> " 22.008 IV Drying at 135°C. (Not to be used when fat detn is to be made on same sample).
> Regulate elec. air oven to 135 ± 2°. Using low, covered Al. dishes, 22.003, weigh ca 2 g sample into each dish and shake until contents are evenly distributed. With covers removed, place dishes and covers in oven as quickly as possible and dry samples 2 hr. Place covers on dishes and transfer to desicator to cool. Weigh and calc. loss in wt as H20".

Temperatures were recorded every 12 hours during the first four days, and daily troughout the rest of the experiment.

Third Test.

The third and last experiment was conducted using the same basic procedures of the former ones, but low level aeration was installed in order to compare the findings of the different tests. Yellow dent corn was used in the four bins, in order to compare the results due to different air rates through the grain.

Clean grain with an initial moisture content of 14.8% was dried with heated air in a static bed about 3" deep, for a period of 2 hours. The temperature of the air was aproximately 120°F. When corn was first introduced to the bins it had two different moisture contents: 10.7% in bin 2 and 11.5% in bins 1, 3 and 4.

Rates of air flow used in aeration have a very wide range of values. According to Hall (8) grain can be aerated efficiently, using only 1/50 of cfm. per bushel of grain. Values of 1/10 and 1/20 cfm/bu. are given as standard. The Feed Manufacturing Technology book (6) recommends rates up to $\frac{1}{2}$ cfm/bu. in certain conditions. Flow rates depend on the type of bin, size and characteristics of the installation, weather conditions, and other factors such as the temperature and moisture content of the material, and the moisture equilibrium properties of the grain (13).

Johnson (12) calculated the convection currents that occur in stored grain. He reported that:

> "...temperature differences of 40 to 50 F. are found to result in significant differences in the specific weight of air. For example, air at 85 F. and 75 percent humidity has a specific weight of 0.07 lb. per cu.ft. at standard atmospheric pressure, while air at 45 F. and 75 percent relative humidity weighs 0.078 lb. per cu. ft. or 11 percent more".

He also states that:

> " The bin is 120 ft. in diameter and 30 ft. high. The difference in specific weigh of the interstitial air which results from the difference in temperature would produce a pressure of 0.017 in. of water for movement of air along flow path A a distance

of 90 ft. An extrapolation of the data of Shedd (12) for air flow in grain indicates an air flow of 0.05 cfm. per sq.ft. through clean shelled corn".

The above air current is equivalent to 0.002 cfm. per bushel of grain in that bin, or 1/500 cfm./bu. which is one-tenth of the lowest rate recommended for aeration. As can be observed, the air flow rates due to convection are extremely low.

Two rates of air flow were used. Two bins received one-fourth of the total capacity of the pump, which is equivalent to 50 cu. in. per minute, or 0.029 cubic feet per minute. One bin received one half of the capacity, or 0.058 cfm. The fourth bin was used as a control bin. The above rates are within accepted levels of aeration, and the related calculations are as follows:

Volume of a bin: $V = \pi R^2 h$.

$V =$ 2035. cu. in. or 1.178 cu. ft.

Area of the cross section of a bin:

$A = \pi R^2$

$A =$ 28.27 sq. in or 0.196 sq. ft.

The capacity of the commercial pump used in the experiment is 200 cu. in./min., equivalent to 0.1157 cfm. The above capacity was checked before the experiment started.

Table 1 shows the values of the air flow per bin, per cubic foot and per bushel of grain.

Those rates are equivalent to 1/50 cfm. per bushel, the lowest level of aeration generally recomended, and 1/25 cfm./bu. which is within comercial rates of air flow through grain.

Table 1. Air flow through stored grain.

	Bins 1 and 2	Bin 3
cfm./Bin	0.029	0.058
cfm./cu.ft.	0.0246	0.0492
cfm./bushel	0.0197	0.0395

The resistance to the air flow was calculated using the information given by Sheldon et al (17) for very low air flows and the data given by Shedd (18)

The calculated air flows per sq. foot of cross area are 0.148 and 0.2959 cfm./sq. ft. respectively.

Corresponding values for corn were found directly from the chart. It was noticed that the increment of resistance to the air flow was proportional to the rate of flow, within the range used in the present research.

Table 2 shows the resistance to air flow per foot of depth and the total resistance per bin.

Table 2. Resistance of Corn to air flow.

	Bins 1 and 2	Bin 3
In. of water per foot of depth	0.0010	0.0020
Total resistance per bin, in. of water.	0.006	0.012

After the four bins were filled with corn, the system was tested to check on the proper performance of the air pump. Due to the very low rates and air pressures, the air flow could not be detected by conventional physical means. A gas-chromatograph was used to detect traces of a gas vaporized in the wooden chamber. A small amount of ethyl ether was vaporized in the chamber so that the only way grain could adsorb the gas was through the operating pump.

Air samples were taken through the small plastic pipes at the bottom of the bins, 5 and 10 minutes after the gas was released inside the box. An analysis of the gas-chromatograph showed that the samples taken after 5 minutes had no traces of ethyl ether, while those taken after 10 minutes showed a good concentration of the gas in bins 1, 2, and 3. These results corroborate the fact that air was being pumped through the mass of grain. It was noticed that the graph corresponding to bin 3, which had twice the air flow, showed about twice the concentration of gas in bins 1 and 2. Bin 4 did not show any concentration of gas after 15 minutes.

During the time when the third test was being conducted the room temperature was impossible to maintain within controlled limits. However, the box temperature and the relative humidity of the controlled atmosphere remained fairly constant. Room, box and water temperatures and the relative humidity were recorded daily, and samples of grain were taken on the first, fifth, ninth and 14th day.

Since the grain was not subjected to strong changes of temperature, and the difference between the room and chamber temperature was not high the grain temperature was not recorded.

RESULTS AND DISCUSSION

<u>First Test.</u>

Figures 3, 4, 5, and 6 show the moisture content of the stored grains during the 14 day storage. The corresponding numerical values are given in Tables 3, 4, 5, and 6.

No definite conclussions can be made from this first test, due to the short time taken and the wide variation of room temperature which greatly influenced the temperature and behavior of the stored grain. However, it can be noted that although there was a slight increase of moisture in some cases, those increases were not proportional to the relative humidity of the controlled atmosphere and the time the grain was exposed to it.

According to Pixton and Warburton (15), when grain is freely subjected to wet atmosphere, 90% of the moisture change occurs within 5 to 14 days, depending on the grain, temperature and other factors. Therefore, if the stored grain of this first test were acting as freely exposed grain, the moisture would have increased well above 13% at least in the first layers of kernels on the surface of the grain.

The total variation of moisture shown in table 7 correspond to the above test.

The largest single increase occurred in rice, which had 1.5% more moisture content at the end of the test, in grain located 2" below the surface.

By comparing the daily average of the moisture content at the begining and at the end of the test, it can be observed that they are very similar. Again, the maximum increase of 0.78% does not correspond

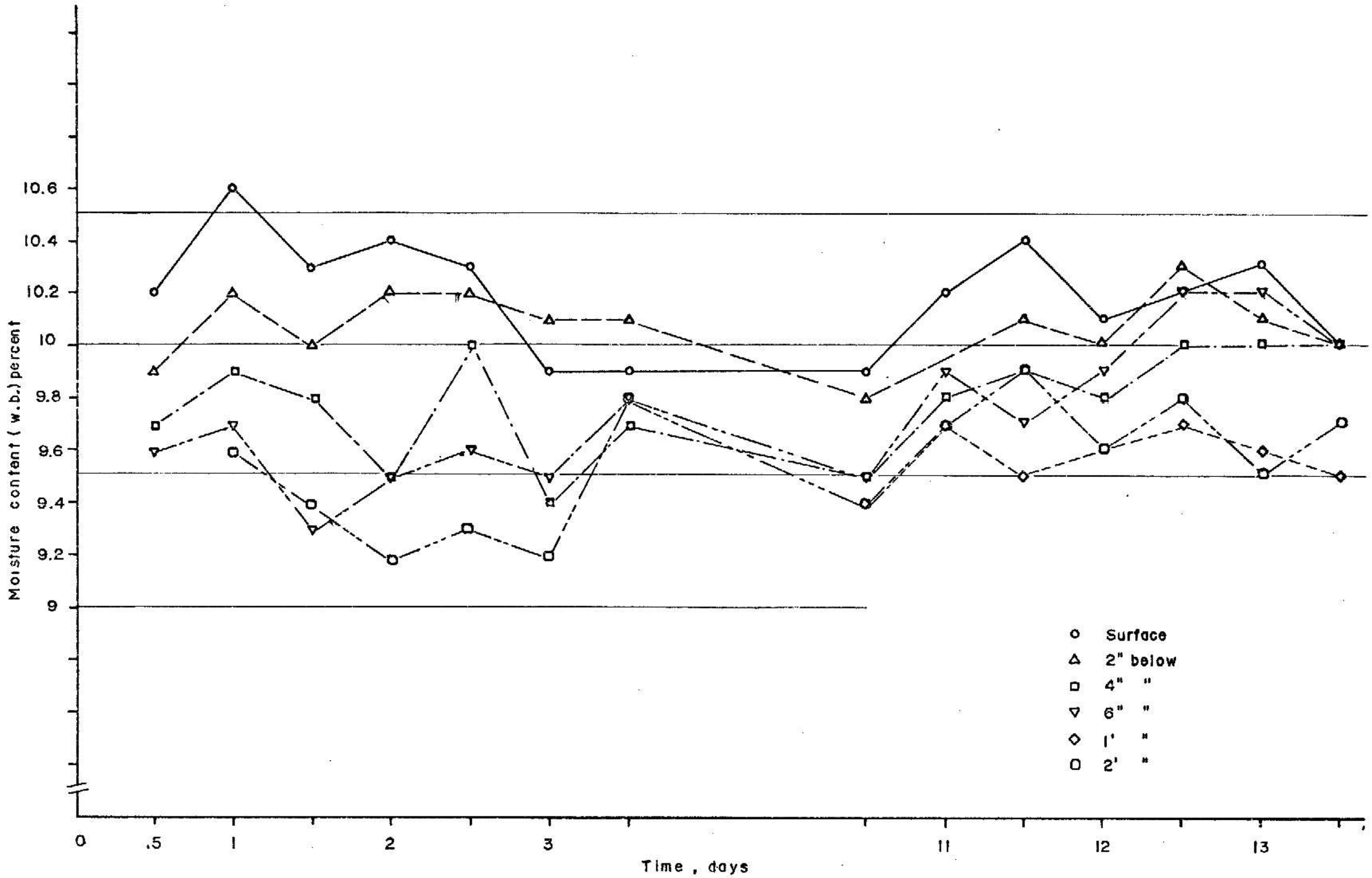

Figure 3. Moisture content change in stored Wheat. First test.

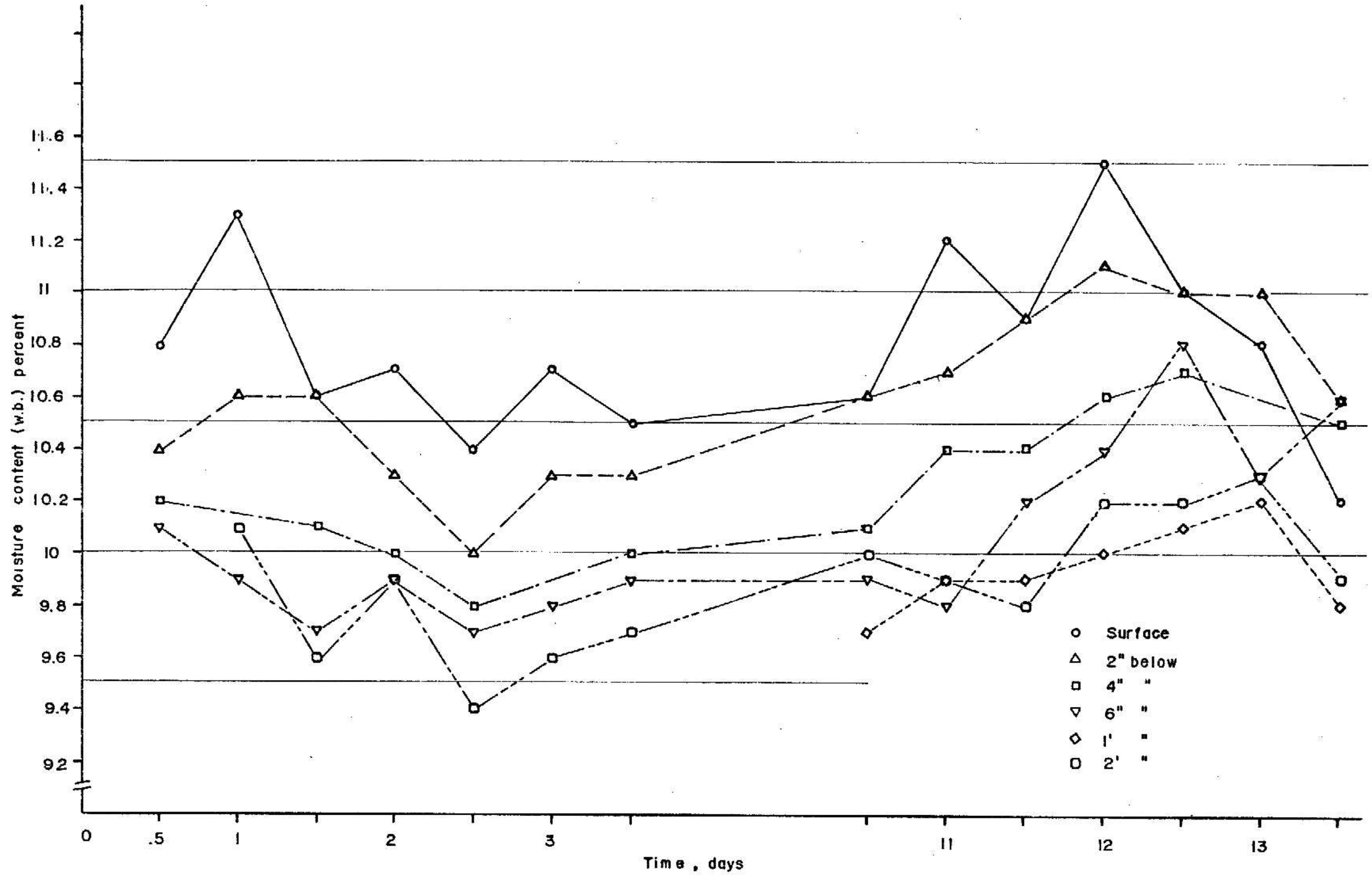

Figure 4. Moisture content change in stored Corn. Second test.

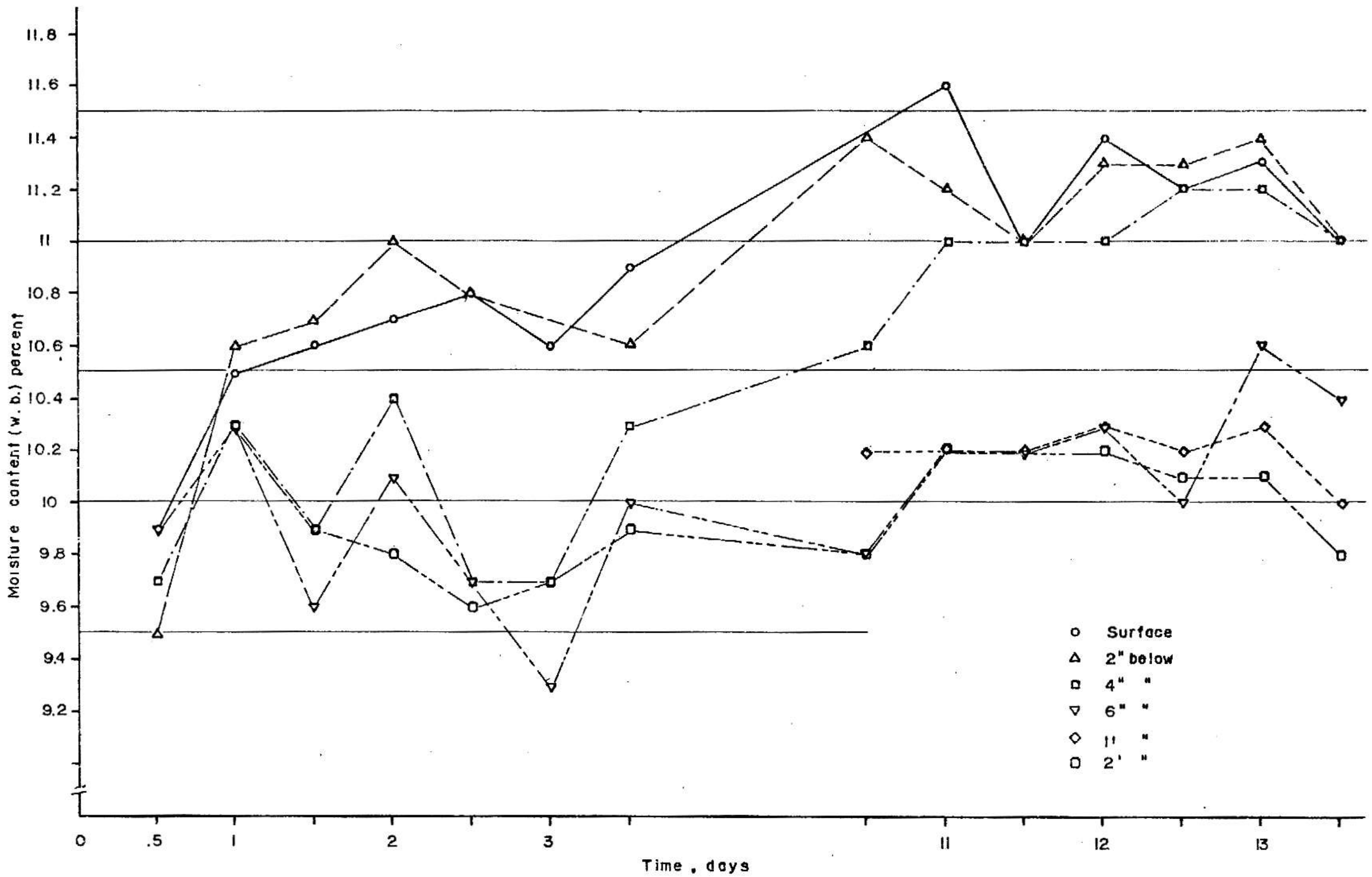

Figure 5. Moisture content change in stored Rice. Second test.

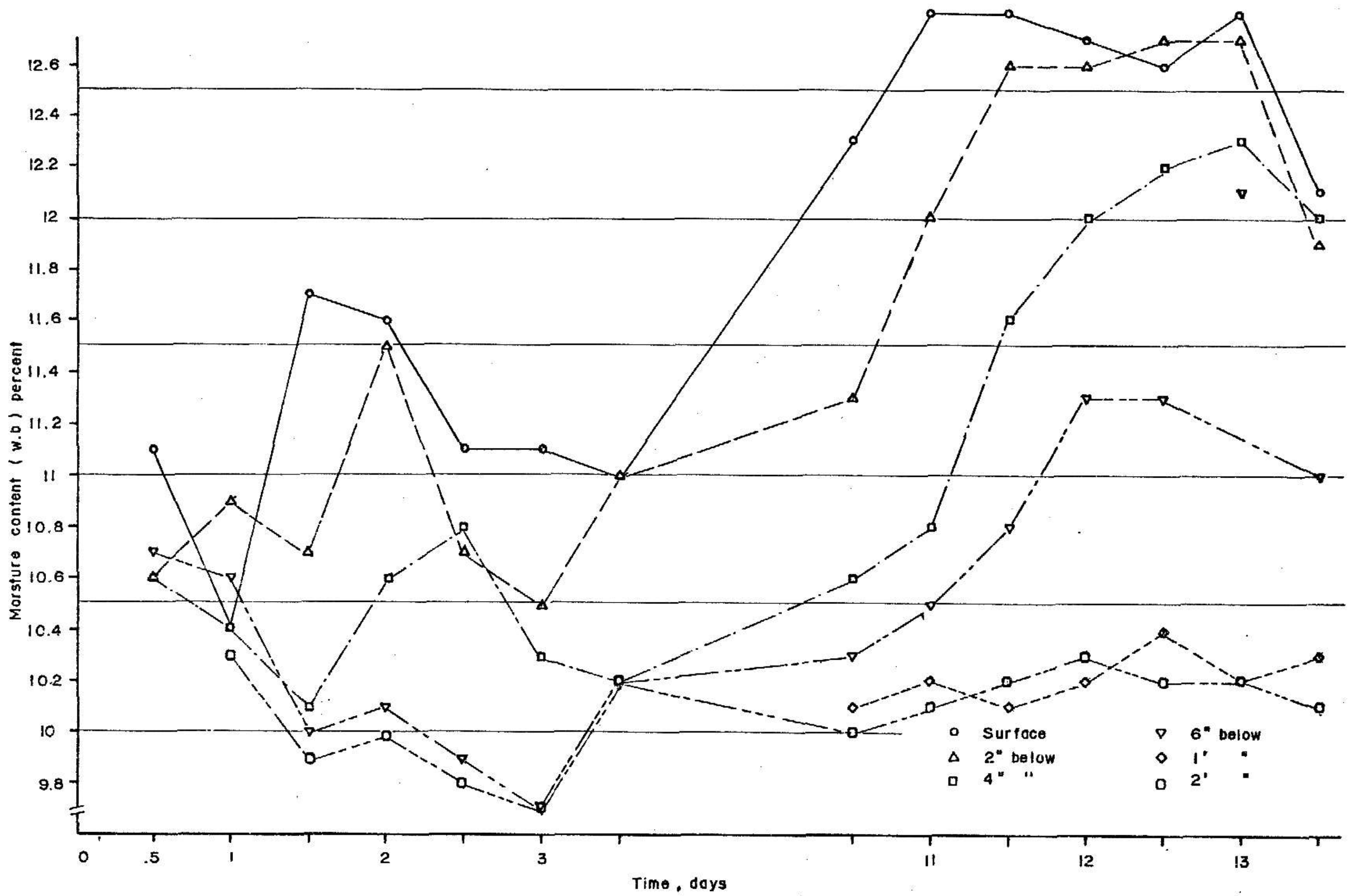

Figure 6. Moisture content change in stored Grain sorghum. First test.

Table 3. Variation of moisture content of wheat at various depths from the surface of the grain. First test.

Time, hours	Top	Distance from the surface 2"	4"	6"	1'	2'
12	10.2%	9.9%	9.7%	9.6%	-	-
24	10.6	10.2	9.9	9.7	9.6	-
36	10.3	10.0	9.8	9.3	9.4	-
48	10.4	10.2	9.5	9.5	9.2	-
60	10.3	10.2	10.0	9.6	9.3	-
72	9.9	10.1	9.4	9.5	9.2	-
84	9.9	10.1	9.7	9.8	9.8	-
252	9.9	9.8	9.5	9.5	9.4	9.4
274	10.2	-	9.8	9.9	9.7	9.7
276	10.4	10.1	9.9	9.7	9.9	9.5
288	10.1	10.0	9.8	9.9	9.6	9.6
300	10.2	10.3	10.0	10.2	9.8	9.7
312	10.3	10.1	10.0	10.2	9.5	9.6
324	10.0	10.0	10.0	10.0	9.7	9.5
Moisture Average	10.19	10.07	9.78	9.74	9.54	9.57

Moisture in percent (w.b.).

Table 4. Variation of moisture content of yellow corn at various depths from the surface of the grain. First test.

Time, hours	Top	Distance from the surface 2"	4"	6"	1'	2'
12	10.8%	10.4%	10.2%	10.1%	-	-
24	11.3	10.6	-	9.9	10.1	-
36	10.6	10.6	10.1	9.7	9.6	-
48	10.7	10.3	10.0	9.9	9.9	-
60	10.4	10.0	9.8	9.7	9.4	-
72	10.7	10.3	-	9.8	9.6	-
84	10.5	10.3	10.0	9.9	9.7	-
252	10.6	10.6	10.1	9.9	10.0	9.7
264	11.2	10.7	10.4	9.8	9.9	9.9
276	10.9	10.9	10.4	10.2	9.8	9.9
288	11.5	11.1	10.6	10.4	10.2	10.0
300	11.0	11.0	10.7	10.8	10.2	10.1
312	10.8	11.0	-	10.3	10.3	10.2
324	10.2	10.6	10.5	10.6	9.9	9.8
Moisture Average	10.8	10.6	10.25	10.07	9.89	9.94

Moisture in percent (w.b.)

Table 5. Variation of moisture content of rough rice at various depths from the surface of the grain. First test.

Time, hours	Distance from the surface Top	2"	4"	6"	1'	2'
12	9.9%	9.5%	9.7%	9.9%	-	-
24	10.5	10.6	10.3	10.3	10.3	-
36	10.6	10.7	9.9	9.6	9.9	-
48	10.6	11.0	10.4	10.1	9.8	-
60	10.8	10.8	9.7	9.7	9.6	-
72	10.6	-	9.7	9.3	9.7	-
84	10.9	10.6	10.3	10.0	9.9	-
252	-	11.4	10.6	9.8	9.8	10.2
264	11.6	11.2	11.0	10.2	10.2	10.2
276	11.0	11.0	11.0	10.2	-	10.2
288	11.4	11.3	11.0	10.3	10.2	10.3
300	11.2	11.3	11.2	10.0	10.1	10.2
312	11.3	11.4	11.2	10.6	10.1	10.3
324	11.0	11.0	11.0	10.4	9.8	10.0
Moisture average	10.87	10.90	10.50	10.02	9.95	10.20

Moisture in percent (w.b.).

Table 6. Variation of moisture content of grain sorghum at various depths from the surface of the grain. First test.

Time, hours	Distance from the surface Top	2"	4"	6"	1'	2'
12	11.1%	10.6%	10.6%	10.7%	-	-
24	10.4	10.9	10.4	10.6	10.3	-
36	11.7	10.7	10.1	10.0	9.9	-
48	11.6	11.5	10.6	10.1	10.0	-
60	11.1	10.7	10.8	9.9	9.8	-
72	11.1	10.5	10.3	9.7	9.7	-
84	11.0	11.0	10.2	10.2	10.2	-
252	12.3	11.3	10.6	10.3	10.0	10.1
264	12.8	12.0	10.8	10.5	10.1	10.2
276	12.8	12.6	11.6	10.8	10.2	10.1
288	12.7	12.6	12.0	11.3	10.3	10.2
300	12.6	12.7	12.2	11.3	10.2	10.4
312	12.8	12.7	12.3	12.1	10.2	10.2
324	12.1	11.9	12.0	11.0	10.1	10.3
Moisture average	11.86	11.55	11.03	10.06	10.07	10.21

Moisture in percent (w.b.).

to the increase that was expected with a controlled atmosphere of 75% relative humidity.

Table 7. Total variation of moisture content of grain stored under controlled relative humidity, in percent.

Grain	Distance from the surface					
	Top	2"	4"	6"	1'	2'
Wheat	-0.2%	+0.1%	+0.3%	+0.4%	+0.1%	+0.1%
Corn	-0.6	+0.2	+0.3	+0.5	-0.2	+0.1
Rice	+1.1	+1.5	+1.3	+0.5	-0.5	-0.2
Sorghum	+1.0	+1.3	+1.4	+0.3	-0.2	+0.2

The daily average of moisture content and the net difference is shown in table 8.

Table 8. Average moisture content of stored grain.

Grain	Average initial moisture	Average final moisture	Difference in percent
Wheat	9.85%	9.86%	+ 0.01%
Corn	10.37	10.26	- 0.11
Rice	9.75	10.53	+ 0.78
Sorghum	10.75	11.23	+ 0.48

Moisture content in percent (w.b.).

The above table shows that the net increase of moisture was less than one percent in all grains. Rice experienced the largest increase, followed by grain sorghum. Corn had a slight decrease and wheat remained unchanged.

At the time when this first experiment was conducted, it was believed that grain should adsorb moisture but at a much slower rate than if it were freely exposed in small quantities to the controlled atmosphere.

Grain temperature did change due to the influence of the warmer box temperature. However it is not possible to determine which proportion of the variation was due to this factor or to changes in the room temperature.

The temperature of the kernels near the surface increased accordingly, until they reached the box temperature of 90°F in less than 48 hours. Sorghum reached that level even sooner: only 24 hours after the test started. By analyzing the temperature curves shown in figures 7, 8, 9, and 10, it can be observed that the room temperature influenced the lower levels of grain more than the upper ones. The curves representing the lower levels are almost parallel to the room temperature. This phenomenon suggested the need for improved insulation and better control of the room temperature for the following tests.

Second Test.

Table 13 shows the values of room and chamber temperatures, as well as the relative humidity of the air in the controlled atmosphere. Although it was very difficult to control the room temperature due to mechanical failures in the air conditioning system, it has smaller variations than in the first experiment, Figure No. 11. The chamber temperature remained fairly constant, with an average of 89.95°F., which is

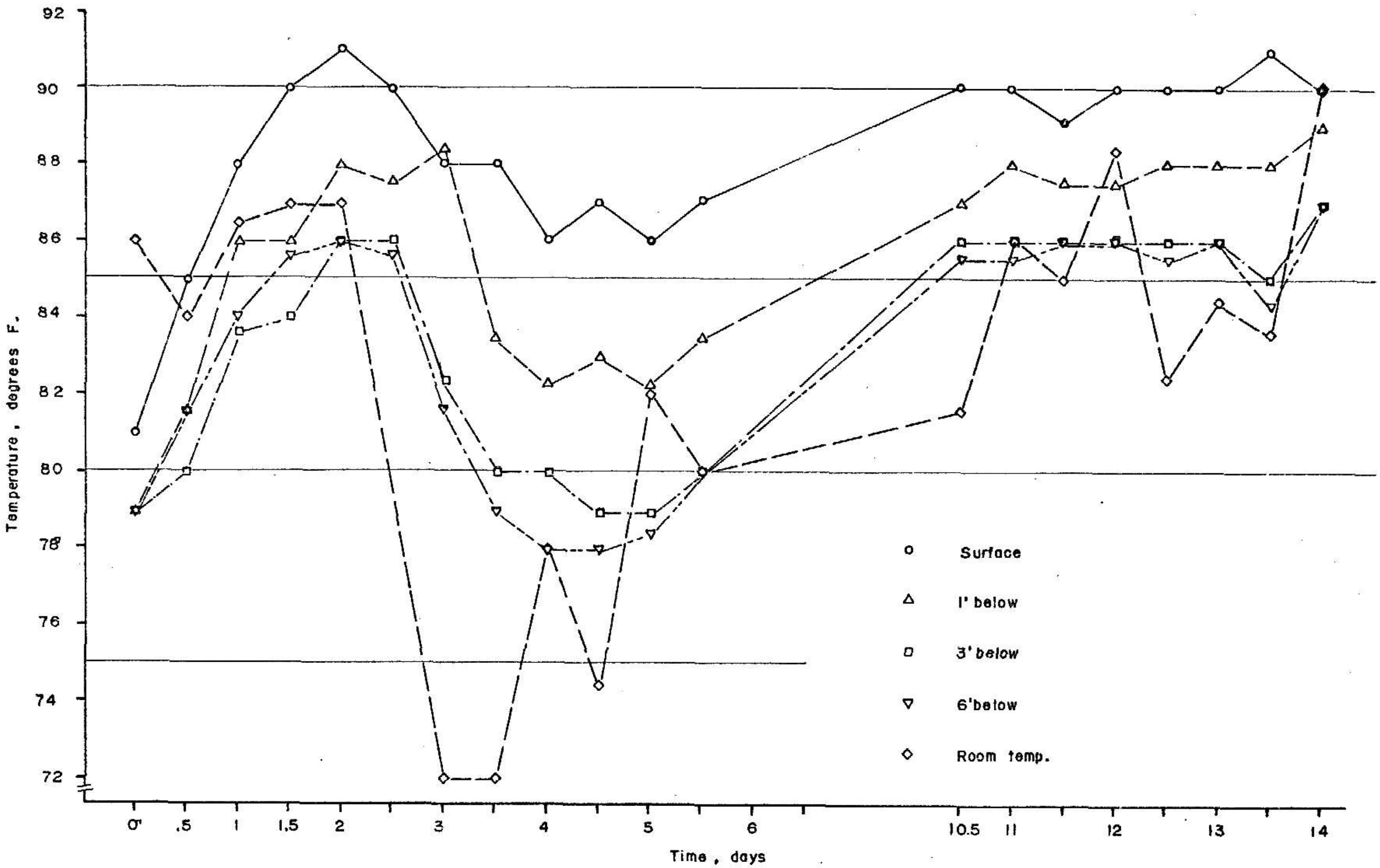

Figure 7. Temperature change in stored Wheat First test.

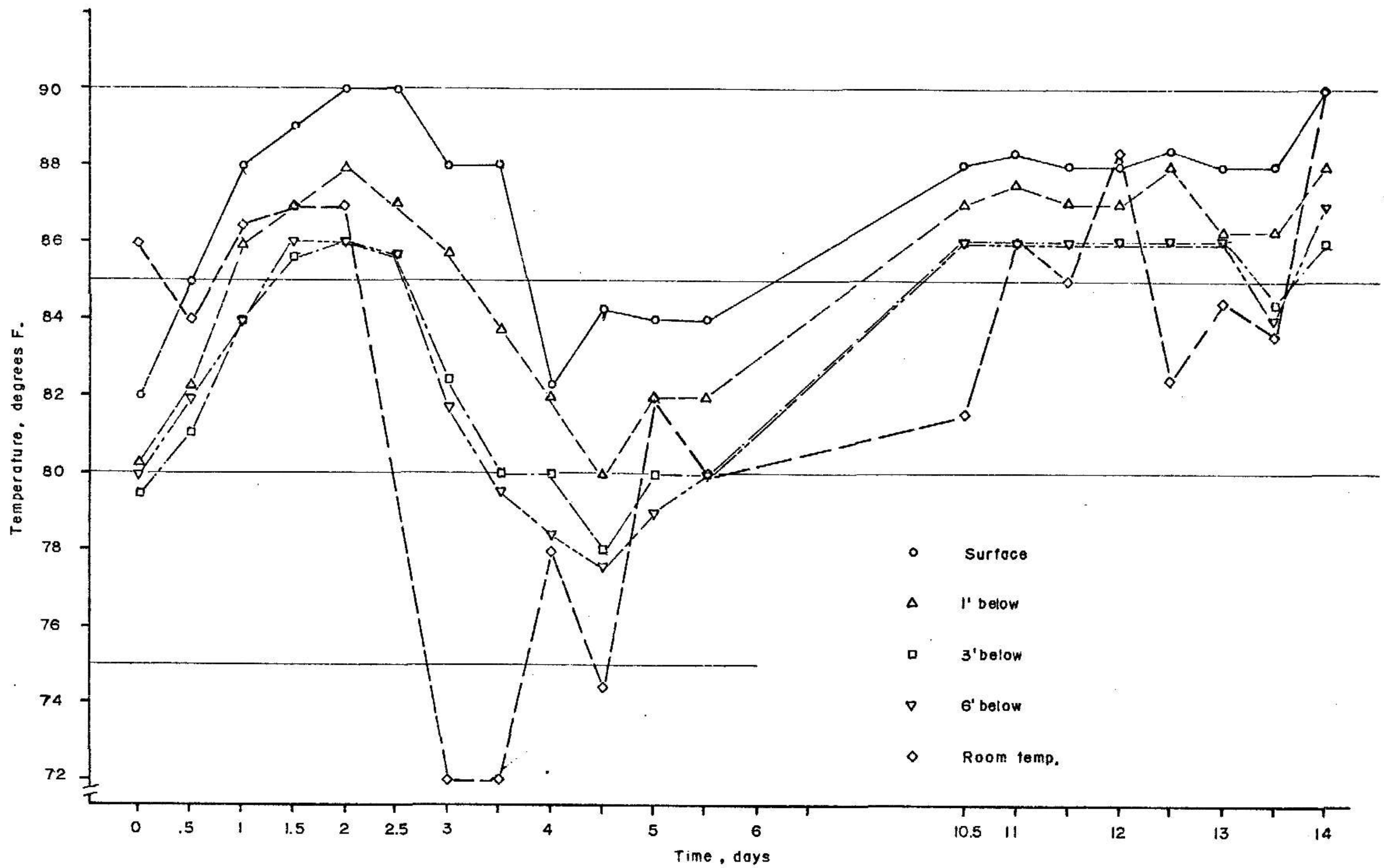

Figure 8. Temperature change in stored Corn. First test.

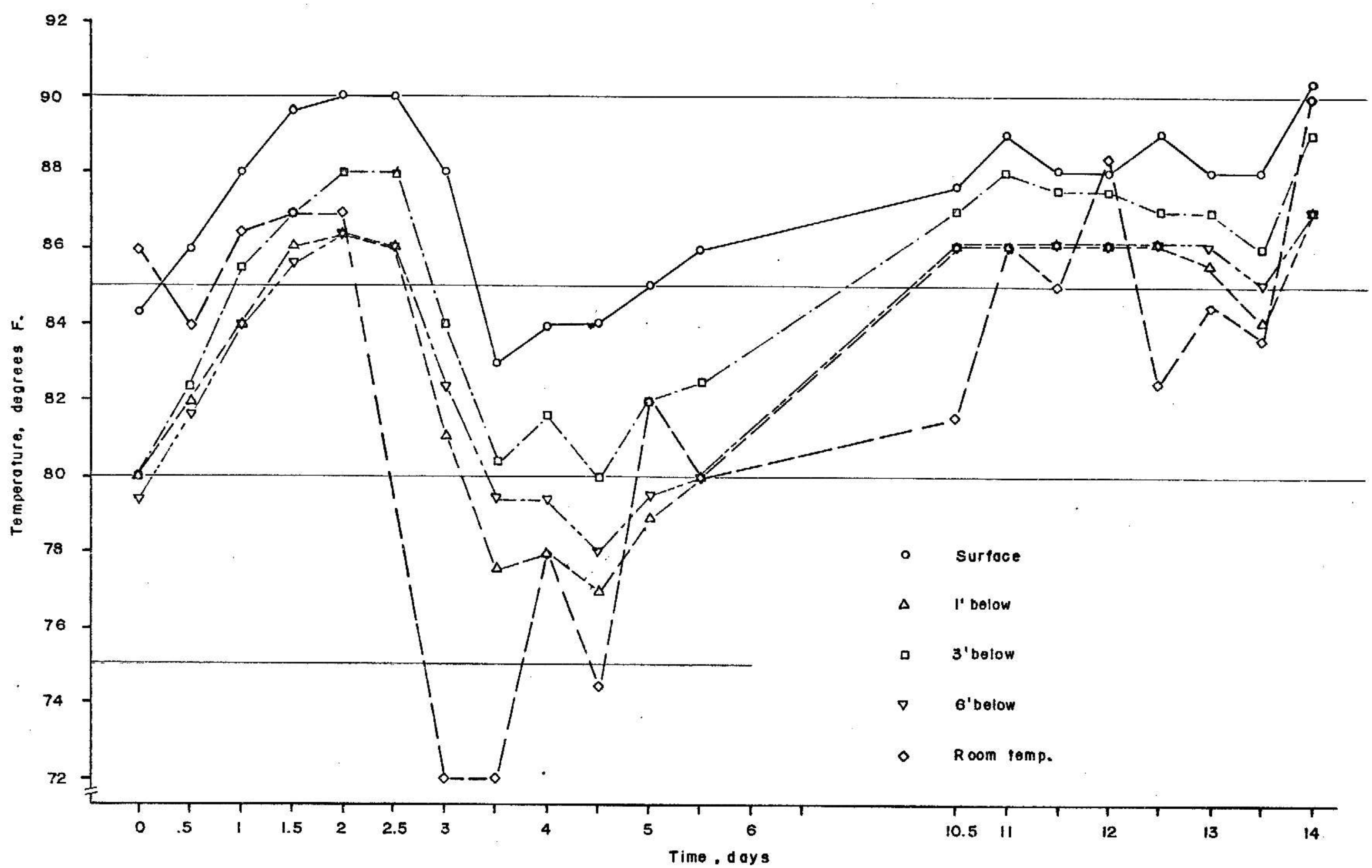

Figure 9. Temperature change in stored Rice. First test.

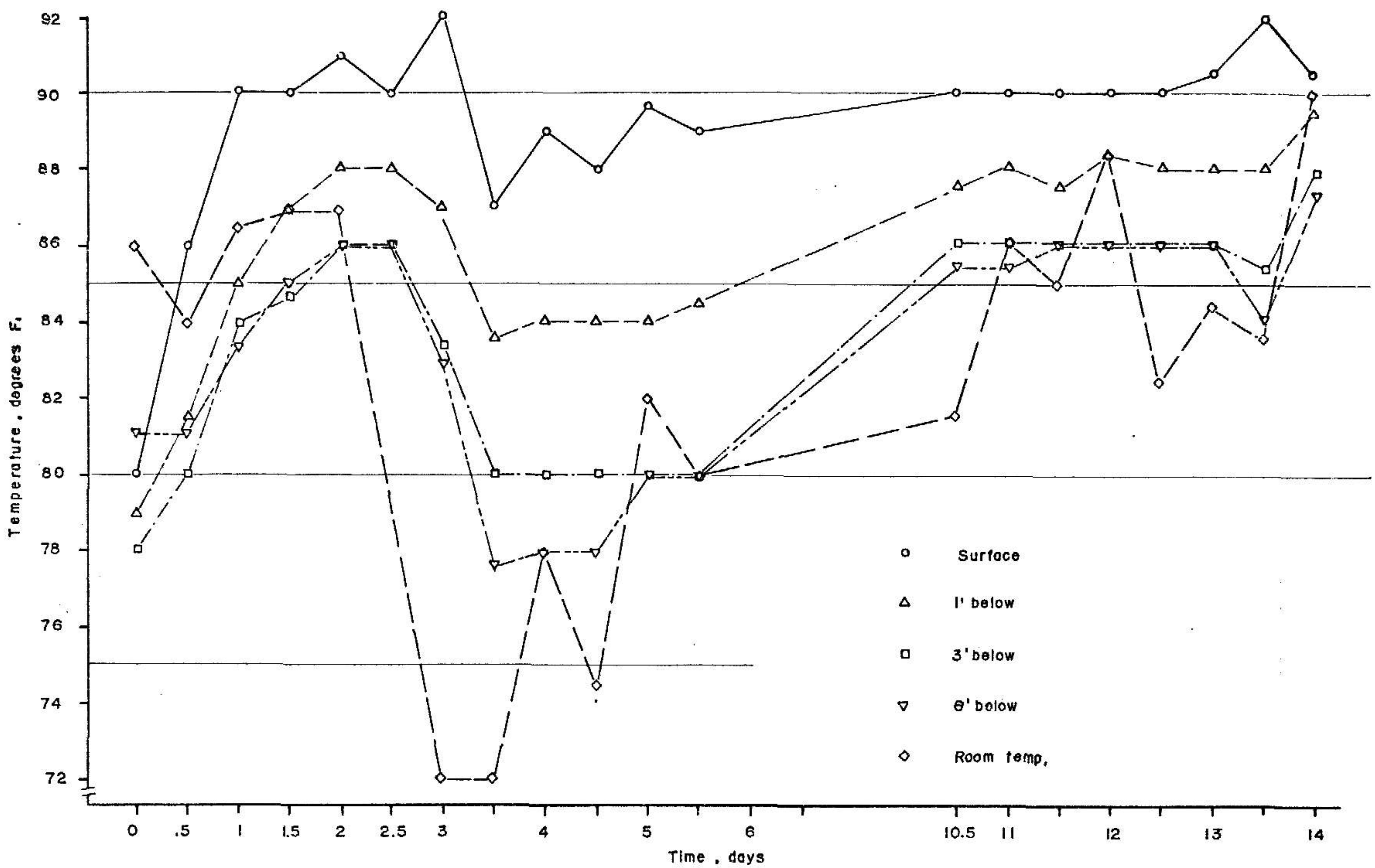

Figure 10. Temperature change in stored Grain sorghum. First test.

Table 9. Temperature of wheat at different depths from the surface of the grain ($^{o}F.$). First test.

Time, hours	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
0	86°	81°	79°	79°	79°	78.5°	78°	79°
12	84	85	81.5	80.5	80	80	80	81.5
20	86	88	84.5	83	82	82	81.5	83
24	86.5	88	86	84	83.5	82.5	82	84
36	87	90	86	85	84	84	84	85.5
48	87	91	88	86	86	85.5	85	86
60	-	90	87.5	86	86	85.5	85.5	85.5
72	72	88	88.5	84	82.5	82.5	82.5	81.5
84	72	88	83.5	81.5	80	80	79.5	79
96	78	86	82.5	81	80	80	78.5	78
108	74.5	87	83	80.5	79	78.5	78.5	78
120	82	86	82.5	80	79	79	78.5	78.5
132	80	87	83.5	81	80	80	79.5	80
252	81.5	90	87	86	86	85.5	85.5	85.5
264	86	90	88	86.5	86	86	85.5	85.5
276	83	89	87.5	86	86	85.5	85.5	86
288	85.5	90	87.5	86.5	86	86	86	86
300	82.5	90	88	86.5	86	86	85.5	85.5
312	84.5	90	88	86.5	86	86	86	86
324	83.5	91	88	86	85	84.5	84	84.5
336	90	90	89	88	87	86.5	86	87

Table 10. Temperature of yellow corn at different depths from the surface of the grain (°F.). First test.

Time, hours	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
0	86°	82°	80.5°	80°	79.5°	79°	79°	80°
12	84	85	82.5	81	81	81	80	82
20	86	88	85.5	84	83.5	83	82.5	83.5
24	86.5	88	86	84.5	84	84	83.5	84
36	87	89	87	86	85.5	85	85	86
48	87	90	88	86.5	86	86	86	86
60	-	90	87	86	85.5	85	85.5	85.5
72	72	88	85.5	84	82.5	82.5	82.5	81.5
84	72	88	83.5	81.5	80	80	79.5	79
96	78	82.5	82	80	80	79	79	78.5
108	74.5	84.5	80	80	78	78	78	77.5
120	82	84	82	80	80	79	78.5	79
132	80	84	82	80	80	79.5	79	80
252	81.5	88	87	86	86	86	86	86
264	86	88.5	87.5	86.5	86	86	86	86
276	83	88	87	86	86	86	86	86
288	85.5	88	87	86	86	86	86	86
300	82.5	88.5	88	86.5	86	86	86	86
312	84.5	88	86.5	86	86	86	86	86
324	83.5	88	86.5	85.5	84.5	84.5	84	84
336	90	90	88	87	86	86	86	87

Table 11. Temperature of rough rice at different depths from the surface of the grain ($^{o}F.$). First test.

Time, hours	Room temp.	Top layer	Distance from the surface 1'	2'	3'	4'	5'	6'
0	86°	84.5°	80°	79.5°	79.5°	79°	79°	80°
12	84	86	82.5	81.5	81.5	81	81	82
20	86	89	85	83.5	83	83	82.5	83.5
24	86.5	88	85.5	84	84	84	83	84
36	87	89.5	87	86	85.5	85	85	86
48	87	90	88	86.5	86.5	86	86	86.5
60	-	90	88	86.5	86	86	86	86
72	72	88	84	85	82.5	82	82	81
84	72	83	80.5	80	79.5	79	79	77.5
96	78	84	81.5	80	79.5	79	78.5	78
108	74.5	84	80	79	78	78	78	77
120	82	85	82	80	79.5	79	78.5	79
132	80	86	82.5	80.5	80	79.5	79.5	80
252	81.5	87.5	87	86.5	86	86	86	86
264	86	89	88	87	86	86	86	86
276	83	88	87.5	86.5	86	86	86	86
288	85.5	88	87.5	86.5	86	86	86	86
300	82.5	89	87	86	86	86	86	86
312	84.5	88	87	86	86	86	85.5	85.5
324	83.5	88	86	86	85	84.5	84	84
336	90	90.5	89	88	87	86.5	86.5	87

Table 12. Temperature of grain sorghum at different depths from the surface of the grain (°F.). First test.

Time, hours	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
0	86	80	79	78	78	79	79	81
12	84	86	81.5	80.5	80	80	80	81
20	86	89	85	83	82	82	82	82.5
24	86.5	90	85	84	84	83	82	83.5
36	87	90	87	85.5	84.5	84	84	85
48	87	91	88	86.5	86	86	86	86
60	-	90	88	86	86	86	86	86
72	72	92	87	84	83.5	83	83	81
84	72	87	83.5	81.5	80	80	79.5	77.5
96	78	89	84	81.5	80	79.5	79.5	78
108	74.5	88	84	81	80	79	78	78
120	82	89.5	84	82	80	79.5	79.5	80
132	80	89	84.5	81.5	80	80	79.5	80
252	81.5	90	87.5	86.5	86	86	85.5	85.5
264	86	90	88	86.5	86	85.5	85.5	85.5
276	83	90	87.5	86.5	86	86	86	86
288	85.5	90	88.5	86.5	86	86	86	86
300	82.5	90	88	87	86	86	86	86
312	84.5	90.5	88	86.5	86	86	86	86
324	83.5	92	88	86	85.5	85	84.5	84
336	90	90.5	89.5	88.5	88	87	87	87.5

Table 13. Room and chamber temperatures and relative humidity of the controlled atmosphere.

Time days	Room temp.	Chamber temp.	Relat. humid.	Time days	Room temp.	Chamber temp.	Relat. humid.
0	74°	89.5°	84%	21	77°	90°	77%
1	73	91	76	22	74	90	74
2	73.5	90	77	23	74	91	77
3	71	90	75	24	72	90.5	74
4	72	90.5	75	25	72	90	74
5	74	-	77	26	70	91	74
6	72	90.5	73	27	74	91	78
7	72	88	-	28	75	89	79
8	72	90.5	77.5	29	76	90	81
9	72	89.5	77	30	76	89	81
10	74	90	74	31	78	90	-
11	74	90	76	33	74	90	74
13	76	90.5	80	35	73	90	80
14	76	90	80	36	72	90.5	77
15	80	86.5	80	37	73	90	82
18	73	90.5	74	38	74	90	82
19	-	90	74	39	75	89.5	80
20	76	89.5	80	40	72	90	78

Temperatures are given in degrees farenheit and relative humidities in percent close to the theoretical value of 90°F.

The relative humidity had wider variations, but it was always above that in equilibrium with the moisture content of grain. Consequently, the vapor pressure of the air was always greater than that of the grain and hence the main purpose of the test was attained.

The average relative humidity was 77.4% which is in equilibrium with rice, corn, wheat and sorghum that have between 14 and 14.5% moisture content.

The development of the grain moisture content during the 40 day period is shown in fugures 12, 13, 14, and 15. The corresponding numerical values are indicated in tables 14, 15, 16, and 17.

A very special behavior is observed in the four grains during and after the 40 days of storage under tropical conditions. The first and more important phenomenon is that the stored grain did not adsorb moisture from the damp air above the free surface of the bins. Moreover it is noted that in some instances they either lost some moisture, or remained in the same state as they were when first introduced to the bins.

A definite pattern is observed in all four grains. A wide variation of moisture occurred within the first four days of testing, when a sharp decrease of moisture content was observed followed by an increase of aproximately 2%. Corn had smaller variation but at the end of the third day, it also had over 11% moisture content.

These sharp variations were noticed several times although they were smaller than those during the first time. No attempt is made to explain those changes in moisture since no apparent relationship

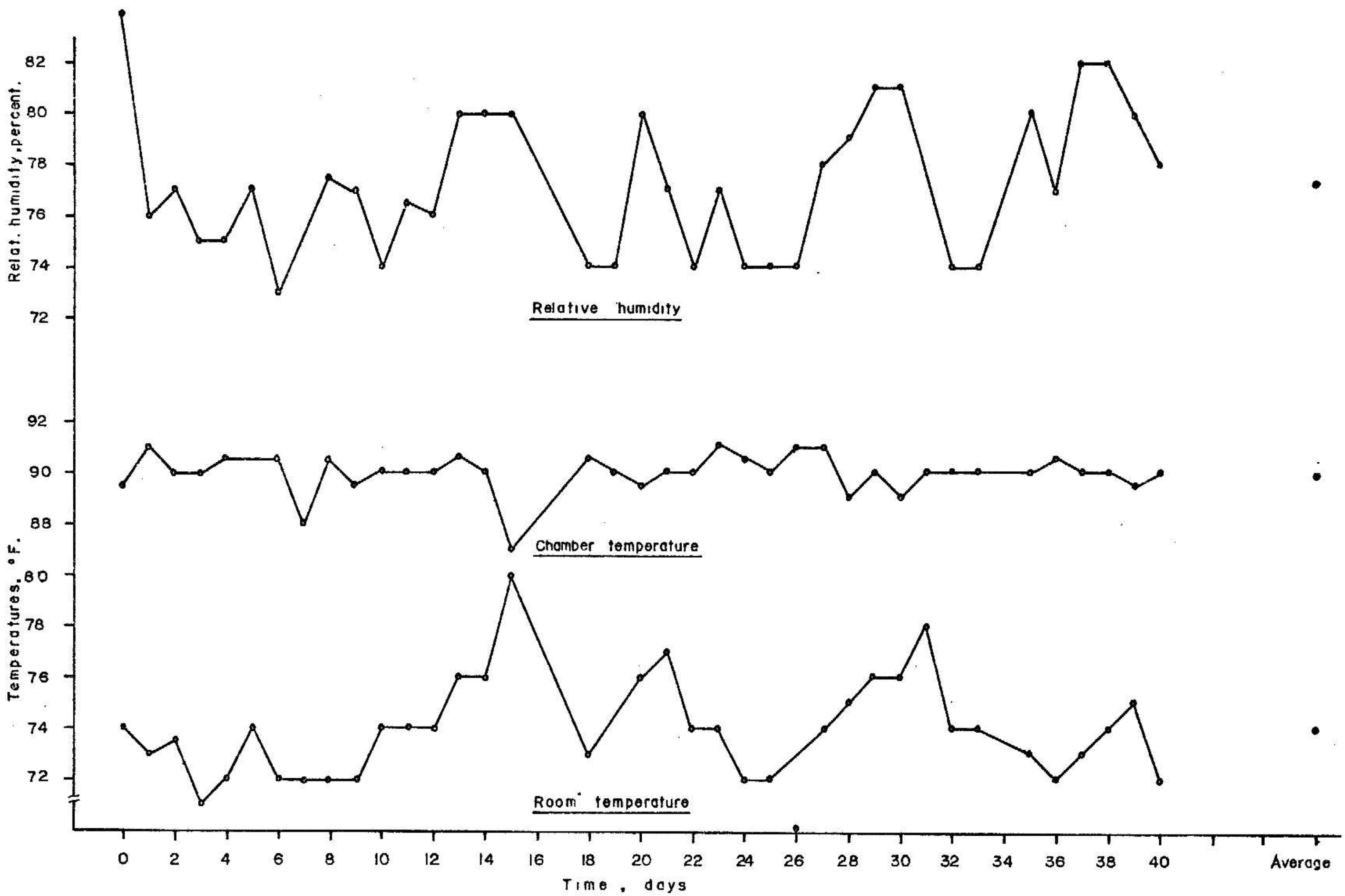

Figure II Temperature and relative humidity of the controlled atmosphere. Room temperature.

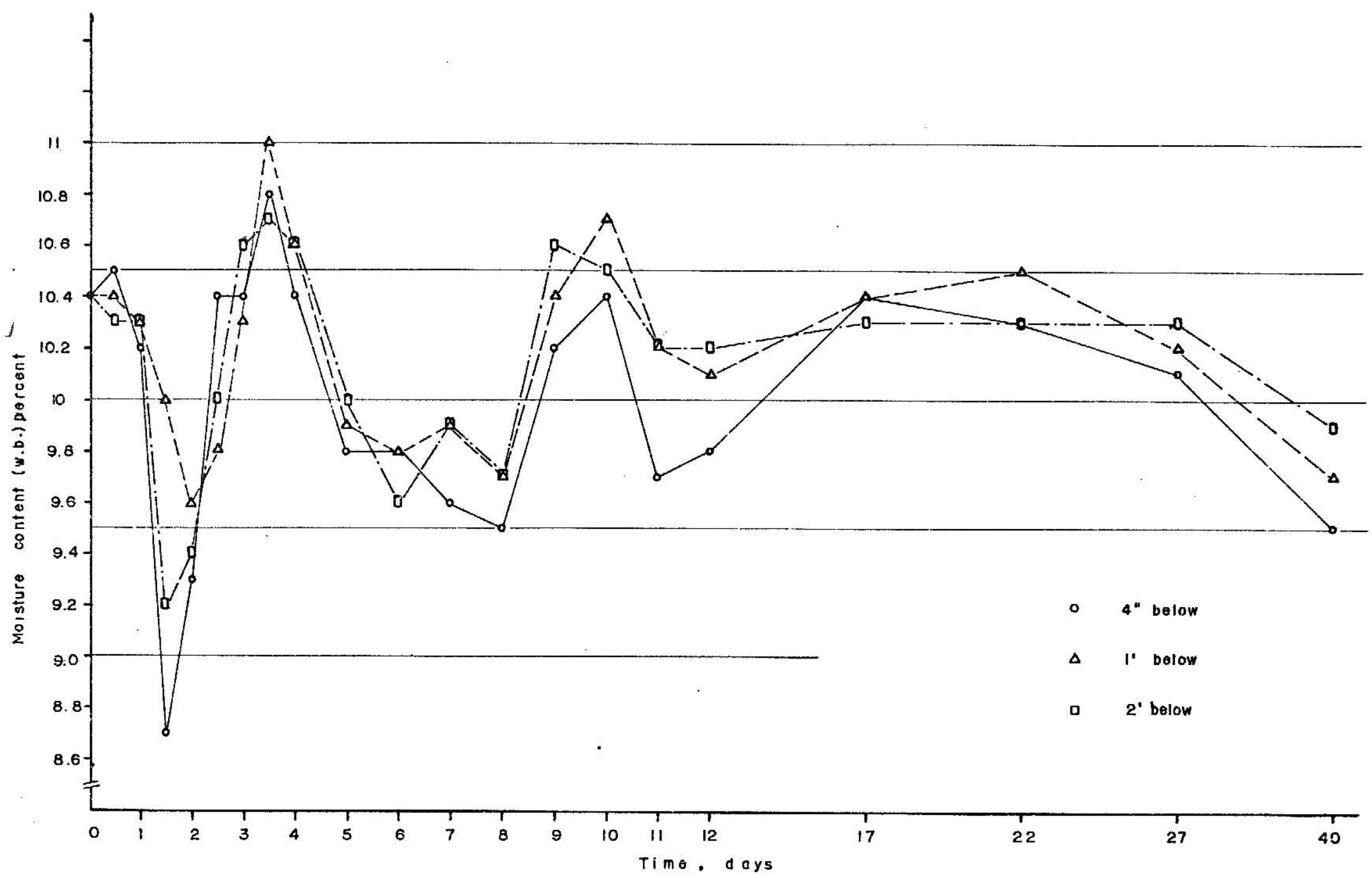

Figure 12. Moisture content change in stored Wheat. Second test.

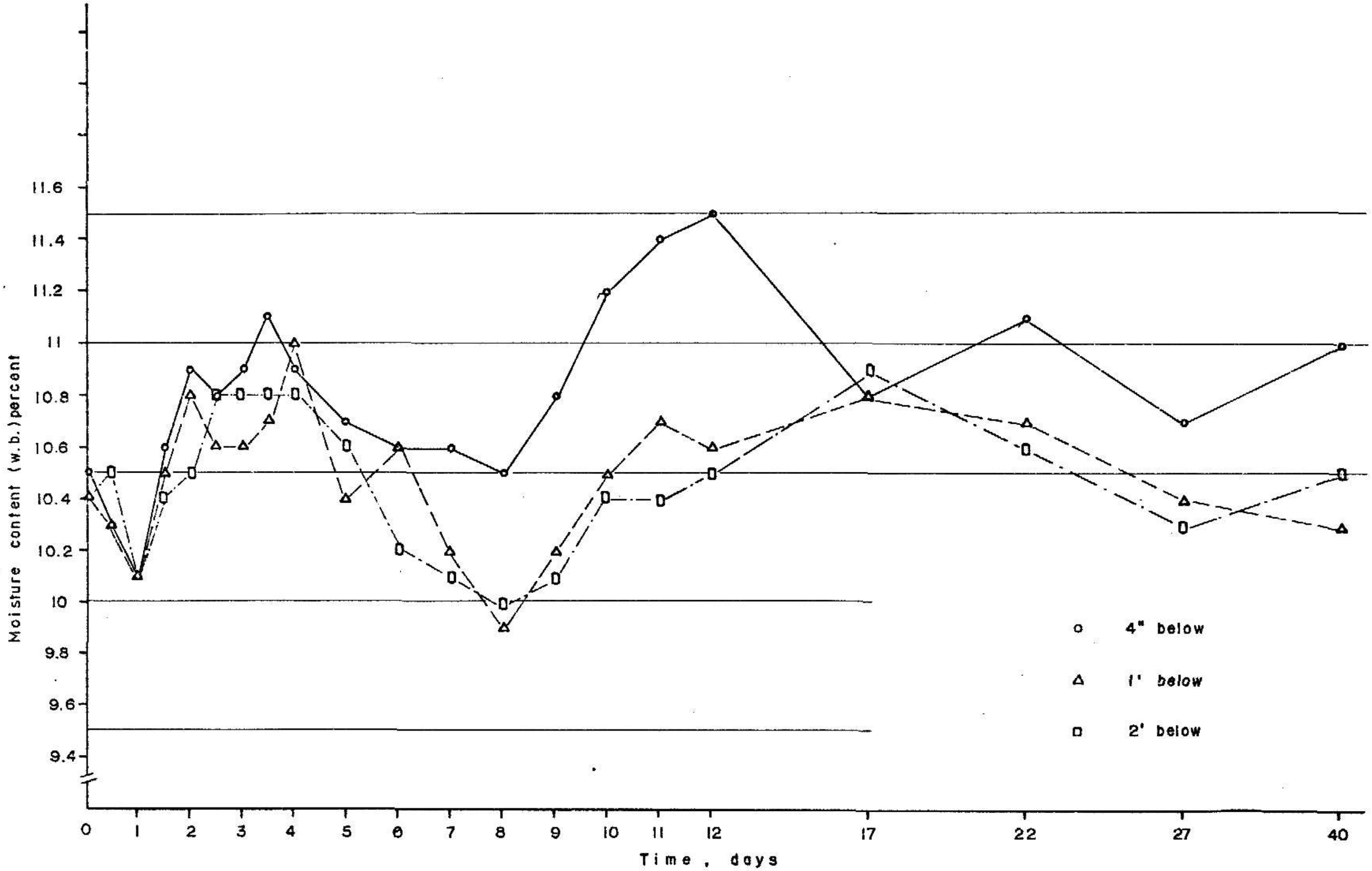

Figure 13. Moisture content change in stored Corn. Second test.

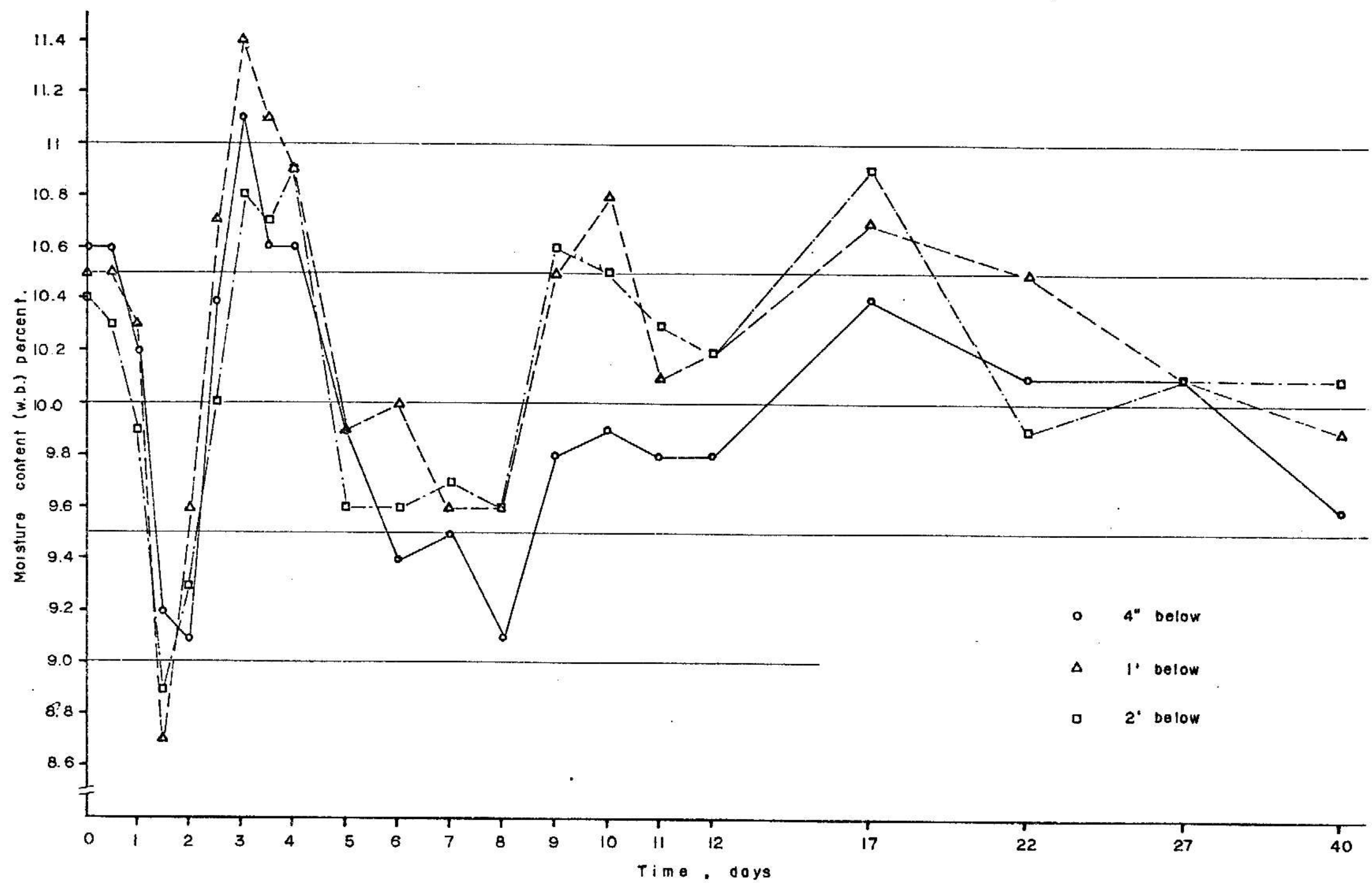

Figure 14. Moisture content change in stored Rice. Second test.

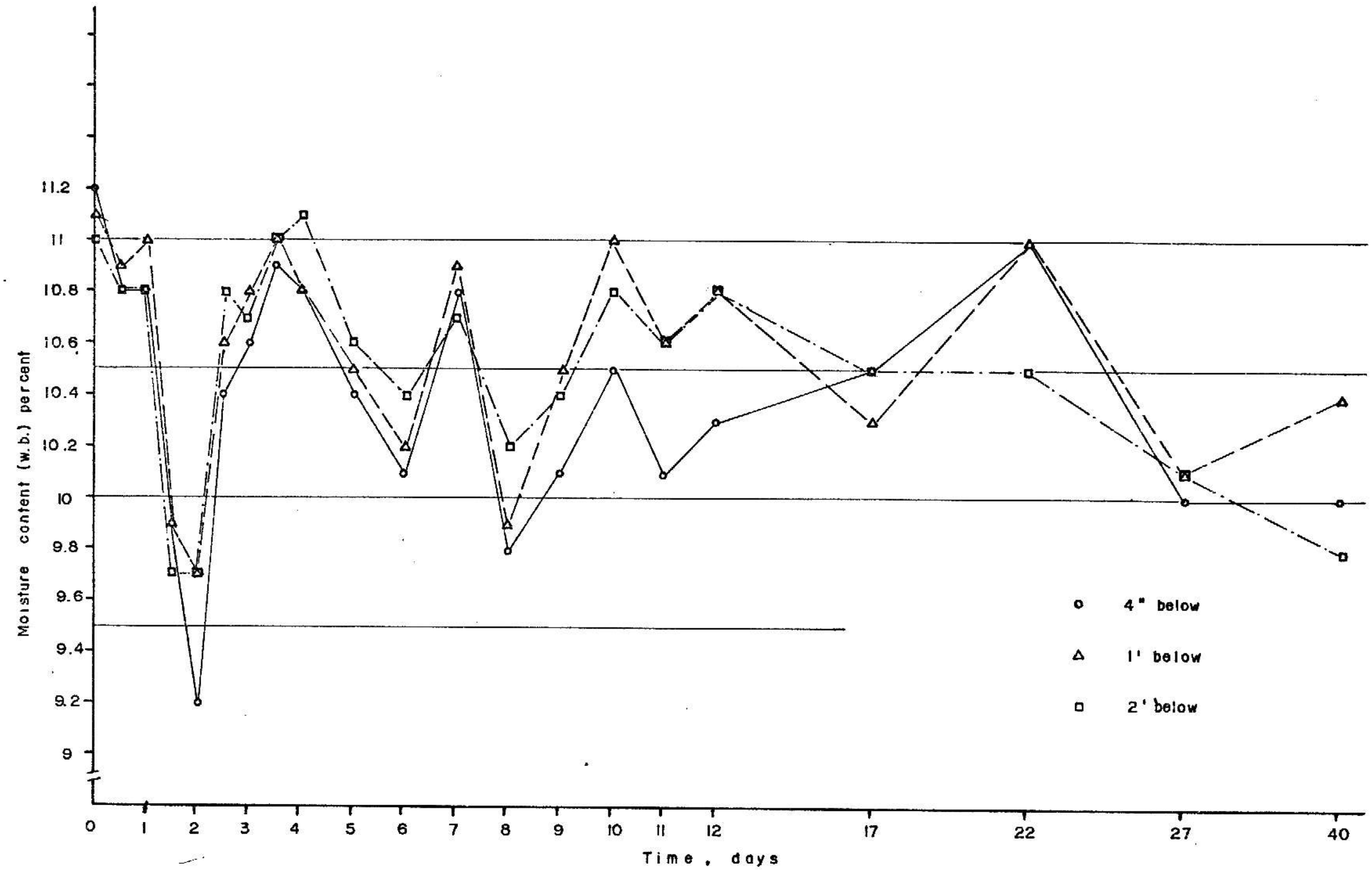

Figure 15. Moisture content change in stored Grain sorghum. Second test.

Table 14. Variation of moisture content of wheat at various depths from the surface of the grain.

Time, hours	days	Distance from the surface 4"	1'	2'	4'	6'
0	0	10.4%	10.4%	10.4%	10.5%	10.2%
12	0	10.5	10.4	10.3	10.1	10.2
24	1	10.2	10.3	10.3		
36	1	8.7	10.0	9.2	9.0	9.2
48	2	9.3	9.6	9.4		
60	2	10.4	9.8	10.0	9.7	9.8
72	3	10.4	10.3	10.6		
84	3	10.8	11.0	10.7		
96	4	10.6	10.4	10.6		
120	5	9.8	9.9	10.0		
144	6	9.8	9.8	9.6		
168	7	9.6	9.9	9.9		
192	8	9.5	9.7	9.7		
216	9	10.2	10.4	10.6		
240	10	10.4	10.7	10.5		
264	11	9.7	10.2	10.2	10.2	10.0
288	12	9.8	10.1	10.2		
312	17	10.4	10.4	10.3	10.4	10.5
528	22	10.3	10.5	10.3	10.5	10.3
648	27	10.1	10.2	10.3		
960	40	9.5	9.7	9.9	9.6	9.8
Average m. content		10.01	10.16	10.13	10.0	10.0

Table 15. Variation of moisture content of yellow corn at various depths from the surface of the grain.

Time, hours	days	Distance from the surface 4"	1'	2'	4'	6'
0	0	10.5%	10.4%	10.4%	10.3%	10.2%
12	0	10.3	10.3	10.5	10.6	10.6
24	1	10.1	10.1	10.1		
36	1	10.6	10.5	10.4	10.5	10.4
48	2	10.9	10.8	10.5		
60	2	10.8	10.6	10.8	10.7	10.7
72	3	10.9	10.6	10.8		
84	3	11.1	10.7	10.8		
96	4	10.9	11.0	10.8		
120	5	10.7	10.4	10.6		
144	6	10.6	10.6	10.2		
168	7	10.6	10.2	10.1		
192	8	10.5	9.9	10.0		
216	9	10.8	10.2	10.1		
240	10	11.2	10.5	10.4		
264	11	11.4	10.7	10.	10.4	10.3
288	12	11.5	10.6	10.5		
312	17	10.8	10.8	10.9	10.8	10.3
528	22	11.1	10.7	10.6	10.6	10.7
648	27	10.7	10.4	10.3		
960	40	11.0	10.3	10.5	10.3	9.7
Average m. content		10.80	10.49	10.46	10.52	10.36

Table 16. Variation of moisture content of rough rice at various depths from the surface of the grain.

Time, hours	days	Distance from the surface 4"	1'	2'	4'	6'
0	0	10.6%	10.5%	10.4%	10.4%	10.4%
12	0	10.6	10.5	10.3	10.3	10.2
24	1	10.2	10.3	9.9		
36	1	9.2	8.7	8.9	8.5	8.5
48	2	9.1	9.6	9.3		
60	2	10.4	10.7	10.0	10.1	10.6
72	3	11.1	11.4	10.8		
84	3	10.6	11.1	10.7		
96	4	10.6	10.9	10.9		
120	5	9.9	9.9	9.6		
144	6	9.4	10.0	9.6		
168	7	9.5	9.6	9.7		
192	8	9.1	9.6	9.6		
216	9	9.8	10.5	10.6		
240	10	9.9	10.8	10.5		
264	11	9.8	10.1	10.3	10.3	10.4
288	12	9.8	10.2	10.2		
312	17	10.4	10.7	10.9	10.6	10.3
528	22	10.1	10.5	9.9	10.0	10.3
648	27	10.1	10.1	10.1		
960	40	9.6	9.9	10.1	-	9.7
Average m. content		10.0	10.25	10.09	10.02	10.05

Table 17. Variation of moisture content of grain sorghum at various depths from the surface of the grain

Time, hours	days	Distance from the surface 4"	1'	2'	4'	6'
0	0	11.2%	11.1%	11.0%	11.0%	11.0%
12	0	10.8	10.9	10.8	10.7	10.7
24	1	10.8	11.0	10.8		
36	1	9.9	9.9	9.7	9.4	8.9
48	2	9.2	9.7	9.7		
60	2	10.4	10.6	10.8	10.7	10.4
72	3	10.6	10.8	10.7		
84	3	10.9	11.0	11.0		
96	4	10.8	10.8	11.1		
120	5	10.4	10.5	10.6		
144	6	10.1	10.2	10.4		
168	7	10.8	10.9	10.7		
192	8	9.8	9.9	10.2		
216	9	10.1	10.5	10.4		
240	10	10.5	11.0	10.8		
264	11	10.1	10.6	10.6	10.4	10.6
288	12	10.3	10.8	10.8		
312	17	10.5	10.3	10.5	10.5	10.7
528	22	11.0	11.0	10.5	11.5	11.0
648	27	10.0	10.1	10.1		
960	40	10.0	10.4	9.8	10.1	9.8
Average m. content		10.39	10.54	10.50	10.53	10.38

could be found with the temperature or relative humidity changes.

The net variation of moisture content between the first and the last days of the experiment are compared in tables 18, 19, 20, and 21. Those tables show that wheat, rice and sorghum had a negative net variation, or a decrease in their moisture content, while corn remained unchanged. It may be observed that grain sorghum and corn were the most and least influenced, respectively.

Moisture content of samples taken from the surface as well as from several inches below on the last day of the test, indicates that the wet atmosphere had no influence over the moisture of kernels placed close to the surface. Table 22 indicates the moisture values for samples taken from the surface, and from $\frac{1}{2}$", 1", and $1\frac{1}{2}$" below. A comparison is made with the moisture content of samples taken four inches below the free surface of the grain.

Table 18. Net variation of moisture content of wheat during storage under tropical conditions for 40 days.

Sample from	Initial moisture	Final moisture	Difference of m. content *
Surface	10.4%	9.5%	- 0.9%
1' below	10.4	9.7	- 0.7
2' below	10.4	9.9	- 0.5
4' below	10.5	9.6	- 0.9
6' below	10.2	9.8	- 0.4

* Moisture content in percent (w.b.)
The plus sign means an increase of moisture.
The minus sign means a decrease in moisture.

Table 19. Net variation of moisture content of rough rice during storage under tropical conditions for 40 days.

Sample from	Initial moisture	Final moisture	Difference of m. content *
Surface	10.6%	9.6%	- 1.0%
1' below	10.5	9.9	- 0.6%
2' below	10.4	10.1	- 0.3%
4' below	10.4	-	-
6' below	10.4	9.7	- 0.7%

* Moisture content in percent (w.b.)
The plus sign means an increase of moisture.
The minus sign means a decrease of moisture.

Table 20. Net variation of moisture content of grain sorghum during storage under tropical conditions for 40 days.

Sample from	Initial moisture	Final moisture	Difference of m. content *
Surface	11.2%	10.0%	- 1.2%
1' below	11.1	10.4	- 0.7
2' below	11.0	9.8	- 1.2
4' below	11.0	10.1	- 0.9
6' below	11.0	9.8	- 1.2

* Moisture content in percent (w.b.).
The plus sign means an increase of moisture
The minus sign means a decrease of moisture

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Table 21. Net variation of moisture content of yellow corn during storage under tropical conditions for 40 days.

Sample from	Initial moisture	Final moisture	Difference of m. content *
Surface	10.5%	11.0%	+ 0.5%
1' below	10.4	10.3	- 0.1
2' below	10.4	10.5	+ 0.1
4' below	10.3	10.3	0.0
6' below	10.2	9.7	- 0.5

* Moisture content in percent (w.b.).
The plus sign means an increase of moisture.
The minus sign means a decrease of moisture.

Table 22. Moisture content of samples taken from the surface and several levels below on the 40th day.

Grain	Surface	Distance from the surface $\frac{1}{2}$"	1"	$1\frac{1}{2}$"	4"
Wheat	9.7%	9.6%	9.6%	9.5%	9.5%
Corn	12.8	12.1	11.7	11.6	11.0
Rice	9.6	9.3	9.2	9.0	9.6
Sorghum	9.8	9.7	9.7	9.5	10.0

It can be observed that moisture content went down gradually, in relation to the place where they were taken. While wheat and corn show a continuous decrease up to the 4" level, rice and sorghum had higher moisture content in that level.

By analyzing the values of moisture content at the surface, it may be noticed that grains did not reach the equilibrium moisture content with the atmosphere. In this respect, the four grains were observed to show the same behavior in both, the first and second tests.

A further analysis was made on the daily average moisture content of the four products. It was found that wheat and rice had a similar behavior, as can be seen in figure 16. Their moisture content variation was approximately the same and both had a decrease of 0.6% during the experiment. However, the above statement does not apply to corn and sorghum, since each one had different changes in moisture content as well as in the net variation of their moisture.

The temperature within the mass of grain varied considerably during the 40 day period. As was the case in the first test, it was found that the room temperature influenced that of the grain, mainly in the lower sections of the bins. This was true in spite of the improvement made on the insulation. Figures 17, 18, 19, and 20 show the temperature curves, and tables 23, 24, 25, and 26 indicate the numerical values and the 40 day period average.

Temperatures taken near the surface show that all grains had a very fast increase in the first 48 hours, and maintained higher values throughout the experiment. Curves corresponding to lower levels are almost parallel and they are influenced more by the room temperature than by the chamber controlled temperature. The above phenomenon is a confir-

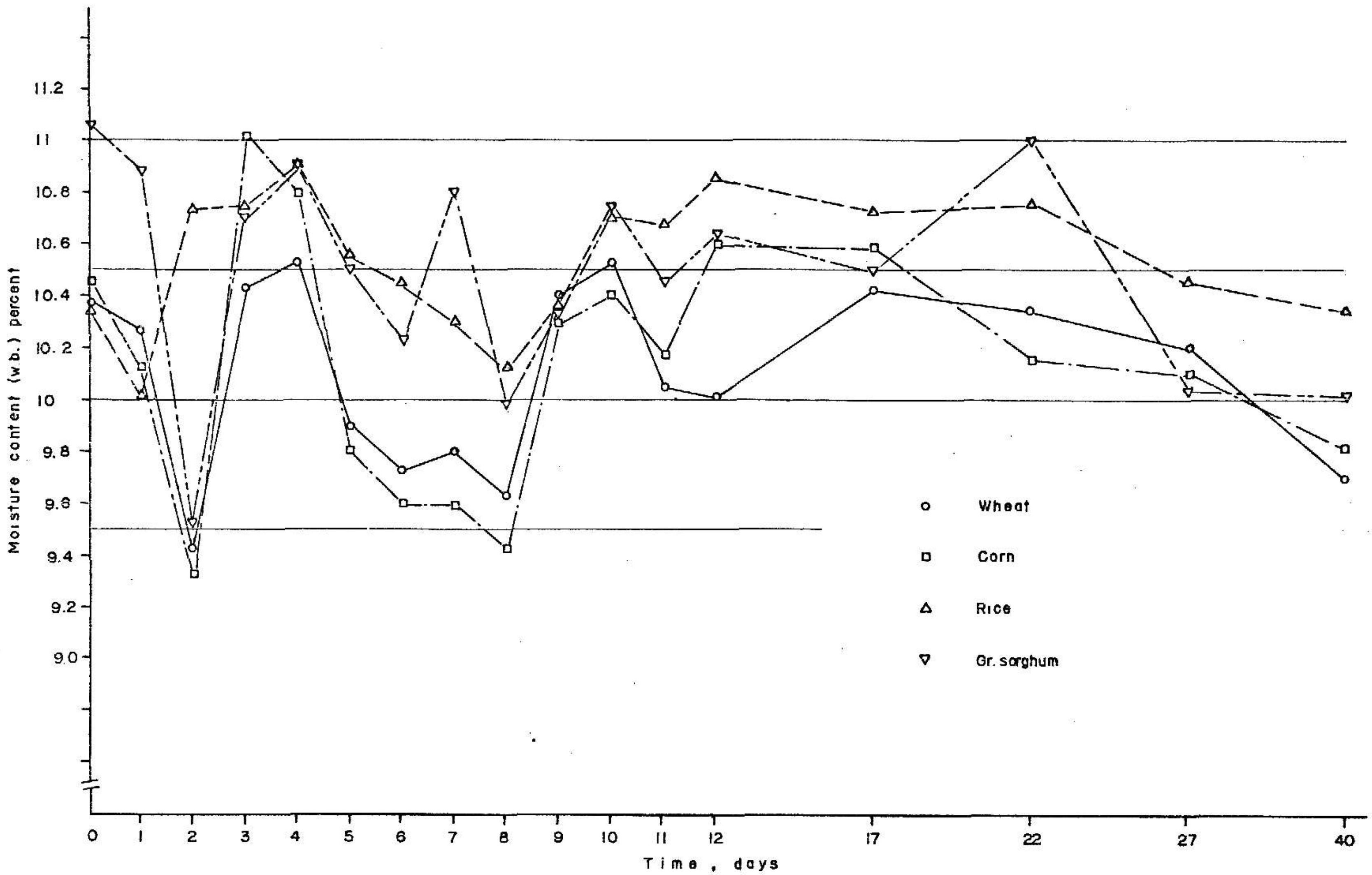

Figure 16. Average moisture content change in the stored grains. Second test.

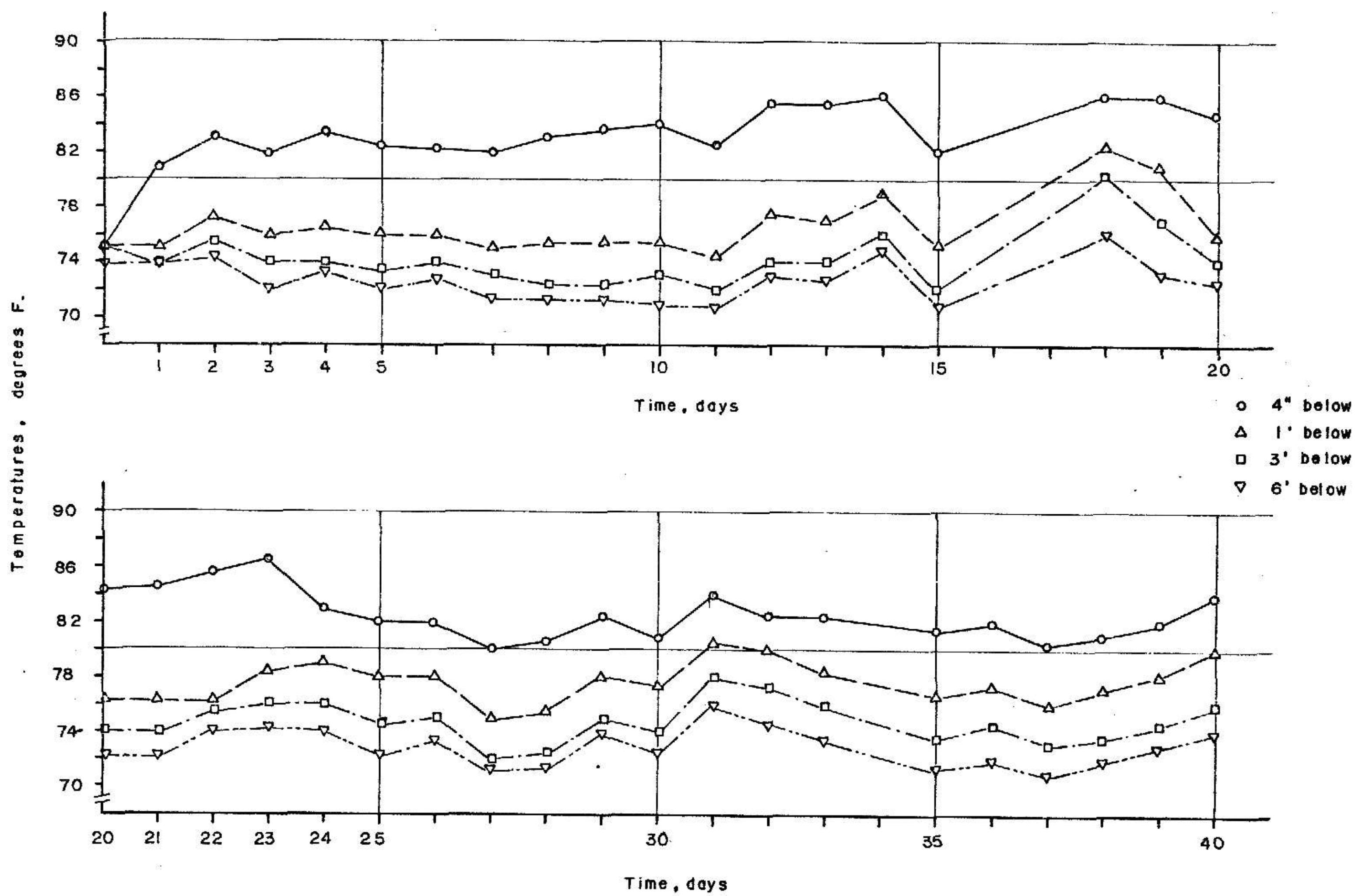

Figure 17. Temperature change in stored Wheat. Second test.

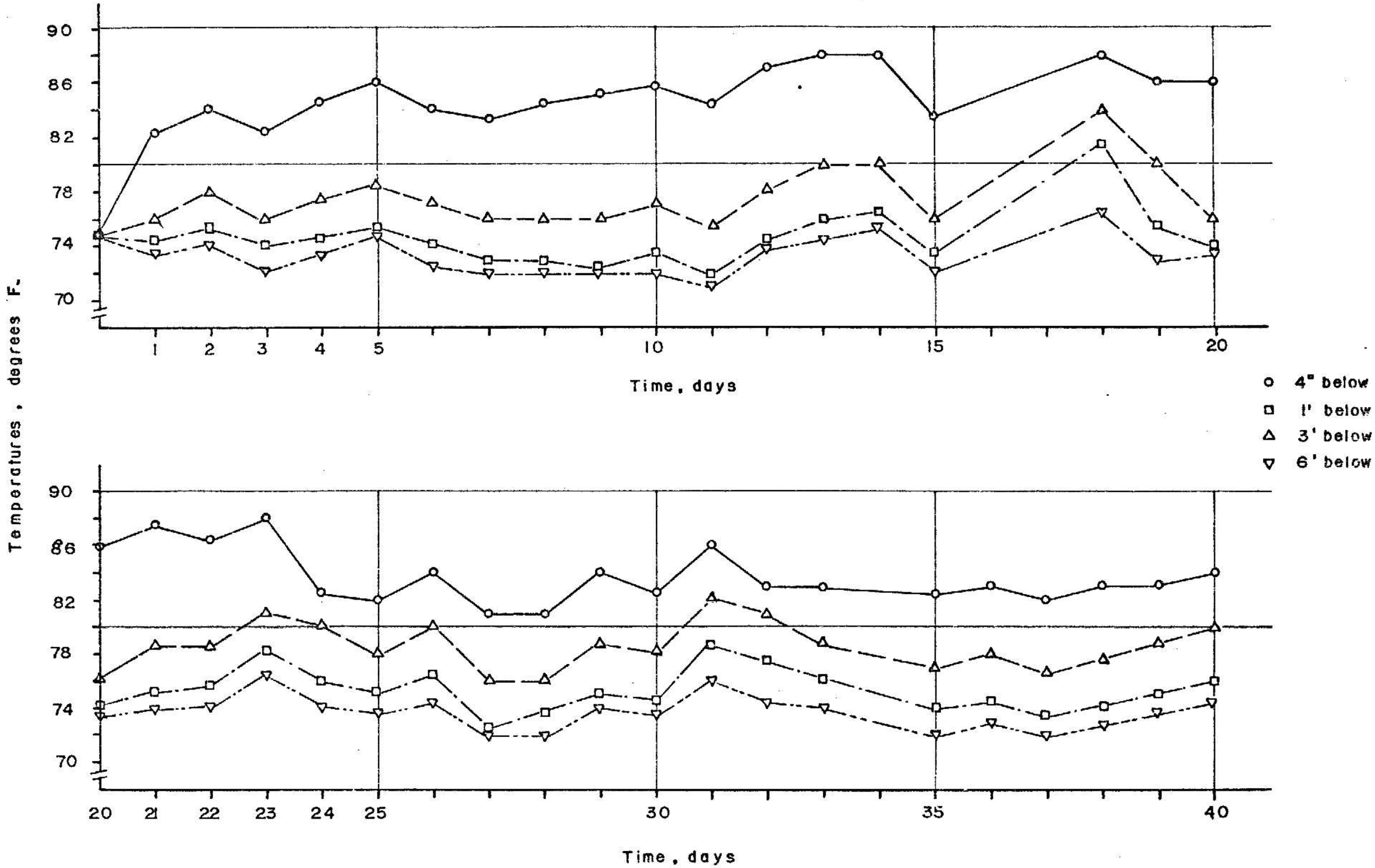

Figure 18. Temperature change in stored Corn. Second test.

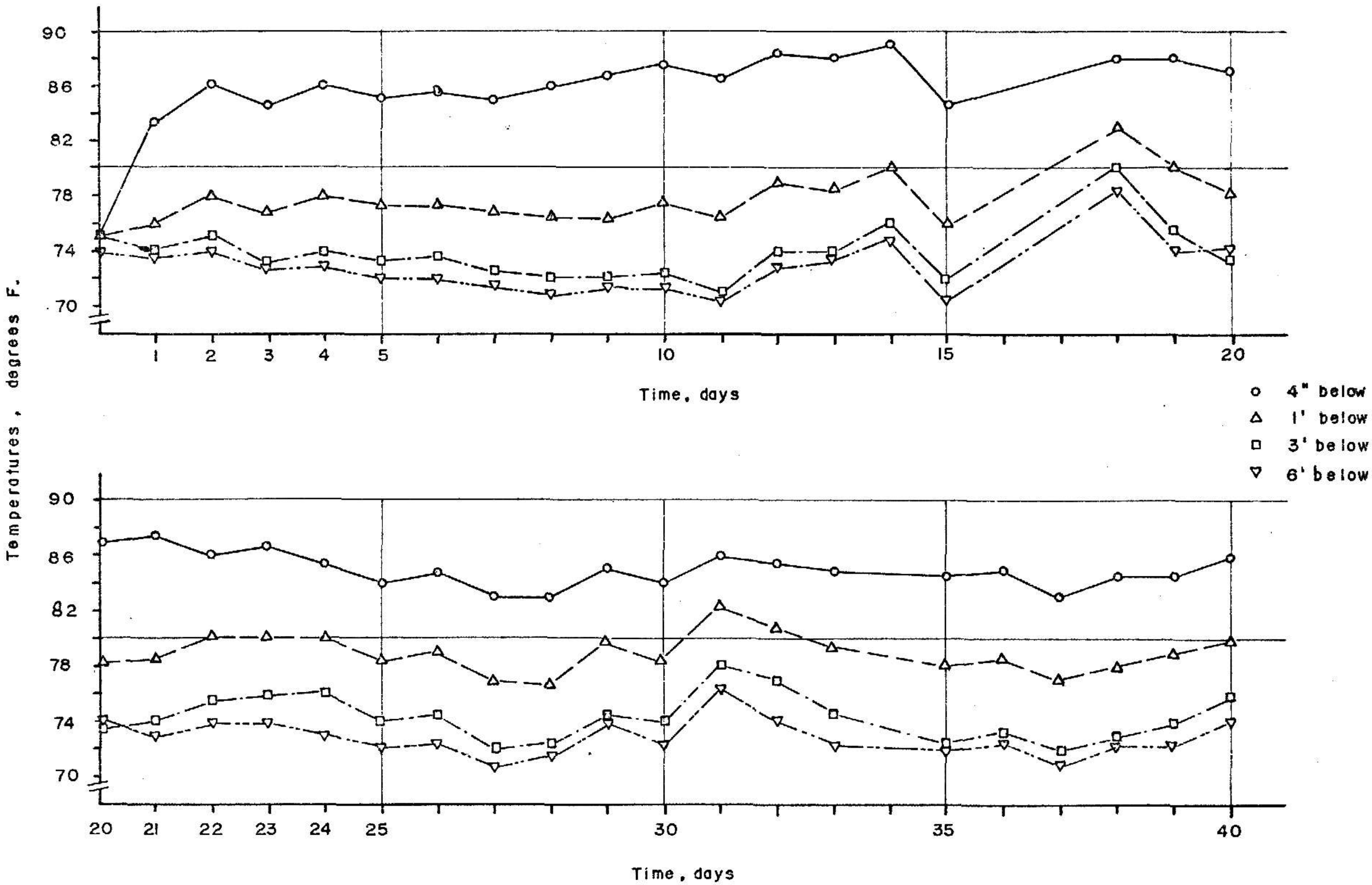

Figure 19. Temperature change in stored Rice. Second test.

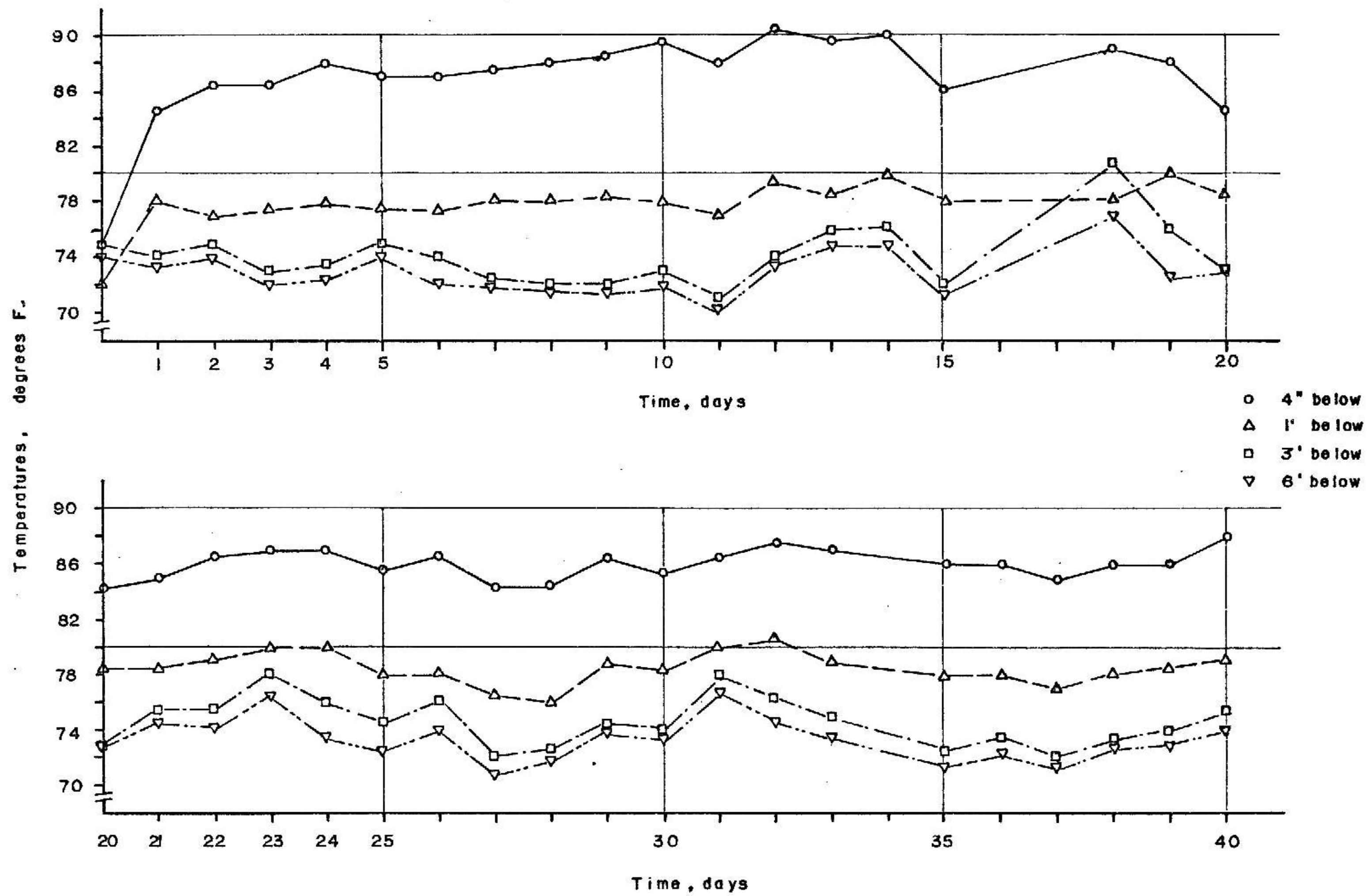

Figure 20. Temperature change in stored Grain sorghum. Second test.

Table 23. Temperature of wheat at different depths from the surface of the grain. (°F.)

Time, days	Room temp.	Top layer	Distance from the surface 1'	2'	3'	4'	5'	6'
0	74°	75°	75°	75°	75°	75°	75°	74°
½	73.5	80	74.5	74	74	74	73.5	73.5
1	73	81	75	74	74	74	74	74
1½	74	83.5	77	75	75	74.5	74.5	74.5
2	73.5	83	77	76	75.5	75	74.5	74.5
2½	72	82	76.5	74.5	74	74	74	73
3	71	82	76	74	74	73.5	73	72
3½	72.5	82.5	76.5	75	74	74	73.5	73.5
4	72	83.5	76.5	75	74	74	74	73.5
5	74	82.5	76	74	73.5	73	72.5	72
6	72	82.5	76	74.5	74	73.5	73	73
7	72	82	75	74	73	72.5	72	71.5
8	72	83	75.5	73.5	72.5	72.5	72	71.5
9	72	83.5	75.5	73.5	72.5	72	71.5	71.5
10	74	84	75.5	73.5	73	72.5	71	71
11	74	82.5	74.5	72.5	72	71.5	71.5	71
12	74	85.5	77.5	75.5	74	74	73	73
13	76	85.5	77	74.5	74	73.5	73	73
14	76	86	79	76.5	76	75.5	75	75
15	80	82	75	73.5	72	72	71	71
18	73	86	82.5	81.5	80.5	80	79.5	76

Table 23 (Cont.). Temperature of wheat. 19th to 40th day.

Time, days	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
19	-	86°	81°	78°	77°	77°	75.5°	73°
20	76	84.5	76	74	74	73	72	72.5
21	77	84.5	76.5	74.5	74	73	72.5	72.5
22	74	85.5	76.5	76	75.5	75	74.5	74
23	74	86.5	78.5	77	76	75.5	74.5	74.5
24	72	83	79	77	76	76	75	74
25	72	82	78	76	74.5	74.5	74	72.5
26	70	82	78	76	75	74.5	74	73.5
27	74	80	75	72.5	72	71.5	71.5	71.5
28	75	80.5	75.5	73.5	72.5	72	71.5	71.5
29	76	82.5	78	75.5	75	74	74	74
30	76	81	77	74.5	74	73.5	73	72.5
31	78	84	80.5	78.5	78	77	76	76
32	74	82.5	80	78.5	77.5	76.5	76.	74.5
33	74	82.5	78.5	76.5	76	75.5	74.5	73.5
35	73	81.5	76.5	74	73.5	72.5	72	71.5
36	72	82	77.5	75.5	74.5	74	73	72
37	73	80.5	76	73.5	73	72	72	71
38	74	81	77	74	73.5	73	72.5	72
39	75	82	78	75.5	74.5	73.5	73	73
40	72	84	80	77.5	76	76	75	74
Temperature average	74.2	82.64	76.97	75.15	74.46	74.04	73.51	73.0

Table 24. Temperature of yellow corn at different depths from the surface of the grain. (^{o}F.)

Time, days	Room temp.	Top layer	Distance from the surface 1'	2'	3'	4'	5'	6'
0	74°	75°	75°	75°	75°	75°	75°	75°
½	73.5	81	74.5	74	74	73.5	73.5	75
1	73	82.5	76	75	74.5	74	73.5	73.5
1½	74	83.5	76.5	75.5	75.5	74	74	76.5
2	73.5	84	78	76	75.5	75	74.5	74
2½	72	83	77	76	75	74	74	73
3	71	82.5	76	74.5	74	73	73	72
3½	72.5	84.5	77	75.5	74.5	74	74	74
4	72	84.5	77.5	75	74.5	74	74	73.5
5	74	86	78.5	76	75.5	75	74	75
6	72	84	77	75	74	74	74	72.5
7	72	83.5	76	74	73	72.5	72.5	72
8	72	84.5	76	73.5	73	72	72	72
9	72	85	76	73.5	72.5	72	72	72
10	74	85.5	77	74	73.5	73	72.5	72
11	74	84.5	75.5	73.5	72	71.5	71.5	71
12	74	87	78	75.5	74.5	74	74	74
13	76	88	80	76.5	76	75	74.5	74.5
14	76	88	80	77.5	76.5	76	75.5	75.5
15	80	83.5	76	74	73.5	72.5	72	72
18	73	88	84	82.5	81.5	80.5	80	76.5

Table 24 (Cont.). Temperature of corn. 19th to 40th day.

Time, days	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
19	-	86°	80°	78°	75.5°	76.5°	75.5°	73°
20	76	86	76	74.5	74	74	73	73.5
21	77	87.5	78.5	76.5	75	75	74	74
22	74	86.5	78.5	76	75.5	74.5	74.5	74
23	74	88	81	78.5	78	77.5	76.5	76.5
24	72	82.5	80	77	76	76	75	74
25	72	82	78	76	75	74.5	74	73.5
26	70	84	80	77.5	76.5	76	75.5	74.5
27	74	81	76	73.5	72.5	72	72	72
28	75	81	76	74	73.5	72,5	72	72
29	76	84	78.5	76	75	74	74	74
30	76	82.5	78	75.5	74.5	74	74	73.5
31	78	86	82	80	78.5	78	77	76
32	74	83	81	78.5	77.5	77.5	76	74.5
33	74	83	79	77	76	76	75	74
35	73	82.5	77	74.5	74	73	72.5	72
36	72	83	78	75.5	74.5	74	73	73
37	73	82	76.5	74.5	73.5	72.5	72.5	72
38	74	83	77.5	75.5	74	73.5	73	73
39	75	83	78.5	76	75	74	74	73.5
40	72	84	80	77	76	76	75	74.5
Temperature average	74.2	83.88	77.81	75.69	74.93	74.39	73.95	73.62

Table 25. Temperature of rough rice at different depths from the surface of the grain ($^{o}F.$).

Time, days	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
0	74°	75°	75°	75°	75°	75°	75°	74°
½	73.5	82	75	74	74	73.5	73.5	73.5
1	73	83.5	76	74	74	74	73.5	73.5
1½	74	85	78	75	74.5	74	74	74
2	73.5	85	78	76	75	74	74	74
2½	72	86	77.5	74.5	74	74	74	74
3	71	84.5	77	74	73	73	73	73
3½	72.5	86	78.5	75	74.5	74	74	73
4	72	86	78	75	74	74	73	73
5	74	85	77.5	74.5	73	72.5	72.5	72
6	72	85.5	77.5	74.5	73.5	73	72.5	72
7	72	85	77	73.5	72.5	72	72	71.5
8	72	86	76.5	73.5	72	72	71.5	71
9	72	86.5	76.5	73	72	71.5	71.5	71.5
10	74	87.5	77.5	74	72.5	72	71.5	71.5
11	74	86.5	76.5	72.5	71	70.5	70.5	70.5
12	74	88.5	79	75.5	74	74	74	73
13	76	88	78.5	75	74	74	73.5	73.5
14	76	89	80	77.5	76	75	75	75
15	80	84.5	76	73	72	71.5	71.5	70.5
18	73	88	83	81.5	80	79	78.5	78.5

Table 25 (Cont.). Temperature of rice. 19th to 40th day.

Time, days	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
19	-	88°	80°	76°	75.5°	74.5°	74°	74°
20	76	87	78	74.5	73.5	72.5	72	74
21	77	87.5	78.5	75	74	73	73	73
22	74	86	80	76	75.5	74.5	74	74
23	74	86.5	80	77	76	75	74.5	74
24	72	85.5	80	76.5	76	75	75	73
25	72	84	78.5	75.5	74	73	73	72
26	70	84.5	79	76	74.5	74	74	72.5
27	74	83	77	73.5	72	71	71	71
28	75	83	77	73.5	72.5	71.5	71.5	71.5
29	76	85	80	76	74.5	74	74	74
30	76	84	78.5	75.5	74	73	72.5	72.5
31	78	86	82.5	80	78	77.5	76.5	76.5
32	74	85.5	81	78.5	77	76	76	74
33	74	85	79.5	76	74.5	74	74	72.5
35	73	84.5	78	74	72.5	72	72	72
36	72	85	78.5	75	73.5	73	72.5	72.5
37	73	83	77	74	72	72	71	71
39	75	84.5	79	76	74	73.5	73.5	72.5
40	72	86	80	77	76	75	74.5	74
Temp. Average	74.2	85.09	78.23	75.23	74.11	73.55	73.32	73.02

Table 26. Temperature of grain sorghum at different depths from the surface of the grain ($^{o}F.$).

Time, days	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
0	74	75	72	74.5	74.5	74.5	-	74
½	73.5	82	77	74	74	74	73	73
1	73	74.5	78	74	74	74	73.5	73.5
1½	74	85.5	76	74.5	74.5	74.5	73.5	74
2	73.5	86.5	77	75.5	75	74.5	74	74
2½	72	86.5	77.5	75	74	74	73.5	73.5
3	71	86.5	77.5	74	73	73	72.5	72
3½	72.5	88	78	75	74	73.5	73.5	73.5
4	72	88	78	75.5	73.5	73.5	73.5	72.5
5	74	87	77.5	76	75	74.5	74.5	74
6	72	87	77.5	75	74	73.5	73.5	72
7	72	87.5	78	73	72.5	72.5	72	72
8	72	88	78	74	73	72	71.5	71.5
9	72	88.5	78.5	73.5	72	72	72	71.5
10	74	89.5	78	74	73	72	72	72
11	74	88	77	72.5	71	71	71	70.5
12	74	90.5	79.5	75	74	73.5	73.5	73.5
13	76	89.5	78.5	76.5	76	75	75	75
14	76	90	80	77	76	75	75	75
15	80	86	78	73	72	72	72	71.5
18	73	89	78	82	81	81	80	77

Table 26 (Cont.). Temperature of sorghum. 19th to 40th day.

Time, days	Room temp.	Top layer	1'	Distance from the surface 2'	3'	4'	5'	6'
19	-	88°	80°	77°	76°	75.5°	74.5°	72.5°
20	76	84.5	78.5	74	73	72.5	72	73
21	77	85	78.5	76	75.5	75.5	74.5	74.5
22	74	86.5	79	76.5	75.5	74	74	74
23	74	87	80	78.5	78	78	76.5	76.5
24	72	87	80	77	76	75	75	73.5
25	72	85.5	78	75.5	74.5	74	74	72.5
26	70	86.5	78	77.5	76	75.5	75	74
27	74	84.5	76.5	73	72	71	71	71
28	75	84.5	76	73.5	72.5	72	72	72
29	76	86.5	79	76	74.5	74	74	74
30	76	85.5	78.5	75	74	73.5	73.5	73.5
31	78	86.5	80	79	78	77	77	77
32	74	87.5	80.5	78	76.5	76.5	76	74.5
33	74	87	79	76.5	75	74	74	73.5
35	73	86	78	74	72.5	72	72	71.5
36	72	86	78	74.5	73.5	73	73	72.5
37	73	85	77	74	72	72	71.5	71.5
38	74	86	78	74.5	73.5	73	73	73
39	75	86	78.5	75	74	73	73	73
40	72	88	79	76.5	75.5	75.	75	74
Temp. Average	74.2	86.32	78.04	75.32	74.34	73.93	73.64	73.25

mation of the former findings, and can be attributed to the good heat insulating quality of grain kernels.

It is interesting to see that the average temperatures recorded during the 40 day period are arranged in descending order, from top to botton. Figure 21 indicates that the temperature drops drastically in the first foot of depth and then starts to stabilize slowly.

The findings of the above two tests are in accordance with previous investigations. Work conducted by Houston et al. (11) about changes in rough rice of different moisture content during storage at controlled temperatures, used Caloro rice containing 11.2, 13.8, 15.3, and 16% moisture content and stored it at 70°F. and 90°F. during seven months. The author reports that the moisture content of the samples remained fairly constant, except during the later stages, when mold growth increased the readings in the wetter grain.

In the light of the present research it seems reasonable to conclude that grain reacts to moisture and temperature changes in manner similar to that described by Pixton and Griffits (14). Further if the bulk stored product does not have aeration, the influence of the outside atmosphere is minimal in both instances, and consequently temperature and moisture will not vary considerably beyond the first layers of kernels. On the other hand, when some kind of air flow is present, a much faster interchange of heat and moisture will take place within the mass of stored grain.

Third Test.

A third test was developed to corroborate the former results by comparing the behavior of grain without aeration and grain that had

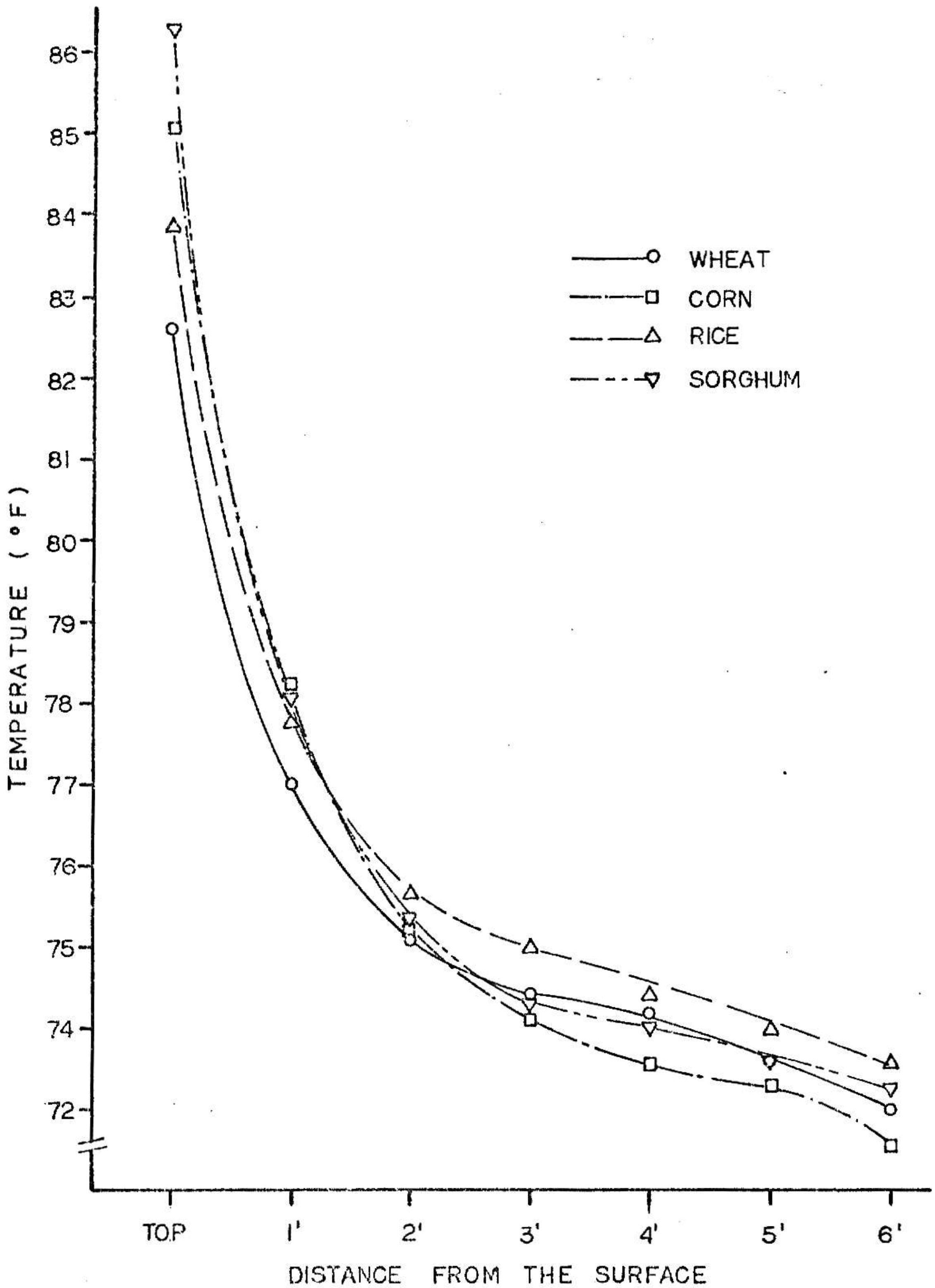

Figure 21. Variation of temperature

been subjected to some kind of air flow, either naturally by means of convection currents or artificially, by means of mechanical aeration system.

The moisture content of corn stored with and without aeration is shown in figures 22, 23, 24, and 25 and values in tables 27, 28, 29 and 30.

A very important difference is noticed between bins 1, 2, and 3 that received aeration, and bin 4 that did not have air flow. It can be observed that the moisture content of grain stored in those three bins did increase steadily while corn stored in bin 4 had a decrease of its moisture content. The slope of the moisture content curve that correspond to bin 3 indicates that grain subjected to a larger air flow had a faster increase in its moisture content than grain stored in bins 1 and 2.

Table 27. Moisture content change in corn subjected to aeration, Bin 1.

Sample from	First day	Fifth day	14th day
4" below surface	12.1%	12.9%	14.0%
1' below	11.9	12.3	13.0
2' below	11.9	11.9	12.4

Moisture content in percent (w.b.).

Table 28. Moisture content change in corn subjected to aeration, Bin 2.

Sample from	First day	Fifth day	14th day
4" below surface	10.7%	11.0%	12.4%
1' below	10.7	10.9	11.7
2' below	10.6	10.7	11.4

Table 29. Moisture content change in corn subjected to aeration, Bin 3.

Sample from	First day	Fifth day	14th day
4" below surface	11.5%	12.3%	13.8%
1' below	11.7	12.0	13.3
2' below	11.8	11.7	12.7

Table 30. Moisture content change in corn stored in control Bin 4 without aeration.

Sample from	First day	Fifth day	14th day
4" below surface	11.8%	11.3%	11.7%
1' below	11.5	11.3	11.8
2' below	11.0	11.0	11.5

The above observation demostrates the importance of air flow through stored grain. Although this is not a new concept and aeration has been treated extensively, the fact that grain does not adsorb moisture without aeration emphazises the critical role of air currents. Further it gives them practically all the responsibility for moisture migration leading to insect and fungi growth.

It was observed that grain remained in good condition during the tests. Its quality was preserved by the low moisture content of the grain.

The findings of the present research suggest that air currents are the main factor that has to be controlled in stored grain, especially in areas where relative humidity and temperature are proper for grain damage. Hence, by controlling aeration and convection currents, a better product conservation may be obtained.

The results show that grain reacts rapidly to air currents even if such currents are as low as 1/500 cfm per bushel of stored grain, as was the case of the currents used in the research cited above (12), or 1/25 and 1/50 cfm/bu. as used in the present investigation.

It would be worthwhile investigating the control of air currents through a mass of grain stored in bins as a second step toward a better understanding of this phenomenon. The incidence of insulation in bins over the behavior of grain, and the characteristics of different materials such as steel, concrete and others may provide answers to the problem of convection currents due to temperature differences between day and night.

Although the same basic principles of air currents would apply to bag stored grain, more investigation is recommended in this field.

Emphasis has to be made on operational and control measures that deal with handling of bag stored grain, since grain held in a warehouse is more likely to be exposed to wind air currents than bulk stored product in bins.

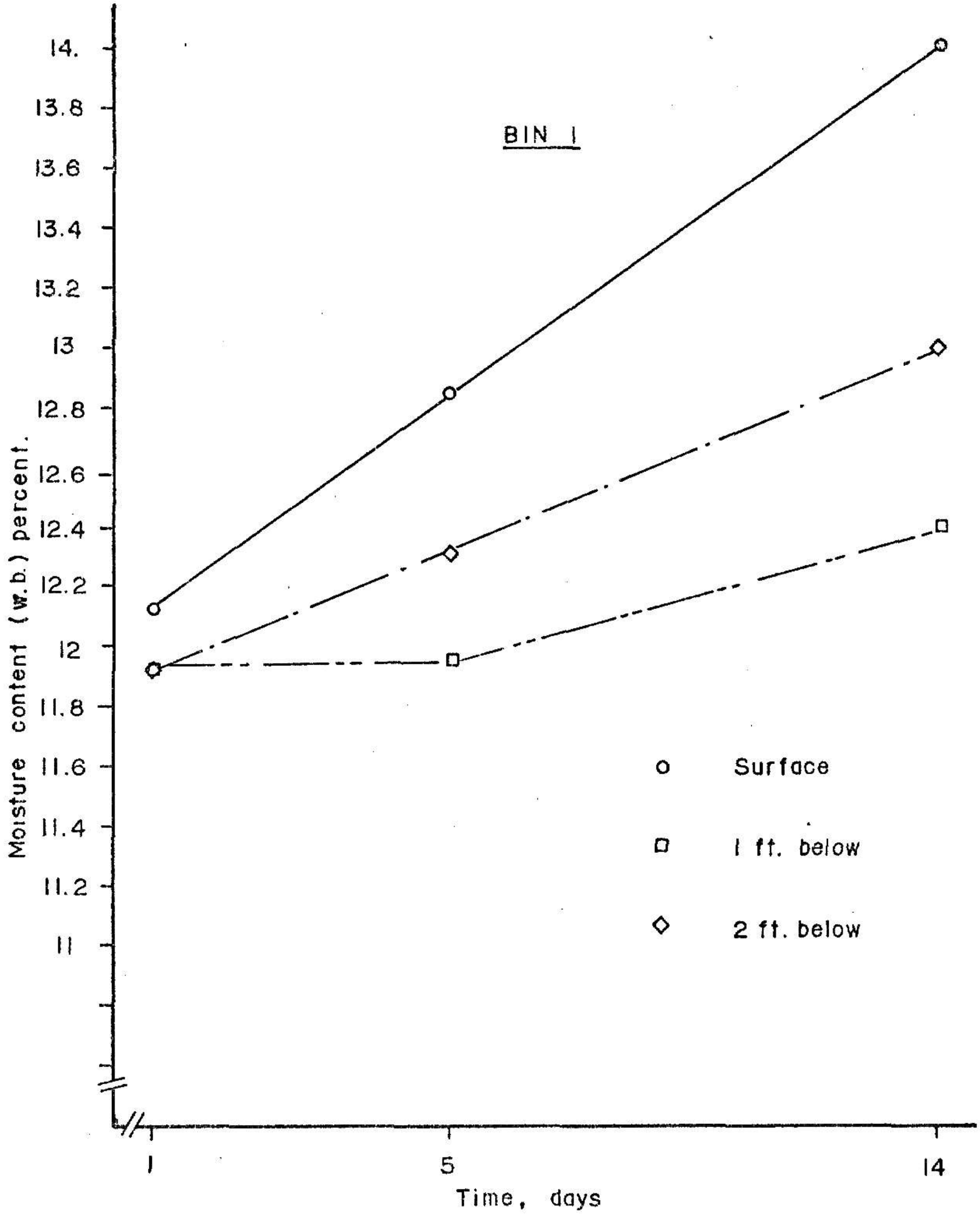

Figure 22. Moisture content change in stored corn. Bin I.

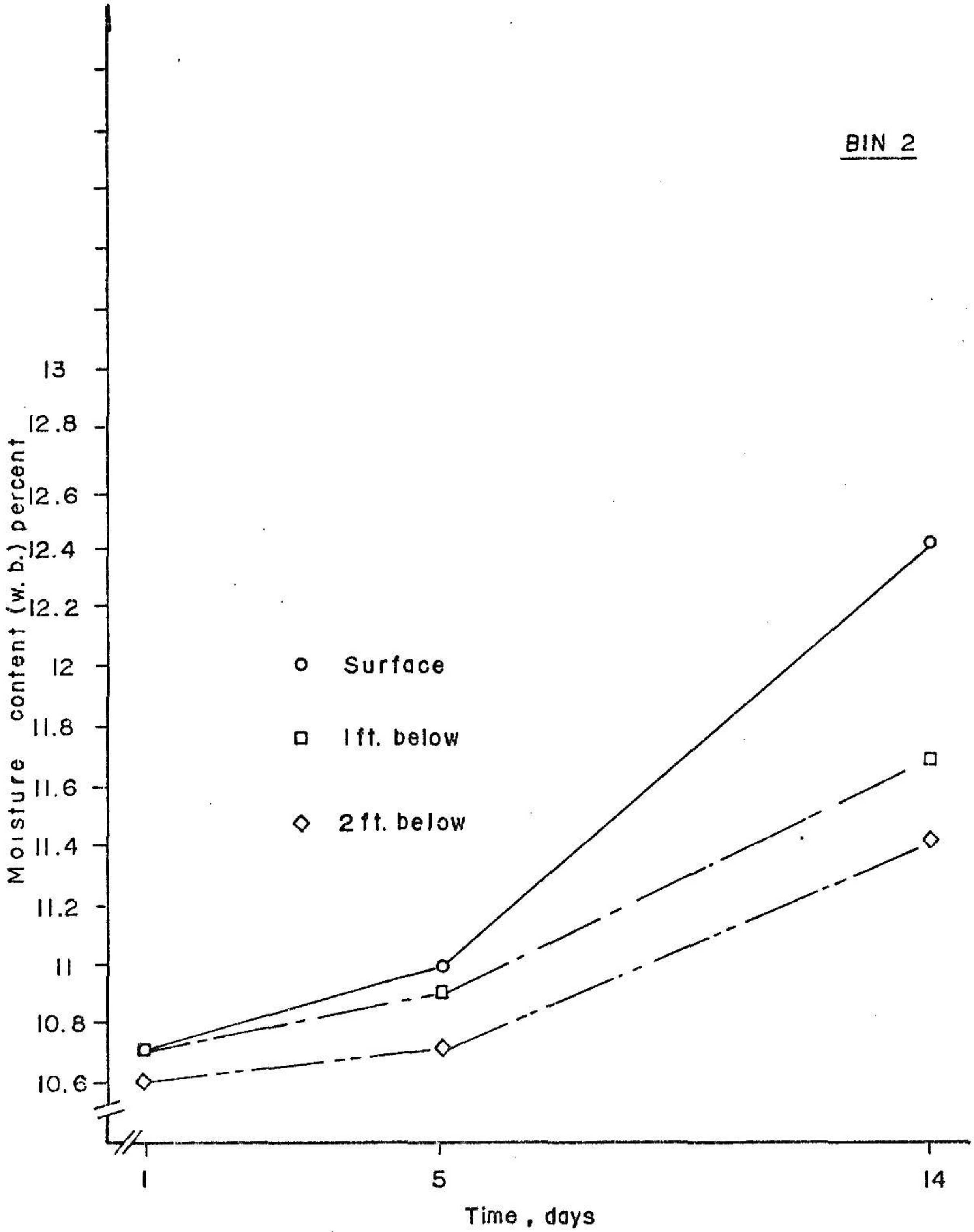

Figure 23 Moisture content change in stored corn. Bin 2.

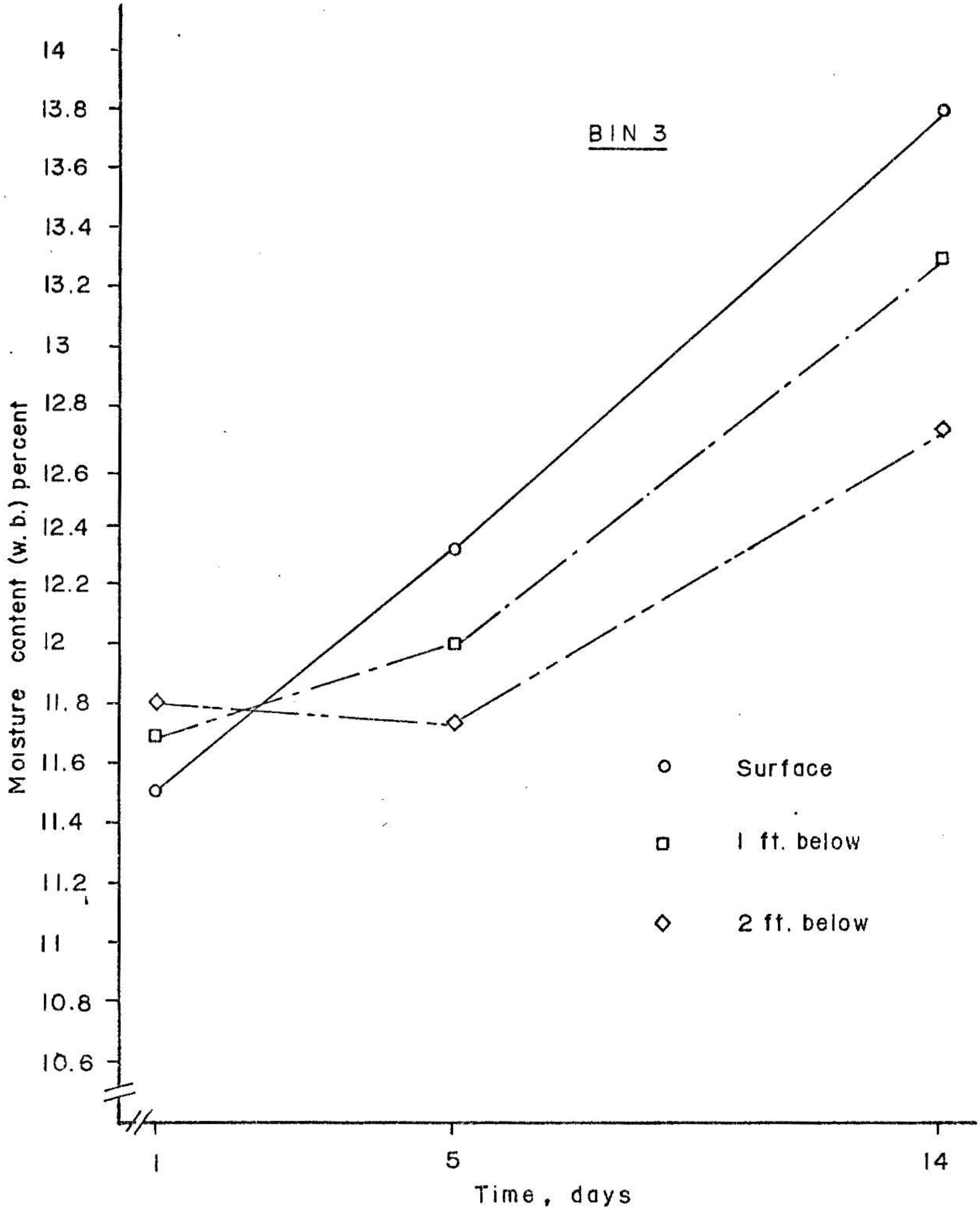

Figure 24. Moisture content change in stored corn. Bin 3.

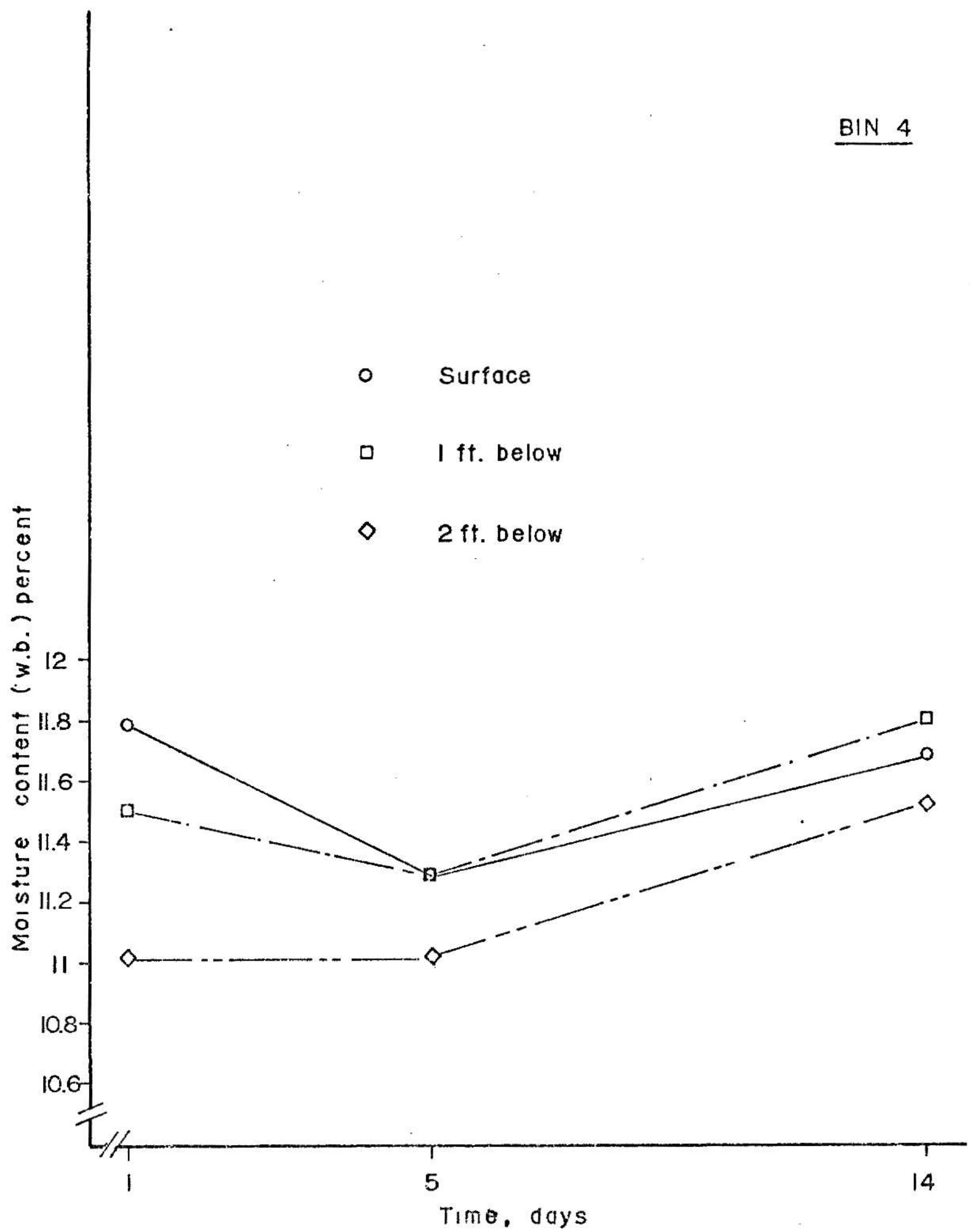

Figure 25. Moisture content change in stored corn. Bin 4.

CONCLUSIONS

The conclusions which result from this research can be summarized as follows:

1. There is no adsorption of moisture of practical significance from the surrounding atmosphere in bulk stored grain, unless the moisture reaches beyond the first layers of kernels in the surface of the grain as a consequence of some kind of air flow through the product.

2. Air currents are the main cause of moisture migration and moisture interchange within the mass of grain.

3. Stored grain reacts rapidly to air currents even if such currents are very low. Consequently, an active heat and moisture interchange takes place.

4. By controlling air flow through grain either caused by natural convection currents or by mechanical aeration, a better product conservation can be attained.

5. Special care has to be taken in controlling air flow in areas where temperature and relative humidity are above that in equilibrium with the grain in order to avoid insect infestation and fungi growth.

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MOISTURE ADSORPTION OF BULK STORED GRAIN
UNDER TROPICAL CONDITIONS

by

AXEL CARO GREIFFENSTEIN

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The purpose of the present study was to analyze the behavior of bulk stored grain subjected to tropical conditions. Approximately one bushel of hard red winter wheat, yellow corn, rough rice and grain sorghum were placed in four simulated plastic bins. The controlled conditions over the free surface of the grain were set at 70 - 75% relative humidity and 90°F., similar to those found in tropical areas.

Three experiments were conducted. In the first and second experiments, no aeration was used through the mass of grain. Temperature and moisture content of grain at various levels were recorded periodically during 14 and 40 days respectively. The third test was used to substantiate the former findings. Two levels of aeration were used during 14 days: 1/25 and 1/50 cfm/bu. in three of the bins, and the fourth one was used as a control bin.

The results of the above investigation can be summarized as follows:

(1) There is no adsorption of moisture of practical significance from the surrounding atmosphere in bulk stored grain, unless the moisture reaches beyond the first layers of kernels in the surface of the grain, as a consequence of some kind of air flow through the grain.

(2) Natural or artificial air currents are the main cause of moisture migration and moisture interchange within the mass of grain.

(3) Grain reacts very rapidly to moisture and temperature changes when there is air flow through the products, even if the air current is as low as 1/50 cfm. per bushel.

(4) The above results suggest that by appropriately controlling the natural and artificial air currents, the good quality of bulk stored grain can be maintained. More research along these lines is recommended.