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Aeration of Wheat in Prolonged Storage for Quality Control

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By H. H. DeLong[1]

Introduction

Grain surpluses accumulated since World War II have prompted a re-evaluation of the problems of grain storage and a search for ways to preserve grain quality for longer periods. It is not necessary to point out the statistics of the storage problem; the kinds or quantities in surplus or whether it is stored on the farm, terminal elevators, in Government bin sites, or in the holds of ships not in active service.

Careful studies are being made, or have been made, in connection with grain storage for each one of these structure types. This bulletin will report on studies on aeration of wheat stored in Government Bin Site structures in South Dakota, 1953 to 1956. During the same period similar studies were made in Kansas on wheat and in Iowa and Indiana on shelled corn.[2]

The Problem

Grain in long-time storage must be kept at or near its original quality if the owner is to receive his financial return. The grain in government storage, if not maintained at high quality, will be less valuable and

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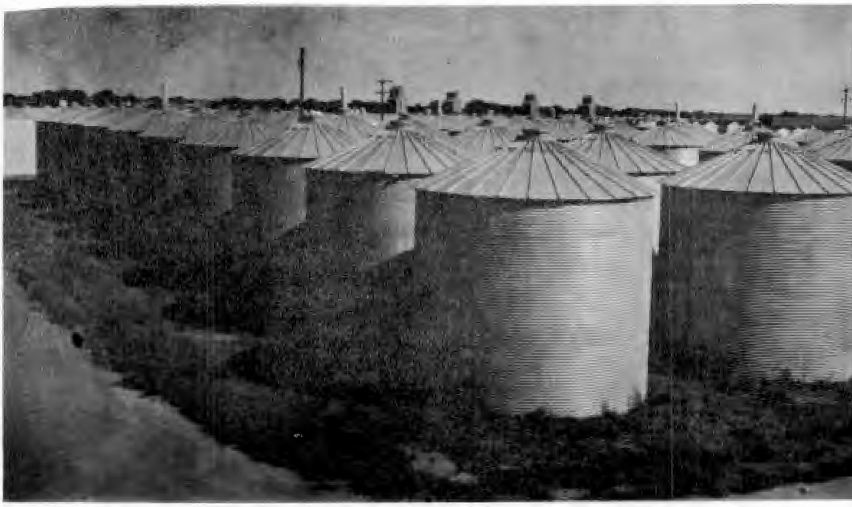
[2]Cooperating agencies were the state Agricultural Experiment Stations (through their Agricultural Engineering Departments), the Commodity Credit Corporation of the USDA, Marketing Research Division, state P.M.A. offices (now ASC), and, in South Dakota, the Sully County P.M.A. (ASC) organization at Onida.

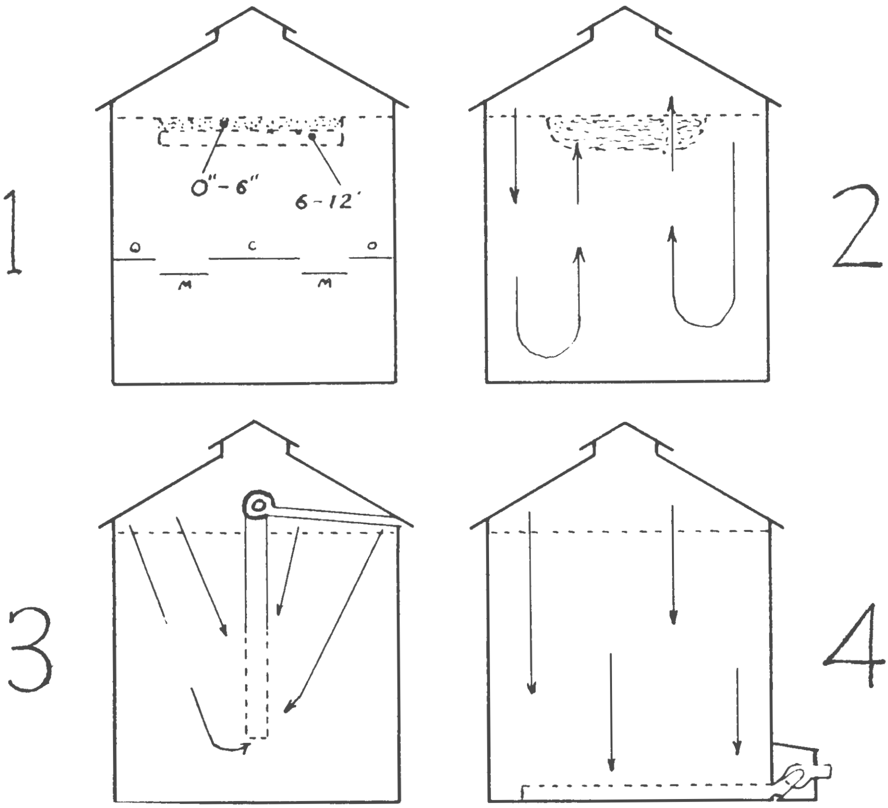
will thus be a financial loss to the government and to the taxpayer. Grain is sold by a grade placed on it by the Federal grain grading agencies at the grain terminal markets. Grain stored in farm bins or bin site bins must be "dry" to start with, or storage problems will develop in the form of heating, mold growth, or insect damage. For safe storage for long periods, grain should be near 12% (wet basis) moisture content, although this is somewhat below the 14% moisture allowed for top grade classifications. See the Handbook of Official Grain Standards of the U. S. for grade definitions (3).

In spite of the dry condition of grain, a moisture movement within the bin takes place each season. It is called "moisture migration." During the winter and early spring months the moisture content of the top central part of the bin will increase by several percent, carrying it beyond the safe "dry" barrier, and making an environment where mold can grow and spoilage can start. Once started it may spread to other portions of the bin. (See figures 1 and 2.)

Temperature changes provide the motive power to bring about such moisture migration. During cold weather, cold heavy air moves down through the cold grain, and air next to the warmer central grain rises. With the warmer air comes some moisture which is condensed onto the cold top layer. This "migration" has been known for many years and was studied in farm type bins at several locations, including Jamestown, North Dakota, and Hutchinson, Kansas (5–9). While wind ventilators were studied to find their effects on the moisture migration, mechanically operated fans with low level circulation were not used. Later tests seemed to indicate that small

Onida Bin Site





Bin cross-sections of elevation view. Figure 1. Location of place of moisture migration—0-12 inch depth (O—outside, M—middle, C—center). Figure 2. Path of slow convection currents of air during fall and winter. Figure 3. Air flow pattern due to forced ventilation of the exhaust fans (counterflow to figure 2). Figure 4. The "F" series bins had air ducts in the bin bottoms, as shown in this cross-section.

fans would provide some relief from moisture migration (4). The type of ventilation was not a drying process, as no drying was necessary for the bulk of the grain, but rather an "aeration" process to help the grain retain its quality.

A Possible Solution

The purpose of the experiment was to find the optimum amount of aeration, and to explore some of the ways to accomplish this with small fans and wind ventilators. The aeration fan installation was partially designed to break up the natural convection currents of air as shown in figure 2. Figure 3 shows how fans can be installed in a "counter flow" pattern. The air is exhausted to the outside, or in cases of high humidity outside, air may be recirculated. Figure 4 shows another installation with air ducts on the bin floor. This gives uniform air flow downward.

Facilities and Bin Site

The Sully County A.S.C. Bin Site at Onida was chosen as a place for the South Dakota trials because it was adequate in size, and was in the heart of the state's spring wheat area. Forty 3,000-bushel bins from the group of nearly 75 were set aside for a long period storage study. Figure 5 shows a plan view of part of the bin site with the 40 bins in the first year's study plus the six added for the second year.

These bins were cylindrical galvanized steel bins of 3,000 bushel size. They had been filled during July 1953 with wheat of the 1952 crop which had been stored on farms through one season. Figure 5 shows location of each type of fan with its eight replications.

The following treatments were used:

(1) Eight bins received no aerations. (Check bins)

(2) Eight bins had 50 c.f.m. fans.

(3) Eight bins had 100 c.f.m. fans.

(4) Eight bins had 200 c.f.m. fans.

(5) Eight bins had a special make of wind ventilator or "cupola."

Each of the fans and the "cupolas" were connected to an 8 inch galvanized steel pipe which was driven down the center of the respective bin about 12 feet of the 18-foot depth (figure 3). Such an installation can be made after the bin is full of grain. The top center lid of the bin is removed and the ventilator pipe is driven downward. Grain from within the pipe must be extracted by an "Evacuvator" or some other means to facilitate driving the ducts down. The lower end of the ducts had perforated sections, but the top part of the pipe, next to the fan, was solid for 6 feet. (Variation in the amount of the perforated part gave no evidence that this was a major design problem.) The tube and fan assemblies cost from $30 to $50 depending on the motor size and type. Installation cost was not included. The wind ventilator, a special Braidert pattern of 36 inch height, cost about $30.

No exact pattern was followed in placing the fans and cupolas in the bins except to avoid placing all of one kind adjacent. The grain was brought in from many parts of the county at the time of filling, and the grain was not uniform as to grade and test weight.

The fans and exhaust pipes were then installed, as were the cupolas, in August 1953. The bins with fans and motors were wired for energizing the electric motors. Three thermocouple wires were inserted in each bin as shown in figure 6. The first year these were in location "m," "n," and "o". After that the locations were "n," "o," and "p."

The second year (summer 1954) six more bins were added. In these the air ducts were placed in the bin floor before the bins were filled. Motor and fan were installed at the scoop door location and covered with a protecting sheet metal house.

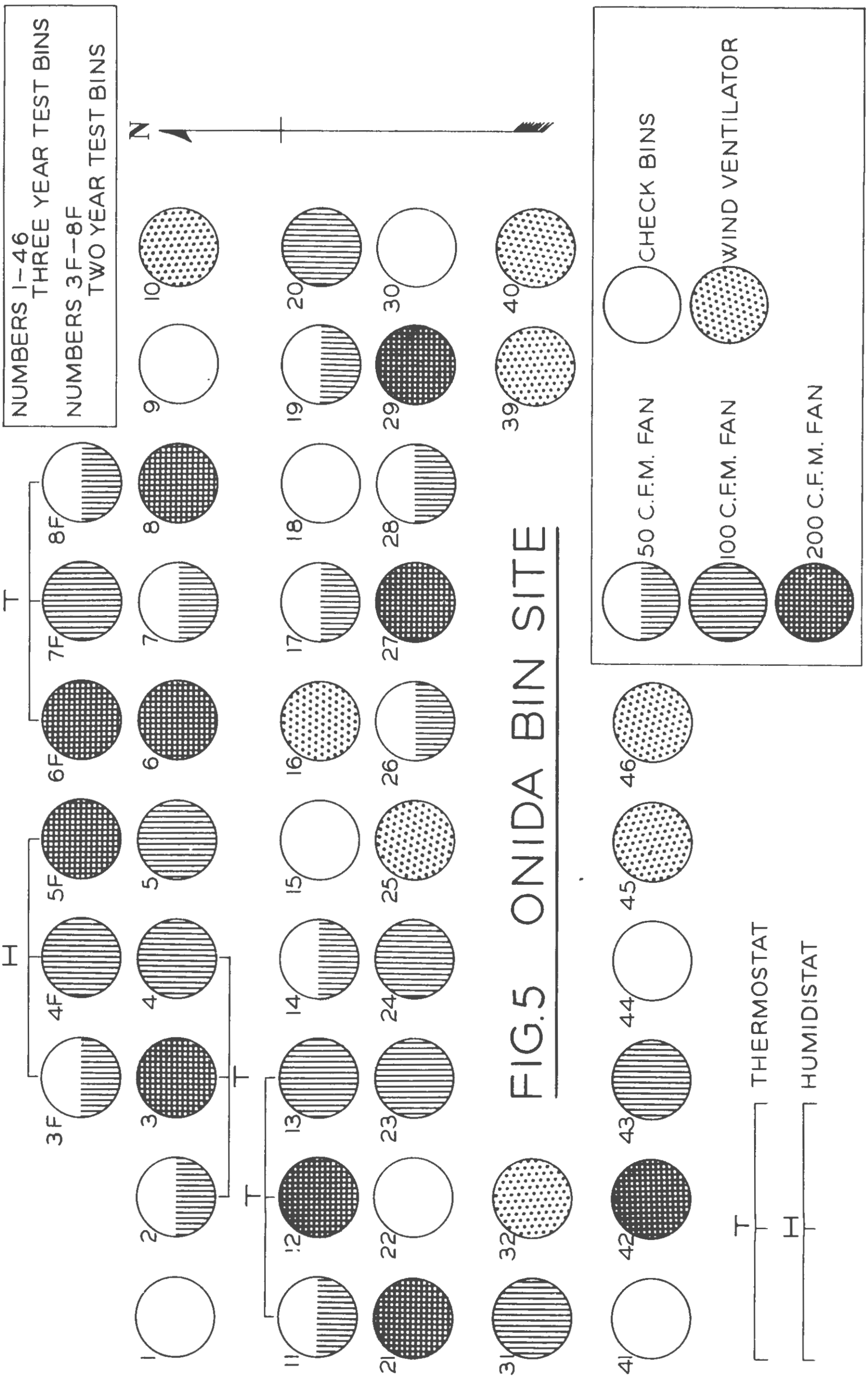
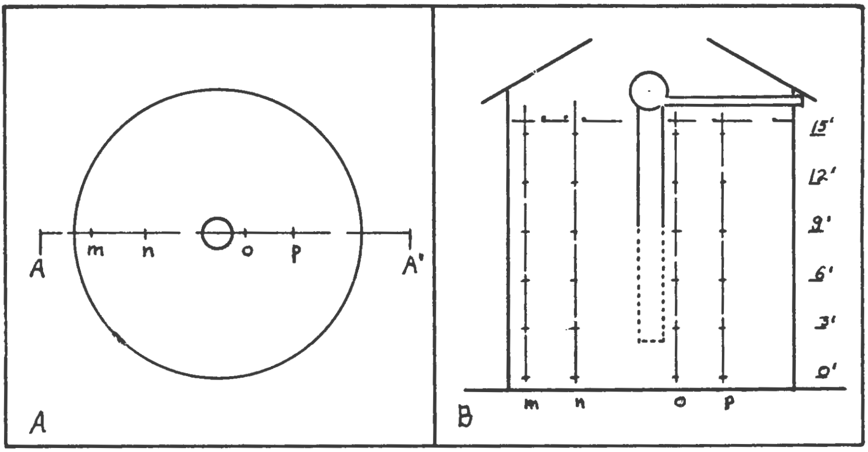


FIG.5 ONIDA BIN SITE



Bin plan *Vertical section through A-A'*

Figure 6. Location of ventilator tube and thermocouples.

The grain used in these bins was similar in quality to that stored a year earlier. Three of the fans were controlled by a humidistat and the other three by a thermostat. Both instruments were activated by outdoor air. Each trio had one 50 c.f.m., one 100 c.f.m., and one 200 c.f.m. fan. At the same time two other similar groups of three bins from among the original 40 were put on thermostatic control. (See groupings in figure 5.)

All fans were adjusted to the desired output by throttling the inlet or outlet with partial closure. When first installed, the back pressure of operation was so low that all fans produced more than their rated capacity except on bins 4F and 5F. A vane anemometer was used to determine air velocities in the delivery tubes, from which was calculated the c.f.m. output.

Procedures

Temperatures

The procedures were designed to gain three sets of data: (1) monthly temperature changes, (2) monthly moisture changes on the top surface, and (3) yearly inspections of the grade of the grain and its quality. Temperatures were read each month from three strings of thermocouple wires, each with six junctions, giving 18 temperature readings per bin. A potentiometer calibrated to read direct for the Fahrenheit scale was used. The first year it was noticed that the top junctions and the entire outer string gave temperatures that reflected outdoor temperature of the past day or two, and not necessarily the typical one for the month. These readings were not included when making up an "average" temperature for a bin. During the remaining tests the wires were at locations "n," "o," and "p."

The temperature data, which were detailed and extensive for each year (720 readings per month), were summarized in a line-graph for each point for the year on figures 7 through 17. This gives every reading for the year for a group of bins. There are 18 line graphs in each figure, and each line consists of 10 monthly readings. In the case of a group of eight bins each point reading is an average of eight bins at similar location in that group.

The temperature itself is not an indication of grain condition but can be used to estimate what is happening or what may happen. "Hot spots" caused by insects or molding could have been detected; however there was no serious disturbance from either in this 3-year test, except those that showed up at the top center. There the condition was observed and not located by temperature change.

Moisture Migration

Each month samples of grain were taken from four locations in the trouble zone of moisture migration. Four to six probings went into the "sample" and they were taken from these four locations: (1) 0-6 inch layer near the bin center, (2) 6-12 inch layer near the center, (3) 0-6 inch layer one-half way out from center and (4) 6-12 inch layer one-half way out from center. This area is referred to as "Middle" in contrast to center or outside. These samples were taken from every bin and the moisture content determined on a Tagg-Hepinstall moisture tester. These were recorded in the field books for individual bins, but on annual reports the group figures were averaged and a line graph made such as appears in figure 7 through 17. The results show a seasonal trend, with moisture contents getting up to troublesome levels in many cases. When groups of eight bins were divided for some variation of treatment two group averages were made and are shown in figure 12 through 17.

Grain Grade

Each year about September 1 and May 30, each bin was probed for samples for grading by the Federal grain inspectors at Minneapolis. One sample was taken from the 0-6 inch layer in the trouble area, one from the 6-12 inch layer below the first, and the third was a composite sample from six or more places in the entire bin. The samples, when probed, were placed in air-tight containers, identified, and shipped to Minneapolis. Their inspection was the routine type and included test weight, moisture content, dockage, percent damage, and grade. In table 1 the first two and the last two grades of the entire 3-year period have been recorded. This indicates the results of the experiment, showing grade preservation or deterioration.

The taking of samples for grade testing has its problems. Once a sample is removed and sent away it can never be taken again. The next sample almost surely is not from the same six or more locations as the first. That is why the first two and the last two samples are quoted, rather than depending on first and last. One must go by trends or by group averages. It is possible that when individual bins are noted, a few may show improvement in grade which one can not explain except to question the sampling procedures.

Bin Management

During the first year of operation, fans were started October 1 and ran continuously until December 30 for part of the bins and February

Table 1. Grade at Beginning and End of 3-Year Test

Bin No.	0"—6" Oct. '53	0"—6" June '54	0"—6" June '56	0"—6" Sept. '56	6"—12" Oct. '53	6"—12" June '54	6"—12" June '56	6"—12" Sept. '56	Composite Oct. '53	Composite June '54	Composite June '56	Composite Sept. '56
1	—	1DNS	1DNS	1DNS	—	1DNS	1DNS	1DNS	2DNS	1DNS	1DNS	1DNS
2	—	4DNS	4DNS	4DNS	—	4DNS	4DNS	4DNS	3DNS	2DNS	2DNS	1DNS
3	—	4DNS	3DNS	3DNS	—	3DNS	3DNS	3DNS	2DNS	3DNS	3DNS	3DNS
4	—	2DNS	2DNS	2DNS	—	1DNS	1DNS	1DNS	2DNS	3DNS	3DNS	3DNS
5	—	1DNS	1HDNS	1DNS	—	1HDNS	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS
6	—	3DNS	—	3DNS	—	3DNS	—	3DNS	1DNS	3DNS	—	4DNS
7	—	1DNS	1DNS	—	—	1DNS	1DNS	1DNS	1DNS	2DNS	1DNS	1DNS
8	—	1DNS	—	1DNS	—	1DNS	—	1DNS	2DNS	3DNS	—	3DNS
9	—	3DNS	4DNS	3DNS	—	4DNS	4DNS	3DNS	2DNS	2DNS	1DNS	2DNS
10	—	1DNS	1HDNS	1DNS	—	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS
11	—	1DNS	1DNS	1DNS	—	2DNS	1DNS	2DNS	2DNS	1DNS	3DNS	3DNS
12	—	1DNS	1DNS	1DNS	—	1DNS	1DNS	1DNS	1DNS	1DNS	2DNS	2DNS
13	—	2DNS	3DNS	3DNS	—	2DNS	3DNS	3DNS	1DNS	1DNS	1DNS	1DNS
14	—	1DNS	1DNS	1DNS	—	1DNS	1DNS	2DNS	SGDNS	SGDNS	2DNS	1DNS
15	—	1DNS	1DNS	2DNS	—	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS
16	—	1DNS	1DNS	SGDNS	—	1DNS	1DNS	SGDNS	1DNS	1DNS	1DNS	2DNS
17	—	1DNS	1HDNS	1DNS	—	1HDNS	1HDNS	1DNS	1DNS	1DNS	1DNS	1DNS
18	—	2DNS	1DNS	1DNS	—	1DNS	1DNS	1DNS	1HDNS	1DNS	2DNS	1DNS
19	—	1DNS	1DNS	SGDNS	—	1DNS	1DNS	1DNS	2DNS	2DNS	2DNS	2DNS
20	—	2DNS	2DNS	2DNS	—	3DNS	4DNS	2DNS	3DNS	3DNS	3DNS	3DNS
21	—	2DNS	—	SGDNS	—	2DNS	—	SGDNS	SGDNS	1DNS	—	2DNS
22	—	1DNS	1DNS	1DNS	—	1DNS	1DNS	1DNS	SGDNS	1DNS	1DNS	1DNS
23	—	2DNS	2DNS	1DNS	—	1DNS	2DNS	2DNS	1DNS	1DNS	1DNS	4DNS
24	—	1DNS	1DNS	1DNS	—	1DNS	2DNS	1DNS	SGDNS	2DNS	2DNS	1DNS
25	—	1HDNS	1HDNS	1HDNS	—	1DNS	1DNS	1HDNS	3DNS	1DNS	3DNS	3DNS
26	—	2DNS	3DNS	2DNS	—	3DNS	3DNS	SGDNS	3DNS	3DNS	2DNS	2DNS
27	—	1DNS	—	2DNS	—	1DNS	—	2DNS	2DNS	2DNS	—	2DNS
28	—	2DNS	2DNS	2DNS	—	2DNS	3DNS	2DNS	2DNS	1DNS	1DNS	1DNS
29	—	1DNS	—	1DNS	—	1DNS	—	2DNS	1DNS	1DNS	—	1DNS
30	—	2DNS	2DNS	1DNS	—	2DNS	2DNS	1DNS	1DNS	1DNS	1DNS	1DNS
31	—	—	2DNS	2DNS	—	—	1DNS	2DNS	2DNS	—	1DNS	3DNS
32	—	2DNS	2DNS	3DNS	—	2DNS	2DNS	3DNS	1DNS	2DNS	1DNS	1DNS
39	—	2DNS	2DNS	2DNS	—	2DNS	1DNS	2DNS	1DNS	1DNS	1DNS	1DNS
40	—	1DNS	1DNS	1DNS	—	1DNS	1DNS	1DNS	1DNS	1DNS	2DNS	1DNS
41	—	3DNS	3DNS	3DNS	—	3DNS	3DNS	3DNS	1DNS	1DNS	1DNS	1DNS
42	—	2DNS	—	3DNS	—	2DNS	—	2DNS	1DNS	2DNS	—	1DNS
43	—	3DNS	3DNS	3DNS	—	2DNS	3DNS	3DNS	1DNS	1DNS	1DNS	1DNS
44	—	3DNS	3DNS	3DNS	—	3DNS	3DNS	3DNS	1DNS	2DNS	1DNS	1DNS
45	—	1DNS	1DNS	1DNS	—	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS
46	—	1DNS	1HDNS	1HDNS	—	1HDNS	1HDNS	1HDNS	1HDNS	1HDNS	1DNS	1HDNS
	Sept. '54	**June '55**	**June '56**	**Sept. '56**	**Sept. '54**	**June '55**	**June '56**	**Sept. '56**	**Sept. '54**	**June '55**	**June '56**	**Sept. '56**
3F	4DNS	4DNS	4DNS	5NS	4DNS	3DNS	3NS	3NS	3DNS	3DNS	3DNS	3DNS
4F	2DNS	2DNS	3DNS	2DNS	2DNS	3DNS	3DNS	1DNS	3DNS	2DNS	3DNS	2DNS
5F	4DNS	4DNS	4DNS	4DNS	3DNS	3DNS	4DNS	4DNS	4DNS	4DNS	4DNS	3DNS
6F	4DNS	4DNS	4NS	5DNS	5DNS	5DNS	5NS	4DNS	3DNS	3NS	3DNS	3DNS
7F	2DNS	2DNS	2DNS	2DNS	2DNS	3DNS	2DNS	2DNS	4DNS	4DNS	3DNS	3DNS
8F	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS	1DNS	4DNS	4DNS	4DNS	3DNS

Abbreviations: NS—Northern Spring; SG—Sample Grade; HDNS—Hard Dark Northern Spring; DNS—Dark Northern Spring.

1 for the others. The December shut-off date proved to be the best for the 50 c.f.m. bins, but showed no advantage with the other bins. On the second year most of the manually controlled fans were turned off March 1 but some of each manually controlled groups were left with the fans or cupolas operating through the spring and summer. Those bins on thermostat control or humidistat control were left running, subject to their automatic controls. During the final year the manually controlled fans and the cupolas were run from September 1 to March 1. Those on automatic control ran until June 1.

Most fans were shut off during the spring season, when there is apt to be considerable rain, to prevent warm, humid air from depositing some of its moisture on the cold grain. The operation of a few fans during the spring was tried to get comparisons with the others, and with the automatic controls.

Snow leakage into the bins gave some trouble in spite of well assembled bins. This additional moisture may have contributed in a small way to the increase of moisture in the upper layers. The quantity was never large, it was not uniform for all bins, and the frequency of its occurrence was controlled by the weather and was not predictable.

Insect infestation showed up occasionally and when noted, such was reported to the bin site management. Effective methods of fumigation were used which controlled the insects adequately.

On a few occasions the wind would blow off an inspection door or a bin grain inlet cover. These were replaced by the bin site crew as soon as noticed. It is not believed to have resulted in any excessive snow or rain intake on any of the test bins. It is an ever present threat to bins in a windy location and bins need to be inspected frequently.

Results

Outstanding among all of the results of the tests was the repeated occurrence of of seasonal moisture migration. Some controls were better than others, but moisture migration occurs in some measure in both check bins and those with aeration. Management of the time of aeration has much to do with the effectiveness of some of the methods.

Each year the data were assembled into tables and graphs, for a year's summary. There was close and consistent agreement among the results for the 3 years. In control of moisture migration the ratings for the five methods were as follows for each of the 3 years:

First—wind ventilator

Second—50 c.f.m. fans

Third—check bins

Fourth—100 c.f.m. fans

Fifth—200 c.f.m. fans

Since the results are so consistent, the second year's tests will be quoted as being typical for all 3 years.

The graphs in figures 7 through 27 are those for the second year in which a few more bins were used and a few more variations were tried. The data for all three years was not averaged nor summarized. It was felt that such an average would reduce the value of the data as compared to yearly summaries. For instance, if temperatures for a "cold" January were averaged along with those for a "mild" January, one would average out the peaks. Data for several "actual" seasons seemed more helpful than data for an "average" season. In general, the tests of each of the 3 years gave the same order or rating of the five systems.

Figures 7 through 27 show the second year's results in detail. To add the other two years would have meant minor differences only and much duplication. A few more variations were used during the second year and gave greater insight into the problem than on the other two years.

Figures 7 through 11 are averages for groups of eight bins or six bins and show both temperature at points within the bin and moisture content from four locations in the upper layers, with monthly inspections September 1954 to June 1955. Charts for the temperatures are detailed, showing line graphs of a given temperature point in the bin. All points within the bin follow a common pattern and lag behind the outdoor temperatures. The interior part of the check bins lag far behind the outside temperature, reaching their high point only in September or October, and their coldest temperatures as late as April or May. Slight aeration such as 50 c.f.m. fan bins (figure 8) and the cupola bins (figure 11) are not far different. Temperature low points are reached earlier when 100 c.f.m. fans (figure 9), or 200 c.f.m. fans (figure 10), are used.

Moisture migration seems to reach its peak in March, April, or May. (See upper parts of figures 7 through 10.) Smaller test bin groups have their data plotted on figures 12 through 17. Figures 12, 14, and 16 are for groups of three bins each on thermostatic control at the aeration levels of 50, 100, and 200 c.f.m., respectively. The alternate figures, 13, 15, and 17, are for only one bin each and these are for humidistat control at the same three aeration levels. Both temperature and moisture curves in these six figures show the general trend. It is only as we compare the five groups on a common chart that the minute differences become clear.

The temperature summary lines as shown in figures 18, 20, 22, and 24 are made up from a monthly average of interior bin temperatures. During the first year of operation the "m" thermocouple string was found to follow rather closely the outside temperature. This outside set of readings was dropped out of the bin averages as were the top temperature readings of each string. The average for each bin for a given month was again averaged with the others of the like groups, providing the data for figure 18.

While interior bin temperature curves all follow the same pattern, the check bin line shows the greatest lag behind outdoor temperature, and does not have the high or low peaks of the other bins. The moisture readings from the bin group charts were averaged by the month so that a line graph could be made of the trend during the season (figures 19, 21, 23, and 25). The comparison shows that the cupola group and the 50 c.f.m. group kept the moisture in the upper layer lower than the check bins. However the 100 c.f.m. and the 200 c.f.m. bins seemed to aggravate the situation and there the moisture migration during late winter and spring rises considerably above that of the check bins.

A special chart (figure 20) was prepared to show how control of the 50 c.f.m. fans might vary the temperature condition of bins. The continuous running fan was compared with one on humidistat control and three on thermostat control, while all three can be compared to the check bins. The continuous fans gave the most rapid response to temperature change while the check bins gave the slowest response. It should be noted, however, that although the check bin line is based on a group of eight bins and the continuous running fan group of six, there were only three thermostatically controlled, and only one by humidistat. All controls mentioned above did a good job of controlling moisture migration at the 50 c.f.m. level, and all were better than the check bin as shown in figure 21. This same plan of comparison was followed through in the case of the 100 c.f.m. fans and the 200 c.f.m. fans

In figure 22 the temperature lines are shown for 100 c.f.m. fans under the three controls, compared to the check. It is similar to figure 20 but lines show greater divergence. In figure 23 the accompanying moisture lines are shown. Here the continuous running fan is definitely detrimental from February until May, with the six bins concerned reaching nearly a 15% moisture level in April.

In figure 24 the same comparison of temperature is shown with 200 c.f.m. fans. Continuous fans gave a rapid response and had a high spring temperature. It was exceeded in high fall and spring temperatures by the humidistat control. When the moisture is considered, (figure 25) it is noted that the humidistat held below the check bin and the continuous running fan allowed the moisture content to go up to a high peak in March and April. By June however, its line is the lowest.

Further comparisons of spring operation are shown in figure 26. Here groups of bins with the same ventilation mechanism and level were divided into two groups on March 1. Part of the bins had their motors turned off or their cupolas disconnected. The remainder of each class showed continuous operation until June 1. Solid lines show no ventilation, and the dotted line shows ventilation going on. In all cases temperatures rise faster with the fans or cupola operative. When the moisture in the upper layer is considered (figure 27), cupolas gave fair control either way, with slight favor of no spring operation. Little preference can be noticed on the 50 c.f.m. curves. With the 100 c.f.m. fans and the 200 c.f.m. fans it would seem that operation from March until June on that year was beneficial. It did lower the moisture in the top layer considerably. It must be said, however, that previous winter operation had brought this grain up from 12% to 14% and 15%. There is also the chance that the accumulated moisture moved lower in the bin and was deposited on grain in the cold interior areas.

Grade Changes in 3 Years

The real value of the bin aeration at various levels must be judged finally on the grade record of the grain itself. As previously mentioned, three samples from each bin were sent in for grading September 1 and June 1 of each year. The first two and the last two tests of each bin were assembled in table 1. In the October 1953 inspections, only one sample per bin was sent in and that was the composite of the entire bin. Grain in the top layers at this time had the same moisture content as the composite and thus the one big sample could well be used for the top-layer grades for that beginning date. Six of the 200 c.f.m. fans and their bins were dropped from the third year tests, and thus there are those blanks appearing in the June 1956 test column. These bins were included in the last grade report, however.

Table 2. Change in Grade for Wheat over the 3-Year Storage Period

Bin Group	Location	3-Year Grade Change: No Change	Increase	Decrease	General Trend
Check	x-0-6″ top	6	1	1	Essentially
	y-6-12″ top	7		1	the
	Composite	4	2	2	same
50 c.f.m.	x-0-6″ top	6		2	Essentially
	y-6-12″ top	6	1	1	the
	Composite	4	3	1	same
100 c.f.m.	x-0-6″ top	7		1	Slightly
	y-6-12″ top	2	2	4	Lowering
	Composite	5	2	1	
200 c.f.m.*	x-0-6″ top	6	1	1	
	y-6-12″ top	4	1	3	Lowering
	Composite	3	1	4	
Cupola	x-0-6″ top	6		2	Essentially
	y-6-12″ top	6	2		the
	Composite	7		1	same

*2-year period only.

Table 1 gives the data for the bins in numerical order, and singly; not by treatment groups. When the bins are grouped and their change in grade summarized a clearer picture is presented. Here the group grade changes were summarized as follows: the bins with no change in grade were counted and listed, those with an increase or better grade listed, and those with a decrease in grade listed. From this tabulation the conclusion for that group was drawn. Table 2 shows the listings and the conclusions. Only in the case of the 200 c.f.m. fan group is there a noticeable lowering of grade. The 100 c.f.m. fan group showed slight lowering. The other three groups showed no significant change, even in the case of the cupola or wind ventilator group.

This speaks favorably for the natural effects of central South Dakota weather on dry grain in long time storage.

Basic Considerations

Moisture content of grain, if in contact with air, will come to a given moisture content in keeping with the natural property of the grain and the amount of moisture in the air. This is assuming constant temperature, constant air conditions, and time for the air and grain to equalize or come to a moisture balance point. In nature the temperature and moisture content of the air are constantly changing. For the sake of the explanation, however, examples of specific temperatures and moisture contents will be used.

Central South Dakota Weather

The U. S. Weather Bureau has collected weather data for many years from stations at Aberdeen, Pierre, and Huron, South Dakota. These are near the Onida bin site. Examination of summaries of temperature and humidity records in these areas enables one to predict "typical" situations. It is understood that conditions change and that some days out of each month are not typical.

Table 3 has been prepared to compare vapor pressure in the air with a grain moisture content in equilibrium with that air condition. The left hand part gives the vapor pressure in pounds per square inch that is associated with a given temperature and relative humidity. An example will be given, after the discussion of the hygroscopic properties of wheat.

Hygroscopic Properties of Wheat

Wheat, like all other grains, has the ability to hold some moisture at normal air conditions. The moisture may be absorbed, adsorbed, or held in chemical union. Whatever its form, it presents a potential vapor pressure to the surrounding air. The grain will lose moisture if conditions are such that the moisture is carried away. Movement of the moisture from the interior of the kernal to the surface is controlled by temperature and a time rate problem.

High temperatures in grains produce slightly higher vapor pressures, or slightly lower equilibrium moisture balance points. The right hand side of table 3 shows data collected from several sources on the moisture equilibrium of wheat. Most of these tests are collected and published in the book, "Drying Farm Crops," by Dr. Carl Hall (2). Two tests were made by Whitehead and Gastler (10) at the South Dakota Agricultural Experiment Station.

Quoting extreme figures in connection with temperature effects, it is noted that at 32° and 34° F. and 60% relative humitity (R.H.), the moisture content is 13.4 and 15.62% respectively. At 122° and 60% R.H. the moisture balance is 10.8%. This lowering of moisture is in spite of the tremendous increase in the vapor pressure of the air as seen on the left hand column.

Using varying relative humidities at constant temperatures (50°) it is noted that at 80% R.H. the moisture balance is 16.0% and at 40% R.H. the moisture balance is 10.3%.

Examples. When weather is at 20° and 70% R.H. in mild fall or winter weather, the accompanying wheat moisture balance is 15.6%. Several other cases will be listed.

Dry Fall Weather – 20°F – 40% R.H.–11.3%

Warm Spring Weather–50°F–70% R.H.–14.5%

Dry Spring Weather–50°F–50% R.H.–11.7%

Humid Summer Weather–77°F –70% R.H.–13.9%

Dry Summer Weather–77°F–40% R.H.–9.8%

These examples are enough to show how the South Dakota weather is very cooperative in grain storage and how aeration of grain in bins can be carried out without radical changes in the grain moisture content.

What happens at the lower winter temperatures has not been well explored. When grain cools, its ability to hold moisture increases. The capacity of the air to hold and transmit moisture drops to a very low amount. This is good, in a way. Yet if this very dry air moves through to a warm part of the bin its temperature increases and it increases its ability to hold moisture and will take up moisture from normal or reasonably dry grain. When this same air is forced by convection currents to the upper layer of grain, and if this layer is cold, this moisture is driven out of the air and condenses on the grain. The right amount of "reversed" circulation by forced air can prevent this convection current of air from promoting moisture migration.

Table 3. Vapor Pressures and Moisture Balance Figures for Varying Temperatures and Relative Humidities

Temperature (F.)	Accompanying Vapor Pressure for Air (psi) at Given Relative Humidity and Given Temperature								Equilibrium Moisture Content of Grain at Given Temperature and at Given Relative Humidity						
R.H.—	100%	80%	70%	60%	50%	40%	30%	20%	80%	70%	60%	50%	40%	30%	20%
0°	.018	.0144	.0126	.0108	.009	.0072	.0054	.0036	------	------	------	------	------	------	------
10°	.031	.024	.022	.0186	.016	.0124	.0093	.0062	------	------	------	------	------	------	------
20°	.050	.040	.035	.030	.025	.020	.015	.010	17.0*	15.6*	14.1*	12.8*	11.3*	------	------
30°	.081	.065	.0655	.0486	.0405	.0324	.019	.013	------	------	------	------	------	------	------
32°	------	------	------	------	------	------	------	------	16.3*	14.7*	13.4*	12.3*	11.0*	------	------
34°	------	------	------	------	------	------	------	------	22.13†	------	15.62†	------	12.86†	------	9.46†
40°	.122	.097	.085	.073	.061	.0487	.0366	.0244	------	------	------	------	------	------	------
50°	.178	.142	.125	.107	.089	.0711	.0534	.0356	16.0*	14.5*	13.1*	11.7*	10.3*	------	------
60°	.256	.205	.179	.154	.128	.102	.077	.0513	------	------	------	------	------	------	------
68°	------	------	------	------	------	------	------	------	20.49†	------	15.27†	------	11.97†	------	9.05†
70°	.363	.291	.254	.218	.182	.146	.109	.073	------	14.0*	12.5*	11.0*	9.7*	------	------
77°	.462	.370	.323	.277	.231	.185	.139	.093	------	15.0‡	13.0‡	11.0‡	9.0‡	------	------
77°	------	------	------	------	------	------	------	------	15.9§	13.9§	12.5§	11.1§	9.8§	8.5§	7.2§
80°	.507	.405	.354	.320	.254	.203	.152	.103	------	------	------	------	------	------	------
90°	.698	.558	.487	.418	.348	.280	.209	.139	------	------	------	------	------	------	------
100°	.950	.760	.665	.570	.475	.380	.285	.190	------	------	------	------	------	------	------
122°	------	------	------	------	------	------	------	------	15.1‖	12.6‖	10.8‖	10.0‖	8.1‖	6.7‖	5.8‖

*Thompson, H. J., and Shedd, C. K. †Whitehead, E. I., and Gastler, G. F. ‡Hylmka and Robinson.
§Coleman, D. A., and Fellows, H. C. ‖Becker, H. A., and Sallans, H. R.

FIGURE 7
AVERAGE CONDITIONS FOR EIGHT CHECK BINS

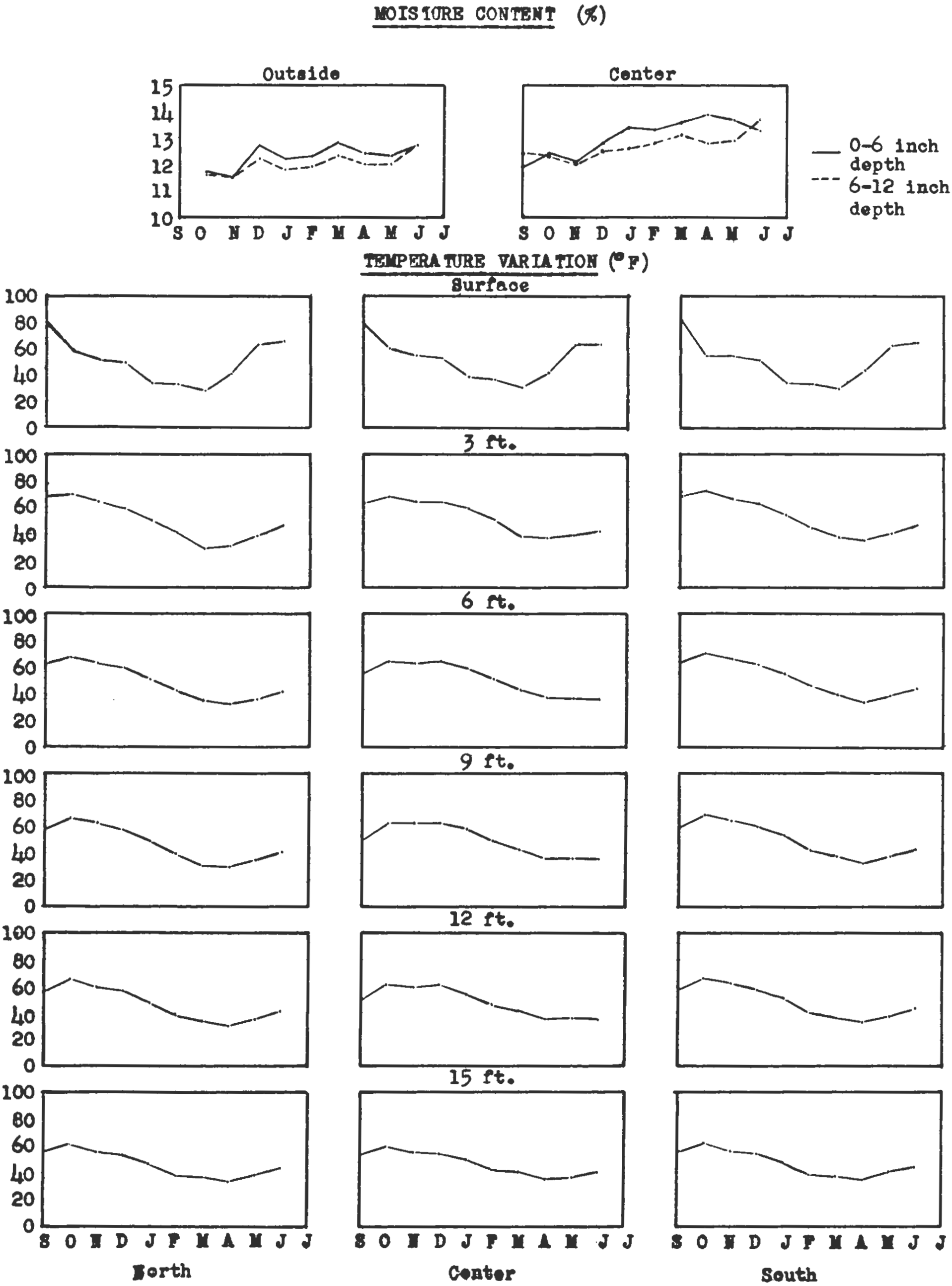


FIGURE 8

AVERAGE CONDITIONS FOR SIX BINS WITH 50 CFM. FANS

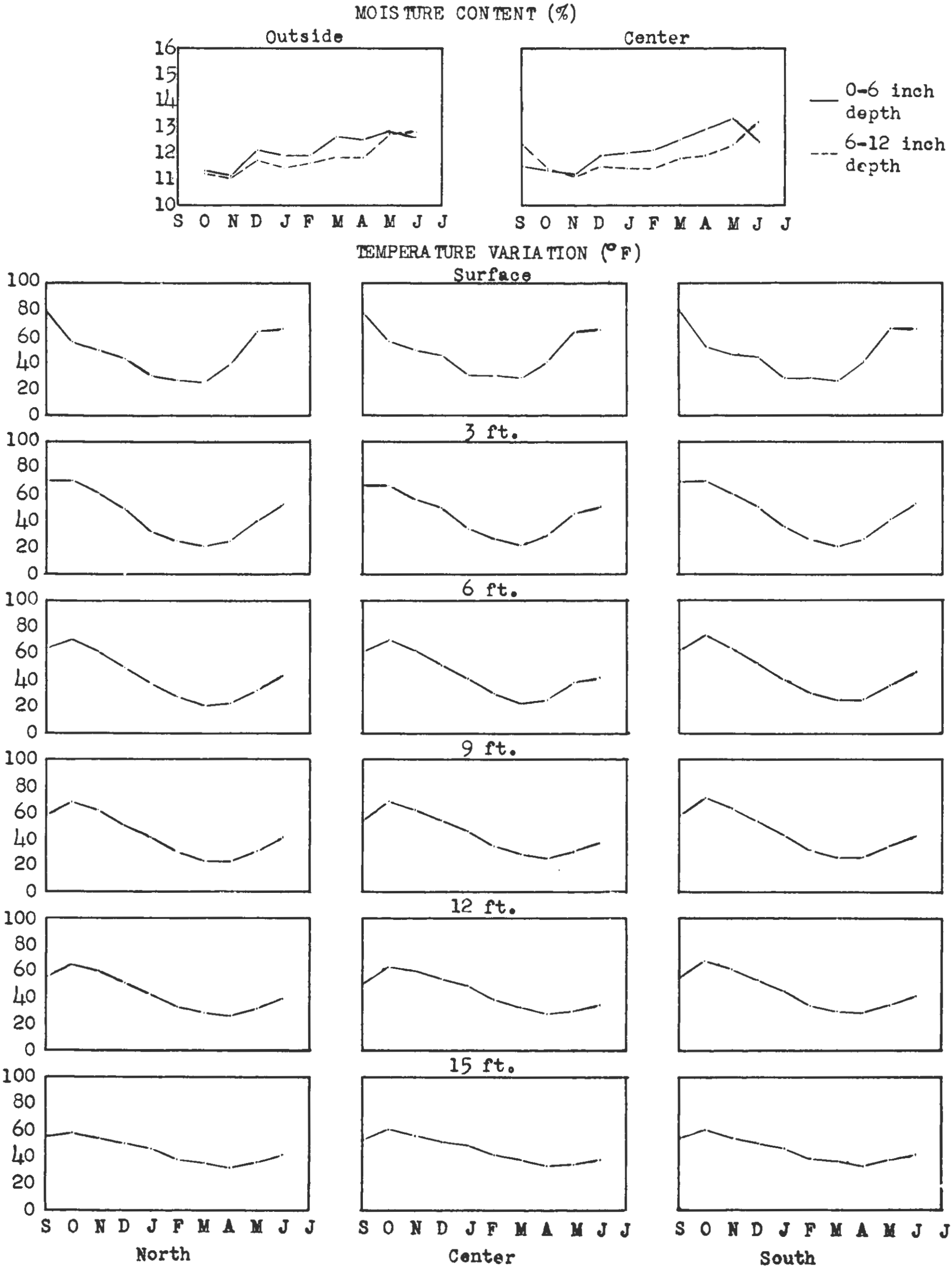


FIGURE 9

AVERAGE CONDITIONS FOR SIX BINS WITH 100 CFM. FANS

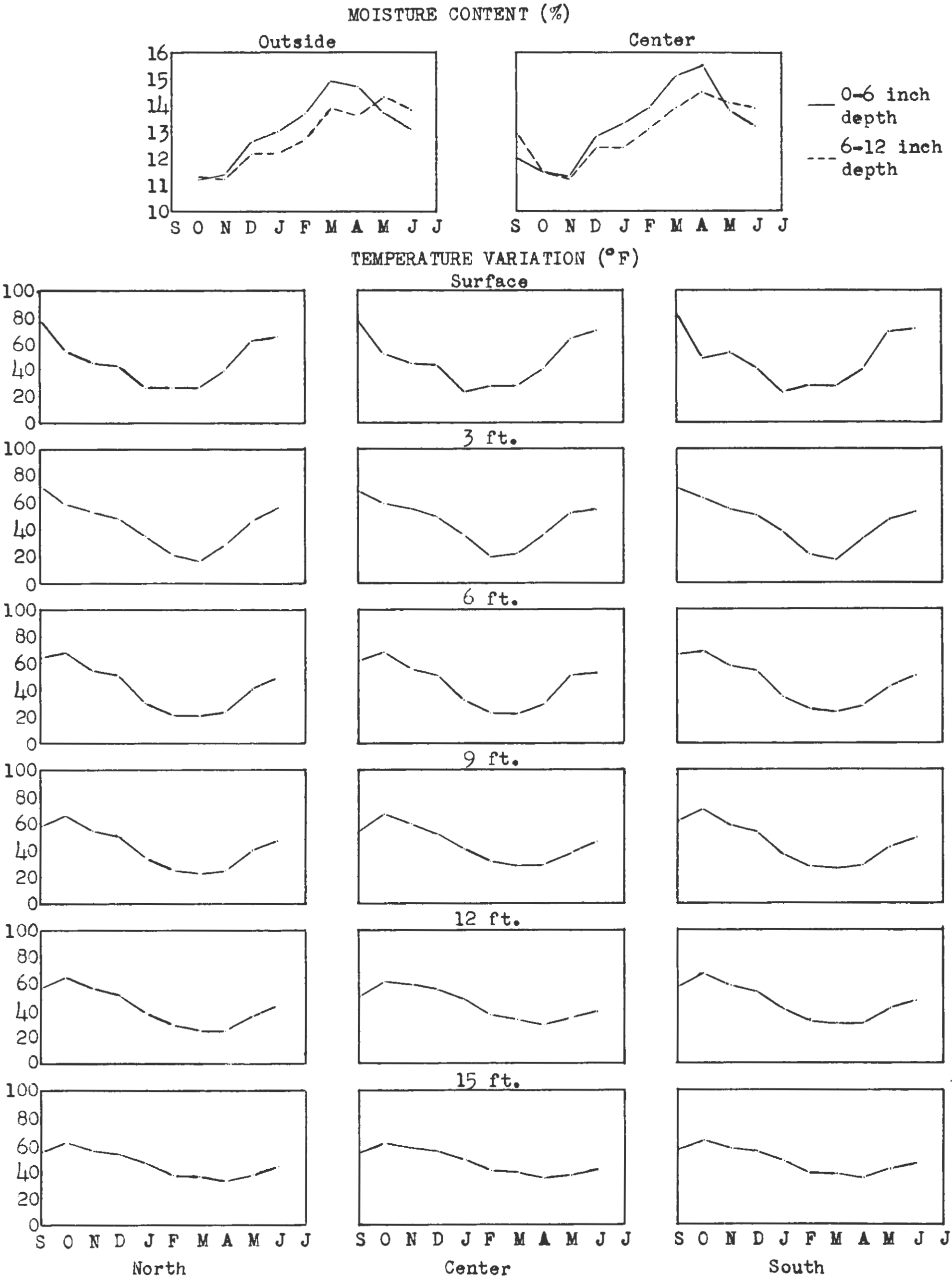


FIGURE 10

AVERAGE CONDITIONS FOR SIX BINS WITH 200 CFM. FANS

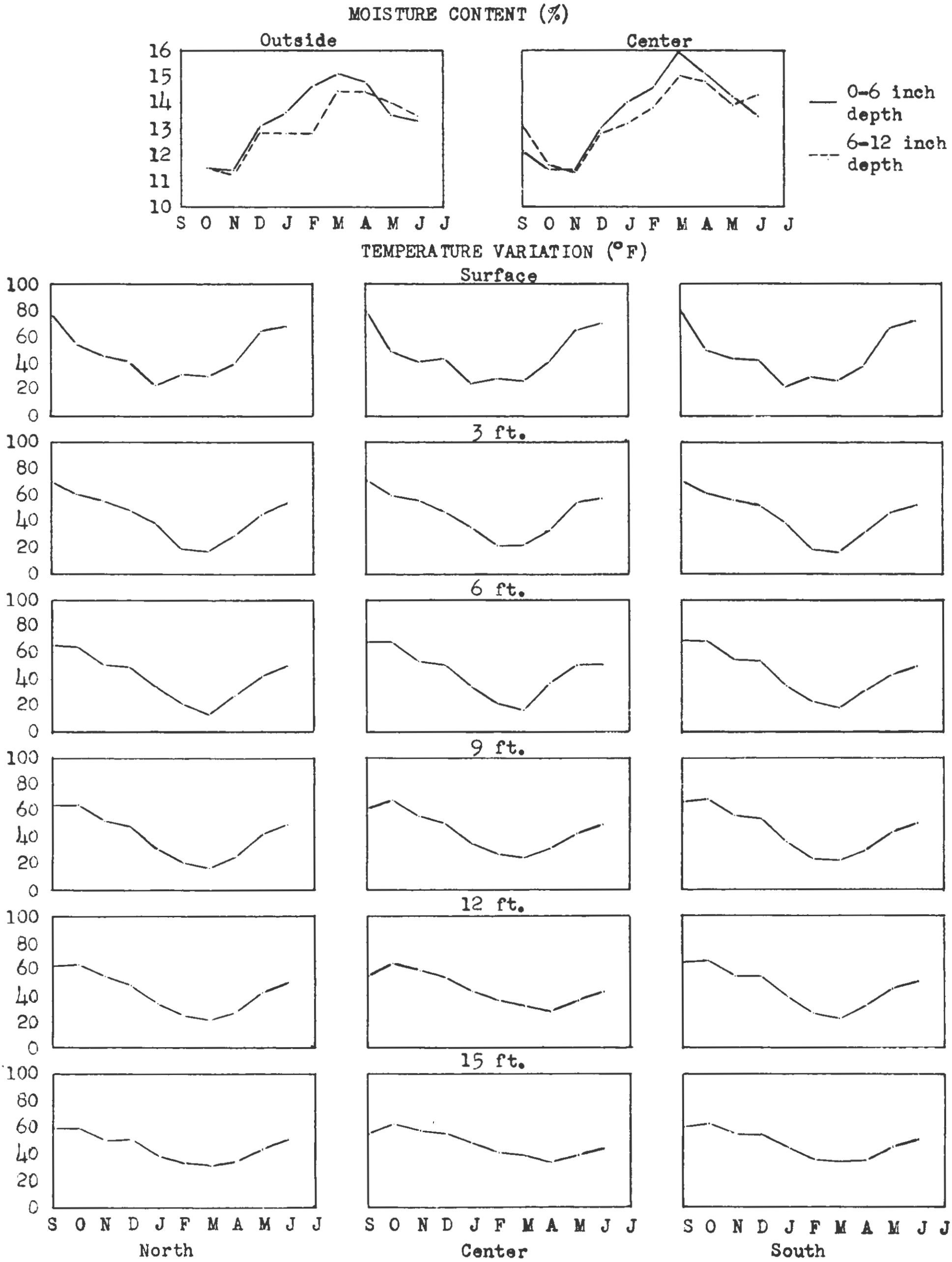


FIGURE 11

AVERAGE CONDITIONS FOR EIGHT CUPOLA BINS

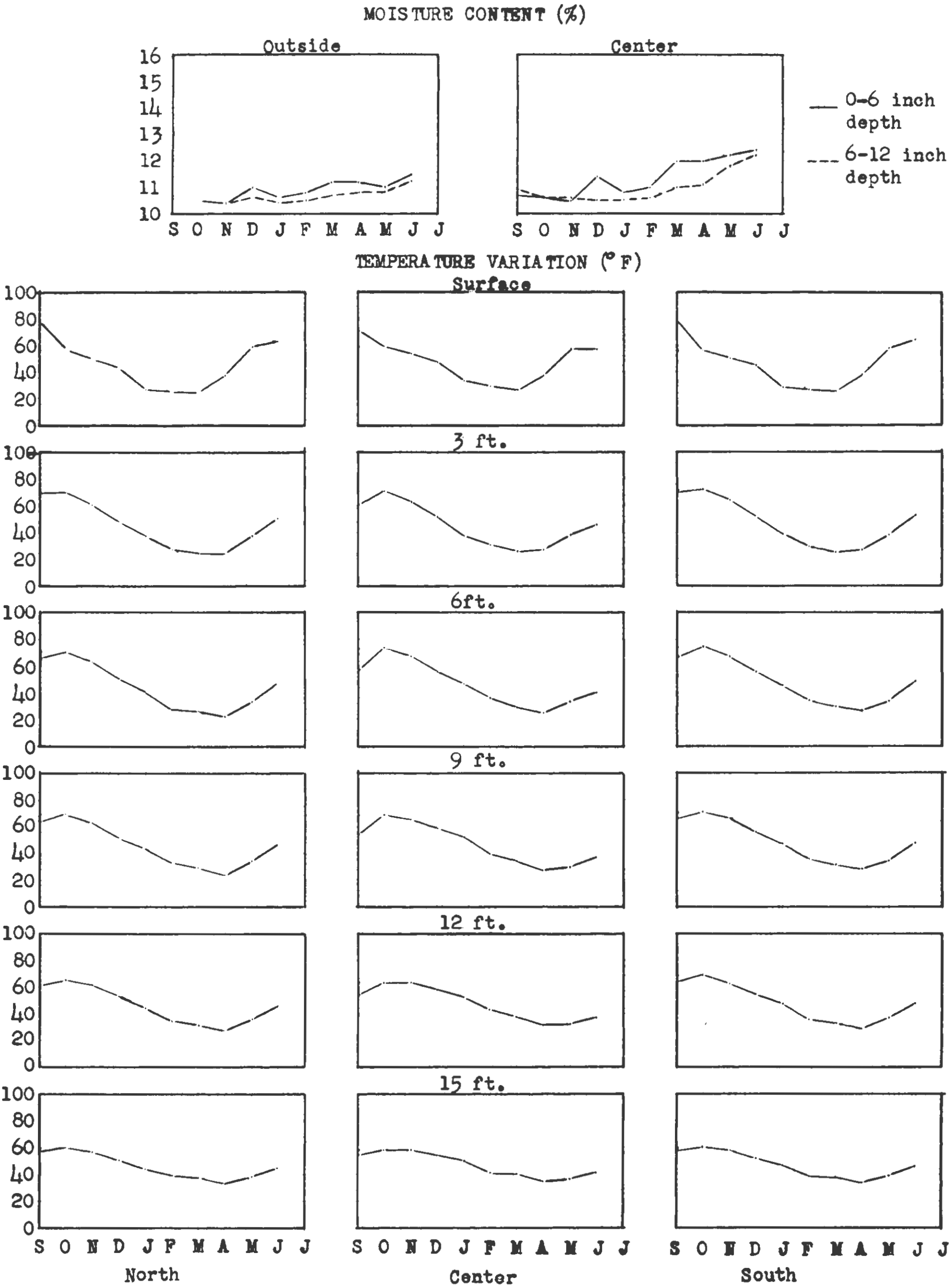


FIGURE 12

AVERAGE CONDITIONS FOR THREE BINS WITH 50 CFM. FANS CONTROLLED BY THERMOSTAT

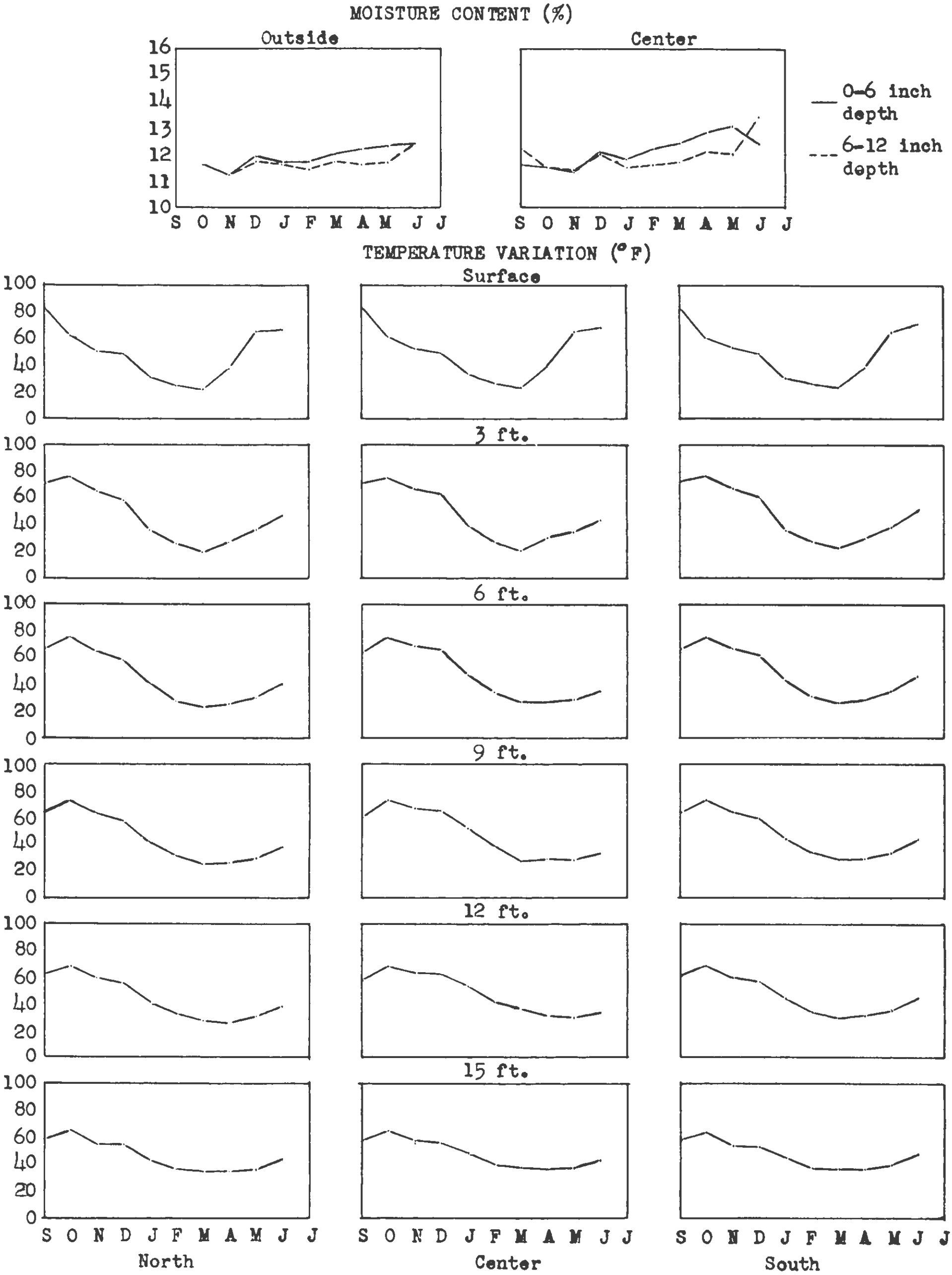


FIGURE 13

CONDITIONS FOR ONE BIN WITH A 50 CFM. FAN CONTROLLED BY HUMIDISTAT

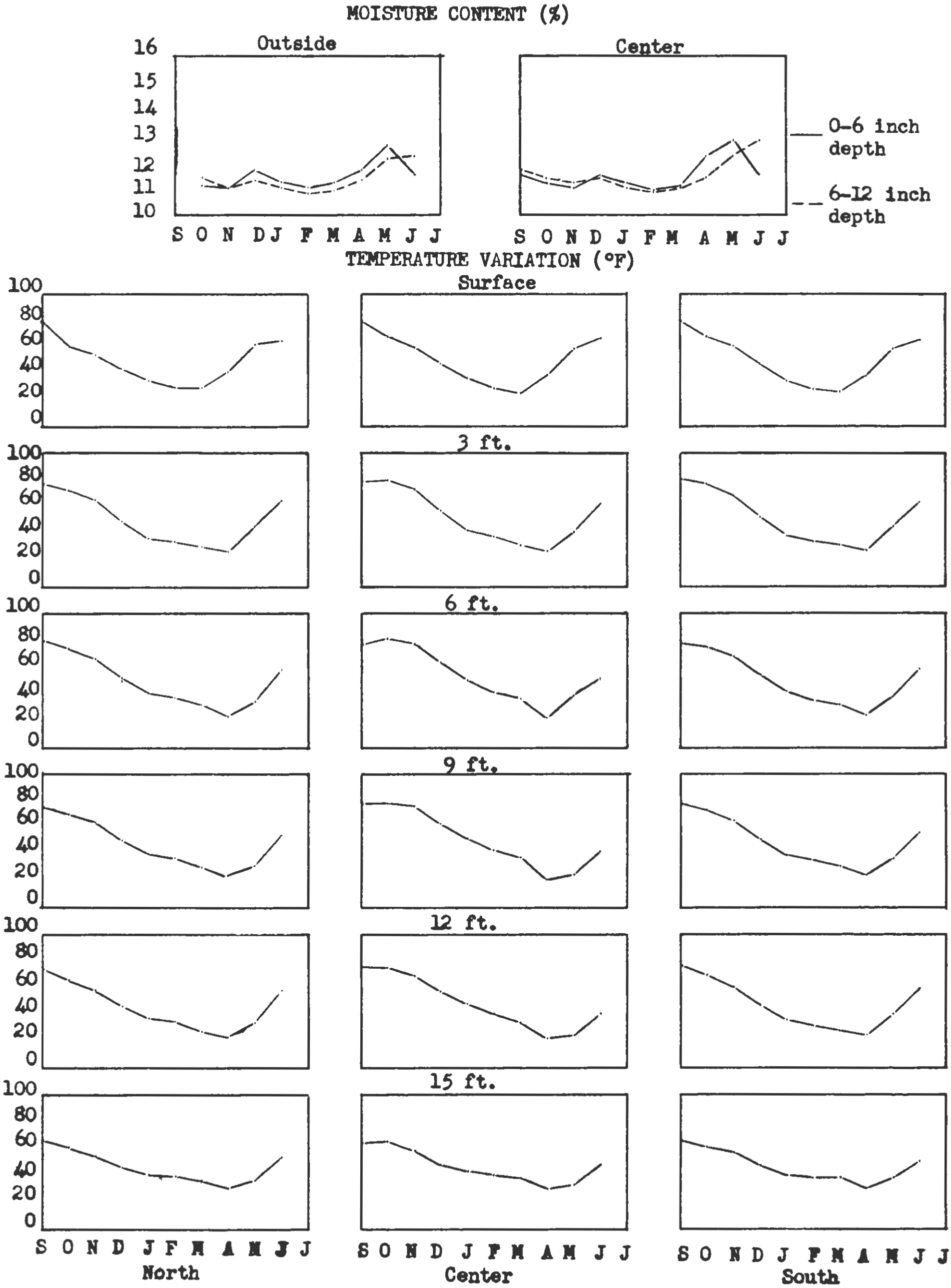


FIGURE 14

AVERAGE CONDITIONS FOR THREE BINS WITH 100 CFM. FANS CONTROLLED BY THERMOSTAT

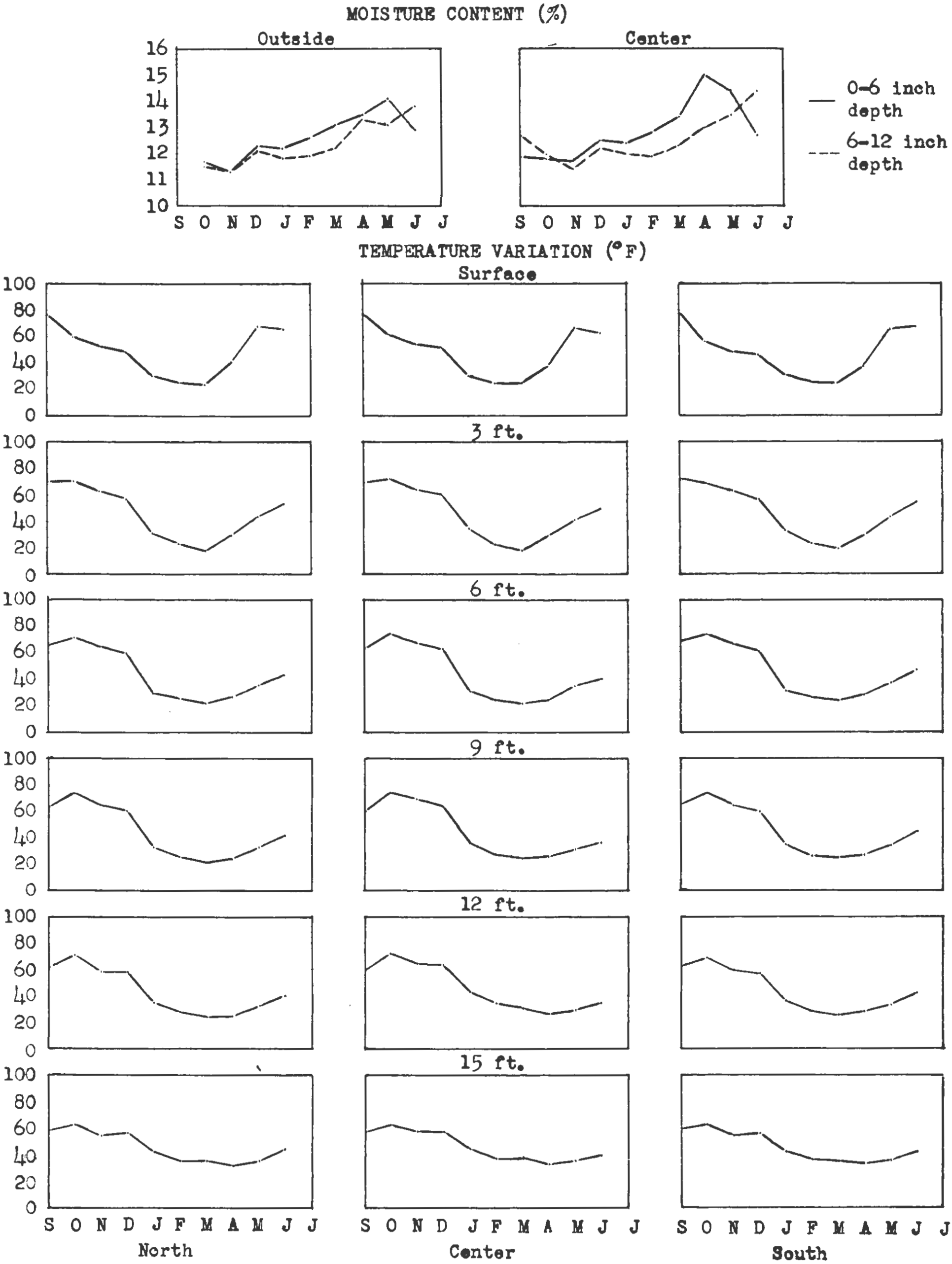


FIGURE 15

CONDITIONS FOR ONE BIN WITH A 100 CFM FAN CONTROLLED BY HUMIDISTAT

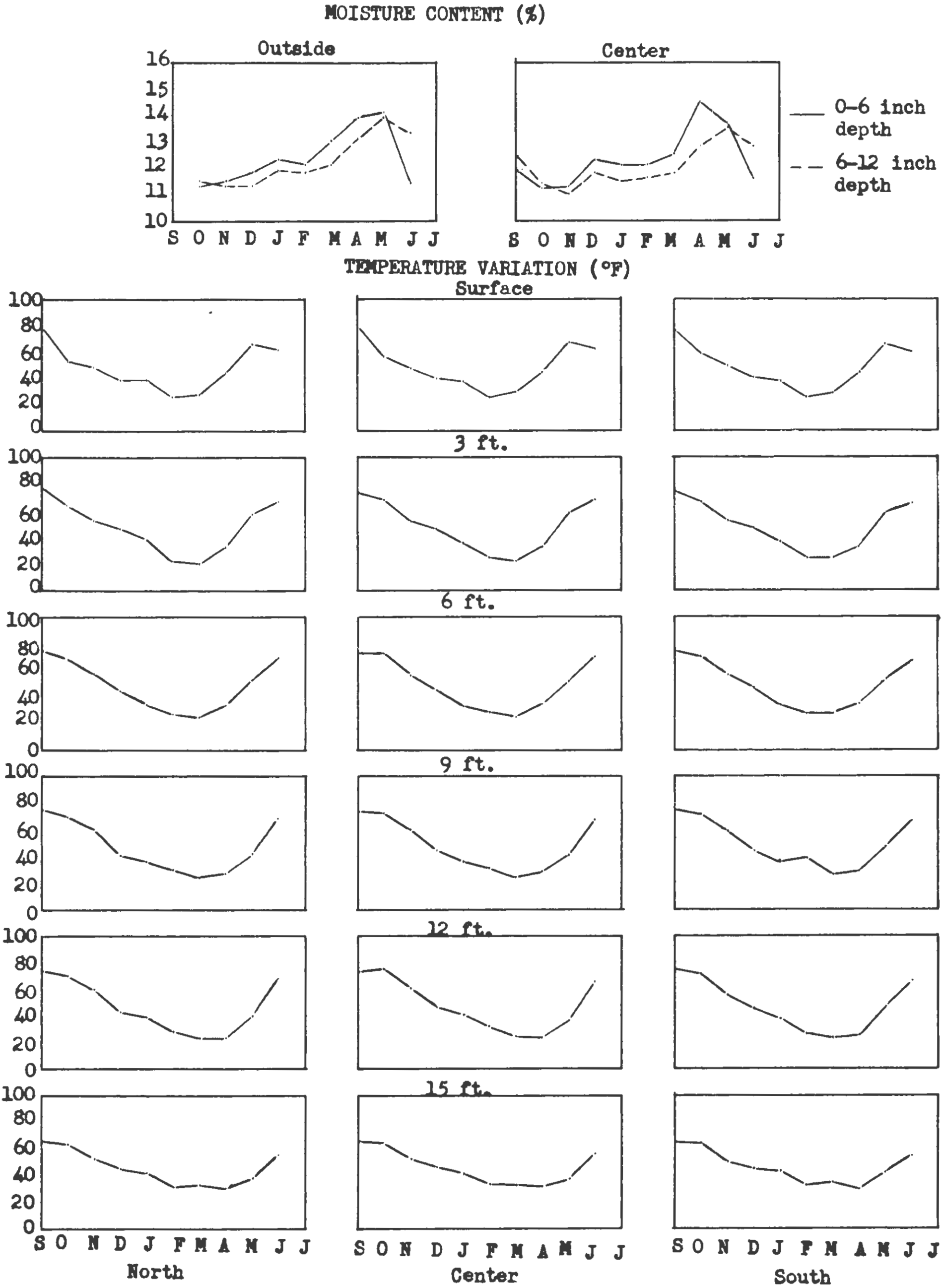


FIGURE 16

AVERAGE CONDITIONS FOR THREE BINS WITH 200 CFM. FANS CONTROLLED BY THERMOSTAT

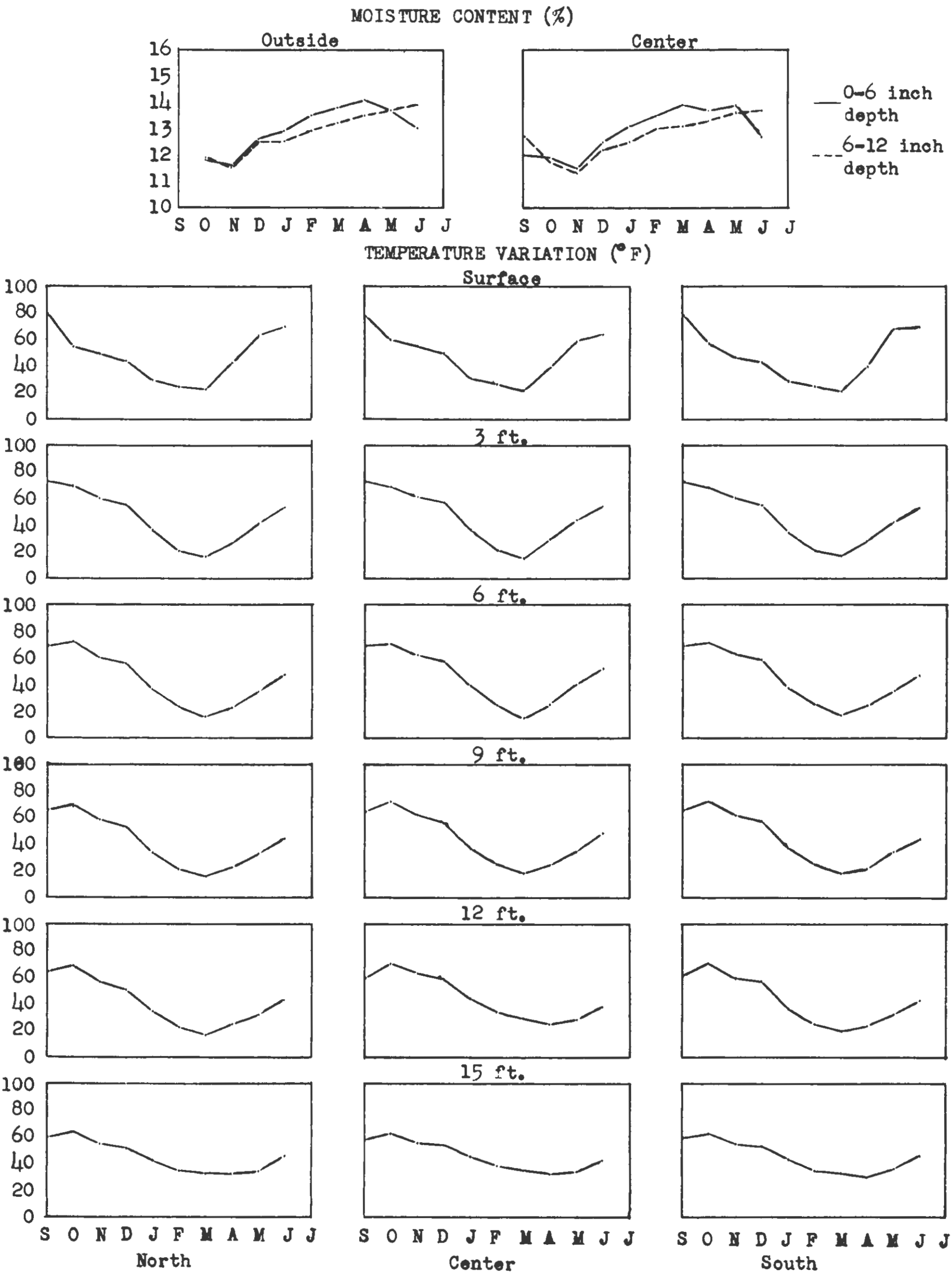


FIGURE 17

CONDITIONS FOR ONE BIN WITH A 200 CFM FAN CONTROLLED BY HUMIDISTAT

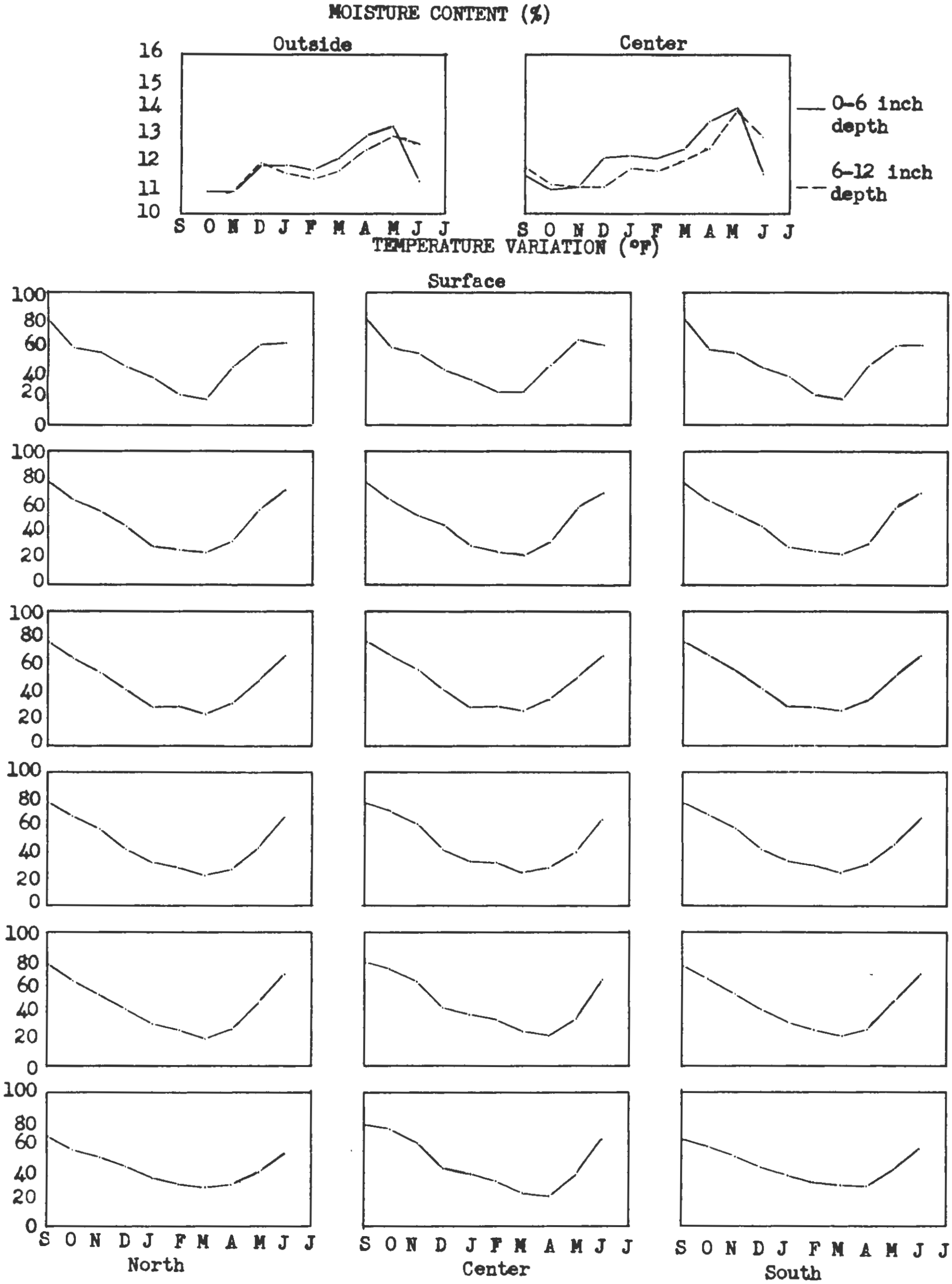
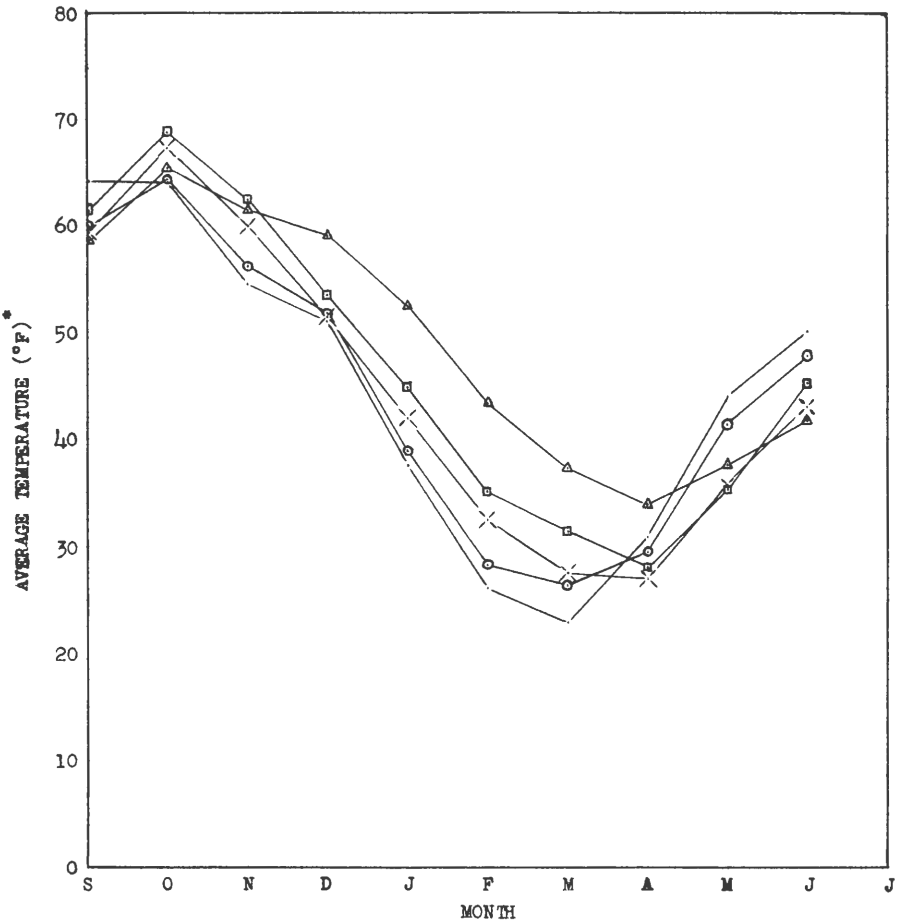


FIGURE 18

TEMPERATURE SUMMARY FOR EACH TYPE OF BIN VENTILATION

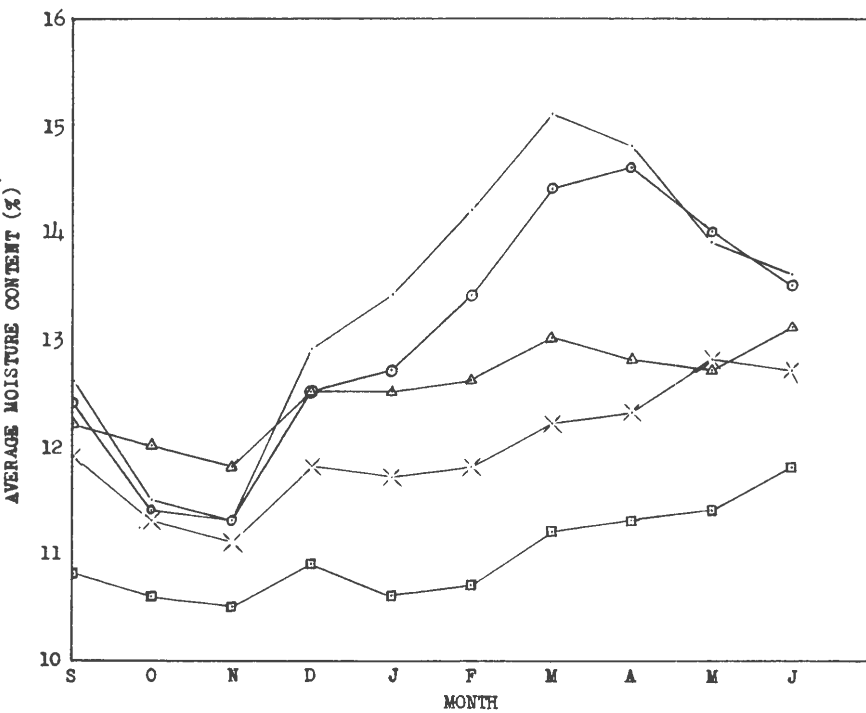


Avg. for 8 check bins
Avg. for 8 cupola bins (5 disconnected Mar. 4)
Avg. for 6 bins with 50 cfm. fans (5 turned off Mar. 4)
Avg. for 6 bins with 100 cfm. fans (4 turned off Mar. 4)
Avg. for 6 bins with 200 cfm. fans (4 turned off Mar. 4)

*Does not include surface temperatures

FIGURE 19

MOISTURE CONTENT SUMMARY FOR EACH TYPE OF BIN VENTILATION



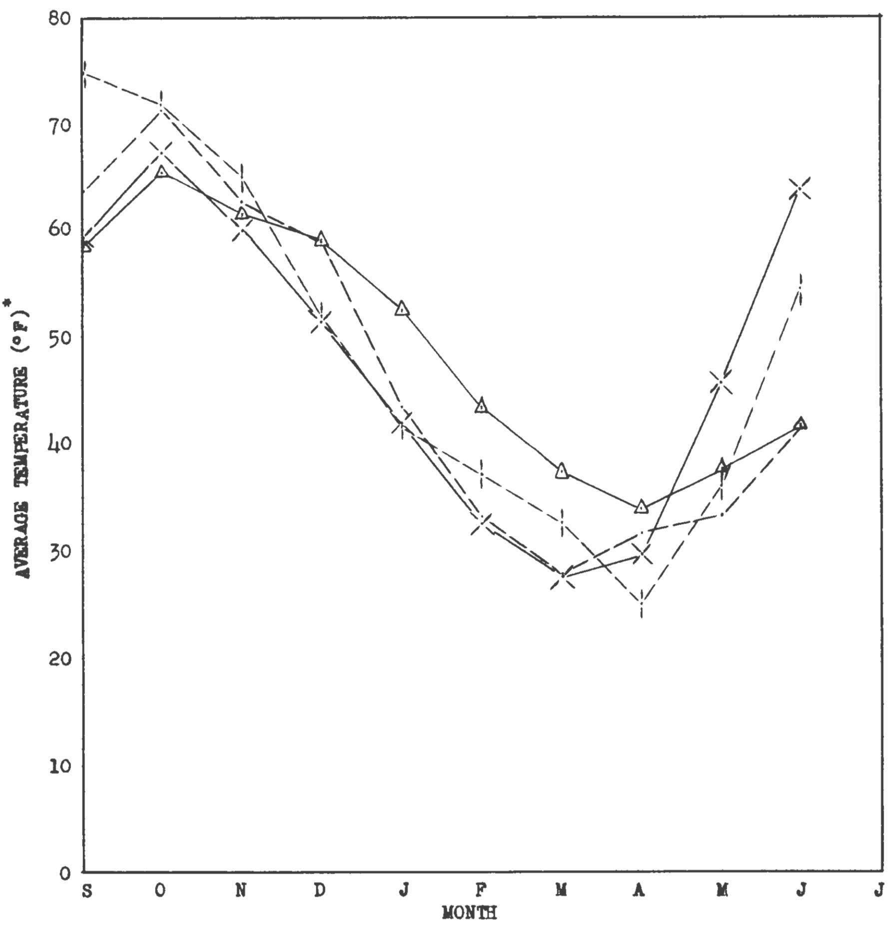
—△— Avg. for 8 check bins
—□— Avg. for 8 cupola bins (5 disconnected Mar. 4)
—×— Avg. for 6 bins with 50 cfm. fans (5 turned off Mar. 4)
—⊙— Avg. for 6 bins with 100 cfm. fans (4 turned off Mar. 4)
—•— Avg. for 6 bins with 200 cfm. fans (4 turned off Mar. 4)

*Average for four positions in top foot of grain

FIGURE 20

TEMPERATURE SUMMARY FOR BINS WITH 50 CFM FANS UNDER

DIFFERENT TYPES OF CONTROL OF OPERATION



—△— Avg. for eight check bins (no ventilation)

—✕— Fans operating continuously without controls
Includes avg. for six bins until Mar. 4 and one bin after Mar. 4

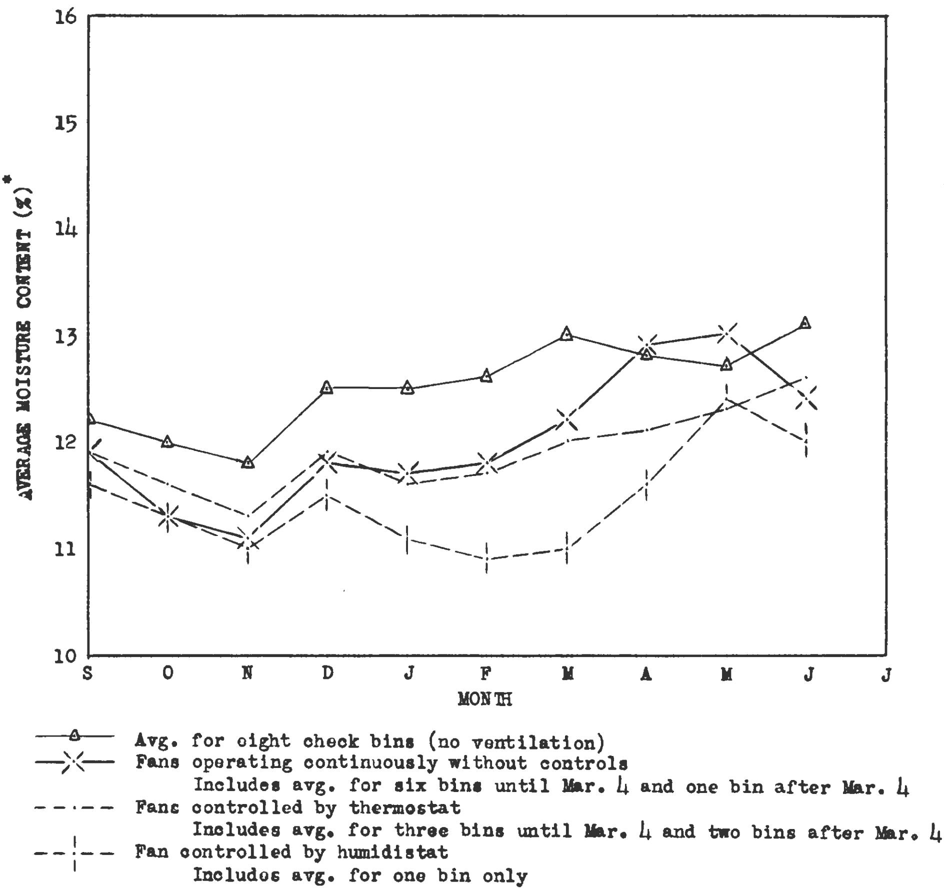
— · — Fans controlled by thermostat
Includes avg. for three bins until Mar. 4 and two bins after Mar. 4

— ¦ — Fan controlled by humidistat
Includes avg. for one bin only

*Does not include surface temperatures

FIGURE 21

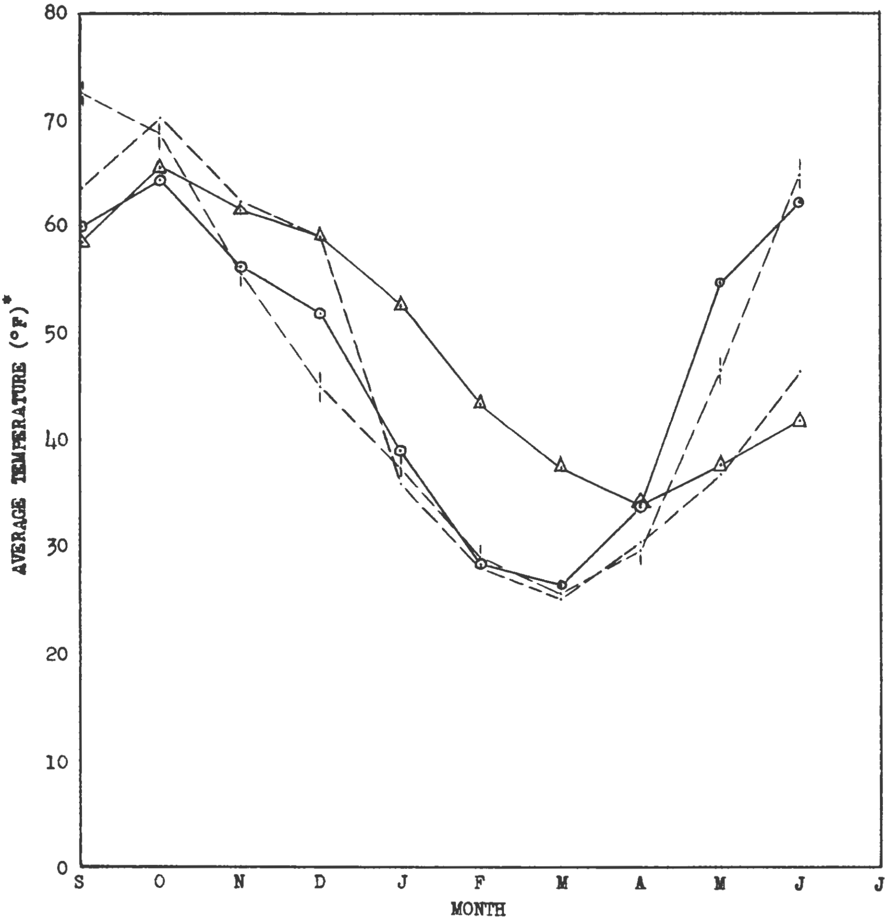
MOISTURE CONTENT SUMMARY FOR BINS WITH 50 CFM FANS UNDER DIFFERENT TYPES OF CONTROL OF OPERATION



*Average for four positions in top foot of grain

FIGURE 22

TEMPERATURE SUMMARY FOR BINS WITH 100 CFM FANS UNDER DIFFERENT TYPES OF CONTROL OF OPERATION



—△— Avg. for eight check bins (no ventilation)

—⊙— Fans operating continuously without controls
Includes avg. for six bins until Mar. 4 and two bins after Mar. 4

— — · — — Fans controlled by thermostat
Includes avg. for three bins until Mar. 4 and two bins after Mar. 4

— — ¦ — — Fan controlled by humidistat
Includes avg. for one bin only

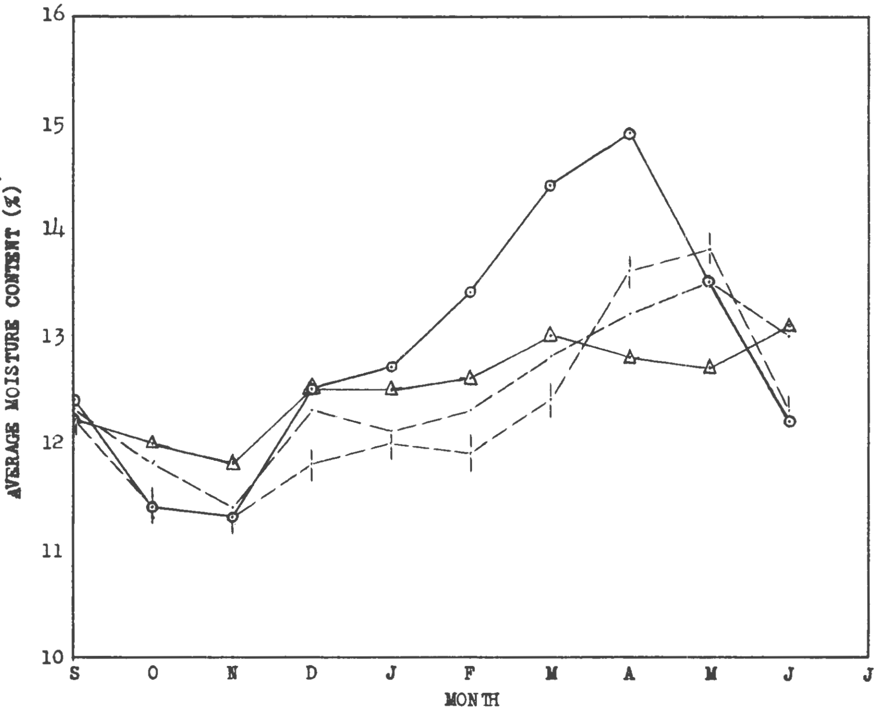
*Does not include surface temperature

FIGURE 23

MOISTURE CONTENT SUMMARY FOR BINS WITH 100 CFM FANS

UNDER DIFFERENT TYPES OF CONTROL OF

OPERATION



—△— Avg. for eight check bins (no ventilation)

—○— Fans operating continuously without controls
Includes avg. for six bins until Mar. 4 and two bins after Mar. 4

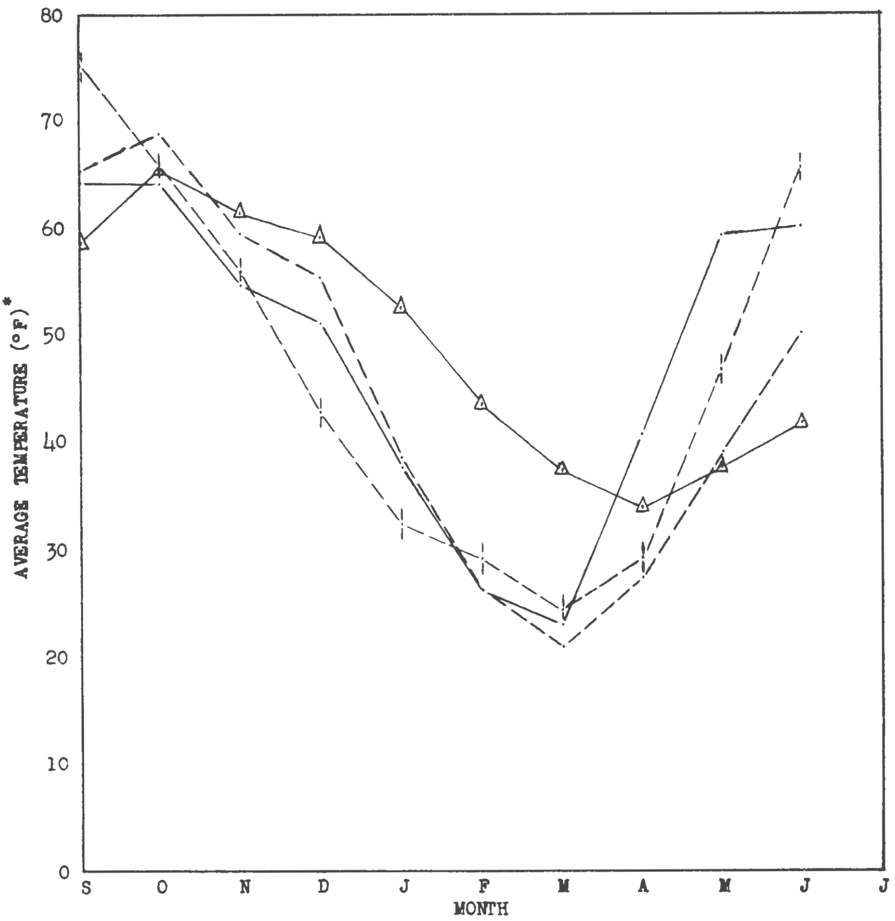
—·— Fans controlled by thermostat
Includes avg. for three bins until Mar. 4 and two bins after Mar. 4

--¦-- Fan controlled by humidistat
Includes avg. for one bin only

*Average for four positions in top foot of grain

FIGURE 24

TEMPERATURE SUMMARY FOR BINS WITH 200 CFM FANS UNDER DIFFERENT TYPES OF CONTROL OF OPERATION



—△— Avg. for eight check bins (no ventilation)

—·— Fans operating continuously without controls
Includes avg. for six bins until Mar. 4 and two bins after Mar. 4

--·-- Fans controlled by thermostat
Includes avg. for three bins until Mar. 4 and two bins after Mar. 4

--|-- Fan controlled by humidistat
Includes avg. for one bin only

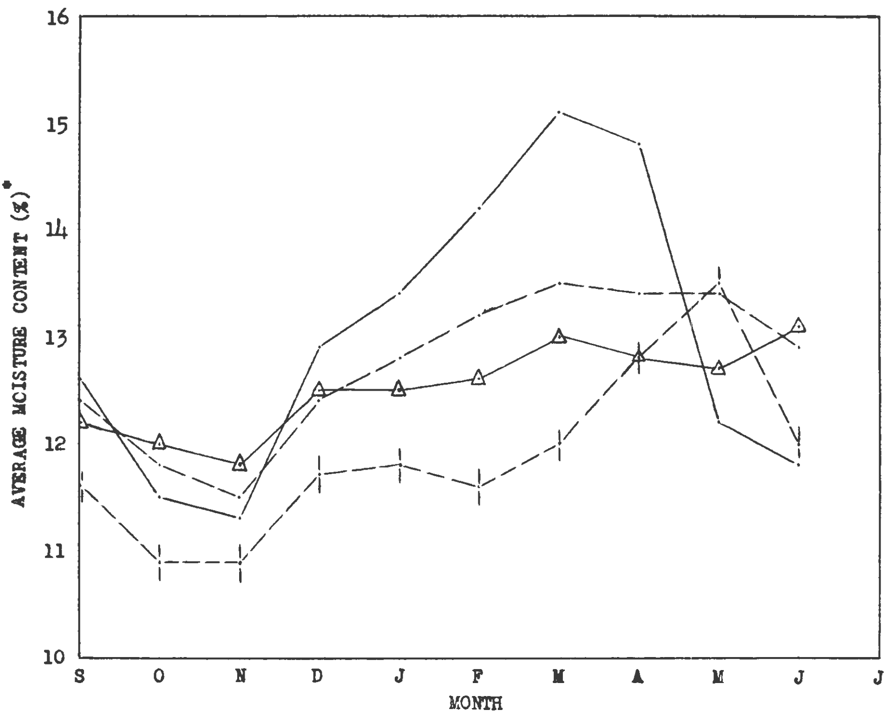
*Does not include surface temperature

FIGURE 25

MOISTURE CONTENT SUMMARY FOR BINS WITH 200 CFM FANS

UNDER DIFFERENT TYPES OF CONTROL OF

OPERATION



—△— Avg. for eight check bins (no ventilation)

—·— Fans operating continuously without controls
Includes avg. for six bins until Mar. 4 and two bins after Mar. 4

– –·– – Fans controlled by thermostat
Includes avg. for three bins until Mar. 4 and two bins after Mar. 4

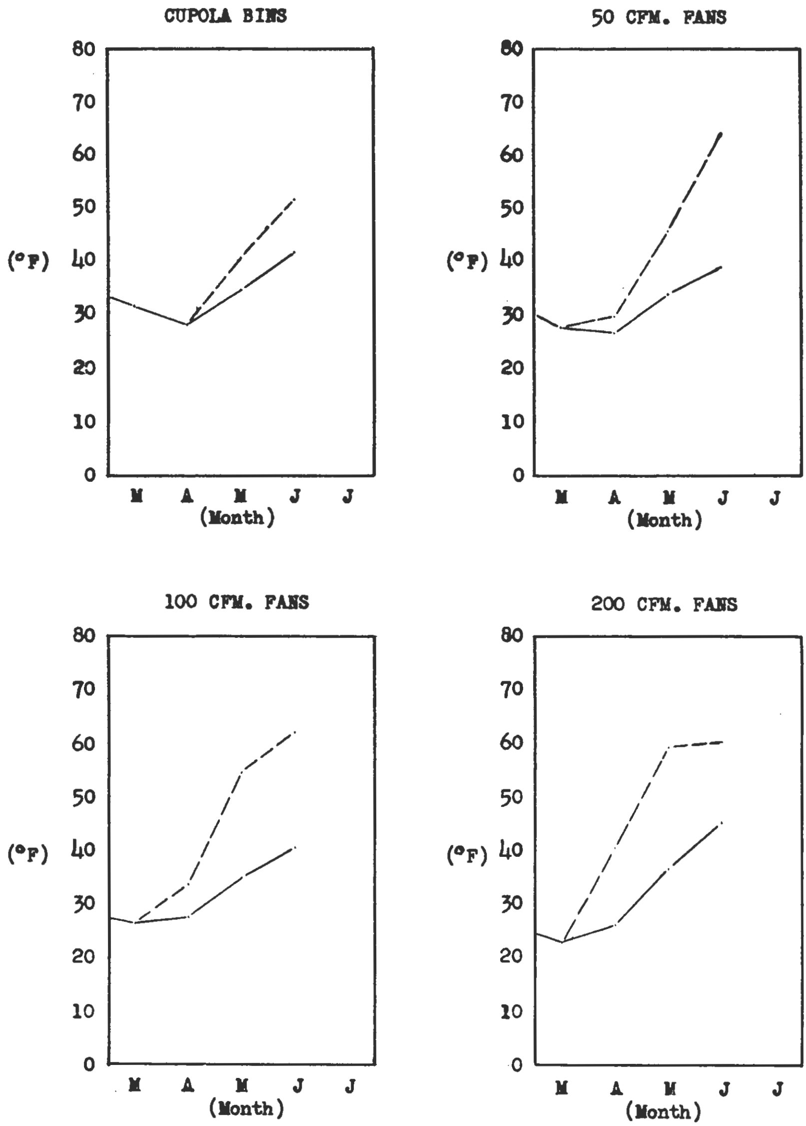
– –¦– – Fan controlled by humidistat
Includes avg. for one bin only

*Average for four positions in top foot of grain

FIGURE 26

AVERAGE TEMPERATURE VARIATION DUE TO FAN OPERATION

DURING SPRING MONTHS[a]



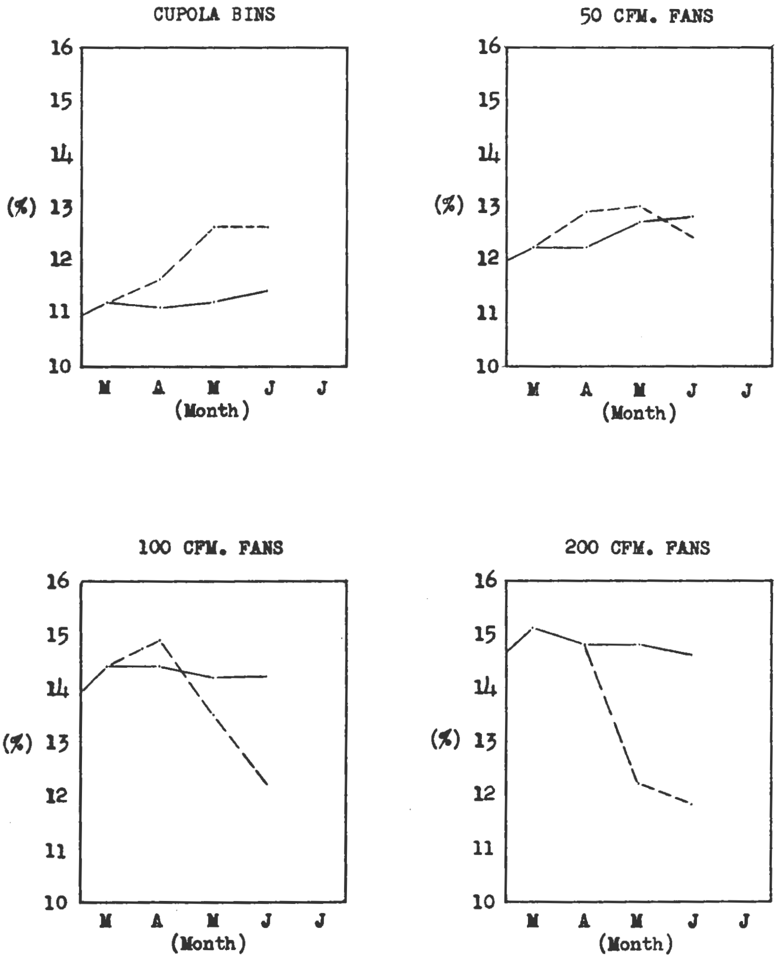
———— Represents no ventilation

– – – – – Represents ventilation system operating

[a]Does not include surface temperatures

FIGURE 27

AVERAGE MOISTURE VARIATION DUE TO FAN OPERATION DURING SPRING MONTHS[a]



——— Represents no ventilation
– – – – Represents ventilation system operating

[a]Average for four positions in top foot of grain

Conclusions

1. Weather conditions in central South Dakota are naturally favorable for long-time storage of dry grain, as shown by the check bin records.
2. Because of the favorable natural drying conditions present at the test site, the 3-year change in grade was not drastic in any of the 46 test bins involved. However, there were definite variations in the amount of moisture migration under different treatments which might have made considerable difference in results between treatments, had the weather been less favorable or the storage period longer.
3. Moisture migration is a definite occurrence during winter and spring in bins with no aeration equipment.
4. The level of aeration most favorable for reducing moisture migration was 50 c.f.m. for a 3,000 bushel bin or that which is provided with a suitable wind ventilator.
5. The higher levels of aeration (100 c.f.m. and 200 c.f.m.), with management as described, increased the moisture migration.
6. Aeration of grain from September to January 1 or February 1, accomplishes the desired cooling, but fans should then be turned off during the warming up period of humid weather in the spring. It is best to disconnect wind ventilators at the same time.
7. Thermostatic control showed little advantage over continuous fan operation except that more rapid cooling could be done.
8. Humidistat control (with fans turned on at lower humidity levels) gave more favorable results than continuous running of fans.
9. Operation of the fans in early spring was detrimental as compared to no operation. The operation of fans in May and June will help remove moisture from a top layer of grain that has a high moisture build up. This may be moisture dispersal rather than removal, however.

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