EFFECTS OF TEMPERATURE ON INSECT POPULATIONS IN AERATED AND NONAERATED STORED SHELLED CORN

by

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TABLE OF CONTENTS

INTRODUCTION AND LITERATURE REVIEW

Research has been conducted by Marketing Research, Agricultural Research Service, United States Department of Agriculture, at an experimental bin site to determine better ways to maintain the quality of corn stored at Commodity Credit Corporation bin sites. The research was a cooperative effort in the fields of entomology, agricultural engineering and plant pathology. One of the most important phases of the research was with the aeration of shelled corn.

Holman (1960) defined aeration as the moving of air through grain at low airflow rates for purposes other than drying to maintain or improve its value. Holman (1960) also presented the many uses of aeration: (A) cooling to prevent or minimize mold growth and insect activity; (B) equalizing stored grain temperatures to prevent moisture movement from warm to cooler grain; (C) removing odors from stored grain; (D) applying fumigants to stored grain; (E) holding moist grain in storage for brief periods.

There is a large number of papers reporting on research conducted on the effect of lowered temperatures on the biology of stored grain insects. Three reviews have been published in recent years, two in England and one in India. Solomon and Adamson (1955) reviewed previous low temperature studies and reported on the ability of stored product insects to survive the winter in unheated buildings in England. The temperatures to which the insects were exposed were quite variable as they approached outside temperatures and covered a period from November 1 to May 1. This study presents observations on the relative resistance of stored product insects to cold temperatures. Burges and Burrell (1964) also reviewed some of the effects of lowered temperatures on nine stored product insects and reported that temperatures in grain needed to be lowered to 17 to 22°C to limit the developmental time from oviposition to adult to a mean of 100 days. Girish (1965) gave an extensive review on the effect of temperature on the development of stored-grain insects. He reported that the minimum temperature at which stored-grain insects are able to develop lies between 15.56 to 18.3°C, depending on the species involved.

Even though aeration has been used to minimize insect activity by Holman (1960) and Chapman (no date) under field storage conditions, and in numerous laboratory studies on the biology of stored product insects at lowered temperatures, only one known detailed field study involving actual insect populations has been conducted. Rouse et al. (1958) found that aeration was very effective during the fall and winter in reducing the numbers of live insects found in Arkansas farm-stored rice. Observations have been made on the behavior of insects in grain that has been aerated under field conditions. Hukill (1953), Foster and Stahl (1959), and Mathlien (1961), all reported that insects in the grain tended to move to warm areas of grain under aeration that had not yet cooled.

It is of interest to note that other methods are used to lower temperature of stored grain to retard insect activity. Cotton et al. (1960) and Schmidt (1955) showed that galvanized bins painted white maintained a lower average and lower maximum wheat temperature throughout the season. Watters (1959) suggested the turning of infested grain on cold days during the winter.

Further reference will be made to most of the work cited above and other work in the "Discussion Section" of this thesis.

Considering that aeration is already used and recommended to inhibit insect development, and recognizing that lowering temperatures of the grain to below 15.56°C. stops insect development, and realizing that previous work is limited to only one detailed field observation, it was believed that more field studies were needed. If more were known about the effectiveness of aeration to minimize insect activity and about its influence on their behavior, the feasibility of adopting aeration for quality maintenance in 3,250-bushel bins could be more accurately assessed. With these points in mind, the present studies were undertaken to determine the effectiveness of aeration of corn stored in 3,250-bushel circular bins as a method to minimize insect activity in commercial corn growing areas.

MATERIALS AND METHODS

Experimental Bin Site

Location and Operation. This study was conducted at the Watseka, Illinois, Experimental Bin Site (Plate I, Fig. 1 and Fig. 2), operated by the Marketing Research Division, Agricultural Research Service, U. S. D. A., in cooperation with the Commodity Credit Corporation. The bin site was located almost in the center of the commercial corn growing and storage area.

Facilities. There were 210 3,250-bushel capacity round bins and two 40,000-bushel capacity flat storage structures on the site. Also there was a grain processing laboratory, an equipment storage shed with a work shop, and numberous types of grain handling equipment.

EXPLANATION OF PLATE I

Fig. 1. Circular metal bins, 3,250-bushel capacity. Watseka, Illinois, Experimental Bin Site.

Fig. 2. Grain processing laboratory, trucks and bins, at Watseka, Illinois, Experimental Bin Site.

PLATE I

Fig. 1

Fig. 2

Corn

Source. The shelled yellow corn (varieties unknown) used in this study was grown on Iroquois County, Illinois, farms during 1956. In the fall and early winter of 1956 it was mechanically picked and stored on the farm as ear corn in wooden and wire cribs. It remained in storage until the fall (September-October) of 1957 at which time it was mechanically shelled on the farm and trucked to a commercial elevator.

Blending. The corn was blended at the commercial elevator located 9 miles west of the bin site at Gilman, Illinois. It was blended to obtain a moisture content of 13.0 ($\pm$ 0.2) percent and to a damage content of less than 3.0 percent so that it would be as uniform as possible for research purposes. After the corn was blended, it was trucked to the bin site and augered into the bins.

Storage Equipment

Storage Bins. The corn was stored in 10 circular, galvanized steel, standard USDA bins (Plate I, Fig. 1 and Fig. 2). Each bin was 16 feet tall and 18 feet in diameter with a rated capacity to store 3,250 bushels of shelled corn by volume. Each bin was equipped with a hinged door mounted on the roof for access to the overspace of the grain for inspection. Next to the ground was a removable section with sliding door used to enter an empty bin and for unloading the corn from the bin. A circular metal roof cap mounted on a hinge was located at the top of the bin to allow natural air convection currents to pass through the bin. It was opened when the corn was loaded into the bins. The bins were constructed of sheets of corrugated galvanized steel, 32 inches wide and 9 feet long, bolted together and sealed with a caulking material at the vertical seams. The floor was made of fine sand about one foot deep with a round piece of sheet metal laid on it. Before each bin was filled, the floor was thoroughly swept with a broom and care was taken to remove all corn adhering to the sidewalls.

Filling Bins. The corn was unloaded from the trucks into the auger hopper. A screw-type auger, 45 feet long and 9 inches in diameter, delivered the corn into the bins through the roof cap ventilator-filler hole. Each truck was loaded with approximately 300 bushels of corn. The bins were filled within about three feet of the top of the bin wall; thus, each bin contained approximately 2,700 bushels of corn by volume. The corn was loaded into the bins over a period of about three weeks. The first bin was filled on September 18, 1957 and the last one on October 7, 1957. The bins were loaded as follows:

Date bin filled	Treatment	Bin designation
September 18	Nonaerated	1
September 21	Nonaerated	2
September 21	Nonaerated	3
September 21	Nonaerated	4
September 23	Nonaerated	5
September 27	Aerated	6
October 4	Aerated	7
October 5	Aerated	8
October 5	Aerated	9
October 7	Aerated	10

Aeration Duct. Five aeration systems were installed in the corn on October 15, 1957 after the corn was binned. This was done with the aid of a pneumatic-type grain conveyor to which a flexible hose was attached. Each aeration duct (Plate II, Fig. 2) was nine feet long and eight inches in diameter and was fabricated of 22-gauge galvanized steel. Six feet of the duct was perforated (Plate IV, Fig. 1) with rectangular perforations three-sixteenth inches wide and one-half inch in length. The assembled duct was placed vertically in the center top of the bin, directly under the ventilator cap so that six feet of perforated section and three feet of the solid supply section were in the corn.

Aeration Fan. A 100-cubic-foot-per-minute fan (1/30 c.f.m./bu.) was attached to the pipe which extended slightly out of the corn (Plate II, Fig. 1). It was an 8-inch diameter propeller fan, direct-connected to an electric motor. The fan exhausted air from the duct directly into the bin overspace. The motor was hooked to a 110-volt power source which was supplied from the outside of the bin. The fans were installed and put in operation on October 25, 1957. They were operated continuously through the observation period.

Airflow Pattern. The airflow was determined by the agricultural engineers of the Transportation and Facilities Branch, Marketing Research, U.S.D.A. The airflow pattern was diagrammatically illustrated by Winter (1958) (Plate III).

Temperature Determination

Equipment. Corn temperature measurements were obtained each month in each bin by means of a system of thermocouple temperature devices.

EXPLANATION OF PLATE II

Fig. 1. Vertical aeration system with 100-cubic-feet-per-minute fan in operation.

Fig. 2. Aeration duct assembly before installation.

PLATE II

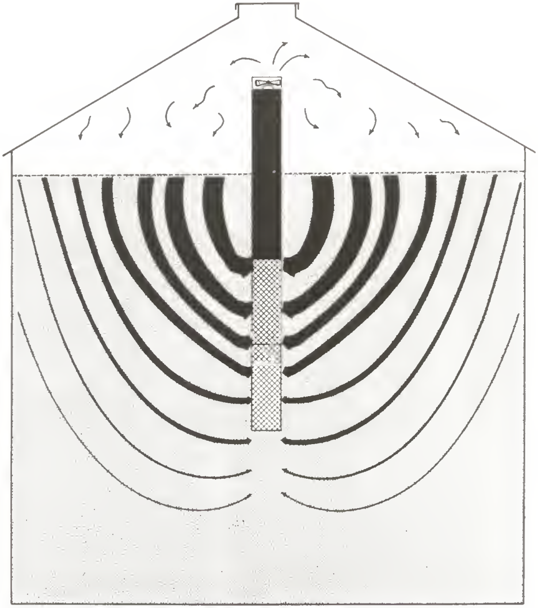
Fig. 1

Fig. 2

EXPLANATION OF PLATE III

Diagrammatic pattern of air flow through aerated corn stored in a 3,250-bushel steel bin. Vertically placed aeration system with 100-cubic-feet-per-minute fan. Taken from "Aeration of shelled corn in CCC storage," U. S. D. A., A. M. S., Transportation and Facilities Branch, T. & F.-5, by D. W. Winter and H. F. Mayes (1958).

PLATE III



PATTERN OF AIR FLOW THROUGH GRAIN IN STANDARD BIN

VERTICAL DUCT AND FAN

A portable electronic potentiometer (Plate IV, Fig. 1) was used to indicate the temperature at each thermocouple location and at each of the five cable junctions. The potentiometer and thermocouples were manufactured by the Minneapolis Honeywell Company.

Location. The thermocouple points were at the end of the cable and at three-foot intervals. Three cables were placed in each aerated and nonaerated bin vertically from the bin floor to the grain surface; three feet from the bin wall, three feet from the center, and in the center (Plate V, Fig. 1).

The first temperature determinations were obtained on November 21, 1957.

Sampling

Equipment. After the bins were filled samples for insect population and moisture determinations were drawn at approximately monthly intervals using a brass five-foot long, 1 3/8-inch diameter, 11-celled grain trier. Each of the 11 cells was three inches long, and the 11 cells occupied 50 inches of the total probe length. The filled probe held approximately 400 grams of corn. The trier was equipped with four two-foot pipe extensions and one handle. The samples were transferred from the trier to a galvanized metal trough five feet long. The trough was separated so that the corn was divided into four samples, each representing about one foot of corn. The individual samples weighed approximately 100 grams. Each sample was placed in a 4-mil, polyethylene-lined Kraft paper envelope and taken to the laboratory for examination.

EXPLANATION OF PLATE IV

Fig. 1. Portion of aeration duct assembly showing perforations.

Fig. 2. Portable electronic potentiometer used in measuring temperature of stored grain.

PLATE IV

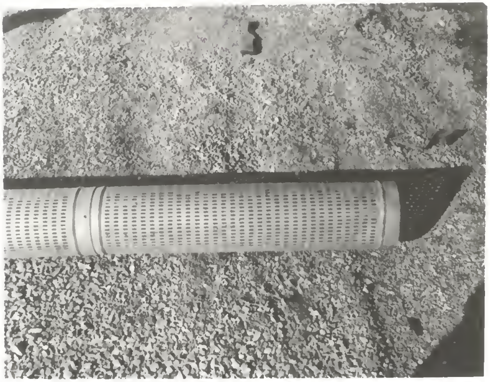


Fig. 1

Fig. 2

EXPLANATION OF PLATE V

Fig. 1. Diagrammatic presentation of a 3,250-bushel bin showing points at which temperature determination was made.

Fig. 2. Diagrammatic presentation of a 3,250-bushel bin showing areas sampled for insect population.

PLATE V

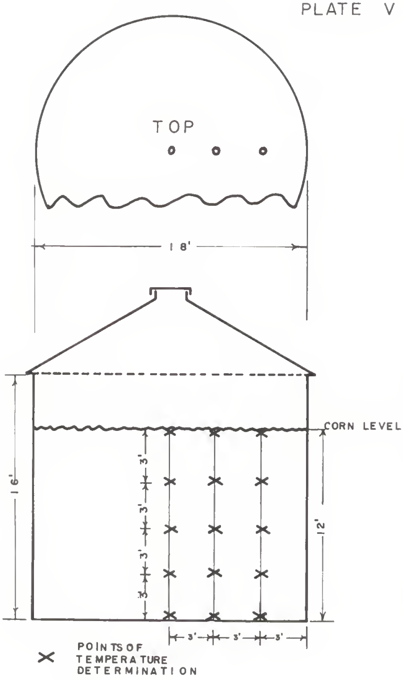


Fig. 1

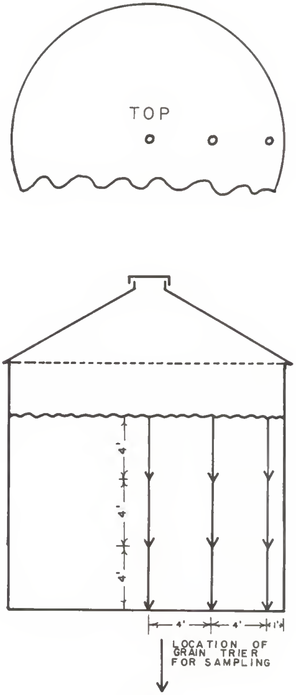


Fig. 2

Sample Location. The samples used to determine insect populations and percentage moisture were taken vertically in the center of the bin from the top, middle, and bottom four feet of corn. A similar sampling procedure was used four feet from the center toward the bin door and one foot from the wall toward the bin door (Plate V, Fig. 2). As mentioned previously, the samples were divided into one-foot intervals; thus, a total of 36 samples were taken for insect population and moisture determinations from each bin of corn.

The samples for commercial grade determinations were taken from the same locations vertically in the center of the bin from the top, middle, and bottom four feet of corn. These three samples were then composited. A similar sampling procedure was used four feet from the center toward the bin door and one foot from the wall toward the bin door.

Sampling Frequency. The samples for insect population determinations and moisture determinations were drawn at monthly intervals from November 21, 1957, to December 1959 in the aerated corn and from November 21, 1957, to December 1958 in the nonaerated corn. Four of the five nonaerated bins of corn were dropped from the study and fumigated after the December 1957 samplings as insect populations were high. The fifth bin was dropped from the study for the same reason in December 1958.

The samples for commercial grade determinations were taken from the aerated and nonaerated corn November 21, 1957, and again in June 1959.

Sample Processing

Insect Observation. The samples were taken to the grain inspection laboratory within two hours after sampling. They were left in the laboratory overnight to equilibrate with the room temperature of 77°F. so that accurate moisture determinations could be made with a constant temperature for all samples. The corn was poured from the sample bags into a round commercial dockage sieve with 12/64-inch diameter round perforations. The screenings passing through the sieve fell into a round pan and there were carefully examined for the number, stage, and species of living and dead stored-grain insects. The numbers, stage, and species were noted and recorded. The insects and screenings were then returned to the samples and the moisture content determined.

Moisture Determination. The moisture content of the corn was determined by using a Steinlite Electronic Tester, Model No. 400-G. It is advertised as correct to 0.25 percent (±). Temperature and test weight correction factors were applied to each moisture determination. The tester was sent to the factory for calibration and inspection at yearly intervals.

Commercial Grade. After the moisture determinations were made, the 12 samples taken from each of the three vertical positions were composited. The three samples from each bin were placed in 4-mil polyethylene bags and sent by parcel post to the Federal Grain Supervisor's Office at Indianapolis, Indiana for grade determinations.

RESULTS

Corn Temperatures

Aerated Corn and Nonaerated Corn. The data presented in Table 1 illustrate the changes in temperature in the aerated corn. Table 2 shows the temperature fluctuations in the nonaerated corn. A comparison of the

Table 1. Temperature of shelled corn aerated by 100 c.f.m. fans. Corn stored in 3,250-bushel circular metal bins, Watseka, Illinois. Average of 5 bins.

Location in bin	Mean temperature by months ($^{o}F.$)													
	1957		1958											
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							AERATED							
Center														
0 ft.	39.2	24.2	25.0	25.8	31.0	43.0	63.0	64.6	67.8	79.8	79.0	65.4	47.8	33.8
3 ft.	44.0	33.2	25.2	21.4	29.8	41.0	60.0	64.4	67.0	80.8	78.6	65.8	54.4	28.0
6 ft.	44.4	32.6	29.2	26.8	34.8	37.8	57.6	61.4	67.2	78.2	76.8	60.4	55.2	39.8
9 ft.	49.4	41.2	37.4	31.4	25.4	33.4	49.8	54.8	61.0	70.0	72.8	65.2	54.0	49.2
Floor	51.2	45.2	41.0	36.0	33.8	35.0	44.2	47.0	51.6	61.8	65.2	61.6	57.8	50.2
3 ft. from center														
0 ft.	37.8	21.0	24.8	27.0	31.0	44.0	63.8	64.6	69.0	79.4	78.6	66.0	46.2	34.4
3 ft.	44.6	33.0	27.8	22.0	29.6	40.4	59.0	63.8	67.2	70.8	78.0	66.0	54.6	26.4
6 ft.	44.2	31.6	28.2	26.6	34.8	37.4	57.6	61.0	66.6	77.8	76.2	59.6	53.0	38.4
9 ft.	44.2	36.2	35.4	28.4	19.6	34.6	52.6	61.6	64.6	74.0	63.0	64.8	57.0	45.5
Floor	49.0	42.2	39.2	34.2	31.0	34.6	45.8	49.0	56.0	64.2	66.6	61.8	57.0	47.2
3 ft. from outside														
0 ft.	37.6	19.4	26.0	27.0	31.6	45.2	64.0	65.2	69.8	79.4	78.0	66.0	45.4	35.4
3 ft.	44.2	33.0	26.8	19.4	30.4	40.6	59.2	64.4	67.8	81.4	76.6	64.6	52.8	27.6
6 ft.	45.6	31.6	24.8	24.0	35.4	38.4	59.8	61.6	66.6	78.4	73.4	58.8	50.6	33.2
9 ft.	41.6	32.2	29.8	25.8	25.8	37.2	55.2	63.4	65.6	75.4	73.2	59.6	51.2	38.4
Floor	45.2	37.0	34.0	30.6	28.4	35.8	49.6	54.4	59.4	67.8	67.6	58.8	51.8	39.2
Average grain temperature	44.1	32.9	30.3	27.1	30.2	38.6	56.1	60.1	64.5	75.3	74.2	63.0	52.6	37.8

Table 2. Temperature of nonaerated shelled corn. Corn stored in 3,250-bushel circular metal bins, Watseka, Illinois. Average of 5 bins.

Location in bin	Mean temperature by months (°F.)													
	1957		1958											
	Nov.	Dec.	Jan.[1]	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							NONAERATED							
Center														
0 ft.	63.2	72.4	64.4	41.6	38.4	35.4	61.2	65.6	70.6	82.8	83.0	72.8	64.2	51.7
3 ft.	70.4	76.2	64.4	48.2	44.2	40.0	44.6	48.6	58.8	70.0	74.2	72.4	78.8	64.8
6 ft.	67.2	69.8	56.6	44.2	45.0	39.0	39.4	41.6	50.0	61.2	66.8	67.8	68.0	62.2
9 ft.	61.4	57.6	49.2	41.2	39.6	38.0	38.2	39.2	45.0	55.0	61.4	64.4	64.6	58.2
Floor	55.6	52.0	46.2	39.0	38.2	38.2	43.0	45.0	50.2	56.6	61.0	61.8	60.4	53.8
3 ft. from center														
0 ft.	60.2	62.4	53.2	36.2	36.2	41.0	63.4	66.4	70.6	84.2	83.2	71.4	61.0	54.2
3 ft.	67.0	66.4	56.2	43.8	40.2	37.6	45.8	49.4	59.6	70.8	74.4	72.0	69.6	63.6
6 ft.	63.0	60.8	51.0	41.4	38.4	36.4	40.2	41.8	51.4	63.0	68.0	68.0	66.8	61.0
9 ft.	59.2	54.2	46.6	39.0	36.8	35.6	38.6	39.4	46.2	56.8	62.4	64.2	63.4	57.2
Floor	54.0	50.2	44.4	37.6	36.2	39.0	43.2	44.0	49.6	56.8	61.0	61.4	59.4	52.6
3 ft. from outside														
0 ft.	51.4	48.0	39.6	32.2	33.4	38.4	59.8	64.4	68.8	82.4	81.4	70.2	62.0	51.8
3 ft.	57.8	52.0	44.2	36.0	33.0	35.2	48.6	54.2	61.8	72.0	74.4	69.2	65.2	56.2
6 ft.	56.4	49.6	42.2	34.8	32.0	34.4	44.4	48.4	56.6	67.0	70.0	67.0	63.0	53.8
9 ft.	54.2	47.4	40.8	33.6	31.0	34.0	42.2	45.0	52.0	62.0	66.2	64.2	60.8	50.6
Floor	51.0	45.4	39.4	33.8	32.8	36.4	44.4	47.0	52.6	60.2	63.6	60.8	56.6	46.0
Average grain temperature	59.5	57.6	49.2	38.4	37.0	37.2	46.5	49.3	56.3	66.7	70.1	67.2	64.3	55.8

1/ After December 1957 temperature of one bin.

temperatures in the aerated and nonaerated corn is also shown in Plate VI. The temperatures in the aerated corn were lower than those in the nonaerated corn during the period from November 1957 to and including March 1958. From April to September 1958, the nonaerated corn was warmer than the aerated corn.

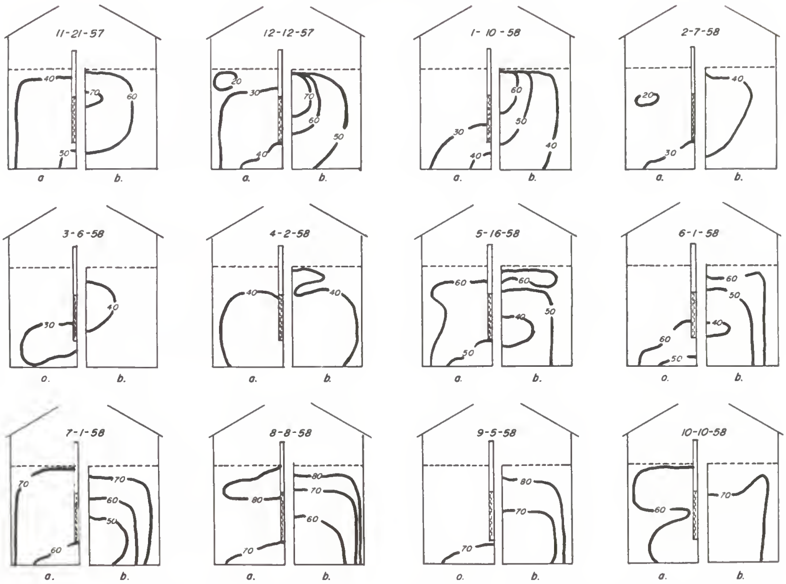
The temperatures for the aerated corn are not included for the 1959 observations as there were only slight differences when compared with those for 1958.

Insect Population Trends

Aerated Corn. The live insect population trends in shelled corn in the aerated and nonaerated corn are presented in Table 3. The mean number of insects recovered from the samples taken at monthly intervals indicates much lower insect populations in the aerated corn than in the nonaerated. There were no insects found in the aerated corn at the first sampling on November 1957 and at subsequent monthly intervals until June 1958. The first insects were recovered during July 1958; the population increased each month thereafter until November 1958, after which progressively fewer insects were recovered until February 1959. During March and April 1959 the number of insects remained fairly constant. From May to July 1959 more insects were recovered than in March and April. During August and September 1959 the insect populations reached the highest level. Fewer insects were recorded in November and December 1959.

The aerated corn was placed in the bins from September 27 to October 7 which was after the nonaerated corn had been binned. Thus,

PLATE VI



COMPARISON OF CORN TEMPERATURES (°F) DURING COOLING AND WARMING PERIODS

NONAERATED CHECK VERSUS 100 CFM FAN
13% INITIAL MOISTURE
1956 CROP YEAR CORN

a - CONTINOUS AERATION
b - NONAERATED

Table 3. Live insect population trends in aerated and nonaerated shelled corn. Corn stored in 3,250-bushel circular metal bins. Experimental Bin Site, Watseka, Illinois.

Bin designation	Mean number of live insects per 1,000 grams of corn												
	1957		1958										
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
	AERATED 100 c.f.m. fan vertical duct												
10	0	0	0	0	0	0	0	0	0.3	1.1	2.2	5.8	3.3
6	0	0	0	0	0	0	0	0	0	1.4	1.9	8.3	2.2
7	0	0	0	0	0	0	0	0	0	0	2.5	4.7	5.0
8	0	0	0	0	0	0	0	0	0	0	1.9	3.9	1.4
9	0	0	0	0	0	0	0	0	.3	0	2.2	5.5	1.9
Mean	0	0	0	0	0	0	0	0	.1	.5	2.2	5.6	2.8
	1958	1959											
	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
10	1.7	1.1	1.7	2.2	0.3	0.6	1.4	1.1	12.8	6.1	-	1.7	3.9
6	3.9	2.2	2.2	1.9	1.4	3.9	1.9	1.9	5.0	6.4	-	5.5	1.9
7	2.5	2.2	.8	3.0	3.3	1.1	3.1	3.3	10.8	6.4	-	2.5	1.1
8	.6	.3	1.4	0	1.4	5.8	4.4	3.3	1.7	8.3	-	4.7	3.1
9	1.7	.3	.3	1.4	2.5	1.7	.8	2.2	4.2	7.0	-	2.2	1.1
Mean	2.4	1.2	1.3	1.7	1.8	2.6	2.3	2.3	6.9	6.8	-	3.3	2.2

Table 3 (concl.)

Bin designation	Mean number of live insects per 1,000 grams of corn													
	1957		1958											
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NONAERATED														
1	14.6	34.4 1/												
2	5.4	4.1 1/												
3	2.8	12.6 1/												
5	.5	1.0	.9	.2	.5	0	0	0	.5	.5	2.9	3.1	6.7	8.3 1/
4	2.0	3.3 1/												
Mean	5.1	11.1	.9	.2	.5	0	0	0	.5	.5	2.9	3.1	6.7	8.3

1/ Bins were terminated due to excessive weevil populations.

the aerated corn may have been subjected to lower temperature before it was placed into the bins.

Nonaerated Corn. The insect populations in the nonaerated corn were high as indicated by the counts at the first sampling during November 1957. The corn was binned between September 18 and September 23. The first samples were not drawn until November 21. Thus, the insects had a 2-month period in which to reproduce before samplings were started. When the samples were taken, moisture was in evidence on the surface of the corn and mold had already developed. This was more in evidence in the heavily infested corn.

Only one bin of corn out of the five did not have high insect populations. Bin number five had low populations from November 1957 until December 1958. Four bins of corn had high populations which were predominantly rice weevil. An average of two or more weevils found per 1,000-gram sample per bin was considered high enough to require the bin to be terminated from the study. Thus, bin numbers one, two, three, and four were taken out of the study and fumigated after the December 1957 sampling.

In the remaining bin, insect populations gradually dropped from January to June 1958. Starting in July 1958 the populations increased progressively until December 1958; at that time weevil populations reached the two-weevil level, and the corn was fumigated.

Location of the Insect Population

Aerated Corn. The location of the live insects recovered is presented in Table 4. No insects were found from November 1957 to June 1958.

Table 4. Live insect infestation by sample location and depth in aerated shelled corn. Corn stored in 3,250-bushel circular metal bins, Watseka, Illinois. Means of 5 bins.

Sample location	Mean number of live insects per 1,000 grams of shelled corn												
	1957		1958										
Depth in bin	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
AERATED 100 c.f.m. fan													
Center													
0-2 ft.	0	0	0	0	0	0	0	0	1	0	6	4	5
2-4 ft.	0	0	0	0	0	0	0	0	0	0	0	0	0
4-6 ft.	0	0	0	0	0	0	0	0	0	1	2	4	1
6-8 ft.	0	0	0	0	0	0	0	0	0	5	7	36	5
8-10 ft.	0	0	0	0	0	0	0	0	0	1	1	19	1
10-12 ft.	0	0	0	0	0	0	0	0	0	0	0	1	1
4 ft. from center													
0-2 ft.	0	0	0	0	0	0	0	0	0	0	0	1	1
2-4 ft.	0	0	0	0	0	0	0	0	1	0	2	2	0
4-6 ft.	0	0	0	0	0	0	0	0	0	0	4	5	5
6-8 ft.	0	0	0	0	0	0	0	0	0	0	4	5	7
8-10 ft.	0	0	0	0	0	0	0	0	0	1	0	7	8
10-12 ft.	0	0	0	0	0	0	0	0	0	0	1	6	12
1 ft. from bin wall													
0-2 ft.	0	0	0	0	0	0	0	0	0	1	1	1	1
2-4 ft.	0	0	0	0	0	0	0	0	0	0	2	1	0
4-6 ft.	0	0	0	0	0	0	0	0	0	0	2	1	1
6-8 ft.	0	0	0	0	0	0	0	0	0	0	1	3	1
8-10 ft.	0	0	0	0	0	0	0	0	0	0	4	2	1
10-12 ft.	0	0	0	0	0	0	0	0	0	0	3	4	1

Table 4 (concl.)

Sample location Depth in bin	Mean number of live insects per 1,000 grams of shelled corn										
	1958	1959									
	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Nov.	Dec.
					AERATED 100 c.f.m. fan						
Center											
0-2 ft.	1	2	0	0	2	4	4	3	11	21	8	1
2-4 ft.	2	1	0	0	1	1	0	1	2	0	0	0
4-6 ft.	1	0	0	0	0	0	0	3	4	4	0	1
6-8 ft.	2	0	0	0	3	1	0	0	5	2	0	0
8-10 ft.	7	0	1	0	1	0	1	0	8	16	1	2
10-12 ft.	4	2	1	0	0	0	0	0	2	0	13	1
4 ft. from center												
0-2 ft.	0	0	0	1	0	1	1	4	3	3	6	1
2-4 ft.	0	0	1	2	0	1	0	3	4	5	2	1
4-6 ft.	5	1	1	1	2	6	2	0	5	7	2	4
6-8 ft.	2	3	4	7	4	6	0	0	7	13	4	3
8-10 ft.	8	4	4	9	6	12	3	1	6	7	2	1
10-12 ft.	2	3	2	7	8	0	13	1	4	10	3	2
1 ft. from wall												
0-2 ft.	1	0	2	1	2	6	2	2	2	3	3	6
2-4 ft.	1	0	0	0	1	0	1	1	4	7	0	1
4-6 ft.	0	0	1	1	0	1	0	2	6	1	1	2
6-8 ft.	1	0	0	0	2	0	3	5	3	2	2	5
8-10 ft.	0	1	1	0	0	1	3	6	8	10	6	6
10-12 ft.	0	5	5	0	0	6	9	10	40	12	7	10

There were only two insects found during July, and nine during August. During September there were 39 insects that were fairly evenly distributed through the corn. During October 1958, however, 56 insects were found below the aeration duct in the center of the bin. A few more (from 1 to 7) were found distributed through the bin at the other locations. During November 1958 more insects were found at the lower portions of the bins but none were recovered in the center. During November 1958 there were 27 insects found in the lower six feet of grain from the samples taken four feet from the center. During December 1958 there were less insects found, and they were distributed more toward the lower area of the grain mass. No apparent changes occurred until August 1959. Then the populations increased, and 40 insects were found near the floor one foot from the bin wall. In September insects were more numerous and in the lower portions of the grain mass. More were also in the lower portions of the grain mass during November and December 1959.

Nonaerated Corn. In Table 5, the insect infestation is presented by sample location. High populations were present in the center of the corn at the initial sampling conducted November 1957. Twelve to 16 insects were present from the floor up to two feet from the surface. Only five insects were in the area from the surface down to two feet in the grain. At four feet from the center, insects were also present but not nearly as many as were found in the center. In the outside samples insects were not present. Conditions were nearly the same during the December 1957 sampling, but more insects were found. After the December sampling the four bins were fumigated leaving one bin which had a low insect population. The January sampling of the remaining bin showed a decrease in

Table 5. Live insect infestation by sample location and depth in nonaerated shelled corn. Corn stored in 3,250-bushel circular metal bins, Watseka, Illinois. Means of 5 bins.

Sample Location	Mean number of live insects per 1,000 grams of shelled corn													
	1957		1958											
Depth in Bin	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
NONAERATED														
Center														
0-2 ft.	5	33	0 1/	0	0	0	0	0	0	5	20	30	30	5
2-4 ft.	12	12	0	0	0	0	0	0	5	5	5	0	35	25
4-6 ft.	13	22	5	0	0	0	0	0	0	0	0	0	10	20
6-8 ft.	12	17	5	0	0	0	0	0	0	0	0	0	10	30
8-10 ft.	12	56	0	0	10	0	0	0	0	0	5	0	0	0
10-12 ft.	16	31	10	0	0	0	0	0	0	0	0	0	0	25
12-13 ft.	14	16	0	0	0	0	2/							
4 ft. from center														
0-2 ft.	1	20	0	0	0	0	0	0	0	0	0	0	5	0
2-4 ft.	4	4	0	0	0	0	0	0	0	0	0	0	5	5
4-6 ft.	6	8	0	0	0	0	0	0	0	0	0	0	5	0
6-8 ft.	10	3	0	0	0	0	0	0	0	0	0	0	5	0
8-10 ft.	6	1	0	0	0	0	0	0	0	0	0	0	0	0
10-12 ft.	1	2	0	0	0	0	0	0	5	0	0	0	0	5
12-13 ft.	0	0	0	0	0	0	2/							
1 ft. from bin wall														
0-2 ft.	0	0	0	0	0	0	0	0	0	0	0	5	0	0
2-4 ft.	0	0	0	5	0	0	0	0	0	0	0	5	0	0
4-6 ft.	0	0	0	0	0	0	0	0	0	0	0	5	0	0
6-8 ft.	0	0	0	0	0	0	0	0	0	0	0	5	10	15
8-10 ft.	0	0	0	0	0	0	0	0	0	0	5	0	0	0
10-12 ft.	0	0	0	0	0	0	0	0	0	0	0	5	0	0
12-13 ft.	0	0	0	0	0	0	2/							

1/ Mean of one bin after December 1957.
2/ Corn level dropped from 13 ft. to 12 ft.

the insect population, and the population continued to decrease in February and March 1958. No insects were recovered from the corn during April, May, and June 1958. Only a few insects were found in July and August. During September and August most of the insects were present on the surface and some on the periphery of the bin. In October they were present in the samples taken one foot from the wall, and 30 were found on the surface. During November the sample pattern that had emerged a year earlier was repeated showing insects predominantly in the center of the bin. This was also true during December 1958. The bin was terminated after the December sampling because of high weevil infestations.

Comparative Abundance of Species of Insects

Aerated Corn. The data on the species of live insects and on their comparative abundance at monthly intervals is presented in Table 6. The predominant species was the rusty grain beetle, *Cryptolestes ferrugineus* (Steph.). Specimens of the insect were sent to Mr. T. J. Spilman, Insect Identification and Biological Control Branch, Entomology Research Division, Washington, D. C. for positive identification. This insect was more abundant every month that insects were found with the exception of the August and October 1958 sampling. Through the observation period the rusty grain beetle comprised 79.6% of the total insects found in the aerated corn. The foreign grain beetle, *Ahasverus advena* (Waltl.), comprised 11.1% of the total insects found.

The presence of the rusty grain beetle in the corn samples during February 1959 is of particular interest as the grain temperature ranged from 19.0° F. to 36.0° F. with an average temperature below freezing at

Table 6. Comparative abundance of species of live stored-grain insects found in aerated shelled corn under observation for the effect of aeration on stored-grain insects. Watseka, Illinois, 1957, 1958, 1959.

Species[1]	Proportion of insects present in samples taken (percent)															
	1957		1958												1959	
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
R.G.B.	0	0	0	0	0	0	0	0	100.0	11.1	65.0	38.2	80.4	67.6	95.5	91.3
F.G.B.	0	0	0	0	0	0	0	0	0	44.4	17.5	55.9	13.7	32.4	0	0
Cad.	0	0	0	0	0	0	0	0	0	0	2.5	2.9	5.9	0	0	8.7
S.	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0	0	0
H.F.B.	0	0	0	0	0	0	0	0	0	33.3	12.5	0	0	0	0	0
Imm.	0	0	0	0	0	0	0	0	0	11.1	2.5	1.0	0	0	4.5	0
R.F.B.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ang.	0	0	0	0	0	0	0	0	0	0	0	1.0	0	0	0	0
L.B.F.B.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Derm.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total insects observed[2]	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(2)	(9)	(39)	(102)	(51)	(37)	(22)	(23)

	1959									Total No. of insects present	Percent of total
	Mar.	Apr.	May	June	July	Aug.	Sept.	Nov.	Dec.		
R.G.B.	100.0	96.9	87.0	97.6	90.5	91.1	84.6	78.0	89.4	660	79.5
F.G.B.	0	0	0	0	0	0	2.4	8.5	0	95	11.4
Cad.	0	3.1	10.9	2.4	9.5	4.8	7.3	8.5	10.6	45	5.2
S.	0	0	0	0	0	3.2	2.4	3.4	0	10	1.2
H.F.B.	0	0	0	0	0	0	0	0	0	8	1.0
Imm.	0	0	0	0	0	.8	.8	0	0	6	0.7
R.F.B.	0	0	0	0	0	0	1.6	1.7	0	3	0.4
Ang.	0	0	0	0	0	0	0	0	0	1	0.1
L.B.F.B.	0	0	2.2	0	0	0	0	0	0	1	0.1
Derm.	0	0	0	0	0	0	.8	0	0	1	0.1
Total insects observed	(29)	(32)	(46)	(42)	(42)	(124)	(123)	(60)	(47)	830	

1/ Scientific and common names given in Table 7.
2/ Numbers in parentheses represent the total of insects found and are not percentages.

27.1° F. It is evident that some of them can survive low temperatures for extended periods.

Nonaerated Corn. These data are found in Table 7. The predominant species of live insects was the rice weevil, *Sitophilus oryzae* (L.). It was the most abundant insect found in the beginning of the study from November 1957 to March 1958. No insects were recovered from April to June, 1958. The most predominant insect from July until November was the rusty grain beetle. During December 1958, the rice weevil was predominant and reached a level of an average of over two per 1,000 grams of corn.

Commercial Grade

Numerical Grade. The numerical commercial grades and the factors which determine the grades are found in Table 8. The average commercial grades taken during November 1957 showed that corn was number one and two when placed in storage. The aerated corn maintained grade better than the nonaerated corn. The nonaerated dropped to grades four and five.

Test Weight. The test weight ranged between 57.2 lbs. and 58.6 lbs. and did not vary through the observation period in the aerated and nonaerated corn.

Moisture. The moisture content during November 1957 was fairly consistent and ranged from 12.6% to 12.9%. The aerated corn gained moisture when the initial samples are compared with June 1959 samples. The nonaerated corn had a reduction in moisture level.

Table 7. Comparative abundance of species of stored-grain insects found in nonaerated shelled corn under observation for the effect of aeration on stored-grain insects. Watseka, Illinois, 1957, 1958.

Species 1/	Proportion of insects present in samples taken (percent) 1957 Nov.	Dec.	1958 Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total No. insects present	% of total
R. W.	85.9	77.8	100.0	100.0	100.0	0	0	0	0	0	0	0	17.4	66.7	285	71.8
R.G.B.	6.1	9.7	0	0	0	0	0	0	50.0	100.0	100.0	90.9	65.2	33.3	71	17.8
F.G.B.	6.1	10.2	0	0	0	0	0	0	0	0	0	0	8.7	0	30	7.5
Cad.	2.0	.5	0	0	0	0	0	0	50.0	0	0	9.1	4.3	0	6	1.5
G.W.	0	1.4	0	0	0	0	0	0	0	0	0	0	0	0	3	.8
R.F.B.	0	.5	0	0	0	0	0	0	0	0	0	0	0	0	1	.3
S.	0	0	0	0	0	0	0	0	0	0	0	0	4.3	0	1	.3
Total insects observed	(99)	(215)	(4)	(1)	(2)	(0)	(0)	(0)	(2)	(2)	(7)	(11)	(23)	(30)	397	

Common name Scientific name

1/ R.G.B. - Rusty Grain Beetle, Cryptolestes ferrugineus (Steph.)
F.G.B. - Foreign Grain Beetle, Ahasverus advena (Waltl.)
Cad. - Cadelle, Tenebroides mauritanicus (L.).
S. - Saw-toothed grain beetle, Oryzaephilus surinamensis (L.).
H.F.B. - Hairy fungus beetle, Typhaea stercorea (L.).
Imm. - Indian-meal moth, Plodia interpunctella (Hbn.).
R.F.B. - Red flour beetle, Tribolium castaneum (Hbst.).
Ang. - Angoumois grain moth, Sitotroga cerealella (Oliv.).
L.B.F.B. - Larger black flour beetle, Cynaeus angustus (LeC.).
Derm. - Dermestidae (Family). Species unknown.
R.W. - Rice weevil, Sitophilus oryzae (L.).
G.W. - Granary weevil, Sitophilus granarius (L.).

2/ Numbers in parentheses represent the total of insects found and are not percentages.

Table 8. Commercial grade and grade factors of aerated and nonaerated shelled corn stored in 3,250-bushel bins. (Average of 5 bins each.)

Sample location	Date samples taken	Commercial grade (yellow corn)	Grade factors			
				Percent		
			Test weight lbs. per bushel	Moisture	Total damage	Foreign material
AERATED						
Center	Nov. 1957	2	57.3	12.6	2.5	4.1
Center	June 1959	2	58.4	12.9	3.0	3.5
4 ft. from center	Nov. 1957	1	58.6	12.9	1.5	1.5
4 ft. from center	June 1959	2	58.6	13.4	3.3	1.3
1 ft. from wall	Nov. 1957	1	57.9	12.8	2.5	1.0
1 ft. from wall	June 1959	1	58.0	13.3	2.9	0.9
NONAERATED						
Center	Nov. 1957	2	58.1	12.7	4.5	2.3
Center	June 1959	5	57.2	12.6	12.8	2.1
4 ft. from center	Nov. 1957	2	58.4	12.9	3.7	2.9
4 ft. from center	June 1959	4	58.4	12.3	10.0	1.1
1 ft. from wall	Nov. 1957	2	58.4	12.7	3.4	0.9
1 ft. from wall	June 1959	4	58.3	12.4	8.2	0.8

Total Damage. The total damage was higher in the nonaerated corn than in the aerated corn as indicated by the initial November 1957 sampling. The nonaerated corn was placed in storage from September 18 to September 27, 1957. Thus, there were two months in which mold and insect damage took place before sampling. The aerated corn was binned from September 27 to October 7 and aeration was started on October 25. The later binning of the corn and the aeration treatment before the November sampling probably accounts for the lower initial total damage.

The total damage in the nonaerated corn increased much more between November 1957 and June 1959 than it increased in the aerated corn during the same period.

DISCUSSION

The differences in insect populations in aerated and nonaerated corn were striking. Heating caused by large numbers of insects was evident in the nonaerated corn; thus the advantage of aeration as a method of insect control becomes obvious. By using aeration the need for fumigants or other control methods to be applied to the stored corn was eliminated, at least for the first year. While the aerated corn had insects present, they were not a problem through the observation period of over two years. The insect species found in the aerated and nonaerated corn are of interest. Rice weevils in the nonaerated corn caused heating, and early fumigation was necessary. However, no rice weevils were recovered in any of the aerated bins of corn during the entire storage period of 26 months. The rice weevil is evidently quite susceptible to lowered temperatures. Solomon and Adamson (1955) classified the rice weevil as moderately susceptible to lower temperatures. Cotton (1956) reported that at temperatures between 30° and 35° F. rice weevils die within 16 days. Robinson (1926) reported that the rice weevil becomes motionless at temperatures below 45° F. Birch (1945) reported that the rice weevil cannot complete development in wheat of 14% moisture at 59.3° F. Cotton (1956) reported some reproduction of the rice weevil at 60° F. in 12% moisture wheat. As the aeration cooled the grain in November 1957 to temperatures which ranged from 39.2° F. to 51.2° F., the lack of live weevils in the corn at that date is explained, at least in part. The nonaerated corn was warmer during November 1957, and temperatures ranged from 51° F. to 70° F. There were enough weevils in December to cause heating as the grain temperatures increased at the center, three- and six-foot levels, 5.8° F. and 2.6° F., respectively.

The insects were found distributed fairly evenly through the grain mass in the aerated corn during the warmer months. During the fall and winter when grain temperatures dropped, they were found more toward the lower portions of the grain where the grain was warmer. In the nonaerated corn the insects were found more towards the outside of the grain mass in October and more toward the center during November and December. They were evidently moving towards the warmer areas of the grain in the aerated and nonaerated corn. Other workers have observed this behavior in stored grain insects. Hukill (1953) and Cotton _et al_. (1960) observed that the grain insects moved toward the areas of wheat that were still warm. In the observations of Foster and Stahl (1959) the insects evidently moved to the warm areas of the aerated corn and were finally blown out by the fan. The aeration in their study, however, failed to control the insects and the grain heating, so it had to be fumigated. Mathlein (1961) pushed cold air into warm grain and the insects moved to the grain surface which was the last area to cool.

The predominant presence of the living rusty grain beetles at many locations in the aerated cold grain is of importance. According to Waters (1959) the rusty grain beetle is the most serious insect pest of stored grain in the Prairie Provinces of Canada. Cotton (1962a) also reported that the rusty grain beetle survives the winter in both wheat and shelled corn in Minnesota and North Dakota. Solomon and Adamson (1955) also noted the rusty grain beetle's ability to survive the winter in unheated warehouses and called it a "hardy" species. Cotton (1962a) stated that almost all stored product insects except the cadelle do not have the ability to hibernate. When one considers that from January 1958 to April 1959 no recorded location within the grain mass was above 40.7^{o} F. and that average grain temperature was 28.7^{o} F., it must be stated that the insect has a remarkable ability to survive low temperatures for long periods.

The cadelle was also found during February and April 1959 but its presence is not too surprising because it is a true hibernating insect. According to Cotton (1962b) the cadelle as a hibernating insect can survive long periods of low temperatures. Back (1926) also reported the cadelle is resistant to low temperature.

The predominant presence of insects in the warmer areas of the grain below the aeration duct near the floor during the fall and winter brings the possibility of using a horizontal aeration system. Perhaps a duct could be placed on the bin floor and a fan placed to blow the air from the grain to the outside. This might allow the entire grain mass to cool quickly and to drop to a lower temperature, thus making it more effective as an insect control method. The use of a larger fan might also be considered with the horizontal system to cool the grain faster and to a lower temperature. The fans used with the vertical system in this study were run continuously throughout the year, thus the grain warmed or cooled dependent upon the ambient temperatures. The operation of the aeration fan only during the fall and winter should be considered in order to keep the grain cool during the spring and summer. Future insect control studies with aeration should, therefore, be considered using a horizontal system with a larger fan operated during the cooler months.

Laboratory studies at lowered temperatures with the rusty grain beetle need to be conducted. The gradual lowering of temperatures should be studied which would be similar to temperature changes in a grain bin. By gradually lowering temperatures this insect may survive for a relatively long time as was the case in these field studies. If there were marked differences in mortality between lowering temperatures rapidly and with gradual lowering of temperatures, consideration could then be given to using a method of lowering temperatures rapidly in actual grain storages as a control method.

There are various changes the author would make in this study if the opportunity arose to conduct additional studies. Total commercial grade damage and the degree of insect damage should have been determined before the corn was loaded into the bins and at quarterly intervals thereafter. The aerated corn and the nonaerated treatments should have been alternated as they were loaded into the bins. This would allow each treatment to be exposed to the same average unknown variables which are probably present. It may have been better if each lot of corn was fumigated and then infested with a known number of a specific species and stage of insect. This would help eliminate the variable insect populations which occur within the grain. Sampling for insects and temperature determination should have been done immediately after the grain was loaded into the bins instead of two months after the corn was in the bins. The aeration fans should have been in operation immediately after the aerated corn was loaded into the bins or at least operated immediately after all of the corn was loaded into the bins. The points sampled for insects and temperature determinations should have been taken from the same areas instead of a distance from one to two feet away from one another. Insects might have been placed in open and closed containers containing grain and placed at various locations in the grain mass during the aeration period. Numerous containers could have been used and one removed from each location at various intervals during the observation period.

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EFFECTS OF TEMPERATURE ON INSECT POPULATIONS IN AERATED AND NONAERATED STORED SHELLED CORN

by

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Aeration is the movement of air through grain at low air flow rates for purposes other than drying. The use of aeration for the quality maintenance of stored grain is a widely accepted practice. One of the reasons for acceptance is that by lowering the grain temperature with aeration, insect activity is reduced.

Considerable laboratory research activity has been directed toward the effect of lowered temperature on stored grain insects. The retarding of insect development at lowered temperatures is well documented. Even though aeration is used for insect control and low temperature laboratory studies have been conducted, few observations have been conducted in the field with actual observations of the insect populations.

Insect population observations were conducted in five continuously aerated and five nonaerated lots of corn stored at 12.8% moisture content in 3,250-bushel circular metal bins at Watseka, Illinois. The aeration system was a 9-foot long 8-inch in diameter galvanized iron tube equipped with a 100 C.F.M. fan placed vertically in the corn at the center of the bin. The corn was blended and then augered into the bins during September and October and sampled for live insects present at monthly intervals. Temperature determinations were also made within the grain mass at monthly intervals.

No insects were recovered from the aerated corn until the following summer while the nonaerated corn was heavily infested with the rice weevil, *Sitophilus oryzae* (L.), at the first sampling in November, 1957.

Insects were not a problem in the aerated corn through the observation period of two years though some insects were found the second year after the study was started.

Insects that were found in aerated corn were fairly evenly distributed through the grain mass during the warmer months but tended to congregate toward the lower portions of the grain mass which were warmer during the fall and winter. In the nonaerated corn, the insects were largely found toward the center of the corn mass during the winter and during the warmer months more towards the periphery of the grain mass.

The predominant species of insect in the aerated corn was the rusty grain beetle, *Cryptolestes ferrugineus* (Steph.), while in the nonaerated corn the rice weevil was predominant. The rusty grain beetle was found at points indicated by the thermocouples to be below freezing and near freezing for periods as long as three months.

The aerated corn was cooler than the nonaerated corn in the fall but was warmer than the nonaerated corn in the spring and summer.

The aerated corn maintained commercial grade better than the nonaerated corn during a period of 19 months.

The use of aeration in these studies eliminated the need for insect control by fumigation or other treatment of the corn for 26 months.

If insect control is needed in the aerated corn it will probably have to be directed toward the lower portions of the grain mass during the fall and winter months.

Future studies should be conducted with aeration systems which will cool the grain more evenly and with fan operation only in the fall and winter to keep the grain cooler through the warmer months.