SAWDUST-SALT MIXTURES TO DRY AND TO STORE SHELLED CORN

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Antonio M. Chaves

1962

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by

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AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Farm Crops

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APPROVED ____________

Antonio M. Chaves

ABSTRACT

A dry mixture of sawdust impregnated with about 10% by weight of NaCl (or $CaCl_2$), when mixed with damp shelled corn absorbed moisture rapidly, converting the dry salt to a saturated solution which was absorbed by the sawdust. The corn dried until the vapor pressure of the air between the kernels approached that of the salt solution. For drying to the equilibrium relative humidity of a saturated salt solution, namely 75% R. H. (or about 14% moisture in the grain), such a sawdust - salt mixture absorbed water to about 30% of its original dry weight. Most of the drying occurred in the first day or two.

The sawdust - salt can be readily removed from the grain if it is originally screened in a suitable manner.

The mixture, and particularly its sawdust component, was a powerful insecticide and repellant for granary weevils (Sitophylus granarius). Such a mixture of salt and an absorbent (sawdust) provides an inexpensive means of drying grain and avoiding infestation by granary weevils.

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ACKNOWLEDGMENT

The author wishes to express his appreciation to several people for their noteworthy contributions to this thesis. Those directly responsible for the production of this work through their efforts are as follows:

To Dr. S. T. Dexter of Farm Crops Department as his major professor and advisor, he expresses his deepest gratitude. Dr. Dexter contributed innumerable hours of technical assistance, aid in experimentation, and patient devotion in the production of the manuscript.

To Dr. C. W. Hall of Agricultural Engineering Department for his interest and suggestions throughout the production of this work.

Grateful appreciation is also extended to all those who provided encouragement and that undefineable something without which this whole endeavor would have been a complete failure.

DEDICATED
TO

MY MOTHER, VIRGINIA, WHO ENCOURAGED ME AS A BOY

AND TO

MY FIANCE LUCIA MARIA, WHO INSPIRED ME AS A MAN.

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INTRODUCTION

* Antonio M. Chaves

Techniques for drying and storing grain depend to a considerable degree upon the culture, degree of mechanization and urbanization, etc. of the country involved. Where hard surfaced truck roads pass every farm and railroads are available near at hand, drying and storage of grain may be economically performed in large central establishments. In Brazil a large proportion of the population inhabits small or middle-sized farms, where the products that are grown are consumed, except when hauled on donkey-back or on wagons hauled by horses and oxen to villages or cities, on paths or roads not designated for heavy traffic.

To document this situation more fully, the first part of this paper is related to Brazil, in the context of storage and the losses of small grain and shelled corn. In brief, the subtropical temperatures and high relative humidity of the air in the grain-producing regions of Brazil give rise to profound problems due to molding and insect invasion in stored grain. The experimental work reported in this thesis outlines a method of drying and storing grain that might be feasible for small farmers in Brazil and the many other subtropical or tropical countries with similar problems.

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* Bachelor Science in General Agriculture, graduated from the U.R.E.M.G. in 1958, and an AID fellowship holder from Brazil, on a project relating to training in grain storage.

A. BRAZIL

I. ITS GEOGRAPHY AND CLIMATE, POPULATION, AGRICULTURE, AND ITS POWER

Geography and Climate - Brazil's area of 3,287,195 square miles resembles roughly the shape of an equilateral triangle. The north-south and east-west dimensions of Brazil at the points of their greatest extent are almost identical - 2,684 and 2,680 miles respectively. The farthest reaches of the country extend from latitude 4°20'45" N. to latitude 33°45'09" S. and from longitude 34°45'54" W. to longitude to 73°59'30" W., covering 38 degrees of latitude and 39 degrees of longitude. Most of Brazil is situated to the east of the United States, for all of its territory lies east of the longitude of New York City.

Brazil's neighbors include all the countries of South America except Chile and Ecuador.

Fifty-seven percent of Brazil is made up of highlands, varying from 650 to 3,000 feet in altitude, in which irregular mountain ranges form high plateaus. The remaining forty-three percent of the land is less than about 650 feet above sea level.

Most of the territory of Brazil lies within the torrid zone. Since the tropic of Capricorn passes through the city of Sao Paulo, only the area to the south, including parts of the states of Santa Catarina and Rio Grande do

Sul, are in the temperate zone.

Practically all of Brazil lies south of the Equator, and the seasons are the reverse of those in the United States. The farther to the south, the more pronounced are the seasonal changes. The Amazon area is rainy and humid, with high average temperatures the year round. The heat in the coastal regions within the torrid zone is tempered by the trade winds and by the proximity of the ocean, and stiff breezes are characteristic of the coastal cities of the Northeast. In the highland areas of the interior, the altitude somewhat offsets the effects of low latitude.

Frost occurs with some frequency in the three southernmost states. The northern limit of the frost line is in northern Parana and the extreme south of Sao Paulo.

There are three main types of climate in Brazil, each of which is subdivided: (1) Equatorial or tropical climate, (2) Subtropical, and (3) Temperate. (Figures 1, 2, 3, and 4)

(1) Equatorial climate. This is characterized by a mean temperature of 26° to 27°C. The area occupied is: Amazonas, Para, Maranhao, Piaui, Ceara, Rio Grande do Norte, Pernambuco, Alagoas, Goiaz, Mato Grosso, and Bahia. It is sub-divided into super humid, continental humid, and semi arid.

(2) Subtropical climate. Average annual temperature varies between 23° and 26°C. This includes Sergipe, part

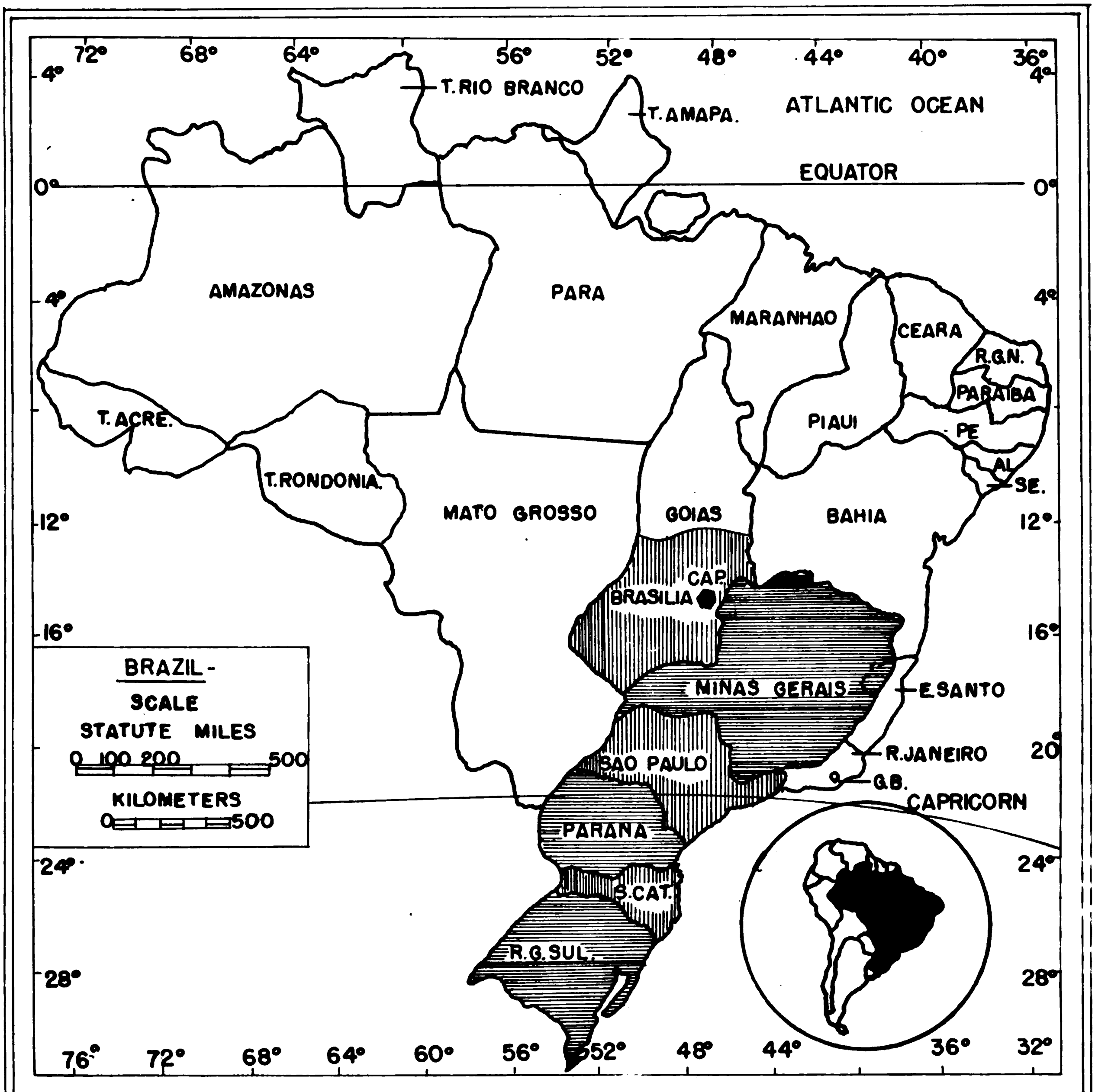


FIG.I. — MAP OF BRAZIL — (4).

(SHADED AREA = REGION OF GRAIN PRODUCTION)

FIG.2 - AVERAGE ANNUAL TEMPERATURE - (4).
(MAXIMUM)

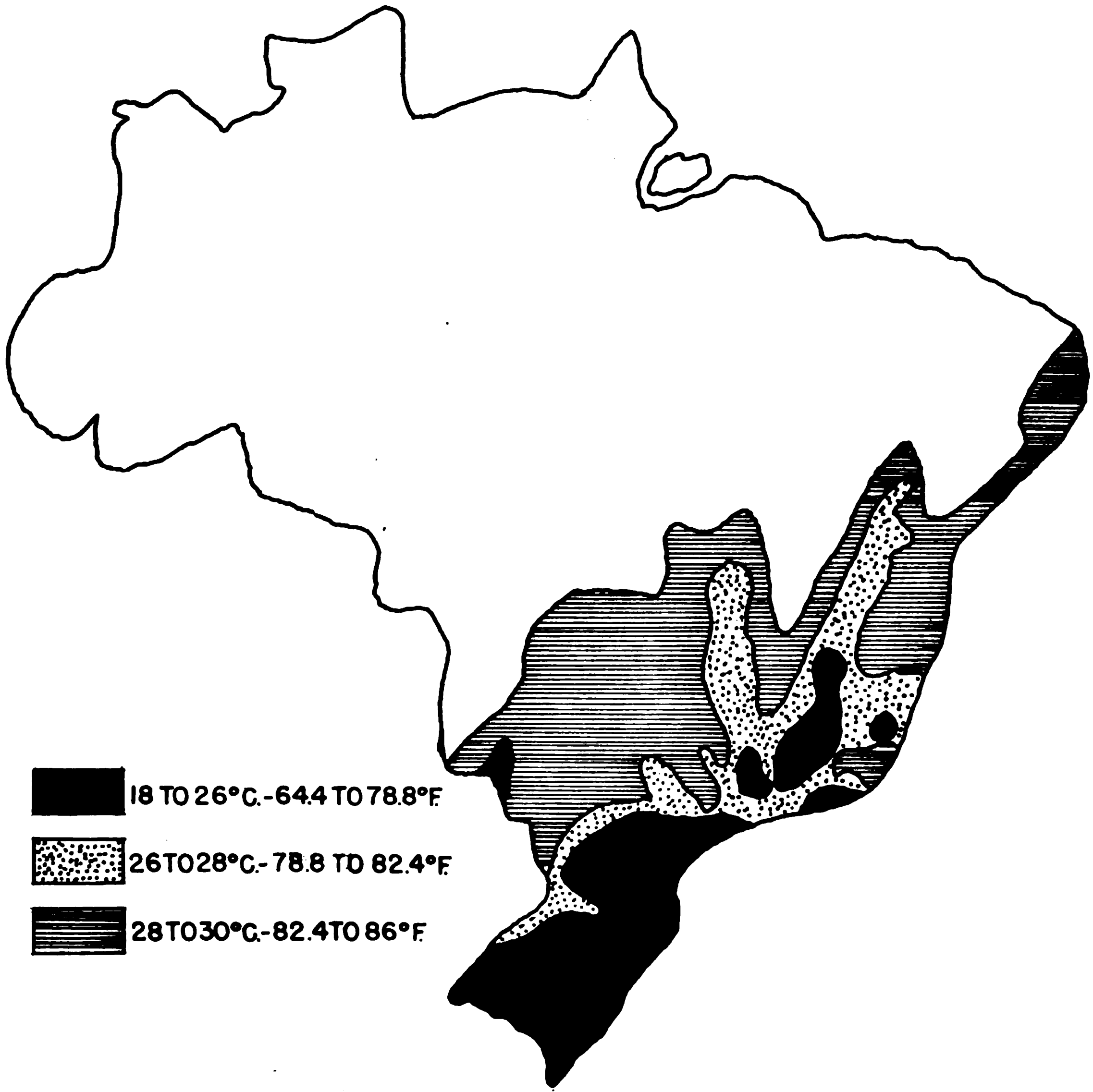


FIG.- 3 - AVERAGE ANNUAL TEMPERATURE-(4).
(MINIMUM)

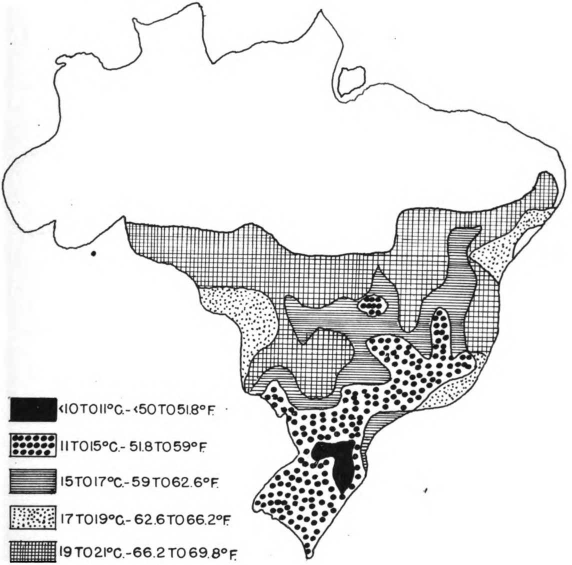


FIG. 4 - ANNUAL AVERAGE TEMPERATURE-(4)

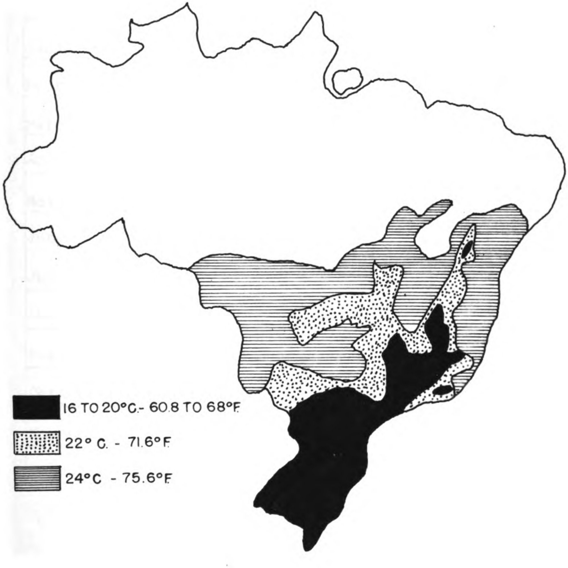


TABLE 1

Weather Data From Brazil

Relative Humidity Percentage (Monthly Average) in the Main Grain Producing States (3)

MONTHS	*MG	*GB	*SP	*PAR.	*SC	*RGS	*GOIAS
January	72	73	81	82	88	74	84
February	62	76	83	84	78	76	78
March	75	79	86	82	79	75	83
April	63	73	78	88	80	82	70
May	59	76	81	84	80	86	65
June	60	70	73	80	82	86	65
July	54	71	68	74	88	81	56
August	52	75	75	72	81	82	54
September	56	76	78	79	82	81	49
October	62	76	77	75	79	76	65
November	74	75	80	80	80	68	79
December	64	74	81	78	83	71	77

* MG - Minas Gerais GB - Guanabara
SP - Sao Paulo PAR - Parana
SC - Santa Catarina RGS - Rio Grande do Sul
GO - Goias

of Goiaz, Espirito Santo, Rio de Janeiro, and Minas Gerais, almost the whole of Mato Grosso and part of Sao Paulo. It comprises two types, two subdivisions: maritime, semi-humid and continental semi-humid.

(3) Temperate climate. Its characteristics are that of the coldest month of the year, where the medium temperature is equal or less than $18^{o}C$.

One-fifth of the total area of Brazil is included in the third climate, about half of the state of Minas Gerais, 50% of the state of Sao Paulo, the whole of Parana, Santa Catarina, and Rio Grande do Sul, part of Mato Grosso. It is subdivided into three types: super-humid on the coast, semi-humid in the interior, and semi-humid in the heights.

To illustrate these, see Figures II, III, and IV where the author shows the map of Brazil with special attention to the most productive states as far as production of rice, corn, black beans, and wheat are concerned. (See also Table 1)

Population - The population of Brazil, according to data from the census of 1960, was 70,527,621; an increase of 36 % over the 51,976,357 recorded in the census of 1950. One half of this population lives in the rural area.

Agriculture - Agriculture continues to be the mainstay of the Brazilian economy, although the rate of agricultural expansion has lagged behind the industrial growth in recent years. Agriculture and industry each contributed 26% of the national income in 1959. Nevertheless, in 1962 our statistics indicated the share of agriculture as 26 percent, against 27 percent for industry. However, 58 percent of the labor force was engaged in agriculture, according to the census of 1950, in addition to 2 percent of the labor force occupied in forestry and fishing. The importance of agricultural products in general, and coffee in particular, in the export sector is predominant, due to the fact that Brazilian farmers have price support program for coffee but not for cereal grains and the rest of our crops and livestock. (25)

Crops, both annual and perennial, accounted in 1959 for 65 percent of the total value of agricultural production, livestock and animal products about 29 percent, and extractive forest products for about 6 percent. (3) Data in the production of cereal grains and its value are shown in Table 3.

Brazil has a large potential for expanding agricultural production. The development of agriculture has been hindered principally by the inadequacy of transportation facilities, lack of storage facilities and rural electrification, insufficient capital and credit availiabilities, deficiencies in the marketing system, the small number of agronomists, the lack of agricultural engineers, and outdated agricultural methods. Only a small proportion of the country's area, representing 2.3 percent of the land area in 1950, is under cultivation. No reliable estimate has been made of the extent of arable land in Brazil.

The basic reason for the lag in agricultural production as compared with the growth of industrial production; however, is widely considered to be the inadequacy of the transportation system. The cost of moving crops to market is a basic factor in determing whether capital and labor can be profitably employed in crop production in a given area. The improvement of the road network within the past few years has increased agricultural production in Goias and other frontier areas, and consequently, the loss of cereal grains and other agricultural products due to the lack of storage facilities has also been increased.

Power - To meet the needs arising from the country's rapid economic development, the expansion of the power generating capacity is one of the major tasks of the Brazilian government. A ten-year program of around 5,000,000 kw of additional capacity is under way and it aims to raise Brazil's generating capacity from about 3,100,000 kw in 1955 to over 8,000,000 kw in 1965, and about 13,000,000 kw by 1970 See Table 2. (25)

Electric energy produced by the principal power companies in the first quarter of 1959 (2, 3) was distributed, by classes of consumers, as follows, in percent:

industrial,40; residential, 20; commercial, 15; and others (including block power sales to electric traction companies and Federal and state government power consumers as well as sales for public lighting 1.25.) (25)

TABLE 2

Electrical Power: Installed Capacity
(in 1,000 kw) (25)

YEARS	HYDRO	THERMAL	TOTAL
1940	1009	235	1244
1950	1536	347	1883
1955	2481	667	3148
1960	3262	801	4063
1065 (Est)	7300	1320	8620

II. THE JUSTIFICATION OF THE AUTHOR FOR THIS THESIS

Unfortunately I do not have enough data from Brazil on the number of storage facilities we have and how many we need in order to overcome this problem which has been well known from generation to generation; but so far it remains the same as in some decades ago. However, I have been in different states of grain production in my country working for Escritorio Tecnico de Agricultura (Brazil and United States) and have received from our farmers requests such as: can't you give me good plans to build a corn crib, a bin, a bulk storage, etc., in order to keep my grain well-stored and safely?

At that time (1959 to 1961) I could not help them because I did not have sufficient background to solve such problems. But, now with the knowledge that I have acquired from specialists in grain storage belonging to the department of Farm Crops and Agricultural Engineering of Michigan State University, I hope that I will be able to overcome at least part of this tremendous problem by using a mixture of sawdust and salt to dry and store shelled corn. When corn is dried with this mixture, it is not necessary to have electricity while the materials sawdust and salt are both readily available and inexpensive. The mixture of sawdust and salt may be used in the regions which are under the following conditions:

1) Corn and other food grains are grown on all farms in Brazil, especially on small ones where they are used for home consumption.

2) Transportation to and from market is expensive and unnecessary for the above reason.

3) When farms get larger and farm populations smaller, when electricity and good roads become universally available, then other mechanical means of drying and storage may be more practicable, and even less expensive than the use of the mixture sawdust and salt.

Any country, in order to survive, needs food, and therefore, food storage. This immediately poses two questions:

(1) Is it possible to improve the conditions of living of a people without having storage facilities and transportation?

(2) Is it worthwhile to increase the agricultural production without having a place to keep such production safely?

The answers for both questions are positively NO. Nevertheless, in my country we are improving our transportation, we are increasing our production, and the problem as concerns storage facilities still remains the same .

With respect to the national grain situation, we (1) have:

a) Brazil will continue to suffer heavy and unnecessary losses of agricultural production; and on an ascending scale as production increases, until there is implementation of a national construction program designed to satisfy the major requirements for storage facilities. A national approach appears justified by the magnitude of the probable investment. However, it might be limited to the provision of credit and technical aid to local entities both public and private, or cooperatives, as the case may be.

b) The need for more grain storage capacity throughout the country is obviously so great that well-designed impending projects, particularly those of commercial and farmers' interests, need not be discouraged or postponed.

c) With respect to individual projects, there is the need for considerably more engineering preparation supported by precise economic data based upon production trends, marketing potential, and research data for our condition due to the fact that grain storage is a regional problem.

d) Brazilian farmers need price support for cereal grains and corn.

e) Brazilian farmers need production credit on reasonable terms.

f) Brazilian farmers need more technical aid, but in order to solve that problem we need to have more specialists in grain storage.

The following is an example of losses in corn, wheat, rice and bean storage in Brazil.

TABLE 3

Brazilian Farm Crops Production 1960 (3)

CROPS	QUANTITY (Thous.met.tons)	CULTIVATED AREA Hectares	VALUE (Mil.Cruzeiros)
Rice	4,865	2,926,000	44,278.0
Corn	7,248	6,580,000	41,059.0
Black Beans	1,676	2,357,143	25,245.0
Wheat	300	1,159,888	11,583.8
TOTAL	14,089	13,023,028	122,165.8

TOTAL PRODUCTION 14,089,000 Tons

TOTAL LOSSES 25% from an annual harvest (this figure is estimated by the author)

This example may be summarized as follows:

(1) Losses due to lack of drying facilities . . . 7%

(2) Losses resulting from weather to grain stored in open or partially covered shelter . 5%

(3) Losses from insects and rodents to faulty storage methods and due to infestation in the field 10%

(4) Losses due to improper handling and transportation in sacks 3%

A 25% loss from an annual harvest of 14,089,000 tons means a loss of 3,522,250 tons valued at 30,541.45 millions of cruzeiros.

The following table shows the most productive states of Brazil by crop. (See Figure 1)

TABLE 4

The most productive states of Brazil are: (1958) (3)

STATES	RICE (tons)	CORN (tons)	BLACK BEANS (tons)	WHEAT (tons)
M. Gerais	728,763	1,660,200	331,489	------
Goias	412,286	258,832	66,188	------
Sao Paulo	833,323	1,404,435	201,402	------
Parana	210,110	1,153,222	304,197	77,529
S. Catarina	134,132	548,287	70,160	96,915
R. G. Sul	805,035	1,483,775	139,194	407,308

The author believes that the data presented justifies the expense in time and money which were necessary to increase his knowledge of grain storage in order to contribute to improvement in this area.

B) GENERAL PRINCIPLES OF GRAIN STORAGE

I) GRAIN STORAGE - GENERAL CONSIDERATION

For anyone who wants to invest money in storage of small grains and shelled corn it is desirable to be or to become acquainted with certain requirements as follows:

(1) Need of temporary or permanent storage.

(2) Data available of temperature and relative humidity.

(3) Kind of grain to be stored.

(4) Market price.

(5) Transportation facilities.

(6) Construction material available.

(7) Enough production to compensate a great investment.

After fulfilling all preliminary requirements above, one should know other requirements such as:

(1) Condition of grain.

(2) The function of the grain storage in order to maintain the condition of grain.

(3) The structural requirements of the buildings.

Any of the above requirements should be followed carefully. It is not necessary to say which requirement is more important than the other, because the main objective is to keep the grain safely and to maintain its quality. (2)

The seven first requirements are not difficult to meet because, roughly speaking, they depend on economic and weather data.

The other three are most important and it seems desireable to summarize them before considering drying agents.

<u>Conditions of Grain for Safe Storage</u>

The principal factors in safe storage are moisture content and temperature. This has been proved in the United States and other countries by many years of experience and research on the storage of grain. Foreign material and cracked grain can also be factors if they occur in excessive amounts.

The maximum moisture content at which grain can be stored safely depends on the kind of grain, the locality in which it is stored, the methods of conditioning, and the length of the storage period. Wheat may be stored safely for a year with moisture content of about 1% higher in North Dakota than in Kansas, because the mean air temperature in North Dakota is about 10°F. lower during the summer. (2) (See Table 5)

The moisture content of grain is also an important factor in the activity of insects. Where it is as low as 9% in shelled corn and wheat, most of the destructive insects become inactive. (2) (See Table 6) Nevertheless, such low moisture content is not easily obtainable in current practice. It is well known that grain can absorb moisture from or give up moisture to the air surrounding it. When the grain neither loses nor gains moisture, it is considered to be at its "Equilibrium Moisture Content," for the temperature and relative humidity surrounding the grain. Some information on equilibrium moisture content is given on Table 5.

The second factor in conditioning for safe storage is temperature. It is already proved that, to some degree low temperature off-sets the effects of high moisture with respect to the hazards of mold growth and insect development. For this reason, in colder weather the grain can be kept safely with a moisture content of 1 to 1.5% higher than in warmer weather. For example, in northern United States, grain moisture content may be 1 to 1.5% higher than in southern United States. (See Table 5) Today, in order to compensate for this advantage it is advisable to use aeration (cooling grain) in localities with warmer climates. (2)

<u>Functions of Storage Buildings</u>

B. M. Stahl (25) has stated comprehensively the functional requirements for a good storage as follows:

The storage should help to:

1. Keep the grain safe from:

a. Damage due to moisture

b. Damage due to heat

c. Damage by insects

d. Loss in quality

e. Objectionable odors and materials

2. Provide job safety and convenience when:

   a. Moving grain (to, into, out of, and from the storage)

   b. Inspecting the grain

   c. Servicing the grain and storage

C. W. Hall (12) lists the functions as follows:

1. The basic requirements of bins for grain are:

   a. There should be no openings or cracks permitting loss of product.

   b. Rain, snow, and soil moisture must be excluded.

   c. Reasonable protection must be provided against thieves, rodents, birds, poultry, insects, and objectionable odors.

   d. Facilities must be permitted for effective fumigation to control insects.

   e. Reasonable safety must be provided from fire and wind damage.

The structural requirements of the building:

1. Special attention should be given to: (24)

   a. Foundations

b. Anchoring

c. Floors

d. Walls

e. Roofs

f. Openings, ducts and closures

TABLE 5

Maximum moisture content for safe storage and corresponding relative humidities for specified kinds of grain and seeds. (11)

Kinds of grain and seed	Maximum moisture content for safe storage (percent wet basis)	Relative humidity of air at which grain is in equalibrium with air (77°F.) (percent R.H.)
Shelled corn, oats	A 13.0	61
Wheat (hard red winter)	A 13.0 - 13.5	64 - 68
Wheat (soft red winter)	A 13.0 - 13.5	67 - 73
Wheat (hard red spring)	B 14.0 - 14.5	73 - 74
Soy beans	11.0	68
Rice	13.0	71
Pea beans	16.0 - 18.0	76 - 84
Grain sorghum	13.0	65

A. South areas of the United States - 12%.
B. Higher moisture limitis applicable because of lower average air temperatures in producing area during the storage period.

II. MOISTURE MIGRATION AND MOISTURE ACCUMULATION

There are marked changes of air temperatures from summer to fall and winter in the United States. Consequently, temperature differences show up within a grain mass where the grain is stored in large bulk. Grain near the bin wall and surface cools or warms faster than in the bin interior. The air, warm or cool, keeps in approximate equilibrium with the grain. Thus, warm air has actually a slightly higher relative humidity than does cool air. The difference in grain temperatures is responsible for convection currents which move downward through the cooler grain and upward through the warmer grain. There is a slow but continuous exchange of moisture from the warmer to the cooler grain due to differences in vapor pressure. (Figure 5A) The moisture tends to move upward due to the effect of the rising convection currents taking place within the central portion of the grain bulk. There the warmer air rises because it is lighter than the surrounding cooler air. As the warmer moist air reaches the cooler grain near the surface, condensation generally takes place to a degree depending upon the conditions of the grain and the atmosphere. (14) (12)

If the grain is cold in the center of the bin as in the winter, the air currents rise along the surface edges of the bin during the late winter and early spring. As

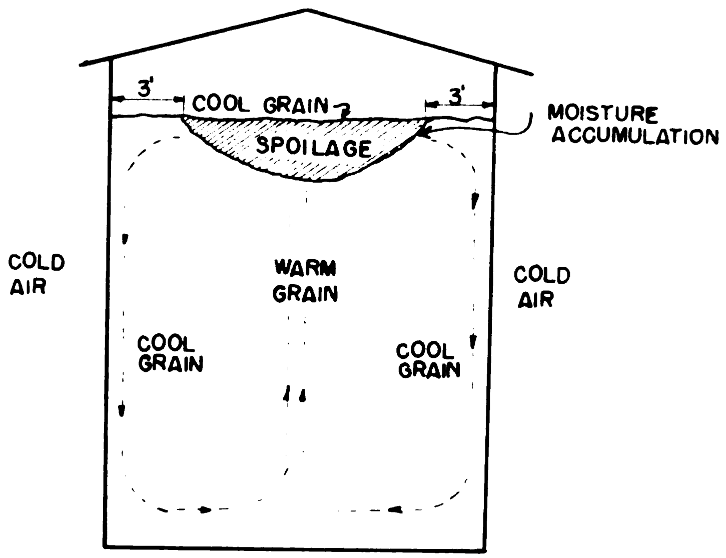


FIG. 5A — CONVECTION AIR CURRENTS WITH WARM GRAIN IN BIN WITH COLDER SURROUNDING AIR. (12)

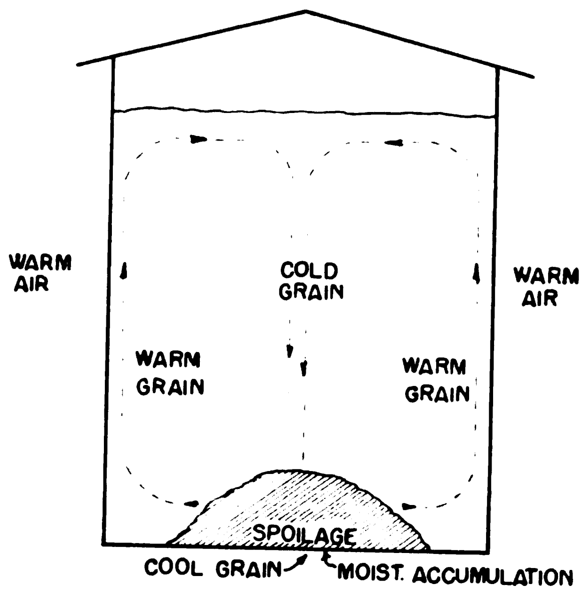


FIG. 5B — CONVECTION AIR CURRENTS WITH COLD GRAIN IN BIN WITH WARMER SURROUNDING AIR. (12)

the outer layers become warmer, the air currents move down through the center of the bin to the bottom where moisture condenses on the cold bottom. The air then moves to the walls and up along the walls upon being heated. In this situation the grain spoilage occurs at the bottom of the bin instead of in the top as explained previously. (12) (Figure 5B)

The most important factors affecting the two statements are:

1) The average moisture content of the stored grain.
2) The size of the storage.
3) The length of the storage period.
4) The atmospheric and grain temperature differences.

The accumulation of moisture at the surface or at the bottom of the stored grain may cause: molding, caking and insect infestation and consequently, the product stored loses in quality.

As previous studies have indicated, an increase in moisture content in the surface layer of grain is first noticed in the late summer or early fall. The relationship between moisture content in the surface layer and in atmospheric and grain temperature is shown in Figure 6.(23)

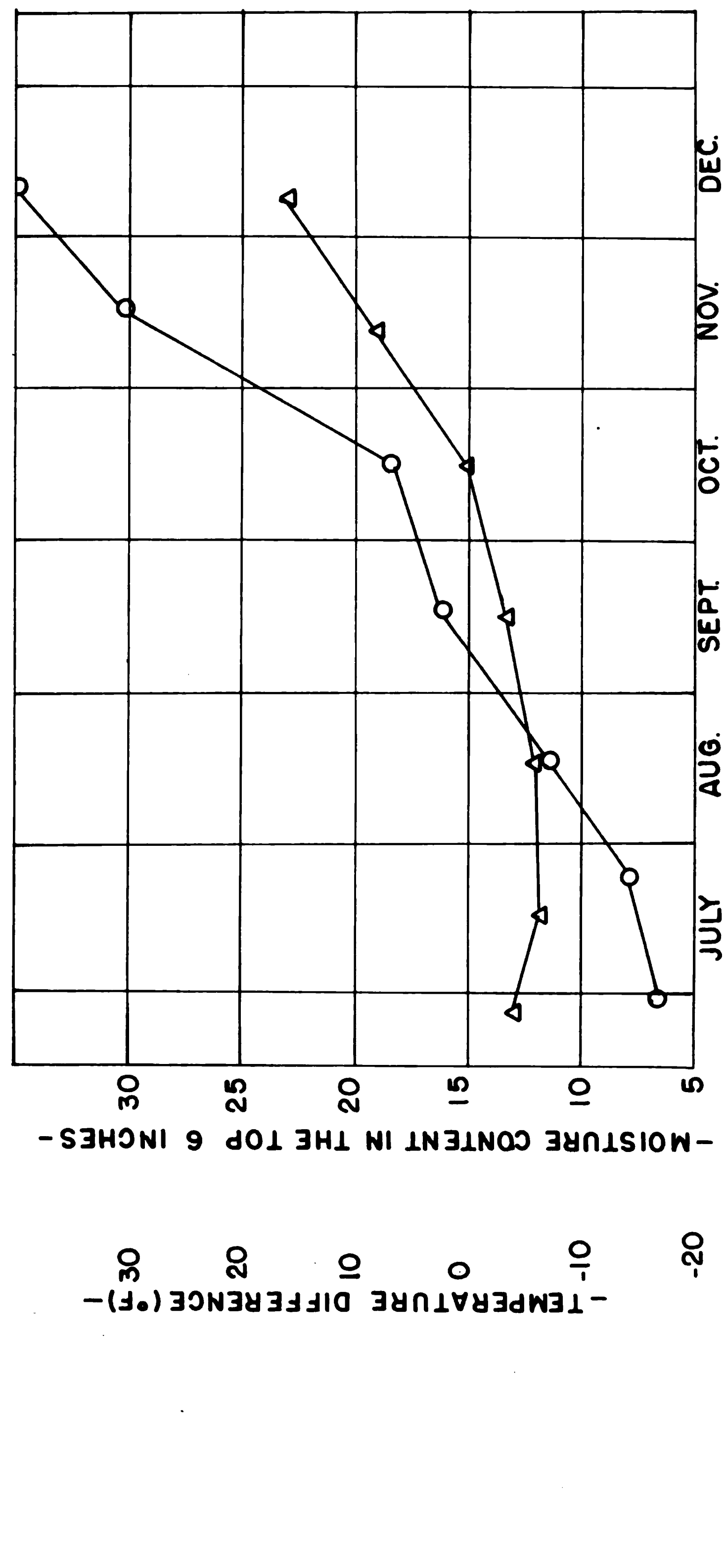


FIG. 6 ○———○ AV. TEMP. OF GRAIN IN CENTER OF BIN MINUS AV. ATMOSPH. TEMP.

△———△ MOISTURE CONTENT IN THE TOP 6 INCHES (23).

III. MOLD GROWTH

Grain is a hygroscopic material and its moisture content determines the relative humidity of the interseed atmosphere. Studies on the role of microorganisms in storage deterioration indicate that mold growth is the primary cause of spoilage and heating. The relative humidity of the interstitial air has a pronounced effect on mold growth and the various species of fungi have definite limits for growth and reproduction in relation to minimum relative humidity. Experimental research on these limits and many years of practical elevator management here in the United States have led to the establishment of maximum moisture levels for the storage of various grains. (17)

The mold activity as related to temperature and relative humidity has been shown that reduction of storage temperature has a marked influence on the respiratory and reproductive process of the common grain storage molds. The prevalent species of aspergillus molds in stored grain can grow 10 to 20 times faster at 70°F. than they will at 60°F. Figure 7 shows how a moderate decrease in storage temperature caused a significant reduction in the percentage of germs invaded by storage molds with shelled corn at 16% moisture content. Thus, with a comparatively short period of storage, all during cold weather, molding and insect problems are relatively insignificant.

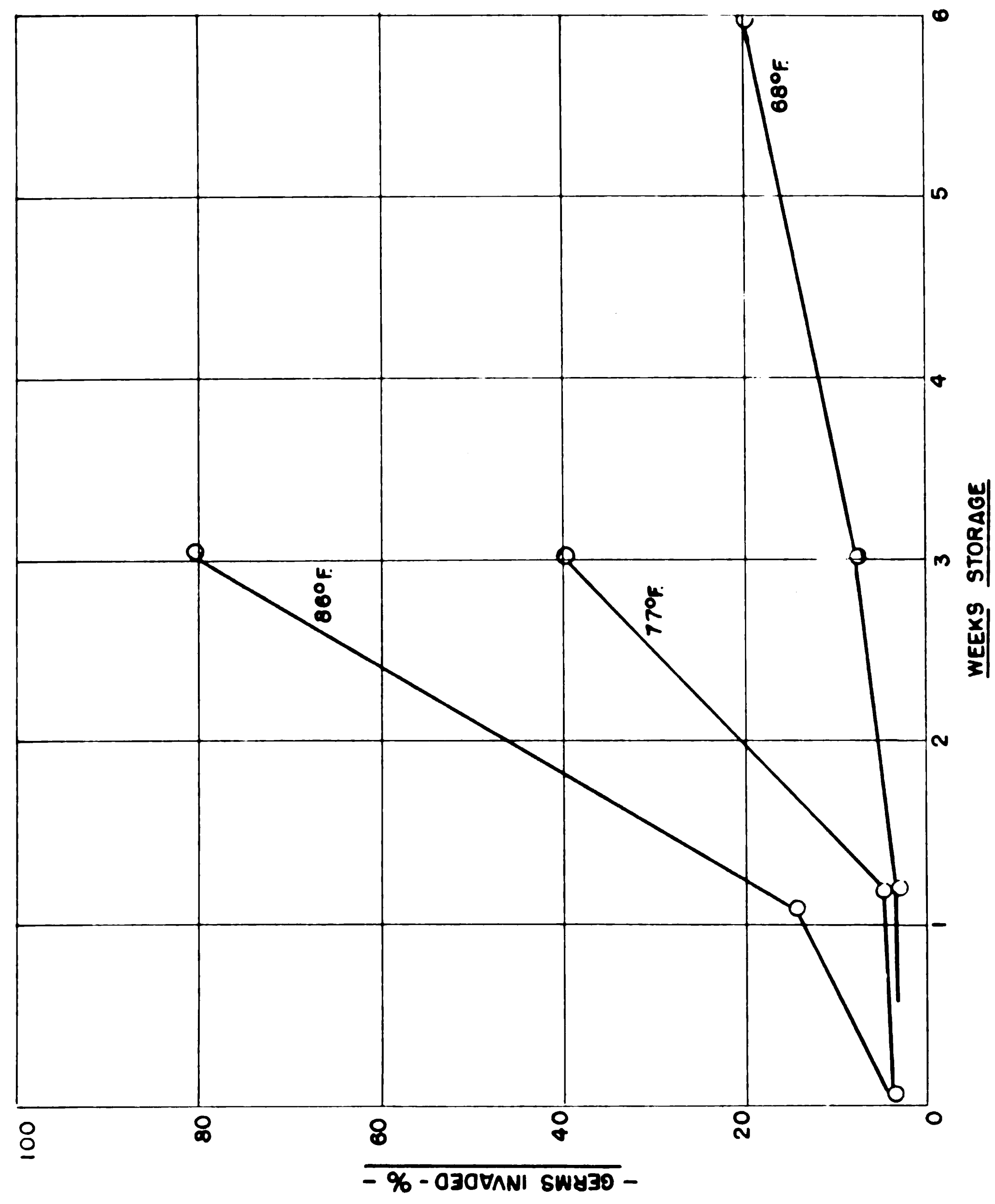


FIG. 7 - EFFECT OF TEMPERATURE ON MOLD ACTIVITY IN SHELLED CORN AT 16% MOISTURE.(17)

IV. INSECT ACTIVITY

The damage of stored corn in Brazil due to the attack of insects in elevators, farmers' bins, corn cribs, etc., is primarily due to the granary and rice weevil. Therefore, a general description of these insects is given below.

1) Classification

Granary weevil - Sitophylus granarius (Linne)
Order: Coleoptera
Family: Curculionidae

Rice weevil - Sitophylus orizae (Linne)
Order: Coleoptera
Family: Curculionidae

2) Distribution

The granary and rice weevil are cosmopolitan. The first one is probably not native to North America, and the second one is supposedly a native of India. They are very frequently found together. The granary weevil is less prevalent, at least in tropical and semi-tropical climates. It prefers a temperate climate and is more frequently found in the northern part of the United States than in the south. In Brazil, it occurs more in the south than in the north.

3) Food

Wheat, corn, macaroni, oats, barley, and other grains and grain products. Adults feed upon whole seeds or flour but the larvae develop only in seeds or pieces of seeds or cereal products large enough for them, and not in flour unless it has become caked. (19)

4) Life History, Appearance, and Habits

In unheated storages, winter may be passed as larvae or adults, the latter stage surviving zero °F. weather for several hours. The adult granary weevil is a somewhat cylindrical beetle, about 1/6 inch in length. It is dark brown or nearly black in color, with ridged wing-covers, and a prolonged snout extending downward from the front of the head for a distance of about one fourth the length of the body. (19)

The rice weevil has much the same general appearance, although on the whole it will average somewhat smaller. There is a patch of somewhat lighter, yellowish color on the front and back of each wing cover. A distinguishing mark is in the shape of the small shallow pits on the prothorax of the beetles; in the rice weevil these are round, in the granary weevil they are oval. (19)

The female weevil chews slight cavities in the kernels of grain or in other foods, and there deposits small white eggs, one in a cavity, sealing it in with a plug or gluey secretion. The eggs hatch in a few days into soft, white, legless, fleshy grubs which feed on the interior of the grain, hollowing it out. On becoming full-grown, they are about 1/8 inch in length. They change to naked white pupae and later emerge as adult beetles. The entire life cycle may be passed under favorable conditions in from four to seven weeks, they live seven or eight months, and may even survive for over two years. The rice weevil has well-developed wings, and frequently flies, especially during periods of high temperature. The granary weevil has the wing covers somewhat grown together and is unable to fly. (19)

The granary weevil has become more specialized than the other members of the genus to which it belongs, has lost the power of flight and is dependent upon more for its dissemination. Unlike the closely allied rice weevil, it is never found breeding in the field. It occurs only in places where grain is stored. In other respects, the two insects closely resemble each other in their life histories, and will very frequently be found associated and working together in the same bins.

5) Effect of Temperature

Within certain limits, the rate of development and reproduction of all grain infesting insects increase with the rising temperatures. A grain temperature of 70°F., is considered to be the danger line. At that or higher temperatures, insect populations increase rapidly and severe damage to stored grain may be expected; whereas below this temperature level little damage need be expected. The effect of temperature on the rate of reproduction of the granary and rice weevil are shown in Table 6. (6)

The abundance of insects in stored grain is directly affected by temperature, moisture and food requirements. The insects that attack stored grain as a group are mostly of sub-tropical origin and do not hibernate. They did not develop resistance to low temperatures, so that in the southern portion of the United States they are in greater numbers than in the northern portions.

6) Effect of Moisture

The insect pests of stored grains depend on their food supply for their moisture requirements. Some insects such as the flour beetle and moths are able to break down the food supply and thus supply their moisture needs. The rice weevil and granary weevil are unable to obtain moisture in this manner. They are unable to breed in grain with a moisture content of nine or below nine per cent, and the adults soon die in dry grain. Little breeding of these grain weevils occurs where the moisture content of grain is below 11 percent, unless grain temperatures are 80°F. to 90°F. The effect of grain moisture on the reproduction of granary weevil and rice weevil is shown in Table 6. (6)

7) Insect Control

Assuming that the grain is dry enough to store without heating when placed in the bin and insects are not present, there is little danger of insect infestation in the northern portion of the United States. This has been discussed in the topic "Effect of Temperature on Insects." In the regions where small grains and corn are produced in Brazil, however, there is a much greater problem of controlling insects than in the area mentioned above.

In order to control insects, there are many methods, and the effectiveness of each one of them depends upon the skill of the person who is using it. They are:

a) Good house keeping - is one of the simplest and best ways to prevent insects.

b) Using grain protectants

c) Drying and heating sterilization of grain

d) Turning the grain or aeration

e) Fumigating

f) Surface spraying for moth infestation

g) Using repellants - substances that keep insects away from crops because of their offensive appearance, odor, or taste.

8) The use of a protective covering of dust, wood ashes or similar finely divided material, or the mixing of the material with grain to prevent insect damage was first practiced many years ago and has never been entirely abandoned. When finely divided chemically inert dusts are mixed with grain, they promote the rapid loss of body moisture of insects infesting the grain and cause their death by desication. (6)

TABLE 6

Reproduction of Rice and Granary Weevils (50 pairs each) in wheat as affected by temperature and grain moisture, indicated by number of progeny after five months. (6)

Percent Moisture	60°F.		70°F.		80°F.		90°F.	
	Rice Weevil	Granary Weevil	Rice Weevil	Granary Weevil	Rice Weevil	Granary Weevil	Rice Weevil	Granary Weevil
9	0	0	0	0	0	22	12	0
10	0	0	0	15	326	422	413	0
11	40	0	87	125	885	1510	984	0
12	58	163	4827	2826	9661	5089	2233	1250
13	514	191	8692	5517	10,267	9321	2230	2193
14	951	624	10,745	3645	13,551	10,950	3934	3194

V. DRYING OF GRAIN

The principles involved in drying of grain are similar to air drying of other solid materials. The general idea in drying of grain is that one is usually concerned with removal of a limited amount of water from the grain in order to keep it safely for a period of time. This limited amount will depend upon the kind of grain and other factors which have been discussed previously. In order to abridge this discussion we can state: Dry the grain until it meets the minimum moisture content required for a safety storage.

C. W. Hall (12) has pointed out the importance of drying farm crops as follows:

(1) Permits "early harvest" by reducing field loss of products from storm, insects, and natural shattering.

(2) Permits "planning the harvest season" to make better use of labor. Farm crops can be harvested when drying conditions are unfavorable.

(3) Permits "long time storage" without deterioration. Extended storage periods are becoming increasingly important with the large amount of grain being stored and carried over through another storage year by the government and industry.

(4) Permits farmer to take advantage of "higher price" a few months after harvest. In the United States from 1945 to 1955, the increase in value of corn and wheat from harvest to the market peak price was about 25¢ per bushel.

(5) Permits "maintenance of the viability" of seeds. By removing moisture the possibility of heating of the grain with subsequent reduction or destruction of germination is decreased.

(6) Permits the farmer to sell a "better quality product" which is worth more to him and to those who must use those products.

Water in the Grain

The amount of water which is held by a kernel of any kind of grain is due to the following reasons:

(1) A certain amount of water may be loosely held in the intergranular spaces and within the pores of the material. The water held in this way may be termed as free water and it possesses its usual properties. In this situation the molecules of the absorbing substances are not concerned except as a supporting structure.

(2) Another portion of the water is more closely associated with the absorbing substance. There is an interaction between the water molecules and those of the substance; in other words, the properties of one substance influence the properties of the other. In this situation, water is said to be adsorbed. To denote such interaction the general term sorption is used, while adsorption and desorption are used specifically to denote the processes of taking up and giving off water of sorption.

(3) The third portion of water may combine in a chemical union with the absorbing substance; and conversely, water which is an integral part of a given substance may be removed by unduly rigorous conditions at time of moisture determination. (2)

Representation of Water (moisture content)

The amount of moisture in a product is designated as the basis of the weight of water and is usually expressed in percent. There are two methods of designating the moisture content: a) wet basis, and b) dry basis. The moisture content on a wet basis is obtained by dividing the weight of water present in the material by the total weight of the material. (Equation 1-A) The percent moisture on a dry basis is determined by dividing the weight of water by the weight of dry matter. (Equation 1-B) (12)

$$\text{Wet basis (\% moisture)} = \frac{Ww}{Ww+Wd} \times 100 \quad \text{(Equation 1-A)}$$

$$\text{Dry basis (\% moisture)} = \frac{Ww}{Wd} \times 100 \quad \text{(Equation 1-B)}$$

The meaning of the symbols used is:

Ww = weight of water   Wd = weight of dry matter

Both ways are widely used to designate the amount of water in a product. However, for grains the wet basis is more commonly used.

Methods of Drying Grain

1. Unheated air { Natural ventilation / Forced ventilation

2. Heated air {Direct heater / Indirect heater}

3. Infrared drying

4. Vacuum drying

5. Drying with absorptive substances

In all of these cases, the object of the method is to make the vapor pressure of the grain higher than that of the surrounding air, and thus permit evaporation.

Table 7 shows the variation of the moisture content of shelled corn (yellow dent) at 0°C., 10°C., 21°C., 30°C., 38°C., and 50°C as a function of the relative humidity of air. This table shows the equilibrium moisture content of shelled corn for a particular temperature and relative moisture content of corn surround by air with a relative humidity of 70% and a temperature of 30°C. is 12.9 percent.

Table 7 also shows that for a specified and constant temperature, the equilibrium moisture content increases as the relative humidity increases.

<u>The Drying Process</u>

When grain or other hygroscopic material is exposed to an atmosphere at constant temperature, water will evaporate until the gas pressure of the vapor balances the vapor tension of the "liquid," water. When equilibrium is reached the gas pressure is referred to as the saturation vapor pressure under these conditions. The drying conditions are obtained when the atmospheric pressure is unsaturated, that

TABLE 7

Shelled corn equilibrium moisture content (wet basis). (12)

Temperature		Relative humidity, percent								
		10	20	30	40	50	60	70	80	90
0°C	32°F				10.1	11.3	12.6	14.0	15.8	
10°C	50°F				9.2	10.7	12.1	13.6	15.5	
21°C	70°F			7.1	8.3	9.8	11.4	13.2		
25°C	77°F	5.1	7.0	8.4	9.8	11.2	12.9	14.0	15.6	19.6
30°C	86°F	4.4	7.4	8.2	9.0	10.2	11.4	12.9	14.8	17.4
38°C	100°F	4.0	6.0	7.3	8.7	9.0	11.0	12.5	14.2	16.7
50°C	122°F	3.6	5.5	6.7	8.0	9.2	10.4	12.0	13.6	16.1

is, lower than the corresponding saturation vapor pressure at the same temperature. The definition of the hygrometric state of the atmosphere can be made in terms of the vapor pressure as, (a) the "relative humidity" which is the observed vapor pressure expressed as a percentage of the saturation vapor pressure exceeds the observed value. It can be shown that for any given temperature the saturation deficit is equal to Ps (100 - R. H.)/100, where Ps is the vapor pressure at saturation and R. H. the relative humidity percent. (22) Therefore, the distribution of saturation deficit is the inverse of that of relative humidity, but since the saturation vapor pressure varies directly with temperature, the saturation deficit for a given value of the relative humidity is greater at higher than at lower temperatures. Thus, for example, it is possible to have a saturation deficit at 70°F. double that at 50°F., although both have R. H. of 85%. (22)

<u>Drying Grain with Unheated Air</u>

The water vapor of air exercises a pressure or tension of vapor, but the water which is held by the grain also develops a vapor pressure. The difference between the vapor pressure of grain and vapor pressure of the surrounding air and its equality will determine the direction of the exchanges of water or their cessation. Dricot, Bruggemans and Dufey (10) illustrate this phenomena very well with the use of Figure 10 which on the left gives the vapor pressure in the shelled corn as a function of its moisture content for various grain temperatures. The same figure on the right shows the vapor pressure in the air, as a function of relative air humidity at various temperatures.

Example 1: If the corn (A_1) contains 18% of water and if its temperature (B_1) is 12°C., one can see that its internal vapor pressure (C_1) will be 9.3 mm of mercury. In order to determine whether the corn will lose or gain moisture in the presence of air having these characteristics, the graph on the right of Figure 10 is used.

Supposing the atmospheric air having a relative humidity (D_1) of 80% and a temperature (E_1) of 20°C., with these conditions the vapor pressure of the air is higher than the vapor pressure of the grain, so the grain will pick up moisture instead of give it off.

Example 2: Considering the same grain at 18% of water at the same temperature (B_1) of 12°C., and having a vapor pressure (C_1) of 9.3 mm of mercury.

Supposing now the grain is located in air (D_2) at a relative humidity of 87.5% and a temperature (E_2) of 12°C., the vapor pressure under these conditions will be also 9.3 mm. So, drying will not occur.

Example 3: Supposing that grain (A_1) having 18% of water at a temperature (B_2) of 20°C. be put in contact with air having a R. H. (D_3) of 65% and a temperature (E_2) of 26°C., it is shown from the Figure 10 that the grain will not be able to dry. For the two vapor pressures (C_3) are equal at 16.6 mm. But if the grain temperature (B_3) rises to 26°C., the grain dries, for its vapor pressure (C_4) is 24.3 mm higher than the air (C_3)

In short we can say that the more the temperature of the grain is raised in relation to the temperature of the air, the faster will be the drying.

In conclusion, one can see that the drying process of grain with the use of unheated air blowing into the mass of grain is a function of the weather. When the atmospheric air is dry and the temperature high, the process will be satisfactory but if the air is damp and cool the drying will not take place.

IV. DRYING AGENTS

Chemical absorbents or dehydrating agents have been used for drying grain at least experimentally. W. M. Hurst and W. R. Humphries (15) conducted an experiment using a silica gel in mixing with grain (they used samples of wheat, soybeans, flax, corn, and rice). The technique used was: The moisture of the grain was determined and sufficient water added to increase the moisture content to 20%. After water was added, the samples were kept in airtight containers for approximately 48 hours. The drier (silica), the equivalent of four times the weight of water was added, and then placed into the container and mixed with the grain by shaking and tumbling. The container was then sealed and allowed to stand for the desired length of time, after which the figures below were taken.

Weight of sample: 400 grams

Water added: 32.5

Quantity of silica used: 130 grams

Percent of moisture content before wetting: 13.5

Percent of moisture content after wetting: 20%

Percent of moisture content after being mixed with drier during 96 hours: 11.5

These figures show that 432 grams of corn at 20% M. C. in mixture with 130 grams of silica lost 40 grams of water. W. M. Hurst and W. R Humphries have made the following statement: "Calcium chloride and sodium chloride and some other chemicals have a high affinity for moisture, but would doubtless have an injurious effect on grain, and they deliquesce when saturated with moisture." Recent work using NaCl and $CaCl_2$, however, avoids most of the objections mentioned by Hurst and Humphries, Dexter and Creighton. (7)

S. T. Dexter and J. W. Creighton (7) describe absorbent blocks which are impregnated with drying salts for imbedding in stored grain to reduce its moisture. The drying agent used was calcium chloride in the form of "Dow Flake" due to many reasons such as: the cheapest desiccant in Michigan, the advantage of taking up large amounts of water as water-of-crystallization, has a positive heat of solution, and it is not in highly soluble harmful to livestock in any reasonable amount, since both the chloride and the calcium ion are common and necessary for livestock. The blocks were of wood and they have been prepared in the following way:

The penetration of liquids or gases into woods is more rapid longitudinally than it is radially or tangentially. The sap wood is more readily penetrated than the heartwood in most cases. From the standpoint of penetration, there is an advantage of cross-sectional sawing. The blocks so prepared are, of course, relatively easily broken, but mechanical strength is not a particularly important factor. The thickness of these blocks was from 1/2 to 1 inch and

1 square inch cross section. After sawing these, they were placed at one time in boiling calcium chloride solution, sp.gr. 1.20, slightly acidified to eliminate troublesome carbonates, and were boiled for 15 minutes. They were left submerged in this solution for about 15 hours and then dried at approximately 102°C. Some species were by no means completely impregnated in this length of time. Most of the blocks failed to float in the solution after impregnation. The following species were exceptions: sassafras, sycamore, magnolia, catalpa, Peruvian mahogany, and arbor vitae, in thicker sections. Elm, ash, and beech were found hard to impregnate in another experiment. Other methods of impregnation were also used. Cold impregnation is possible but is much slower than hot. A vacuum system of impregnation was used with success. (7)

The behavior of blocks as far as relative humidity is concerned was as follows: at high relative humidities when impregnated with a solution as concentrated as 1.20 sp.gr., blocks of dense wood tend to become moist on the surface, due to slow diffusion. This is also true of the exceedingly light woods, which, due to their porosity, have absorbed an unusually large amount of the solution; and consequently, contain a large amount of calcium chloride in comparison with the weight of the wood. For example, the dry pieces of northern white cedar of 1/4 and 1/2 inch thickness weighed 0.94 and 1.74 grams respectively. After impregnating and redrying, they weighed 1.91 and 3.60 grams. They can absorb more water than they can retain. Corresponding aspen blocks went from 1.51 and 3.57 grams to 2.79 and 5.66 grams, respectively, by uptake of calcium chloride. (7)

Dexter and Creighton in another experiment found out that blocks impregnated with solutions of various strengths were kept at 50% relative humidity for a period, after which they were transferred to a chamber with a relative humidity of 75%. At the lower relative humidity, there was a steady increase in the percentage of moisture absorbed as the concentration of the impregnating solution increased, but at the higher relative humidity the blocks with a higher proportion of calcium chloride dripped badly, losing a good deal of the calcium chloride solution that they were unable to absorb. This statement calls our attention to the point that the tendency to drain is decidedly more pronounced in thin (1/4 inch) than in thicker (1 inch) sections. On thinner sections, a more dilute solution should be used as on the very light woods. This avoids undue surface moisture and yet improves the percentage uptake of water. It is definitely an error to believe that the more the calcium chloride, the better the uptake of moisture. (See Table 8) Where the solution is too strong, the absorbing capacity of the wood is decreased. A specific gravity of 1.20 would usually be a maximum in at least the high relative humidities involved in the

TABLE 8

Water taken up by blocks of three species of wood impregnated in the Dow Flake solutions of various concentrations. (7)

Water absorbed from oats in percentage of:	Concentration of impregnating solutions				
	20*	30	40	50	60
Weight of original wood	110	115	90	81	59
Volume of original wood	48	47	39	34	25
Weight of dried, impregnated block	74	67	48	34	32
Weight of absorbed Dow Flake	215	167	103	76	51

*grams of Dow Flake to 100 cc water

situation considered here. (7)

Other results from Dexter and Creighton were found such as: For high relative humidities, above 75%, a sodium chloride solution may be used to impregnate the blocks. Other things being equal, it would be anticipated that, gram for gram, a salt with atoms of small atomic weight would be more effective than one with heavier atoms. Magnesium chloride would appear well adapted for the purpose.

The authors (7) have been using grains and hay with the blocks, but they used mainly oats and beans. One thousand pounds of freshly threshed oat grain with 18.5% moisture were placed in a bin, together with 100 pounds of dehydrator blocks. At the end of 11 days the dehydrator blocks were removed and found to weigh 146 pounds. The oats were found to contain 12.5% moisture at this time.

The conclusions of this experiment are: one advantage of sodium chloride over calcium chloride is sodium chloride blocks dry readily under ordinary atmospheric conditions. Ordinarily, calcium or magnesium chloride blocks require artificial heat or low humidity for drying. Blocks of wood or other porous material impregnated with a suitable proportion of calcium chloride, magnesium chloride, or other desiccant have been found effective in removing moisture from the interstitial atmosphere, and thus from hay or grain in mows or bins with this method of reducing the relative humidity in the storage space, spoilage was prevented. Blocks may be so prepared that they will readily absorb from 50 to 100% or more of their dry weight.

S. T. Dexter (8) has described a method for conditioning popcorn to the proper moisture content for best popping. It has been known that for the best popping, popcorn should contain about 13.5 percent moisture, by weight. Corn that is too dry or too wet pops poorly. When stored in the open air, popcorn commonly dries out until it will give far less than maximum popping volume. On the other hand, if it is stored for a few days in very damp air, it becomes too damp to pop well and may even mold or spoil. Dexter (8) has stated the following conclusion: Popcorn that has been grown and dried in such a manner that it has once possessed good popping quality may be restored to good popping quality in case it becomes too dry. Storage of the corn in an atmosphere of approximately 75 percent relative humidity will bring the moisture content up to the desired figure. A saturated solution of table salt (sodium chloride), absorbed by blotters, corn cobs or other material, may be placed in a closed container with the corn. This solution provides the proper relative humidity. Corn has been stored in such containers for more than a year with no damage to the corn and with the popping quality unimpaired. No sample was discovered, no matter how old, that could not be restored to good popping quality, providing that it had not been injured in the initial drying.

Another experiment that has been conducted by S. T. Dexter (unpublished) was the conditioning of beans with a mixture of sawdust and sodium chloride. The beans were mixed with the mixture sawdust-salt and then kept in a closed container. The initial moisture content of the beans was 22 percent, after several days it had become 16.5 due to the action of the mixture. This little trial has been kept by Dexter for more than two years and the beans still have a good appearance. No damage due to insects or molds has taken place.

C. W. Hall (13) has been conducting an experiment with calcium chloride in order to absorb moisture in corn storage. The reason of this experiment has been already explained when the author discussed the migration of moisture content which occurs in stored grains. The conclusions of C. W. Hall in using calcium chloride to maintain a safe moisture content in shelled corn stored longer than one year can be abridged as such:

a) In 1955 and 1956 in Michigan, six containers of calcium chloride in the top of 3,200 bushels of shelled corn in a storage bin kept the moisture content below 14 percent when the moisture content of the corn was initially 13.5 percent or less at the time the containers were installed.

b) Placing calcium chloride above the grain where there is an interchange of air from the outside does not prevent moisture accumulation in the surface of the grain.

c) Pellet-type calcium chloride was superior to the lump-type.

d) Less than six calcium chloride containers per bin, each container holding 80 pounds, was not satisfactory in preventing moisture accumulation in the surface of the grain.

e) The annual cost of operation for one container based on a four year life is approximately $2.76. Protection is provided for the upper two-foot layer of shelled corn.

f) By coating ferrous metal parts with epoxyl resin plastic and using plastic screen for covering the metal frame work, the container and collecting pail did not deteriorate. The calcium chloride did not damage the shelled corn next to the container.

Since sawdust, sodium chloride, and calcium chloride were used in the experiment to be described, certain facts concerning them are appropriate.

1) Sawdust (wood)

A) Hardwood and Softwood

The trees are divided into two classes: hardwood and softwood. Hardwoods, such as elm, oak, cherry, beech, and bass wood have broad leaves. Some softwoods or conifers, such as the cedars, have scale-like leaves, while others such as the pines, Douglas fir, and the spruces, have

have needle-like leaves. We have to be careful when mentioning the terms hardwood and softwood due to the fact that they are not directly associated with the hardness or softness of the wood. In fact, such hardwood trees as cotton wood and yellow poplar have softer wood than such softwoods as longleaf pine and Douglas fir. (21)

b) <u>Sapwood and Heartwood</u>

Sapwood plays an important part in a tree's living process. Generally, only the last few outside layers of the sapwood are alive. The rest carry moisture from the roots to the leaves and store food for the tree. As far as moisture content is concerned sapwood has a higher moisture content than heartwood. (21)

During the life of a tree, sapwood gradually changes into heartwood, and becomes less permeable as the cell wall thickness and the cell opening become smaller. Since moisture movement is thus retarded considerably, heartwood dries more slowly than sapwood. In general, heartwood is darker in color and also more resistant to decay than sapwood. (19)

c) <u>Equilibrium Moisture Content</u>

The amount of water in sawdust is spoken of as its moisture content, and is usually expressed in terms of percent of moisture content - dry basis. However, we think it is useful to use the moisture content in terms of wet basis due to the moisture content of grains being always expressed in percentage wet basis. Any piece of wood (sawdust) or any hygroscopic material is said to be in equilibrium moisture content when it no longer gives off or picks up moisture, but is in balance with that in the surrounding atmosphere. The percentage of moisture in the sawdust at this point is called the equilibrium moisture content. The equilibrium moisture content of sawdust at different relative humidities and in some constant temperatures is shown in Figure 8. A curve resulting from plotting the equilibrium moisture contents on the ordinate and the respective relative humidities on the abscissa at a constant specified temperature is called an "isotherm". This relationship is illustrated in Figure 8, which shows, for example, that sawdust kept in air constantly at 80°F. and 75% relative humidity will eventually come to equilibrium at a moisture content of about 12.5 percent (wet basis). Similarly other isotherms are shown on the same graph using temperatures of 60°F. and 70°F. (21)

d) <u>How Sawdust Dries</u>

Most woods have a microscopic structure rather similar to a bundle of long connecting capillary tubes, rather than that of a foam (disconnected) bubbles. This anatomy is important in its use as a drier.

Chemically, wood consists mainly of cellulose, hemicelluloses, and lignin. These substances have a strong affinity for water, which explains why dry wood or sawdust absorbs moisture from the air, when the humidity is high. (20)

In sawdust, water occurs in two forms: as free moisture in the cavities of cells, and as bound moisture held within the cell walls. When sawdust dries, the free moisture is removed before any bound moisture can be withdrawn from the cell wall. The reverse is of course true when dry sawdust is allowed to absorb moisture, i.e., no free moisture can form within the cell cavities until the cell walls have been completely saturated. Technically, this state, where there is no free moisture in cells but the cell walls are fully saturated, is known as the fiber saturation point. (20)

Water in sawdust (wood) normally moves from zones of higher to zones of lower moisture content. This fact supports the familiar statement that "wood dries from the outside in," which means that the surface of the wood must be drier than the interior if moisture is to be removed. (21). Similarly, the same happens with sawdust (pieces of wood), and since the size of particles of wood are smaller, the amount of water in the surface and in the interior would be practically the same.

Moisture in wood moves as liquid or vapor through several kinds of passageways. These consist of the cavities of fiber and vessels, wood ray cells, pit chambers and their pit membrane openings, resin ducts of certain softwoods, other intercellular spaces, and transitory cell-wall passage ways. Most of the moisture lost by wood during drying moves through cell cavities and the small openings in the cell walls. Moisture moves in these passage ways in any direction, longitudinally as well as laterally. Lighter woods in general dry more rapidly than do the heavier woods. (20) However, if we are concerned with sawdust, there is no difference; if there is any it should be very small and we can neglect it.

The reasons of movement of water during the drying or wetting process of sawdust are as follows: (21)

1) Capillary action, which causes free water to flow, for the most part, through cell cavities and small openings in the cell wall.

2) Differences in relative humidity in the sawdust that causes water vapor to move through various passageways by diffusion.

3) Differences in moisture content that move the bound water through the small passageways in the cell wall by diffusion.

The factors which influence the drying rate or the wetting rate are:

The rate at which moisture moves into sawdust or moves out from sawdust is dependent upon the relative humidity of the surrounding air, the steepness of the moisture gradient, and the temperature of the sawdust, the lower the relative humidity, the greater the capillary flow. Low relative humidities also stimulate diffusion by lowering the moisture gradient. The higher the temperature of the sawdust, the faster will be the rate at which the moisture moves from the wetter interior to the drier surfaces. (21) For the opposite reasons, the same will take place when dry sawdust is mixed with wet grain.

e) Composition of Sawdust

The average plant-nutrient content of sawdust in comparison with wheat, straw, and alfalfa hay is given in Table 9. It will be observed that sawdust is extremely low in nitrogen, phosphorus and potassium. (1)

TABLE 9

Quantities of the principal plant nutrients contained in various plant products, per ton of dry matter. (1)

Dry material (in lbs.)	Nitrogen (N)	Phosphorus (P_2O_5)	Potash (K_2O)	Lime (CaO)	Mag. (MgO)
Sawdust	4	2	4	6	0.5
Wheat straw	10	3	12	4	1.2
Alfalfa hay	48	10	28	28	7.0

f) Specific Gravity

The specific gravity of the woods (sawdust) which have been used in this project are:

(1) Basswood (Tilia americana) sp.gr. - .32

(2) Beech (Fagus grandifolia) sp.gr. - .56

(3) Cherry (Prunus serotina) sp.gr. - .47

(4) Elm (Ulmus americana) sp.gr. - .46

All are hardwoods.

2) Sodium Chloride (NaCl)

Salt, sodium chloride, has probably been with us from the beginnings of geologic time, and has probably always been necessary either directly or indirectly through all stages of the evolution of living things. The importance of salt in all recorded civilizations may be gauged by the number of salt words in comtemporary literature. With the exception of water, no other chemical substance is mentioned so often. (18)

Composition

In natural occurence salt is never found absolutely pure. Average analysis of large quantities of salt as mined may run well over 98 percent. The most common insoluble impurities in salt stocks are anhydrite, dolomite, calcite, pyrite, quartz, and iron oxides. The most common soluble impurities include the following ones: Ca, Mg, K, Cl, CO_3, and SO_4. (18)

Occurence

The various occurences of salt can be classified geologically as follows: (18)

1) Salt in Solution
   a) Ocean water

2) Dry Deposits
   a) Playa salts

b) Lake water b) Bedded salts

c) Ground water c) Flowage salts

Physical Properties

Doubtless, sodium chloride has been subjected to every known physical test.

Studies of grain storage in closed containers with air at various relative humidities showed that molding occured at more or less constant relative humidities of the air surrounding the particles of grain. The air in the bin between beans at 16% moisture content may be as damp (75% R. H.) as the air between flaxseeds at 10%, or wheat at 14%. (9) Thus, it is now quite generally agreed that the so-called critical moisture level for any individual species is the percentage at which the seed is in equilibrium with an atmospheric humidity of about 75%. (2) From that statement, we have concluded that the way to maintain an environment of 75% relative humidity to materials in storage is with the use of a saturated solution of sodium chloride.

Figure 9 shows the vapor pressure curves for water and for a saturated solution of sodium chloride. (18) The figures given at the various temperatures on the sodium chloride curve are the ratios of the vapor pressure, or the relative vapor pressure (relative humidity) of the air over the salt solution. Supposing the dry bulb reading to be

15°C. and the wet bulk (NaCl) reading 13°C. as located by a circle on each curve. The curve shows that these would correspond to vapor pressures or approximately 9.2 mm and 13.5 mm or a relative humidity of 9.2/13.5 or 68% which is somewhat drier than necessary for safe storage. In general, if the wet bulb (NaCl) is 1°C. colder than the dry bulk, the grain should store without trouble, usually about 71%. (9) Milner and Geddes (2) consider 74% R. H. or less, sufficiently dry for ordinary storage of dry grain. Table 10 shows the vapor pressure and corresponding relative humidity of saturated solutions of NaCl.

Uses of Salt (NaCl)

Among the "big five" (the primary raw materials - salt, sulfur, limestone, coal and petroleum), salt is unique in versality and number of uses, due to application of a large number of its physical and chemical properties. The following brief list contains both large and small uses. (18):

a) Deliquescence: Removal of water vapor from air and gases; removal of water haze from turpentine, gasoline

b) Freezing point depression: Ice and snow removal from streets; refrigerant,brines, etc.

c) Nutritiveness: Human and animal foods; fertilizers; fermentation industries, etc.

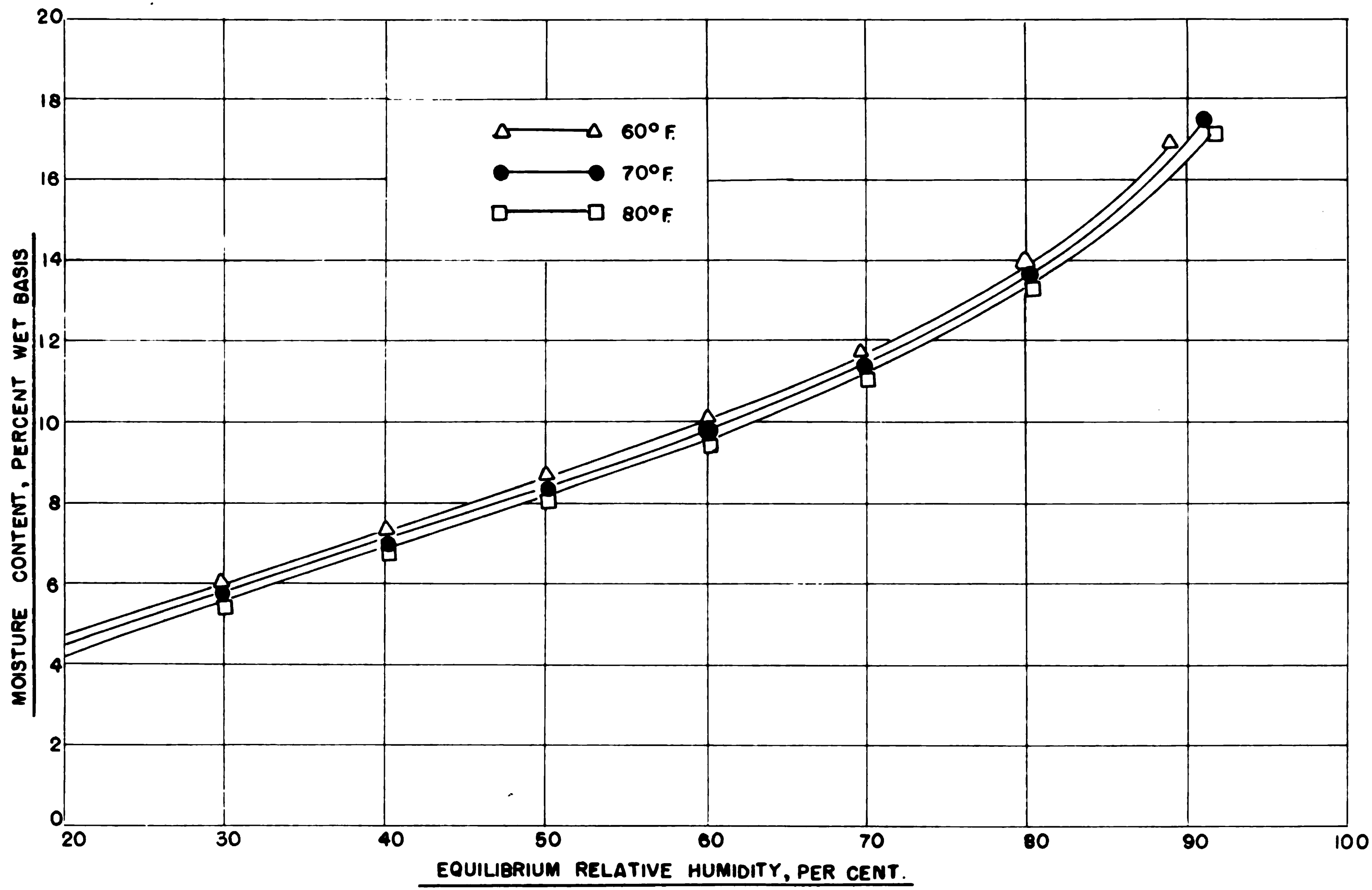


FIG. 8 — DESORPTION ISOTHERMS FOR SAWDUST. (21)

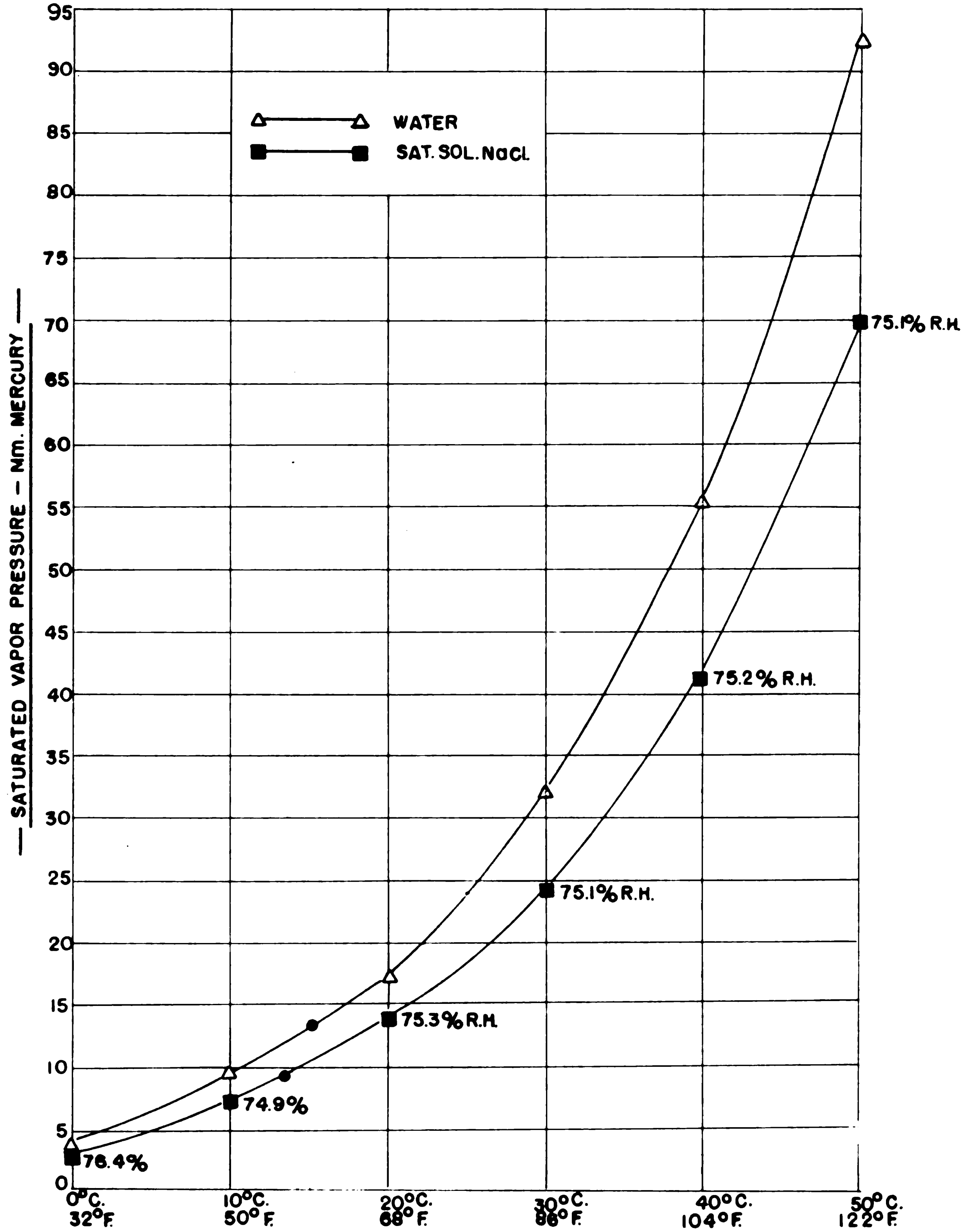


FIG. 9 - THE CURVES SHOW THE SATURATED VAPOR PRESSURE OF WATER AND OF A SATURATED SOLUTION OF NaCl OVER THE TEMPERATURE RANGE OF 0 TO 50°C. AND ALSO THE RATIOS OF THE TWO INTERVALS. (9)(18)

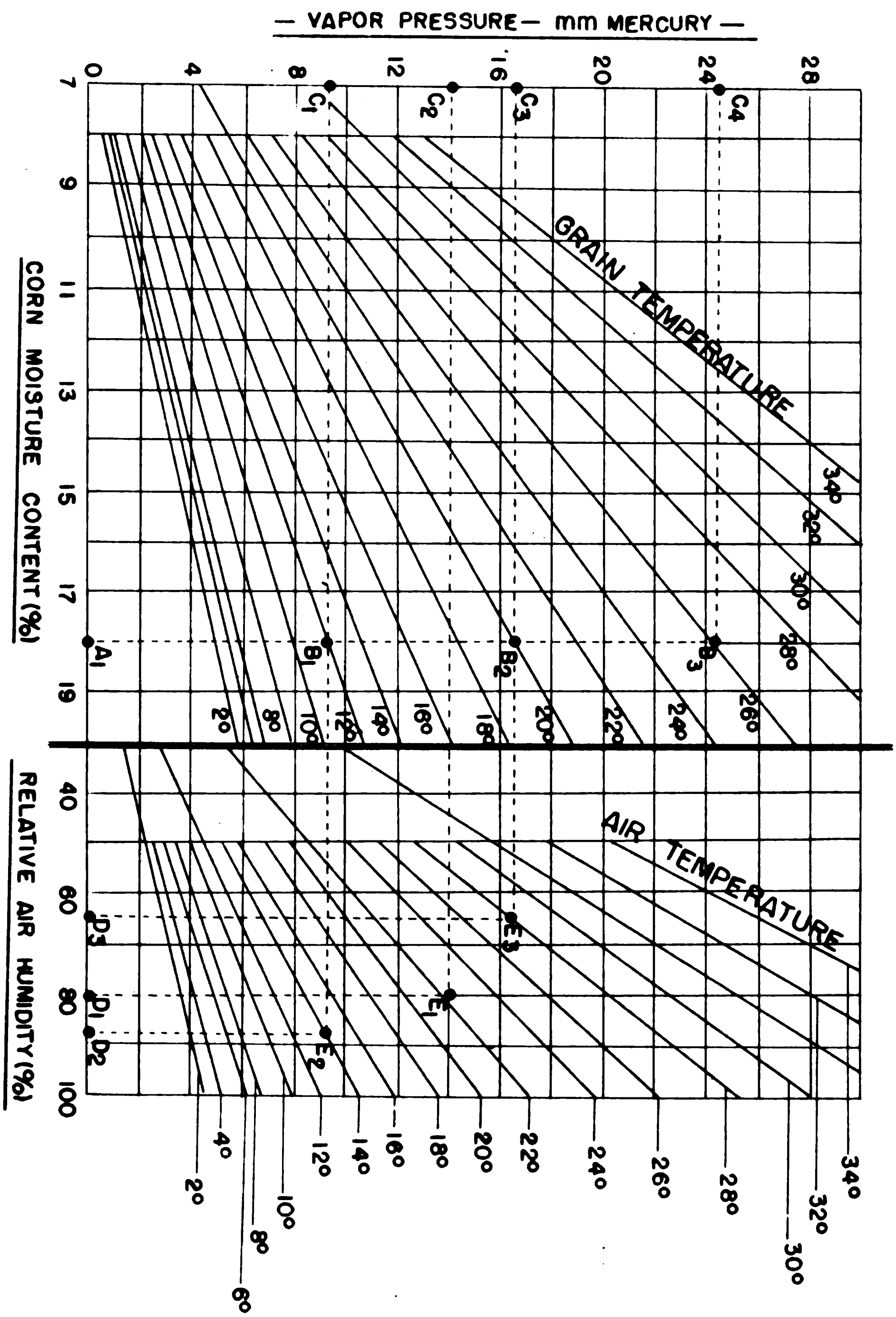


FIG. 10- VAPOR PRESSURE IN CORN, AS A FUNCTION OF ITS MOISTURE CONTENT FOR VARIOUS GRAIN TEMPERATURES, AND IN THE AIR, AS A FUNTION OF ITS RELATIVE HUMIDITY AT VARIOUS TEMPERATURES-°C. (10)

TABLE 10

Vapor Pressure and Relative Humidity of Saturated Aqueous Sodium Chloride Solutions. (18)

Temperature		Vapor Pressure (mm Hg)		Equilibrium Relative Humidity
C°	F°	Sat. Sol. NaCl	H_2O	
0	32	3.5	4.579	76.4%
10	50	6.9	9.209	74.9%
20	68	13.2	17.535	75.3%
30	86	23.9	31.824	75.1%
40	104	41.6	55.324	75.2%
50	122	69.5	92.510	75.1%

Preparation of Saturated Salt Solutions

In order to saturate 100 grams of water, the weight of salt required in grams is: (12)

Chemical	Temperature °C.	Temperature °F.	Weight
NaCl (Sodium chloride)	10	50	35.8
	20	68	36.0
	30	86	36.3
	40	104	36.6
$CaCl_2$ (Calcium chloride)	20	68	59.5
	30	86	74.5
	40	104	102.0

d) Taste: Flavor for foodstuffs, stimulant of sweet flavors, etc.

e) Toxicity: Weed and algae killer, fungicide, germicide, bactericide

f) Preservative action: Curing meats, hides and skins; preserving dairy products, vegetables, fish and shellfish, etc.

g) Vapor pressure: Desiccant, air dryer; wood curing agent.

As we can see, salt has a tremendous application, and we hope very soon to include in this list the property of drying and keeping grain safely with its use in combination with sawdust and other absorbent materials.

3) Calcium Chloride ($CaCl_2$)

Composition

The content of actual calcium chloride in commercial solid calcium chloride is from 73% to 75%, and in flake calcium chloride, it is from 77% to 80%, the balance being principally water of crystallization with a small amount of salt (NaCl). Magnesium chloride is absent, thus precluding the danger of corrosion.

Properties

Calcium chloride dissolves readily in water; in fact, it has such an attraction for water that when exposed to air under ordinary conditions, it absorbs atmospheric moisture until the calcium chloride is dissolved. Its solutions are relatively stable. Such a property makes it a strong drying agent, and its wide use in chemical laboratory as a desiccator.

Table 11 shows the vapor pressure and corresponding relative humidity of saturated solutions of $CaCl_2$. The relative humidity is calculated from P/Po, where P = vapor pressure of saturated air and Po = partial vapor pressure of water.

Other properties and uses of calcium chloride were mentioned already when we covered the topic "Drying Agents."

TABLE 11

Vapor Pressure and Relative Humidity of Saturated Aqueous Calcium Chloride Solutions. (16)

Temperature		Vapor Pressure (mm Hg)		*Equilibrium Relative Humidity
°C.	°F.	Sat. Sol. $CaCl_2$	H_2O	
0	32	2.08	4.579	45.4%
10	50	3.71	9.209	40.3%
20	68	6.06	17.535	34.5%
30	86	7.22	31.824	22.6%

* Computed

- - - - - - - - - - -

MATERIALS AND METHODS

I. SHELLED CORN, DRYING AGENTS, AND INSECTS USED:

The corn used in the first stage of this experiment was a yellow dent hybrid which had been stored at $0^{o}F$. for a period of eight months. It had an average moisture content (wet basis) of 30%. A portion of this corn was dried at room temperature (approximately $77^{o}F$.) in order to reach 20% moisture content.

In the second stage of this experiment, the corn used was a yellow dent hybrid which had been stored in an elevator for a period of more than one year. It had an average moisture content of 12.5%. This corn was wetted to 22.5% and was used in the final experiment.

The drying agents which were used are: sodium chloride (table salt and rock salt), calcium chloride, and dried sawdust which was screened through a 12/64 inch round hole screen. The dried sawdust was a mixture from four different woods: beech, elm, cherry, and basswood.

The insect used to test the DRIERS as an insecticide or an insect repellant was the granary weevil (adults) (Sitophylus granarius - Linne).

II. PREPARATION OF "DRIERS"

Several mixtures of sawdust and salt were prepared using different concentrations of salt. These mixtures will henceforth be designated as:

DRIER - Na5 (1 part NaCl : 5 parts sawdust)

DRIER - Na10 (1 part NaCl : 10 parts sawdust)

DRIER - Na20 (1 part NaCl : 20 parts sawdust)

DRIER - Ca5 (1 part $CaCl_2$: 5 parts sawdust)

DRIER - Ca10 (1 part $CaCl_2$: 10 parts sawdust)

DRIER - Ca20 (1 part $CaCl_2$: 20 parts sawdust)

DRIER - S (plain dried sawdust):

The term DRIER refers to the combination of sawdust and salt either NaCl, $CaCl_2$, or only plain dried sawdust. Na refers to sodium chloride and the number following it refers to the proportion of sawdust as can be seen above. Ca refers to calcium chloride with the same notation as used for sodium, i.e., DRIER - Na10 - 1 part of sodium chloride (40 grams) to 10 parts of dried sawdust (400 grams). The proportions given as the examples refer to concentration by weight, not by volume.

In order to describe how the "DRIERS" were prepared, the DRIER - Na10 may be taken as an example. Supposing that about 500 grams of the mentioned drier is needed. Then to prepare it, the following steps were followed:

1) Weigh 50 grams of sodium chloride and 500 grams of dried sawdust.

2) Prepare an aqueous solution of the salt. The quantity of water has to be sufficient to wet the 500 grams of sawdust because in this way the sawdust will be impregnated with the solution of sodium chloride. Different

quantities of water have been used to prepare the DRIERS and based on these results, an amount of water equal to about 1/3 of the weight of sawdust is needed to prepare the salt solution. Thus, there will be 35 grams of water for each 100 grams of sawdust. In this example, 175 grams of water (about 1/3 of the weight of the sawdust) should be used to dissolve the salt. The quantity of water indicated as percentage of the weight of the sawdust (35%) was used to prepare all the DRIERS.

3) After preparing the salt solution, it is mixed thoroughly with the sawdust. The damp mixture was placed in an oven at 180°F. for 24 hours in order to obtain the DRIER. To mix the sawdust with salt solution is very easy. With small quantities it can be done with the use of hands; otherwise, in large scale as used in the second stage it can be done with a shovel. (See Figure 11C)

III. PREPARATION OF MIX

Different quantities of DRIER in relation to the quantity of wet shelled corn were also used in this experiment, and for these proportions of DRIER to shelled corn the following notations were adopted:

MIX - 1, Na5 (1 part corn : 1 part DRIER - Na5)

MIX - 3, Na5 (3 parts corn : 1 part DRIER - Na5)

MIX - 5, Na5 (5 parts corn : 1 part DRIER - Na5)

MIX - 8, Na5 (8 parts corn : 1 part DRIER - Na5)

MIX -10, Na5 (10 parts corn : 1 part DRIER - Na5)

MIX - 1, Na10 (1 part corn : 1 part DRIER - Na10)

MIX - 3, Na10 (3 parts corn : 1 part DRIER - Na10)

MIX - 5, Na10 (5 parts corn : 1 part DRIER - Na10)

MIX - 8, Na10 (8 parts corn : 1 part DRIER - Na10)

MIX -10, Na10 (10 parts corn : 1 part DRIER - Na10)

MIX - 1, Na20 (1 part corn : 1 part DRIER - Na20)

MIX - 3, Na20 (3 parts corn : 1 part DRIER - Na20)

MIX - 5, Na20 (5 parts corn : 1 part DRIER - Na20)

MIX - 8, Na20 (8 parts corn : 1 part DRIER - Na20)

MIX -10, Na20 (10 parts corn : 1 part DRIER - Na20)

MIX - 1, Ca5 (1 part corn : 1 part DRIER - Ca5)

MIX - 3, Ca5 (3 parts corn : 1 part DRIER - Ca5)

MIX - 5, Ca5 (5 parts corn : 1 part DRIER - Ca5)

MIX - 8, Ca5 (8 parts corn : 1 part DRIER - Ca5)

MIX -10, Ca5 (10 parts corn : 1 part DRIER - Ca5)

MIX - 1, Ca10 (1 part corn : 1 part DRIER - Ca10)

MIX - 3, Ca10 (3 parts corn : 1 part DRIER - Ca10)

MIX - 5, Ca10 (5 parts corn : 1 part DRIER - Ca10)

MIX - 8, Ca10 (8 parts corn : 1 part DRIER - Ca10)

MIX -10, Ca10 (10 parts corn : 1 part DRIER - Ca10)

MIX - 1, Ca20 (1 part corn : 1 part DRIER - Ca20)
MIX - 3, Ca20 (3 parts corn : 1 part DRIER - Ca20)
MIX - 5, Ca20 (5 parts corn : 1 part DRIER - Ca20)
MIX - 8, Ca20 (8 parts corn : 1 part DRIER - Ca20)
MIX - 10, Ca20 (10 parts corn : 1 part DRIER - Ca20)
MIX - 1, S (1 part corn : 1 part DRIER - S)
MIX - 3, S (3 parts corn : 1 part DRIER - S)
MIX - 5, S (5 parts corn : 1 part DRIER - S)
MIX - 8, S (8 parts corn : 1 part DRIER - S)
MIX - 10, S (10 parts corn : 1 part DRIER - S)

The term "MIX" refers to the mixture of shelled corn and DRIER. The first number after the word MIX refers to the quantity of corn in proportion to the quantity of DRIER. The symbols Na5, Ca10,S, Na10, and so forth, are referred to as the DRIER which had been used to prepare the specified MIX. In all cases, the proportions given refer to quantities by weight, and not by volume. To illustrate, an example is given below.

In order to describe how the MIX was prepared, the MIX 3 Ca20 may be used as an example. Supposing that we have 300 grams of wet shelled corn and we would like to use the DRIER - Ca20 as the drying agent to dry it by the use of MIX - 3 Ca20. Then to prepare it, the following steps may be followed:

1) Weigh 100 grams of DRIER - Ca20 that has been prepared as indicated previously.

2) Put the 300 grams of wet shelled corn and the 100 grams of DRIER - Ca2O in a container (bottle), seal it with a lid, shake the container to mix the corn with the DRIER, and then keep it in an appropriate place.

3) An even mixture can be prepared by shaking the corn with the DRIER in a bottle. However, when the quantity of shelled corn is increased as in the second stage of this study, the author advises mixing them in smaller containers before filling the bins (See Figure 11D).

V. MEASUREMENTS (WEIGHING)

An oven method was used to determine the initial moisture content (wet basis) of the shelled corn. To compute the moisture content due to the effect of drying agents the following procedure was used:

At intervals after preparing the MIX, the corn was removed on a 4/16 inch square hole screen. The shelled corn was then weighed. (See Figures 11A and 11E) From this weight the moisture content was computed by using the following equation:

$$M.C.W.B. = 100 - Y$$

$$Y = \frac{\text{Initial weight of S.C.} \times X}{\text{Final weight of S.C.}}$$

Where: M.C.W.B. - Moisture content wet basis

S.C. - Shelled corn

X - Percentage dry matter (initial)

Y - Percentage dry matter (final)

Supposing 200 grams of S.C. at 20% M.C.W.B. has been mixed with DRIER, and that after 2 days in the MIX, the weight of S.C. was 180 grams. Therefore, the M.C.W.B. will be:

X = 80%
100 - 20% M.C.W.B. = 80% Dry matter

$$Y = \frac{200 \times 80}{180} = 88.88\%$$

M.C.W.B. = 100 - 88.88% = 11.12%

Figure 11A - Weighing shelled corn and showing equipment used during laboratory experiments.

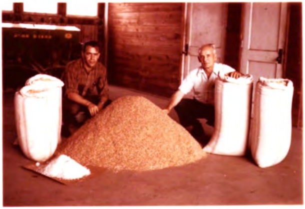


Figure 11B - Dr. S. T. Dexter and the author with the material used in the large scale experiment (corn in bags, salt, and sawdust).

Figure 11C - Shovelling sawdust with salt solutions in preparing the DRIER.

Figure 11D -

Filling the Bin with MIX - 3 Na10.

Figure 11E - Screening to remove the sawdust before weighing the dried corn.

RESULTS

I. PRELIMINARY EXPERIMENTS

A. *DRIER - Na5, DRIER - Na10, and DRIER - Na20

With these DRIERS, the following MIXES were prepared: MIX - 3 Na5, MIX - 3 Na10, MIX - 3 Na20, MIX - 5 Na5, MIX - 5 Na10, MIX - 5 Na20, MIX - 10 Na5, MIX - 10 Na10, and MIX - Na20.

A sample of 200 grams of shelled corn at 30% M.C.W.B. was used in each one of these MIXES. The bottles filled with the MIXES were kept in a temperature-control chamber at 80°F. and the measurements were made at intervals of 1, 2, 4, and 6 days as shown in Table 12.

Table 12 shows that the minimum moisture content reached was 18.13% in MIX - 3 Na5 and 19.45% in MIX - 3 Na10. In the others, the moisture content was greater than 20%.

Mold growth was observed in MIX - 10 Na5, MIX - 10 Na10, and MIX - 10 Na20 at the fourth day; in MIX - 5 Na20, MIX - 3 Na20 at the sixth day. In the other during the first six days mold growth did not take place. One bottle with plain shelled corn at 30% M.C.W.B. was kept under the same conditions and mold growth started at the second day.

B. DRIER - Ca5, DRIER - Ca10, and DRIER Ca20

The same experiments conducted in A as far as MIX,

*The sodium chloride used in this experiment was table salt, only in the experiment conditioning the MIX in bins was the rock salt used.

TABLE 12

The drying of shelled corn (30% M.C.W.B.) when conditioned in sealed containers at 80°F. with: MIX - 3 Na5; MIX - 5 Na5; MIX - 10 Na5; MIX - 3 Na10; MIX - 5 Na10; MIX - 10 Na10; MIX - 3 Na20; MIX - 5 Na20; and MIX - 10 Na20.

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	*MIX - 3 Na5		*MIX - 5 Na5		*MIX - 10 Na5	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	178.00	21.35	181.00	22.65	186.50	24.94
2	172.10	18.65	179.10	21.84	186.40	24.90
4	171.50	18.37	178.40	21.53	186.35	24.87
6	171.45	18.35	178.30	21.50	186.35	24.87
	*MIX - 3 Na10		*MIX - 5 Na10		*MIX - 10 Na10	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	179.40	21.97	183.41	23.67	186.60	24.98
2	174.50	19.77	179.90	22.18	185.70	24.60
4	173.90	19.50	179.80	22.14	185.70	24.60
6	173.80	19.45	179.80	22.14	185.65	24.58
	*MIX - 3 Na20		*MIX - 5 Na20		*MIX - 10,Na20	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	181.52	22.88	185.30	24.45	189.20	26.00
2	178.70	21.76	182.60	23.33	188.00	25.50
4	177.70	21.22	182.40	23.25	188.00	25.50
6	176.70	20.77	182.00	23.10	187.90	25.48

*See pages 70, and 71 for the meaning.

sample of corn, and temperature control are concerned were followed with these DRIERS. The measurements at intervals of 1, 2, 4, and 6 days are shown in Table 12A.

Table 12A shows that the minimum moisture content reached was 18.04% in MIX - 3 Ca5 and 19.08% in MIX - 3 Ca10. In others, as in the experiment with sodium chloride, the moisture content was greater than 20%.

As far as mold growth is concerned, the same results which were observed with the use of DRIER - Na were observed with the use of DRIER - Ca.

C. DRIER - S

With this DRIER, the following MIXES were prepared: MIX - 3 S, MIX - 5 S, and MIX - 10 S. The shelled corn used was the same used in A and B and the bottles with the MIX were kept also in a temperature-control chamber at 80°F. The measurements followed the same procedure as in A and B and they are shown in Table 12B.

Table 12B shows that the minimum moisture content reached was 23.92 with MIX - 3 S and the maximum 27.70% with MIX - 10 S.

Mold growth was observed in all of the MIXES at the second day as in the bottle with plain shelled corn.

From these experiments, the author decided to eliminate the DRIERS: Na5, Na20, Ca5, and Ca20 due to the following:

1) DRIER - Na5 and DRIER - Ca5 have almost the same effect of DRIER - Na10 and DRIER - Ca10 as far as drying shelled

corn is concerned, and 2) DRIER - Na20 and DRIER Ca20 have almost the same effect as DRIER S as far as drying and mold growth are concerned.

TABLE 12A

The drying of shelled corn (30% M.C.W.B.) when conditioned in sealed containers at 80°F. with: MIX - 3 Ca5; MIX - 5 Ca5; MIX - 10 Ca5; MIX - 3 Ca10; MIX - 5 Ca10; MIX - 10 Ca10; MIX - 3 Ca20; MIX - 5 Ca20; and MIX - 10 Ca20.

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	*MIX - 3 Ca5		*MIX - 5 Ca5		*MIX - 10 Ca5	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	174.82	19.92	177.00	20.90	186.95	25.12
2	171.00	18.13	175.50	20.20	186.90	25.10
4	170.90	18.10	175.50	20.20	186.90	25.10
6	170.80	18.04	175.40	20.15	186.80	25.06
	*MIX - 3 Ca10		*MIX - 5 Ca10		*MIX - 10 Ca10	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	178.50	21.53	181.30	22.88	187.70	25.42
2	174.30	19.68	179.80	22.16	186.60	24.98
4	173.40	19.27	179.50	22.00	186.60	24.98
6	173.00	19.08	179.40	21.97	186.50	24.94
	*MIX - 3 Ca20		*MIX - 5 Ca20		*MIX - 10 Ca20	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	180.70	22.53	184.52	24.13	190.30	26.44
2	179.10	21.84	182.80	23.42	189.20	26.00
4	179.00	21.79	182.80	23.42	189.10	25.97
6	178.90	21.75	182.70	23.38	189.00	25.93

*See pages 70,and 71 for the meaning.

TABLE 12B

The drying of shelled corn (30% M.C.W.B.) when conditioned in sealed containers at 80°F. with: MIX - 3 S; MIX - 5 S; and MIX - 10 S.

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	*MIX - 3 S		*MIX - 5 S		*MIX - 10 S	
0	200.00	30.00	200.00	30.00	200.00	30.00
1	187.20	25.22	190.50	26.51	194.90	28.17
2	185.20	24.40	189.60	26.17	194.50	28.13
4	184.50	24.12	189.60	26.17	193.70	27.73
6	184.00	23.92	189.00	25.93	193.60	27.70

* Percent moisture content (wet basis)

II. EXPERIMENTS WITH DRIER - NaIO, DRIER - CaIO, AND DRIER - S

A. DRIER - NaIO

Three samples of shelled corn at 20% M.C.W.B. weighing 100 grams each were mixed with DRIER - NaIO in order to make the MIXES: MIX - 1 NaIO. Three similar replicates were made of the following MIXES: MIX - 3 NaIO, MIX - 5 NaIO, MIX - 8 NaIO, and MIX - 10 NaIO. The bottles filled with these mixes were kept in a temperature-control chamber at 80°F.

The corn was screened from the mix and weighed at intervals of 1, 2, 4, 6, 8, and 10 days. After the tenth day, the bottles were transferred from the chamber to a room without temperature control and at the 30th day the last measurement was taken as shown in Table 13.

Table 13 shows that at the end of six days the minimum moisture content reached was 12.40% in MIX - 1 NaIO and the maximum 17.02% in MIX - 10 NaIO. However, in MIX - 3 NaIO at the end of the same period of time the moisture content reached was 14.17% which is satisfactory for the storage of shelled corn due to the fact that mold growth did not take place. Table 13 also shows that the moisture content at the end of ten days and at the end of 30 days were practically the same, leading to the conclusion that variation of temperature had no effect on the DRIER - NaIO.

Mold growth was observed on MIX - 8 NaIO and MIX - 10 NaIO. In the first one, mold started at the end of 15 days and in the second one at the end of ten days.

TABLE 13

The drying of shelled corn (20% M.C.W.B.) in sealed containers at 80°F. with: MIX - 1 Na10, MIX - 3 Na10, MIX - 5 Na10, MIX - 8 Na10, and MIX - 10 Na10.

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	* MIX - 1 Na10		* MIX - 3 Na10		* MIX - 5 Na10		* MIX - 8 Na10		* MIX - 10 Na10	
0	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00
1	93.18	14.15	94.38	15.24	94.83	15.64	96.20	16.84	96.95	17.49
2	93.02	14.00	93.80	14.72	94.17	15.02	95.95	16.63	96.73	17.30
4	91.66	12.72	93.62	14.55	94.06	14.95	95.85	16.54	96.58	17.17
6	91.33	12.40	93.25	14.17	94.00	14.90	95.82	16.52	96.40	17.02
8	91.26	12.34	93.22	14.16	93.98	14.88	95.78	16.48	96.26	16.90
10	91.15	12.24	93.05	14.03	93.93	14.84	95.75	16.45	96.20	16.84
30	91.06	12.15	93.82	14.00	93.90	14.81	95.72	16.43	96.18	16.83

*See pages 70 and 71 for the meaning.

B. DRIER - CalO

Similar experiments were conducted with DRIER - CalO in the following MIXES: MIX - 1 CalO, MIX - 3 CalO, MIX - 5 CalO, MIX - 8 CalO, and MIX - 10 CalO. (See Table 13A)

Table 13A shows that the minimum moisture content reached at the end of six days was 12.34% in MIX - 1 CalO and the maximum 16.90% in MIX - 10 CalO. In MIX - 3 CalO the moisture content reached was 13.76% which is also satisfactory for storage of shelled corn.

The variation of moisture content from the tenth to the 30th day can be neglected as shown in Table 13A.

Mold growth was observed in MIX - 5 CalO, MIX - 8 CalO, and MIX - 10 CalO, in the first one at the end of 30 days in the second at the end of ten of ten days, and in the last one at the end of eight days.

So far, the data show that as far as drying of shelled corn is concerned, the DRIER - CalO and DRIER - NalO have about the same properties. Nevertheless, from the standpoint of mold growth, sodium chloride has more fungicidal action.

C. DRIER - S

The same procedures which had been followed in the experiments conducted with DRIER - CalO and DRIER - NalO were used with DRIER - S in preparing and keeping the following MIXES: MIX - 1 S, MIX - 3 S, MIX - 5 S, and MIX - 10 S. The measurements are shown in Table 13B.

TABLE 13A

The drying of shelled corn (20% M.C.W.B.) in sealed containers when conditioned at 80°F. with: MIX - 1 Ca1O, MIX - 3 Ca1O, MIX - 5 Ca1O, MIX - 8 Ca1O, and MIX - 10 Ca1O.

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	* MIX - 1 Ca1O		* MIX - 3 Ca1O		* MIX - 5 Ca1O		* MIX - 8 Ca1O		* MIX - 10 Ca1O	
0	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00
1	92.73	13.63	94.00	14.90	95.22	16.00	96.83	17.39	96.96	17.50
2	90.66	12.76	93.50	14.44	94.90	15.70	96.62	17.20	96.55	17.15
4	90.46	12.57	92.96	13.95	94.80	15.62	96.43	17.04	96.42	17.03
6	90.23	12.34	92.76	13.76	94.78	15.60	96.25	16.89	96.26	16.90
8	90.20	12.31	92.73	13.73	94.73	15.55	96.23	16.87	96.24	16.88
10	90.08	12.20	92.42	13.44	94.70	15.53	96.20	16.84	96.23	16.87
30	89.88	12.00	92.25	13.28	94.37	15.23	96.18	16.83	96.23	16.87

* See pages 70 and 71 for the meaning.

Table 13B shows that at the end of six days the minimum moisture content reached was 13.14% in MIX - 1 S and the maximum 18.92% in MIX - 10 S.

Mold growth was observed in MIX - 3 S, MIX - 5 S, MIX - 8 S, and MIX - 10 S. In the first and second one at the end of eight days, and at the end of six days in the other two.

A sample of shelled corn at 20% M.C.W.B. was kept under the same conditions and the mold started to take place at the end of four days.

TABLE 13B

The drying of shelled corn (20% M.C.W.B.) in sealed containers when conditioned at 80°F. with: MIX - 1 S, MIX - 3 S, MIX - 5 S, MIX - 8 S, and MIX - 10 S.

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	* MIX - 1 S		* MIX - 3 S		* MIX - 5 S		* MIX - 8 S		* MIX - 10 S	
0	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00
1	94.76	15.58	96.33	16.94	97.45	17.81	98.60	18.87	98.88	19.10
2	93.26	14.22	96.00	16.67	97.25	17.74	98.46	18.75	98.85	19.07
4	92.45	13.47	95.73	16.42	97.12	17.63	98.26	18.59	98.75	19.00
6	92.10	13.14	95.55	16.24	96.90	17.45	98.10	18.46	98.66	18.92
8	92.06	13.11	95.50	16.22	96.85	17.40	98.07	18.43	98.61	18.88
10	91.95	13.00	95.48	16.21	96.76	17.33	97.95	18.33	98.50	18.79
30	91.90	12.95	95.45	16.19	96.80	17.36	98.20	18.44	98.60	18.87

* See pages 70 and 71 for the meaning.

III. EXPERIMENTS WITH DRIER - NalO, DRIER - CalO, AND DRIER - S PREPARED UNDER SPECIAL CONDITIONS

After preparing the DRIERS(DRIER - NalO, DRIER - CalO, and DRIER - S), they were left for three days spread out on a table at room temperature. The following figures were taken under these conditions:

	DRIER - CalO	DRIER - S	DRIER - NalO
Start	200 gr.	200 gr.	200 gr.
3 days later	218 gr.	213 gr.	209 gr.

From these figures, one can see that the DRIER - CalO picked up from the air twice as much water as the DRIER - NalO.

A sample of 100 grams of shelled corn at 20% M.C.W.B. was mixed with each drier under consideration in order to make the following MIXES: MIX - 3 NalO, MIX - 3 CalO, and MIX - 3 S. The bottles filled with these MIXES were kept in a temperature-control chamber at 80°F. The measurements were taken as in the Experiment II and are shown in Table 14 and illustrated in Figure 12.

Table 14 shows that the minimum moisture content reached at the end of six days was 14.66% in MIX - 3 NalO (a), and the maximum 16.89% in MIX - 3 S (a). At the end of the same period of time the moisture content in MIX - 3 CalO (a) was 15.53%. Mold growth was observed in MIX - 3 CalO (a) at the end of 15 days and in MIX - 3 S (a) at the end of six days.

TABLE 14

The drying of shelled corn (20% M.C.W.B.) in sealed containers when conditioned at 80°F. with: MIX - 3 Na10 (a), MIX - 3 Na10 (b), MIX - 3 Ca10 (a), and MIX - 3 S (a).

TIME DAYS	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %	WEIGHT CORN GRAMS	MOISTURE CONTENT %
	MIX - 3 Na10 (a)		MIX - 3 Na10(b)		MIX - 3 Ca10(a)		MIX - 3 S (a)	
0	100.00	20.00	100.00	20.00	100.00	20.00	100.00	20.00
1	94.80	15.62	94.84	15.65	95.25	16.02	97.00	17.50
2	94.32	15.19	94.23	15.21	95.03	15.82	96.65	17.22
4	93.85	14.75	93.84	14.75	94.84	15.65	96.40	17.02
6	93.74	14.66	93.70	14.63	94.70	15.53	96.25	16.89
8	93.68	14.61	93.68	14.61	94.66	15.49	96.22	16.86
10	93.60	14.53	93.65	14.58	94.56	15.40	96.18	16.83
30	93.35	14.30	93.55	14.49	94.43	15.29	96.18	16.83

(a) After preparing the DRIERS, they were spread out on a table (at room temp.) for 3 days.

(b) The DRIER Na10 was dried at room temperature.

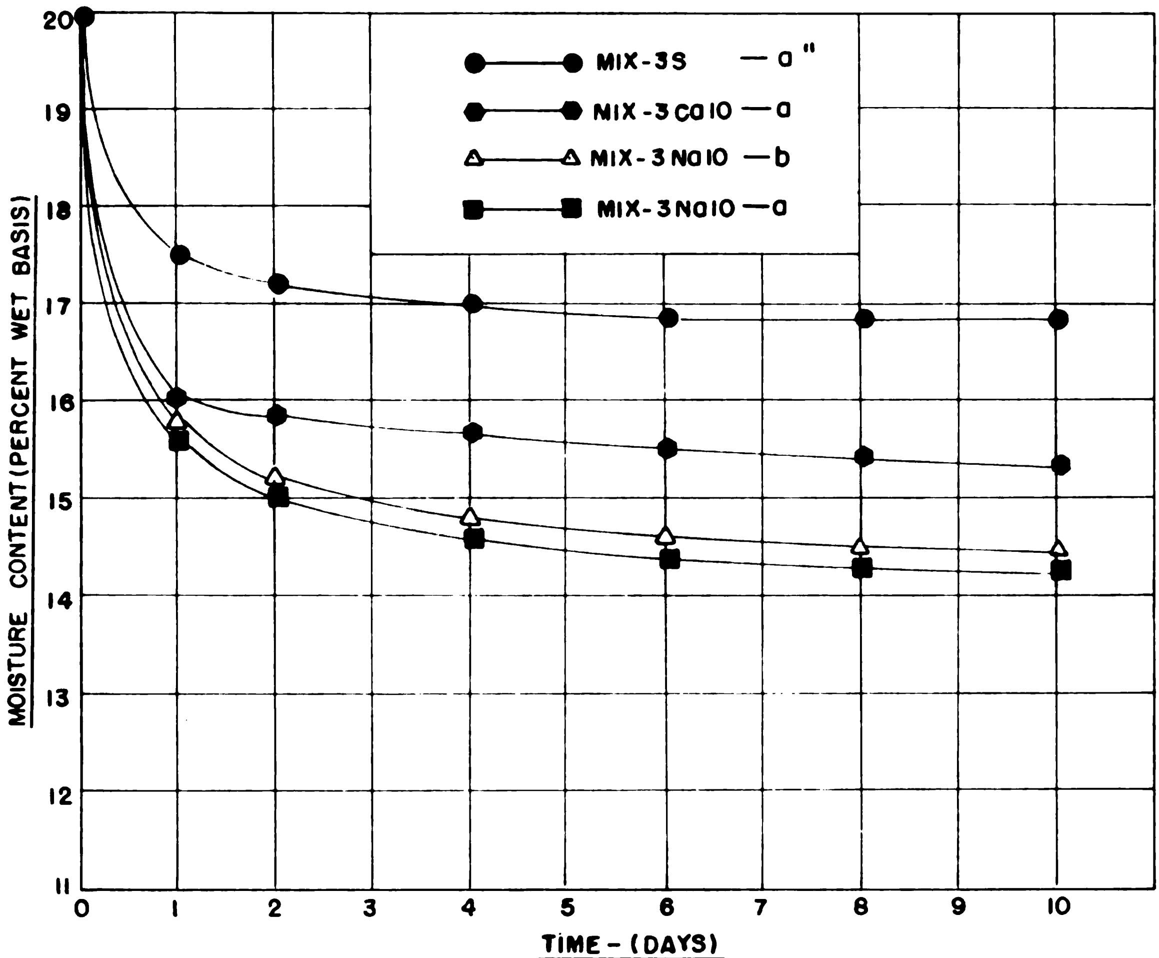


FIG. 12 — MOISTURE CONTENT OF WET SHELLED CORN WHEN STORED WITH MIX-3S, MIX-3Na 10, AND MIX-3Ca 10.

"a - AFTER PREPARING THE DRIERS THEY WERE LEFT FOR 3 DAYS SPREAD OUT ON A TABLE. (AT ROOM TEMPERATURE)

b - THE DRIER-3Na10 WAS DRIED AT ROOM TEMPERATURE.

At the same time, a similar trial was prepared with DRIER - NalO in the following way: the DRIER - NalO was prepared and dried at room temperature for 48 hours, and at the end of this time its moisture content was 5%. MIX - 3 NalO (b) was then prepared under the same conditions as before (See Table 14 and Figure 12).

Table 14 and Figure 12 show that the moisture content reached in MIX - 3 NalO (b) and MIX - 3 NalO (a) are practically the same. From this experiment (Table 13 and 13A) the author concludes that there is no great difference between MIX - 3 NalO and MIX - 3 NalO (a) or MIX - 3 NalO (b). However, there is a great difference between MIX - 3 CalO and MIX - 3 CalO (a). Therefore, he also concludes that DRIER - NalO is better than DRIER - CalO for the following reasons:

1) To obtain the DRIER - NalO it is not necessary to use artificial drying as in obtaining DRIER - CalO.

2) The DRIER - NalO is therefore easier to make than the DRIER - CalO and also less expensive.

3) The DRIER - NalO obtained without using artificial drying is good enough to be mixed with shelled corn at 20% M.C.W.B. and to bring down its moisture content to the limit for safe storage of shelled corn.

IV. EXPERIMENT ON A LARGE SCALE WITH DRIER - NalO)

In this phase, the DRIER - NalO was prepared as described in "materials and methods." The only modification made was in the quality of the sodium chloride. Instead of using table salt, "rock salt" was used. (Rock salt is unpurified salt, as removed from salt mines.)

The containers used were 3 metal cylindrical bins with the following dimensions: diameter - 11 inches, height - 60 inches.

Three samples of shelled corn at 22.5% M.C.W.B. weighing 60 pounds each were mixed with the DRIER in order to make: MIX - 3 NalO. The bins were covered as follows:

Bin (a) - The bin was sealed with a plastic sheet.

Bin (b) - The top of the MIX - 3 NalO was covered with four inches of DRIER - NalO.

Bin (c) - The top of the MIX - 3 NalO was left opened.

(The bins were kept in a room with a great variation of temperature.)

Some phases of this experiment as the quantity of salt, quantity of dried sawdust, and quantity of damp shelled corn used are shown in Figure 11B as the mixing of salt solution with sawdust in Figure 11C. The operations of filling the bin and screening the corn from MIX - 3 NalO are shown in Figures 11D and 11F.

The corn was screened from the MIX and weighed at intervals of 1, 2, 4, 6, 8, and 10 days. (See Table 15) The data from Table 15 are illustrated in Figure 14.

Table 15 shows that the minimum moisture content reached at the end of six days was 13.25% in bin (c). Nevertheless, at the end of ten days the moisture content was computed again and there was no difference between the bin (a) and the bin (b). At the same time, a sample of corn from the three bins was taken and the moisture content determined by using the oven method, and as Table 15 shows, the moisture content as computed or determined was practically the same.

Mold growth was observed in all of these two months later. The degree of mold was not marked but this result leads to the conclusion that after ten days (maximum) the corn should be screened from the mix and kept clean, or mixed with a small amount of dry drier.

From this experiment the author also concludes that to dry wet shelled corn with the use of DRIER - Na10, it is not necessary to have the bin with the mix sealed when the top is covered with four inches of the DRIER. Another conclusion is that rock salt is somewhat more effective than table salt to dry shelled corn.

The relative volumes of corn grain plus DRIER before and after mixing are of some interest. An example is given below for MIX - 3 Na10:

900 grams of shelled corn (20% M.C.W.B.) = 1400 ml

300 grams of DRIER - Na10 = 1350 ml

The total volume is 2,750 ml before mixing and 2,000 ml after mixing. From this result, one can see that it is not necessary to weigh the corn or the DRIER, because they have practically the same volume. (See Figures 13A, 13B, and 11B) So, to dry damp shelled corn (moisture content equal to or less than 22.5%). he advises one volume of corn to one volume of DRIER; with wetter corn more DRIER should be used.

Relative volumes of salt and sawdust used to make DRIER Na10 were: Salt 10 cc and Sawdust 100 cc, or a proportion of about 1 to 50 by volume.

A sample of corn from bin (b) was analysed after two months and the amount of salt which was held by the corn-grain was 0.05%.

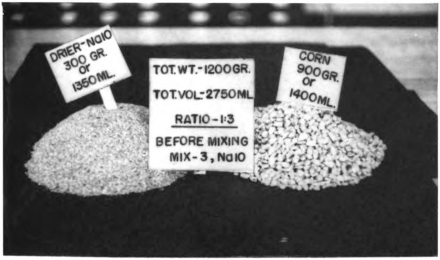


Figure 13A - Relative volumes of DRIER - Na10 to damp corn.

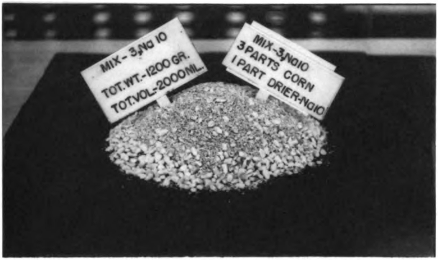


Figure 13B - Weight and volume of MIX - 3 Na10.

Figure 13C - The author showing to Dr. C.W. Hall (his minor professor) the G. Weevils in mixture with DRIER.

TABLE 15

The drying of shelled corn (22.5% M.C.W.B.) in bins (as designated) when conditioned with MIX - 3 Na1O (using rock salt as sodium chloride in DRIER Na1O) and under a great variation of temperature.

TIME DAYS	WEIGHT POUNDS CORN	MOISTURE CONTENT %	WEIGHT POUNDS CORN	MOISTURE CONTENT %	WEIGHT POUNDS CORN	MOISTURE CONTENT %
	*BIN (a)		**BIN (b)		***BIN (c)	
0	60.00	22.50	60.00	22.50	60.00	22.50
1	55.50	15.46	54.50	14.68	57.00	19.42
2	54.50	14.68	54.00	13.89	56.50	17.68
4	54.30	14.37	53.80	13.57	55.70	16.52
6	54.00	13.89	53.60	13.25	55.50	15.46
8	53.80	13.57	53.50	13.09	55.00	15.40
10	53.50	13.09	53.50	13.09	54.50	14.68
10	-----	#13.50	-----	#13.60	-----	# 14.75

*Bin (a) - Bin sealed with a plastic sheet
**Bin (b) - The top of the MIX - 3 Na1O was covered with 4 inches of DRIER - Na1O
***Bin (c) - The top of the MIX - 3 Na1O was left open.
#Moisture content determined in oven.

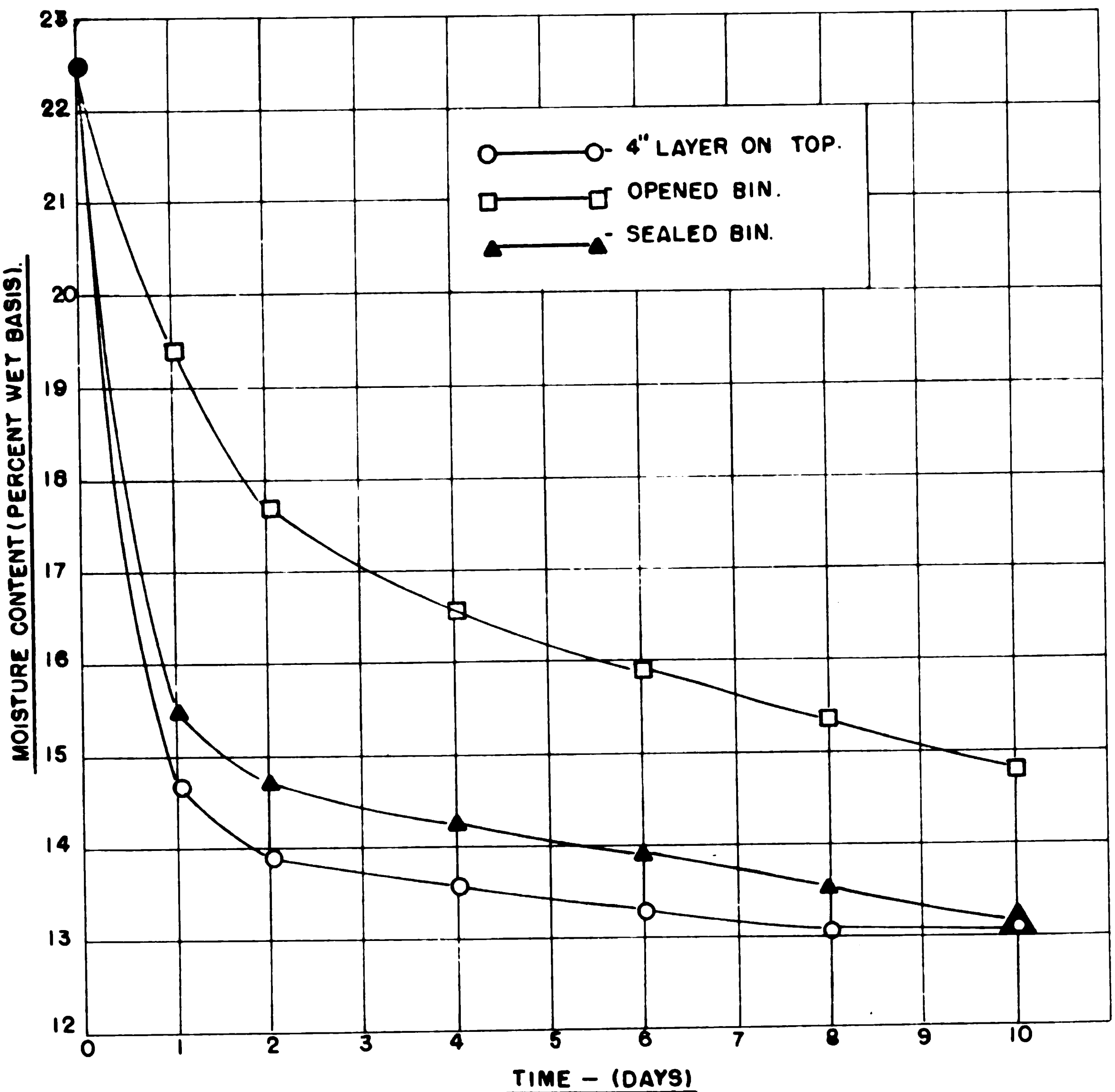


FIG. 14 – MOISTURE CONTENT OF WET SHELLED CORN WHEN STORED IN OPENED BIN, SEALED BIN, AND IN A BIN WITH 4" LAYER OF SAWDUST-SALT ON THE TOP, MIXED WITH SAWDUST AND SODIUM CHLORIDE (NaCl).

V. EXPERIMENTS WITH GRANARY WEEVIL

Nine samples of shelled corn at 20% M.C.W.B. weighing 100 grams each were mixed with DRIERS to make the following MIXES: MIX - 1 NalO, MIX - 3 NalO, MIX - 5 NalO, MIX - 1 CalO, MIX - 3 CalO, MIX - 5 CalO, MIX - 1 S, MIX - 3 S, and MIX - 5 S. At the same time, when the bottles were being filled, 50 granary weevils (adults) were put inside the containers. For illustration see Figure 15E. A bottle with 100 grams of shelled corn was left with 50 insects as a check. All the containers were kept at room temperature (average temperature of five weeks was approximately 80°F).

At the end of five weeks, the MIXES were screened and the insects counted. Table 16 shows the results.

TABLE 16

Behavior of granary weevil when in mixture with MIXES below.

MIX	RATIO BY VOLUME OF CORN TO DRIER	INSECTS DEAD	INSECTS ALIVE	INCREASE OF POPULATION
MIX - 1 NalO	1 : 3	40	10	0
MIX - 3 NalO	1 : 1	10	40	0
MIX - 5 NalO	5 : 2	9	41	0
MIX - 1 CalO	1 : 3	45	5	0
MIX - 3 CalO	1 : 1	11	39	0
MIX - 5 CalO	5 : 2	10	40	0
MIX - 1 S	1 : 3	35	15	0
MIX - 3 S	1 : 1	8	42	0
MIX - 5 S	5 : 2	7	43	0
CHECK	-----	0	75	25

In the bottles where the volume of DRIER was greater than the volume of the corn, the insects did not generally stay in the mixture. At least 80% climbed to the top of the MIX, trying to leave the containers, and most of these eventually died.

Table 16 shows that when the granary weevil was in mixture with corn and DRIER for a period of five weeks, at least seven insects out of fifty were dead. Other conclusions from this experiment are: a) In spite of the fact that five weeks are adequate to allow reproduction, there was no cycle of life except when the granary weevil was in plain corn. b) The effects of DRIER - Na10 and DRIER - Ca10 in comparison with DRIER - S on the insects were almost identical, leading to the conclusion that the insecticidal effect was largely due to the sawdust.

Seven additional experiments were set up based on the fact that the insects climbed to the top of the MIX when the amount of DRIER was increased. (See Figures 15A, 15B, 15C, 15D, 15F, 15G, and 15H). In each of the experiments, all of the DRIERS mentioned were used. In Figure 15F, the DRIERS were mixed as MIX - 3 Na10, MIX - 3 Ca10, and MIX - 3 S and were covered additionally with one inch of each respective DRIER. The methods and results are illustrated in the figures mentioned.

The figures show that in none of the trials, the insects went to the bottom of the container and in all of the trials, they died except in Figures 15B, 15D, and 15H. In Figure 15H, the insects left the bottle.

The main conclusion from this experiment was that the insects died when the air for their respiration was passed through the sawdust, and they were in contact with the DRIER (See Figures 15A, 15C, 15F, and 15G) supporting the point that the sawdust used had some volatile substance which killed the granary weevil if they were unable to excape.

To prove this statement, the author set up the experiment as shown in Figure 16. An Erlenmeyer suction flask was used to supply fresh air to the insects and to avoid air which passed through sawdust. Forty-six insects out of 50 stayed at the bottom of the flask and did not die during a period of three weeks. The four that climbed to the top (after 24 hours) died within a week.

When the direction of the air was reversed, in another trial, so that all air must pass through sawdust, all insects climbed to the top and eventually died.

Figure 13C shows the kind of bottles used in the experiments with the granary weevil.

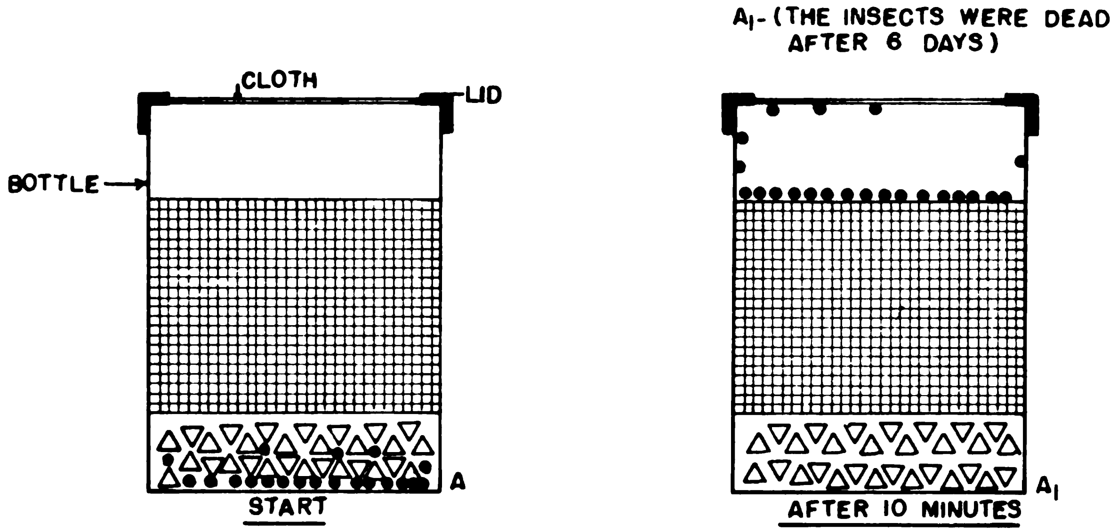


FIG. 15A - MOVEMENT OF G.WEEVIL IN "DRIER"- CORN ENVIRONMENT.

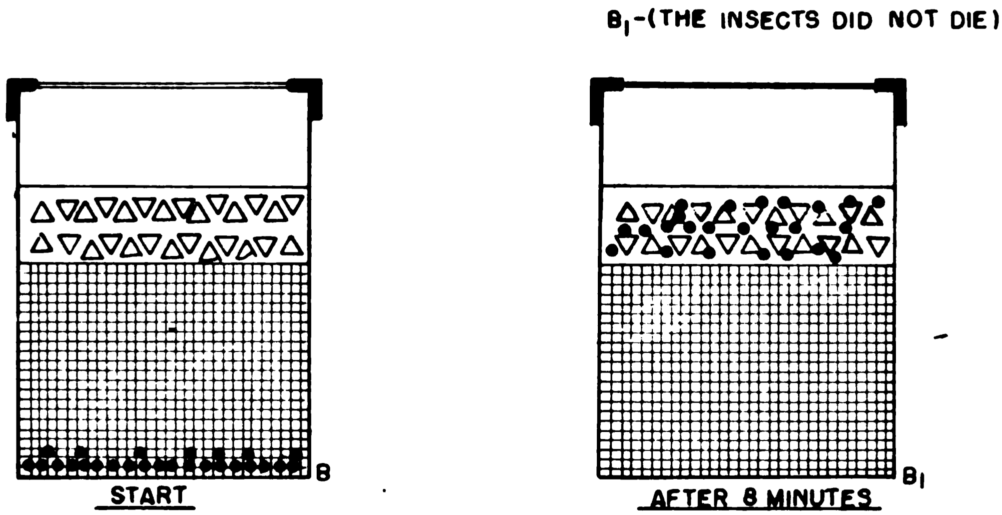
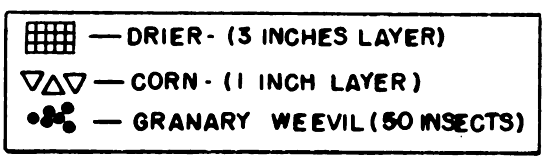


FIG. 15B - MOVEMENT OF G.WEEVIL IN "DRIER" ENVIRONMENT.



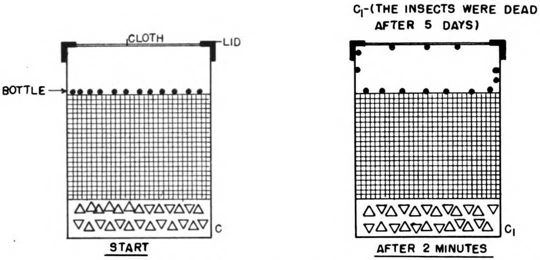


FIG.15C - BEHAVIOR OF G.WEEVIL IN CONTACT WITH "DRIER".

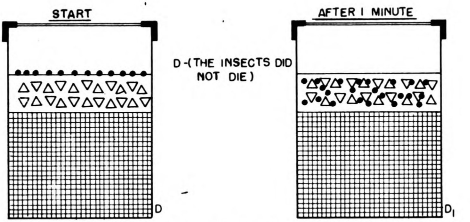


FIG.15D - BEHAVIOR OF G.WEEVIL IN CONTACT WITH CORN.

— DRIER-(3 INCHES LAYER)
— CORN-(1 INCH LAYER)
— GRANARY WEEVIL(50 INSECTS)

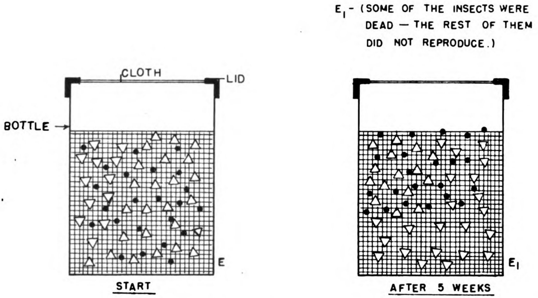


FIG. 15E — BEHAVIOR OF G.WEEVIL IN MIXTURE WITH "DRIER" AND CORN.

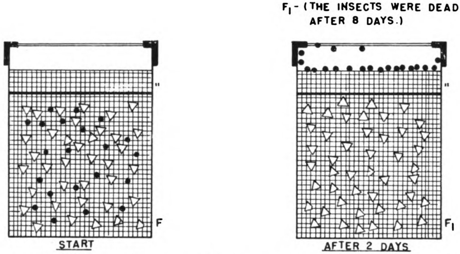


FIG. 15F — MOVEMENT OF G.WEEVIL IN MIXTURE WITH "DRIER" AND CORN.

— DRIER - (66 GR.) - " 1 INCH LAYER _
△▽△ — CORN - (200 GR)
— GRANARY WEEVIL (50 INSECTS)

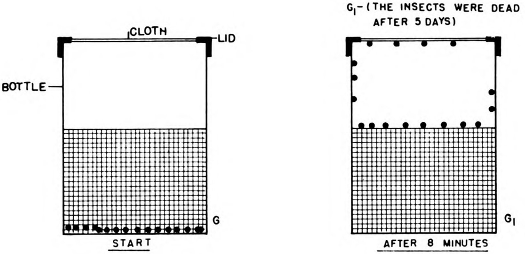


FIG. 15G — MOVEMENT OF G.WEEVIL IN "DRIER".

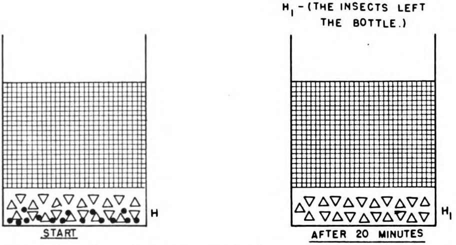
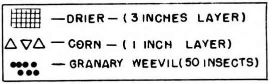


FIG. 15H — MOVEMENT OF G.WEEVIL IN "DRIER"-CORN ENVIRONMENT



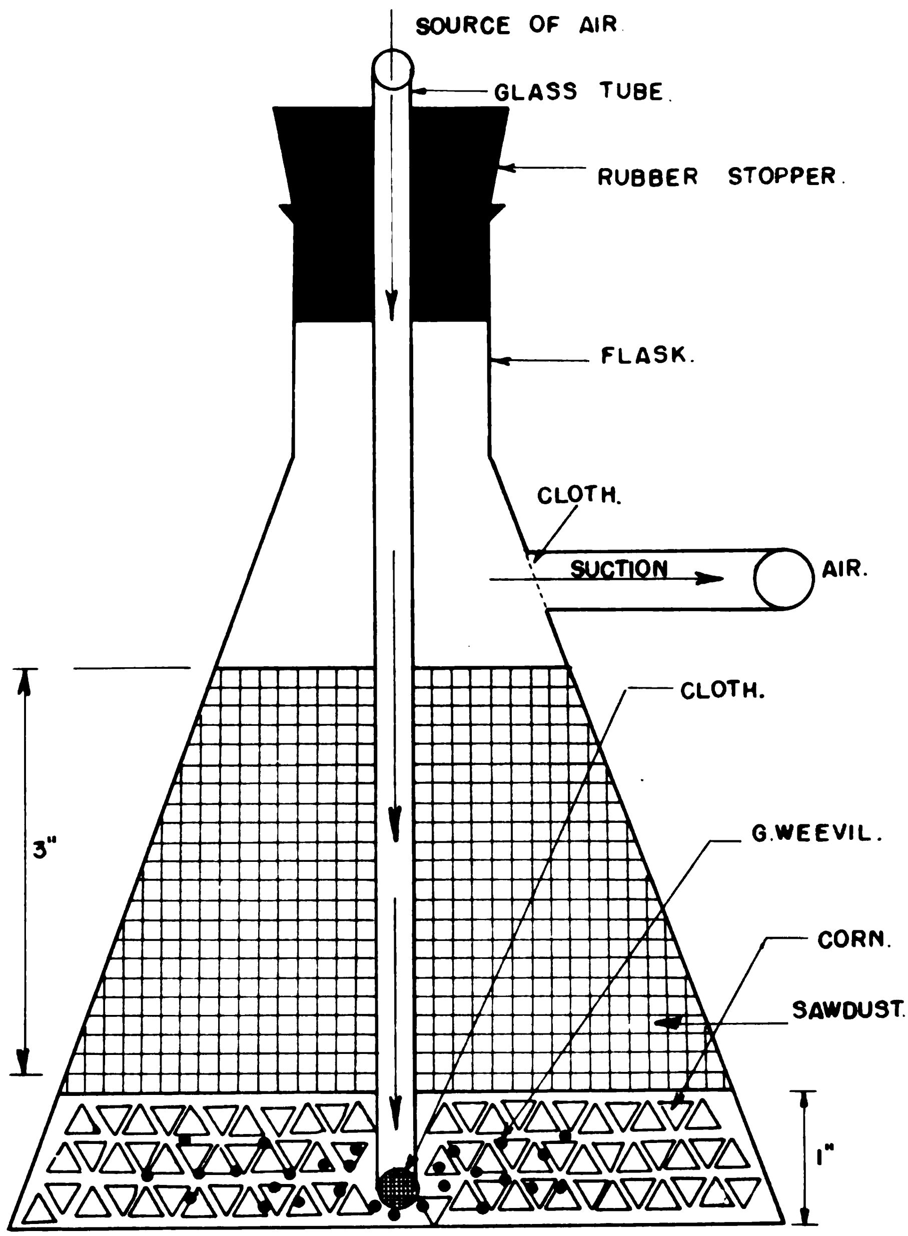


FIG.16 — BEHAVIOR OF GRANARY WEEVIL IN SAWDUST-CORN ENVIRONMENT WHEN A SOURCE OF AIR IS SUPPLIED.

DISCUSSION OF THE THEORY OF DRYING SHELLED CORN USING A MIXTURE OF SAWDUST AND SALT (DRIER)

To explain the phenomena which take place in drying shelled corn with a "DRIER," corn at 20% M.C.W.B. when in mixture with the DRIER - Na10 was chosen as a good representative example.

As the sawdust becomes damp when in mixture with damp corn, the following processes or methods of movement of water from corn to sawdust occur: (a) Capillary action - which causes the free water of damp corn to flow through sawdust, (b) Differences in vapor pressure between damp corn and dried salted sawdust. It is considered that (b) is usually the major drying effect.

The water which is held by the damp shelled corn when in a MIX will move mainly in the form of water vapor. This will be taken up, at first, mainly by the sawdust, because of its low vapor pressure. At the same time, however, some water is absorbed by the sodium chloride and the relative humidity due to the conversion of dry salt to a saturated solution will be 75%. After the sawdust reaches equilibrium at 75% R.H., further solution of salt will maintain approximately 75% R.H. until the salt becomes dissolved.

To saturate 100 grams of water, the weight of sodium chloride required at 80°F. (temperature at which the MIXES were kept) is 36 grams (12). This means that 36 grams of sodium chloride can hold 100 grams of water in a saturated solution at a vapor pressure only 75% that of ordinary water. The relative humidity from the time when the salt absorbs the first drop of water until all 100 grams are absorbed is 75%. This amount is 100/36 or $\sim$2.75 grams of water/gram of NaCl.

The equilibrium moisture content (wet basis) of sawdust at 80°F. and 75% relative humidity (See Figure 8) is 12.5%. Thus, if we have 100 grams of dried sawdust and submit it to these conditions, it will absorb 12.5 grams of water.

From these figures, the theoretical capacity of absorbing water of 100 grams of DRIER - Na10 (90.9 grams of dried sawdust and 9.09 grams of sodium chloride) may be computed to be 36.61 grams (11.36 grams by the sawdust) plus 25.25 grams by the salt)) (See Table 17). This capacity is when the DRIER - Na10 is in equilibrium at 80°F. and 75% relative humidity. Nevertheless, the theoretical capacity of the DRIER for absorbing water under other temperatures will be practically the same. (See Figure 9).

With the data from Table 13 and Table 17, the author made the Table 18, which shows (1) the actual water uptake from 100 grams of shelled corn at 20% M.C.W.B., (2) the actual quantity of water taken up by 1 gram of the DRIER, (3) The percentage of the theoretical drying capacity of DRIER - Na10.

TABLE 17

The theoretical uptake of water from damp shelled corn (100 grams) kept in sealed containers at 80°F. with the designated MIXES, assuming an endpoint at 75% R.H.

MIXES	DRIER		THEORETICAL UPTAKE OF COMPUTED IN GRAMS		TOTAL H_2O UPTAKE (GRAMS)
	SAWDUST (GRAMS)	NaCl (GRAMS)	SAWDUST	NaCl	
*MIX - 1 Na10	90.90	9.09	11.36	25.25	36.61
*MIX - 3 Na10	30.00	3.00	3.75	9.12	12.87
*MIX - 5 Na10	18.18	1.82	2.27	5.05	7.32
*MIX - 8 Na10	11.36	1.14	1.40	3.17	4.57
*MIX -10 Na10	9.09	0.91	1.14	2.52	3.66

*See pages 70 and 71 for the meaning.

In all of the MIXES, except MIX - 10 NaIO, one can see by comparing Table 18 with Table 17, that there was an extra quantity of DRIER which was not used. This is due to the fact that once the equilibrium moisture content of shelled corn was reached its drying process stopped. Nevertheless, with an excess of DRIER, as in MIX 1 NaIO, the corn reached a moisture content of 12.24%, where the relative humidity was below 75%. In this case, little, if any, salt dissolved, all being absorbed by the sawdust. In MIX - 3 NaIO and MIX - 5 NaIO, the corn reached its equilibrium which is in the region of 14% at 80°F. and 75% relative humidity. Considerable salt was still undissolved.

At last the corn in MIX - 8 NaIO and MIX - 10 NaIO reached a moisture content greater than 16% proving that the relative humidity in these cases was above 75% due to scarcity of DRIER. All or most of the salt was dissolved, and the solution became less than saturated.

Table 18 shows that where the quantity of DRIER to dry the same amount of corn was decreased its uptake of water was greater per gram of DRIER. For example, in MIX - 3 NaIO only 54% of the drying capacity of the DRIER - NaIO in picking up moisture from corn was used, and in MIX - 5 NaIO 83%. The author concludes that when the drying capacity used is greater than 83% or smaller than

TABLE 18

Uptake of water from 100 grams of shelled corn at 20% M.C.W.B. kept in sealed containers at 80°F. during 10 days with the designated MIXES.

MIXES	MOISTURE CONTENT PERCENTAGE AT THE END OF 10 DAYS.	GRAMS OF H_2O TAKEN UP BY DRIER - Na10.	COMPUTED MAX. CAPACITY AT 75% R.H. BY THE DRIER.	PERCENTAGE OF DRYING CAPACITY USED BY THE DRIERS.	GRAMS OF H_2O / GRAM OF DRIER (DRIER Na10)
*MIX - 1 Na10	12.24	8.85	36.61	24.30	.0885
*MIX - 3 Na10	14.03	6.95	12.87	54.00	.2106
*MIX - 5 Na10	14.84	6.07	7.32	83.00	.3035
*MIX - 8 Na10	16.45	4.26	4.57	93.20	.3492
*MIX -10 Na10	16.83	3.80	3.66	103.80	.3800

*See pages 70 and 71 for the meaning.

54% the amount of DRIER used is in scarcity and excess respectively. Thus, the DRIER - NalO in MIX - 3 NalO easily met the requirements for safe storage of shelled corn.

From the computations, it is shown that the DRIER - NalO absorbed more than 20% of its weight of water in reducing the moisture content of shelled corn from 20% to 14%. Similarly, DRIER - NalO (having "rock salt" as sodium chloride) dried at room temperature, when in MIX - 3 NalO with shelled corn at 22.5% M.C.W.B. absorbed water to about 30% of its weight in reducing the moisture content of shelled corn from 22.5% to 13.5%.

SUMMARY AND CONCLUSIONS

I. DRYING SHELLED CORN BY USING A SALT - SAWDUST MIXTURE

1. Corn that was too damp for safe storage was dried sufficiently for short periods of safe storage by mixing with it a sufficient amount of a "DRIER" composed of sawdust dried after being dampened with a solution of sodium chloride, or calcium chloride. To prepare the solution a weight of water about 35% of that of the sawdust is needed.

2. The proportion of 10 parts of dry sawdust to 1 part of dry salt (by weight) is recommended, prepared as above.

3. For moisture contents up to about 22.5 - 25% in the corn a proportion of 3 parts of corn, by weight, to 1 part of DRIER was adequate, i.e., MIX - 3 Na10, or MIX - 3 Ca10. This proportion can be attained also by using equal volumes of corn and DRIER.

4. Although calcium chloride had some advantages in a DRIER, the use of sodium chloride seems preferable because it could be prepared by air-drying the impregnated sawdust, whereas a calcium chloride DRIER required oven drying, and, even then required protection to avoid excessive uptake of moisture from somewhat damp air. For longer storage, additional water may be removed with sawdust treated with $CaCl_2$.

5. "Rock salt" was as satisfactory as was purified "table salt," and somewhat more effective.

6. Depending upon the proportion of salts to sawdust, DRIER to corn, the moisture content in the corn, the relative humidity at final equilibrium, the amount of water absorbed from the damp corn may vary widely, from a few percent up to almost 100% of the weight of the DRIER.

7. Screening the sawdust through a 12/64 inch round screen before preparation of the "DRIER", made possible the easy separation of the corn on 1/4 inch square hole screen when drying was completed.

8. Screening to remove the damp sawdust should be done after about 10 days and not longer than a month, to permit examination, mixing, and the decision in regard to the need for further drying. If the sawdust is obviously very damp after a day or two, one may screen and start afresh with additional DRIER.

9. Comparing the drying of shelled corn at 20% M.C.W.B. using the DRIER - NaIO with the drying of the same grain using unheated air (See review of literature), the following advantages in using the first method can be listed:

a) Drying shelled corn with DRIER - NaIO (rock salt) is cheaper than when drying it using unheated air.

b) The drying of shelled corn by using the DRIER does not depend upon the weather after laying the MIX inside the bin. However, using unheated air to dry it, the weather is a crucial factor.

c) To dry shelled corn at 20% M.C.W.B. for a period of ten days to one month mold growth does not take place, but using unheated air under unfavorable conditions (as the climate of Brazil), the shelled corn will not dry in a period of time safe against mold growth and consequently spoilage will take place.

10. The final moisture content of the corn properly dried with salted sawdust, varied from about 13-14.5% M.C.W.B. depending upon the conditions.

II. THE INSECTICIDAL EFFECT OF THE DRIER (MIXTURE OF SAWDUST AND SALT) ON GRANARY WEEVIL

In the experiments conducted with granary weevils as shown in Figures 15A, 15B,15C, 15D, 15E, 15F, 15G, and 15H, the following conclusions were made:

1) The insects when in MIXTURE as illustrated in Figure 15E did not reproduce and a certain proportion died. This proportion increased when the volume of the DRIER was increased in proportion to the volume of corn (See Table 16).

2) The repellant and insecticidal effect of the DRIER on the insects was proven when: (a) the insects climbed to the top of the MIX trying to leave the container. (b) the insects left the container, and (c) when they eventually died if they were not allowed to leave the container (See Figures 15A, 15C, 15F, 15G, and 15H).

3) The insects in all of the trials never went to the bottom of the container (all of the figures illustrate this fact), leading to the conclusion that to avoid granary weevils in storage of shelled corn a good means is to use a layer of the DRIER at the top of the corn mass.

4) The sawdust had some volatile substance(s) in it which was (were) fatal to the granary weevils. This statement is supported by the experiment conducted as illustrated in Figure 15.

SUGGESTIONS FOR FURTHER STUDY

1. Drying to about 12.5% M.C.W.B. rather than 14.5% (65 vs. 75% R.H.) would be helpful for longer storage. How may this be done using a NaCl base?

2. Instead of preparing an aqueous solution of sodium chloride to mix with sawdust to make DRIER - Na10 to use colloidal salt and to compare their effectiveness. Dexter (unpublished) has shown that this can be done.

3. To fill a bin with dried shelled corn (having a moisture content from 13 to 14%) and at the top of the corn to use a layer of four inches of DRIER - Na10 and to verify the capacity of the DRIER in avoiding moisture accumulation at the top and eventually mold growth.

4. To use the DRIER - Na10 in drying coffee due to the fact that coffee is the main crop of Brazil.

5. In regions where sawdust is not available to try other absorbent materials as: ground corn cob, coffee straw, etc.

6. To use sawdust from several different kinds of wood in preparing DRIERS to study the behavior of the granary weevil with only one specified quality of wood. At the same time, it would be advisable to use other species of insects which attack the grain when in storage.

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