THE USE OF CHEMICAL MOLD INHIBITORS IN CURING BALED HAY

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This is to certify that the

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"The Use of Chemical Mold Inhibitors
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Gerald Fennick Richards

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INTRODUCTION

Reason for the Investigation.

Because of the unsettled weather conditions prevailing in most humid and subhumid regions, a practical and economical method of shortening the field curing period of hay was sought. Until the hay crop has been safely placed in storage, it is in constant danger from adverse weather conditions, with the resultant loss in quality and feed value.

Hodgson (8) describes high-quality hay in the following manner:

> We can define high-quality hay as weed-free forage that was dried under such conditions that there was no loss of leaves from handling, no deterioration in dry matter and nutrients from various causes, no mold development, and no loss of the natural green color and sweetness of the original crop.

He also states that hay losses usually originate from three sources: (1) Respiration and fermentation (chemical and bacteriological); (2) Mechanical damage; and (3) Weather damage.

When hay is field cured to a point where the moisture content is sufficiently low to prevent mold formation, there is necessarily a sizable loss in leaves and color. Martin and Leonard (13) state that the loss of alfalfa leaves begins

when the moisture content of the hay drops below forty percent (wet basis). To prevent mold in tightly-baled hay, the moisture content should be less than 20 percent.

Therefore, the problem is clear: to find a practical and economical method, whereby hay can be harvested at a sufficiently high moisture content to prevent undue handling and curing losses, without the mold losses usually encountered. This shortening of the length of the field curing period also substantially reduces the danger of losses due to rain, permitting the farmer to more closely correlate his hay harvest with fair weather.

Mechanical methods have been used as a solution to the problem of hay curing with reasonable success. Those in use at the present time, however, are quite expensive, both in initial cost and cost of operation. For this reason, the quality of the hay or the amount being harvested must be higher than average to make their use economically feasible.

If an inexpensive method of preserving high moisture content hay could be developed, it would be welcomed by the thousands of farmers who wage a constant battle with the elements during the haying season.

REVIEW OF LITERATURE

Importance of Hay

In the years immediately preceding 1940, the hay and forage crop of the United States was second in annual value only to the corn crop, with a total production, in 1939, of 82,413,000 tons of hay. In 1947, a preliminary estimate showed that the total production of hay had risen to 102,500,000 tons, but ranked fourth in annual value because wheat and cotton prices were inflated to a greater extent, during and after World War II, than hay prices.[13]

There are three major reasons why hay is the most important harvested forage.[13] (1) Hay does not deteriorate rapidly; (2) Hay can be handled commercially; and (3) Hay can be harvested with little cash outlay.

Proper haying methods, both in the field and in storage, result in higher-quality hay. The cost of producing high-quality hay is practically the same as for low-quality hay, but the feed value or return per dollar invested is much higher.[22] Since the amount of high-quality hay being placed on the market is quite small, any appreciable improvement in the quality of the crop would substantially increase its total value, together with its importance for feeding purposes.

History of Haymaking

In the first century, A.D., Columella[13] described the curing of hay in a manner that demonstrates how little haying practices have changed since that time.

> It is best to cut down hay before it begins to wither; for you gather a larger quantity of it, and it affords a more agreeable food to cattle. But there is a measure to be observed in drying it, that it be put together neither over dry, nor yet too green, for, in the first case, it is not a whit better than straw, if it has lost its juice; and, in the other, it rots in the loft, if it retains too much of it; and often after it is grown hot, it breeds fire and sets all in a flame. Sometimes also, when we have cut down our hay, a shower surprises us. But, if it be thoroughly wet, it is to no purpose to move it while it is wet; and it will be better if we suffer the uppermost part of it to dry with the sun. Then we will afterwards turn it, and, when it is dried on both sides, we will bring it close together into cocks, and so bind it up in bundles; nor will we, upon any account, delay to bring it under a roof.

Present Methods of Haymaking

Though mechanization has taken over the hay harvest, the fundamental practices have been carried down through the years. Only recently have any real innovations in haymaking been introduced. Forced air mow curing and the field hay crusher may be used as examples.

Most of the hay harvested in the United States is cut with a horse-drawn or tractor mower. In a very limited number of cases, small plots of hay are harvested by other methods. After mowing, the hay is then raked with a dump rake or side-delivery rake for final curing and picking up for storage.

Hay is sometimes loaded by hand, but is usually handled by one of four mechanical methods. When the hay is handled in the long form, a hay loader or sweep rake is used. In the humid and subhumid regions, hay is usually stored in barns, but stack storage is widely used in semi-arid regions.[13] A stacker is usually used to elevate the hay to the top of the outdoor stack, whereas this is usually accomplished with rope tackle in barn storage.

The third method involves the compaction of the loose hay into tight bundles which are tied with wire or twine. Until recent years, hay was baled only for shipment, or in special cases where it was necessary to conserve storage space, but recently the portable pick-up baler has come into common use on farms all over the country. About 40 percent of the hay crop was baled in 1948.[13]

The high cost of equipment has been a major factor in the use of the fourth method of hay harvesting. Within the last few years, however, there has been a very rapid increase in the use of field choppers in the handling of hay. Part of this increase has been due to a reduction in the cost of equipment, and part due to a more general acceptance of the final product as livestock feed. Except for large-scale farming operations, most choppers are operated on a custom basis, with the operator furnishing the necessary equipment.

Molds in Hay

Lewis (9) isolated and identified the fungi found on baled hay in the Lansing, Michigan area. The bales, from which the isolations were made, all showed visible moldiness.

The Ten Most Common Fungi Isolations from Hay in Lansing, Michigan Area[9]

Organism	No. Isolations from 30-40% Moisture Hay	No. Isolations from 10-20% Moisture Hay
Mucor sp.	18	11
Aspergillus niger	11	10
Aspergillus fumigatus	9	4
Penicillium expansum	11	2
Rhizopus sp.	6	9
Alternia sp.	5	8
Fusarium sp.	9	1
Aspergillus glaucus	3	6
Aspergillus repens	4	2
Trichloderma sp.	3	0

Note: Eighteen samples of 30-40% moisture hay used for isolations.

Twelve samples of 10-20% moisture hay used for isolations.

A comparison was made between this table and a list of isolated soil fungi. From this comparison and results furnished by other workers in the field, it was concluded that:

> It is reasonable to assume from these data that the types of fungi causing mold on hay are the predominating fungi in the soil upon which the hay is growing.[9]

A second consideration must include the factors necessary for mold growth. The most important are:

(1) The moisture content or moisture potential of the hay.

> When hay is to be barn dried, it makes little, if any, difference whether moisture potential or moisture percentage is used for characterizing the moisture status of hay for mold growth. This is true because moisture potential under these conditions is always initially high enough for rapid mold growth[6].

(2) The length of storage period;

(3) The balance and type of nutrients present in the hay. Snow (17) states that this factor has been shown to influence the latent period in mold formation as well as the extent of mold formation in the final product.

(4) The temperature of the storage; and

(5) The types of mold species present on the hay.

> While sparse mould development has little deteriorating effect on feeds, vigorous mould growth and abundant production of spores not only causes a breakdown and loss of valuable feeding material (sometimes accompanied by the production of injurious by-products), but also results in the dissemination of the moulds to other materials.[17]

Wheeler (22) states that:

> Sweating of newly harvested hay may increase its palatability by softening the stems and improving the aroma. On the other hand, excessive fermentation may result in serious damage through the destruction of green color and the development of mold and must.

Sometimes fermentation, or oxidation, together with the development of considerable heat, produces a brown hay whose odor resembles cured tobacco. This product is very palatable, but low in feed value.

The following table was adapted by Hodgson (8) from Bechtel et. al., Journal of Dairy Science, 1945.

The Relative Feeding Values of Normal Hay and of Hay that has Heated in the Stack

Item	Normal Hay	Brown Hay	Black Hay
Digestibility Percentages:			
Dry matter	60	41	27
Protein	67	16	3
Fiber	41	36	14
Ether extract	25	33	42
Nitrogen-free extract	72	59	53
Calculated Digestible Nutrients:			
Protein	14.4	3.4	0.6
Total	55.8	37.7	23.4
Palatability: Pounds eaten for 1000 pounds weight	20	15	10

At the present time, forced air mow drying is the most extensively used method of artificial hay curing. The forced air may be either cold or heated, but the use of cold air is generally conceded to be more economical for average conditions. This method involves a reasonably airtight storage compartment, a duct system, and a gasoline engine or electric motor powered fan. Hay is piled over the duct system and air is forced through the entire mass. Though widely used, forced air systems are quite expensive, both in initial cost and operating expense.

A second method of mechanical curing involves the principle of dehydration. The hay is removed from the field as soon as it is cut, is then chopped, and run through a drying chamber where it is exposed to a high initial heat of 1,200 to 1,400 degrees Fahrenheit. Contact with the hot air varies from a few minutes to half an hour, depending upon the temperature of the drier. This method is used in the production of high-quality cattle feed and alfalfa meal, but is not economically feasible for general hay production. The resulting product is high in carotene and riboflavin content.

At the present time, very little work has been done on the use of chemical preservatives in hay, as shown by the fact that only one commercial product is found on the market. This compound has been tested for two years at Michigan State College[4] and the results have shown little, if any, improvement in the quality of the cured hay. The compound is composed, largely, of sodium bicarbonate and calcium bicarbonate which decompose upon contact with moisture in the hay, forming carbon dioxide throughout the hay mass. The carbon dioxide, in turn, displaces the oxygen in the air spaces, which, theoretically, should prevent the growth of molds.

Lewis (9) tested a number of fatty acids on hay. Several, including propionic acid, butyric acid, and valeric acid, proved to be very effective in laboratory tests, but limited field tests show a low effectiveness because of the high volatility of the acids. Several of the acids have a very unpleasant odor, which also limits their use.

Dawson, Musgrave, and Danielson (5) have run tests on a number of compounds having fungicidal properties, but only on a laboratory scale. Four-gram test lots of finely-chopped alfalfa hay were placed in small metal cans. The fungicides were applied by dissolving them in some type of solvent and atomizing the solution onto the hay. The hay was then treated with a fungus spore suspension and stored in air at 85 percent relative humidity. The cans of hay were removed after storage periods of either four or eight weeks. They were dried and weighed, and the hay loss values calculated as an indication of the amount of mold formed.

At the completion of the tests, three compounds had given almost complete control. They were: Mycotox #1, Dowicide #2, and Dowicide #2S. In addition, Mycotox #12, Mycotox #20, and Dowicide #1 were listed by the authors as warranting further study. At the time of this writing, no field test data have been published on the use of these compounds.

LABORATORY TESTS

Objective

The objective of the laboratory tests was to reduce the large number of available mold inhibiting compounds to a number that was within the scope of the final field tests. Because of time limitations on the field test work, it was known that it would be impossible to test all of the available compounds under actual field conditions.

Statement of the Problem

It was felt that the method used to eliminate the least desirable compounds should approximate actual bale conditions as closely as possible, both in environmental conditions and in mold spore inoculation. In addition, the method devised had to be one that could be used in a heated laboratory, because of the winter weather conditions that prevailed at the time of testing.

Because all of the mold inhibiting compounds were obtained in the salt form, it was necessary to choose a solvent to be used in their application to hay. All of the compounds were reasonably soluble in water. Therefore, because of its low cost and ready availability, water seemed to be the most desirable substance to use.

Test Procedure

Clean alfalfa hay, that had been cured in barn storage, was used for the laboratory tests. In future references, this hay will be called storage hay. The hay was free from visible mold, but a few storage bales were slightly musty. Approximately five pounds of hay were placed in each test bale.

The desired quantity of dry hay was first weighed on a set of spring scales, as shown in Fig. 1. An exact quantity of hay could not be used for each test bale because of variations in the texture of hay from different storage bales and different parts of the same storage bale. Within limits, it was thought that uniform test bale size and compaction were more important than uniform test bale weights. Within a single test, bale weights were held as uniform as possible.

As shown in Fig. 2, an ordinary paint sprayer was used to apply the water, or chemical solution to the dry hay. Enough moisture was applied to thoroughly saturate the hay.

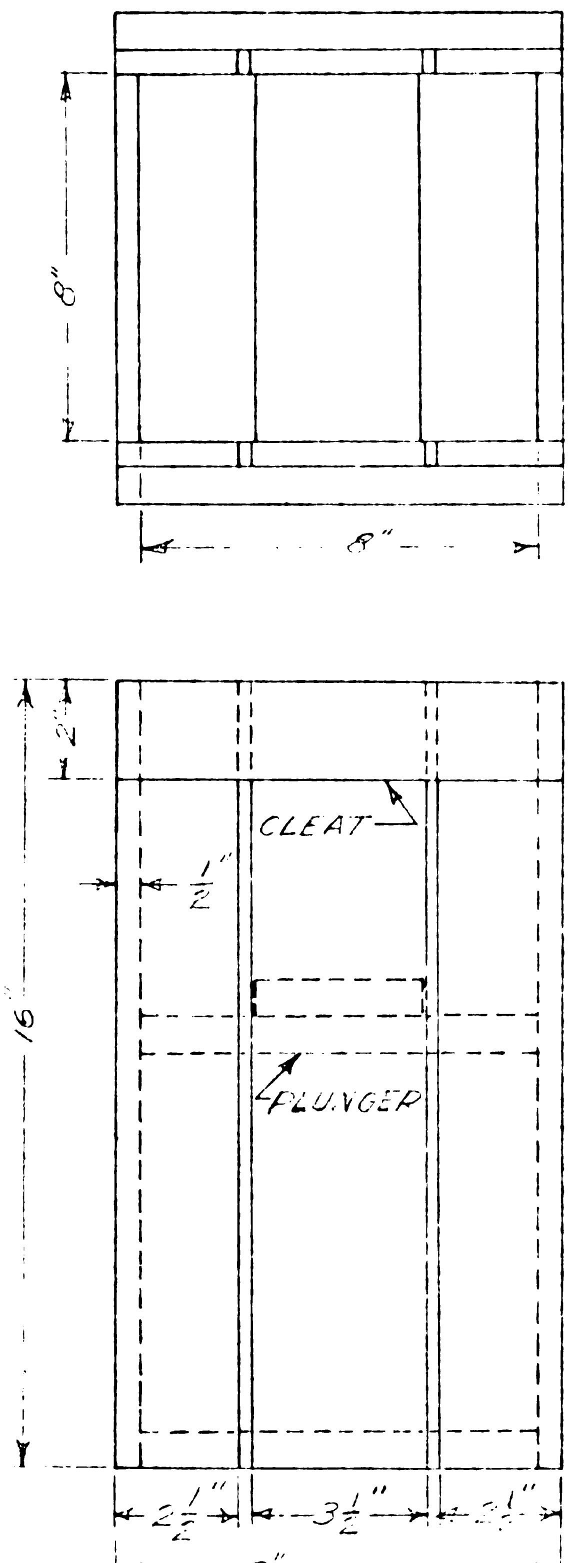
The wetted hay was then placed in the test bale chamber (Fig. 3) and pressure was applied to the movable plate to compress the loose hay. Approximately equal pressures were applied to each test bale, using the hydraulic press shown in Fig. 4. While still under pressure, the bales were tied with ordinary commercial baling wire.

Weighing Dry Hay on Spring Scale

Fig. 1

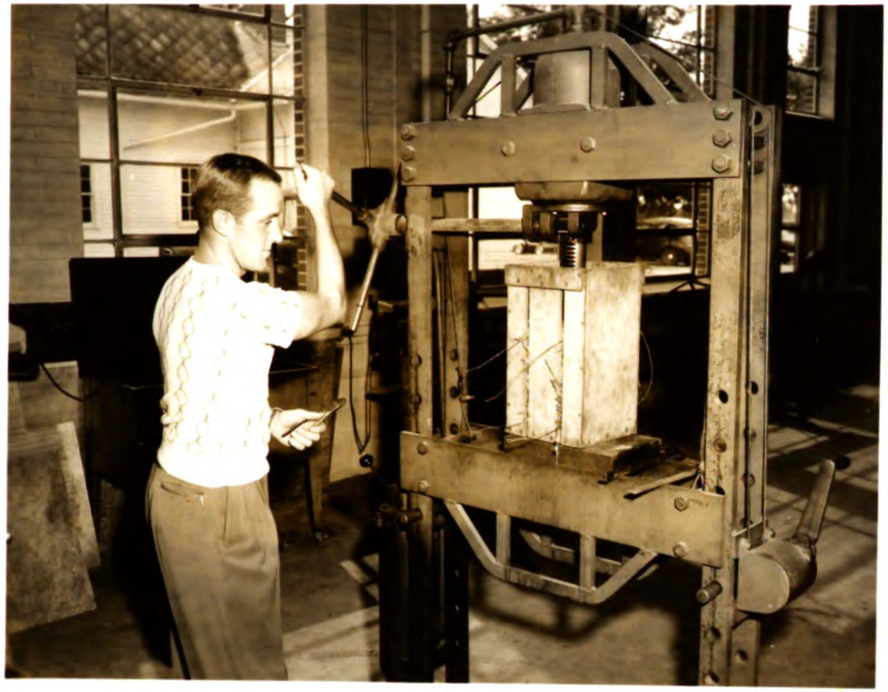
Application of Solution to Hay

Fig. 2



LABORATORY TEST BALL CHAMBER

FIG. 3



Baling in Hydraulic Press

Fig. 4

The finished bales were wrapped with heavy paper to prevent air circulation, reweighed, and allowed to cure at room temperature (approximately 60 degrees Fahrenheit). After the desired curing period, the test bales were opened, and evaluated by visual inspection.

Results and Discussion

Preliminary Tests

As it was not known whether cured hay, to which water had been added, would support mold growth, it was necessary to run a preliminary test in which no treatment was used. The test bale was inspected after 85 hours of curing. The outside of the bale had dried, but the inside was completely covered with mold. This result indicated that the storage hay would prove satisfactory for testing purposes.

After it was found that storage hay would support mold growth, a series of preliminary tests was run to eliminate undesirable compounds and any flaws that might exist in the testing method.

The compounds included in the first test were DHA, Sanobrite, Dowicide G, and DHAS. All compounds, unless otherwise stated, will be listed by the trade names assigned to them by the manufacturer. In addition to one test bale for each of these compounds, two control bales were used in the test. The same hay and baling procedure was used for both the control bales and the treated bales. The untreated bales, used for comparative purposes, will be referred to as control bales in the remainder of this report. It was realized that the results of this type of test would lack statistical significance, but because of time limitations, it seemed to be the only feasible method for eliminating the least desirable compounds.

The test bales were inspected, after a seven day curing period, with the following results: both control bales were completely molded; the bale treated with a one percent solution of Dowicide G contained mold patches throughout the bale; the hay treated with a one percent solution of Sanobrite was still damp with a slightly ensiled odor, but contained no visible mold; and both the DHA and DHAS bales were still damp, released a slightly ensiled odor, and were free of mold. Sanobrite, however, was eliminated from further tests because of its highly irritating effect when sprayed. This characteristic was still clearly evident when the test bale was inspected.

The term "percent solution" as used in the discussion of the laboratory tests refers to the percentage, by weight, of the chemical compound in the water applied to the hay.

The first test indicated that DHA and DHAS showed enough promise to warrant further study. Because DHAS was not readily available, it was decided that more intensive tests should be run on DHA. DHA and DHAS have very similar fungicidal properties, but DHAS is somewhat more soluble in water. For this reason, similar results should be obtained from the use of either compound.

In the second test, the bales were treated with several concentrations of DHA. Five drops of Triton (a commercial detergent) were added to the water to aid in dissolving the salt, and to obtain better coverage. The control bale was inspected after five days of curing, but showed no visible mold. The bale was retied, and all of the bales were inspected after nine days of curing.

The control bale was completely molded; indicating that insufficient time had elapsed, when the bale was first inspected, for the growth of mold. The hay that was treated with a one-tenth percent solution of DHA showed no mold, but exhibited some evidence of bacterial action. This action was indicated by a browned and rotted condition in parts of the test bale. The test bale that was treated with a five-tenths percent solution contained no mold and was still moist, but showed no indication of bacterial action. Two bales were treated with a one percent solution of DHA, with one bale being held for an additional period of seven days before inspection. The first bale contained no mold, but the second bale, after the additional curing period, contained localized patches of mold.

The second test indicated that a five-tenths percent solution of DHA was effective in controlling mold in the test hay. The one-tenth percent concentration seemed to give effective mold control, but failed to check bacterial action. Therefore, the five-tenths percent concentration was the lowest value that could be considered totally effective. Since mold eventually formed in the treated hay, it must be assumed that the DHA compound had a mycostatic effect, instead of a fungicidal effect on the mold organisms in the hay.

At this point in the preliminary test series, there was some question as to the effect, if any, of the detergent that was being used in the water solutions. Therefore, a test was run using two control bales in which no detergent was added to the water, and two bales that were treated with Triton detergent in water. The results of this test indicated that moisture coverage of the hay had been more complete in the treated bales, as shown by heavier mold growth in the bales that were treated with detergent.

The fourth test lot consisted of two series of test bales, each using hay from a different storage bale. Each series consisted of a control bale, and two test bales that were treated with a five-tenths percent solution of DHA. The hay from one storage bale contained many browned and weathered leaves indicating that it had received rain during some part of its field curing period. At the end of a test period of five days, all of the test bales had molded. The hay from the second storage bale was probably harvested when the moisture content was too low, as the leaves were badly shattered. It appeared to be fine, second-cutting hay. At the end of the five-day curing period, the control bale was badly molded, but the treated bales, though still very damp, contained no mold. From these results, it must be concluded that it is more difficult to control mold on poor-quality hay, especially hay that has lain in the field through a rainstorm, than it is on well-cured, good-quality hay.

The results of the fourth test indicate another variable that must be considered in the laboratory tests: that differences in the storage hay cause variations in the results obtained from chemical treatment.

In the fifth of the preliminary tests, five fungicidal compounds were used. They were: Dowicide A, Dowicide B, Dowicide 2, Dowicide 2S, and Dowicide 1. Five drops of Triton were used in each liter of water to obtain better coverage and to produce a better solvent. During the spraying period, it was noticed that Dowicide 2 and Dowicide 2S were quite insoluble. Because of this property, unfavorable test results were expedted.

The test bales were opened and inspected after a seven-day curing period, with the following results: Dowicide A -- still damp with no visible mold; Dowicide B -- very damp with no visible mold; and Dowicide 2, Dowicide 2S, and Dowicide 1 -- badly molded. It was found, at a later date, that the solubility of Dowicide 2S could be increased by mixing it with a strong caustic solution.

At the end of the preliminary tests, the following compounds showed the most promise: DHA, DHAS, Dowicide A, and Dowicide B. It was decided that more intensive laboratory tests should be run on these compounds, using four treated bales and one control bale. The treated bales were to be opened at four-day intervals to check the lasting qualities of the chemical treatment. The data to be recorded consisted of: chemical concentrations, hay weights, bale temperatures, and the condition of the hay when the bales were inspected.

Before starting the final tests, it was decided that a test should be run using Macinaw detergent as a wetting agent, since the Macinaw compound has fungicidal properties under certain conditions. The results of this test indicated no mold-inhibiting action, but demonstrated that the compound is an effective wetting agent. The treated bales contained a heavier growth of mold than either of the two control bales.

Final Tests

Artificially-dried bale samples indicated that the moisture contents of the storage bales were approximately the same. This was to be expected, since the hay in a large mow approaches a point of equilibrium after curing. The samples indicated an average moisture content of 19.5 percent (dry basis), which was used in all computations of actual test bale moisture contents.

The method shown in the following example was used to compute the actual moisture contents of the treated bales.

Known:

(1)	Moisture content (dry basis) of air-dry hay	19.5 percent
(2)	Dry matter content of air-dry hay	80.5 percent
(3)	Weight of air-dry hay used in test bale	3.7 pounds
(4)	Weight of treated bale	5.2 pounds

Computations:

(1)	Weight of dry matter -- 3.7 x 0.805	3.0 pounds
(2)	Total weight of water -- 5.2 - 3.0	2.2 pounds
(3)	Moisture content of test bale (wet basis) - $\frac{2.2}{5.2} \times 100$	42 percent

At the beginning of the final laboratory tests, it was decided that it was necessary to take hay temperature readings only once per day, since temperature changes occur gradually, with the peak temperature being reached after two or three days of slowly increasing temperatures. It was probable, however, that the exact highest temperature would not be obtained from readings taken at one-day intervals.

The first test was run using five drops of Triton in a five-tenths percent solution of DHA. The data, recorded during this test, are shown in Table I and Table II.

The results of the first test indicated that DHA had good mold-inhibiting properties, but only for a limited time. In effect, its action on the test hay was mycostatic rather than fungicidal.

A five-tenths percent solution of DHAS, with five drops of Triton added, was used to treat the hay for the second test. The data are shown in Table III and the bale temperature differences over the curing period are plotted in Fig. 5.

The test bale temperature curves were plotted with the difference between bale temperature and air temperature versus curing time. By the use of this method, the effect of air temperature changes on the plotted curve is largely eliminated.

A comparison of Table III and Fig. 5 shows a definite correlation between the amount of temperature change and the amount of mold growth. Test bale #3 varied much less in temperature than bale #1 or bale #2 and also showed less mold growth when inspected.

The hay used in the test of DHAS was very coarse, first-cutting alfalfa with a trace of brome grass. The storage

TABLE I

DHA -- Baling Data

Test Bale Number	Hay Weights		M.C.*	Length of Curing Period (Days)	Condition of Hay after Curing
	Dry	Wet			
1 (Control)	3.7	5.2	42	8	Very moldy within one-half inch of outside of bale
2	3.3	4.7	43	19	Wettest part of bale - molded and discolored; part of bale - musty; and part - no mold
3	3.1	4.6	46	11	Still damp; three scattered, small spots of mold that might have been due to lack of coverage
4	3.3	4.6	42	8	Slightly damp; no mold; nice odor
5	3.6	5.2	44	4	Damp; no mold; slight ensilage odor

*Moisture content in percent (wet basis).

TABLE II

DHA -- Hay Temperatures

Day of Curing Period	1	2	3	4	5
1	63	61	63	64	65
3	63	61	64	63	62
5	81	60	59	57	68
9	65	60	61	61	-
10	-	60	62	-	-
11	-	60	61	-	-
12	-	59	-	-	-
19	-	75	-	-	-

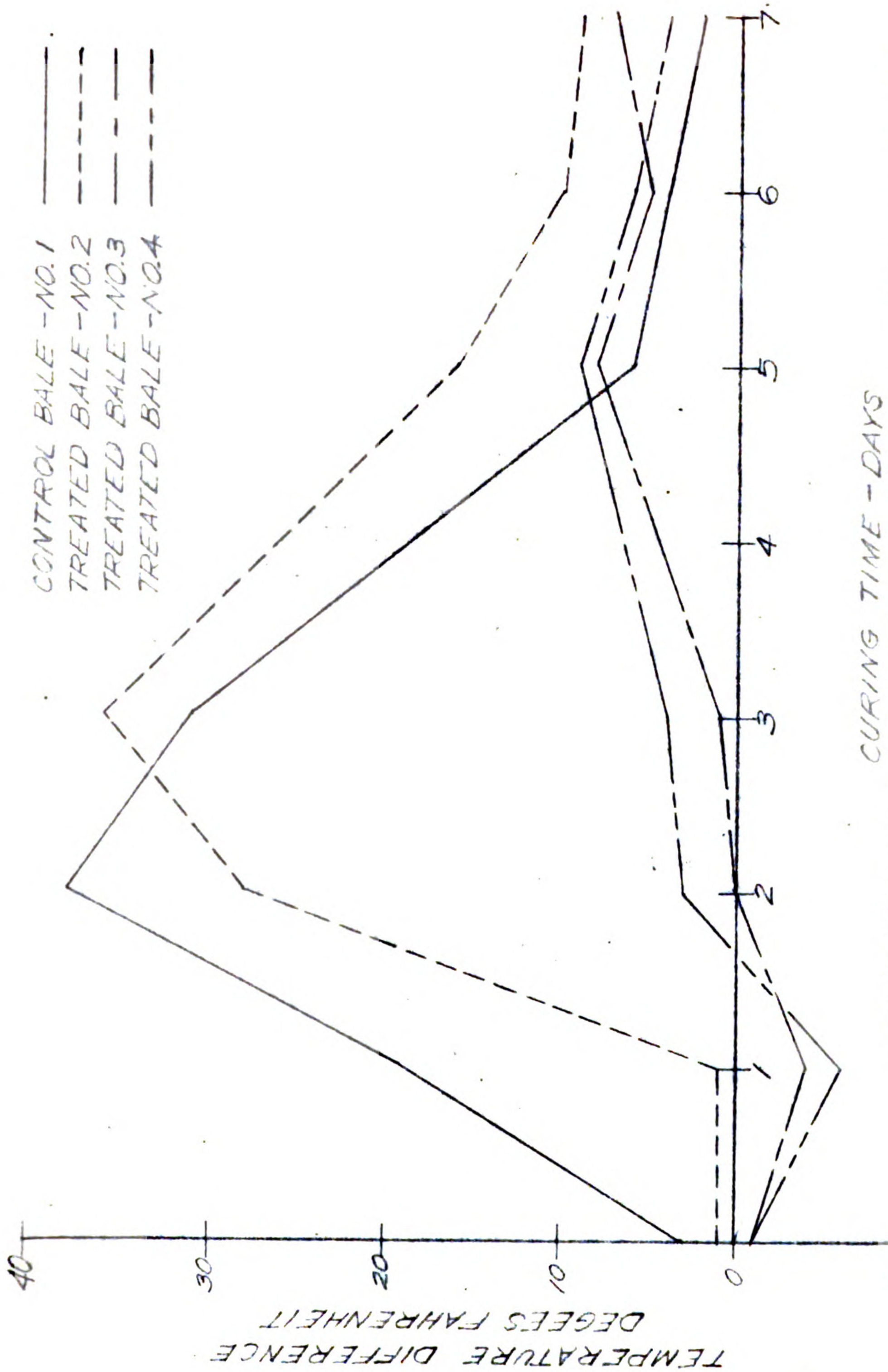
Note: The test bales were inspected at the point where temperature readings ceased.

TABLE III

DHAS -- Baling Data

Test Bale Number	Hay Weights Dry	Hay Weights Wet	M.C.*	Length of Curing Period (Days)	Condition of Hay after Curing
1 (Control)	2.9	4.5	49	8	Moldy
2	3.5	5.0	44	8	Moldy
3	3.5	4.8	42	8	Slightly less mold than #1 and #2
4	3.7	4.9	39	14	Moldy

*Moisture content in percent (wet basis).



COMPARISON OF TEMPERATURE VARIATIONS IN BALES
TREATED WITH DHAS AND UNTREATED BALE

FIG. 5

MAR., 1951

bale also contained patches of mold. Because of the poor quality of this hay, it is doubtful if the results of the test indicate the true worth of the DHAS compound as a mold inhibitor.

At this point in the progress of the tests, the use of salt in hay curing was considered. The merits of both sodium chloride and calcium chloride were discussed, but calcium chloride was used in the third test because it was more readily obtainable. In addition to recording bale temperatures, it was decided that weight records should be kept on the bales to determine the rate of moisture loss. This practice was to be continued throughout the rest of the laboratory tests. Table IV lists the baling data for the test, while the temperature curves and bale weight curves are plotted in Fig. 6 and Fig. 7 respectively.

The bale weight curves, for the calcium chloride test, show a fairly uniform decrease in weight for all of the test bales. As would be expected, however, there is a close correlation between the rate of moisture loss and the amount of temperature variation of the test bales. A comparison of Fig. 6 and Fig. 7 shows that test bale #1 and test bale #4 demonstrate this correlation very well.

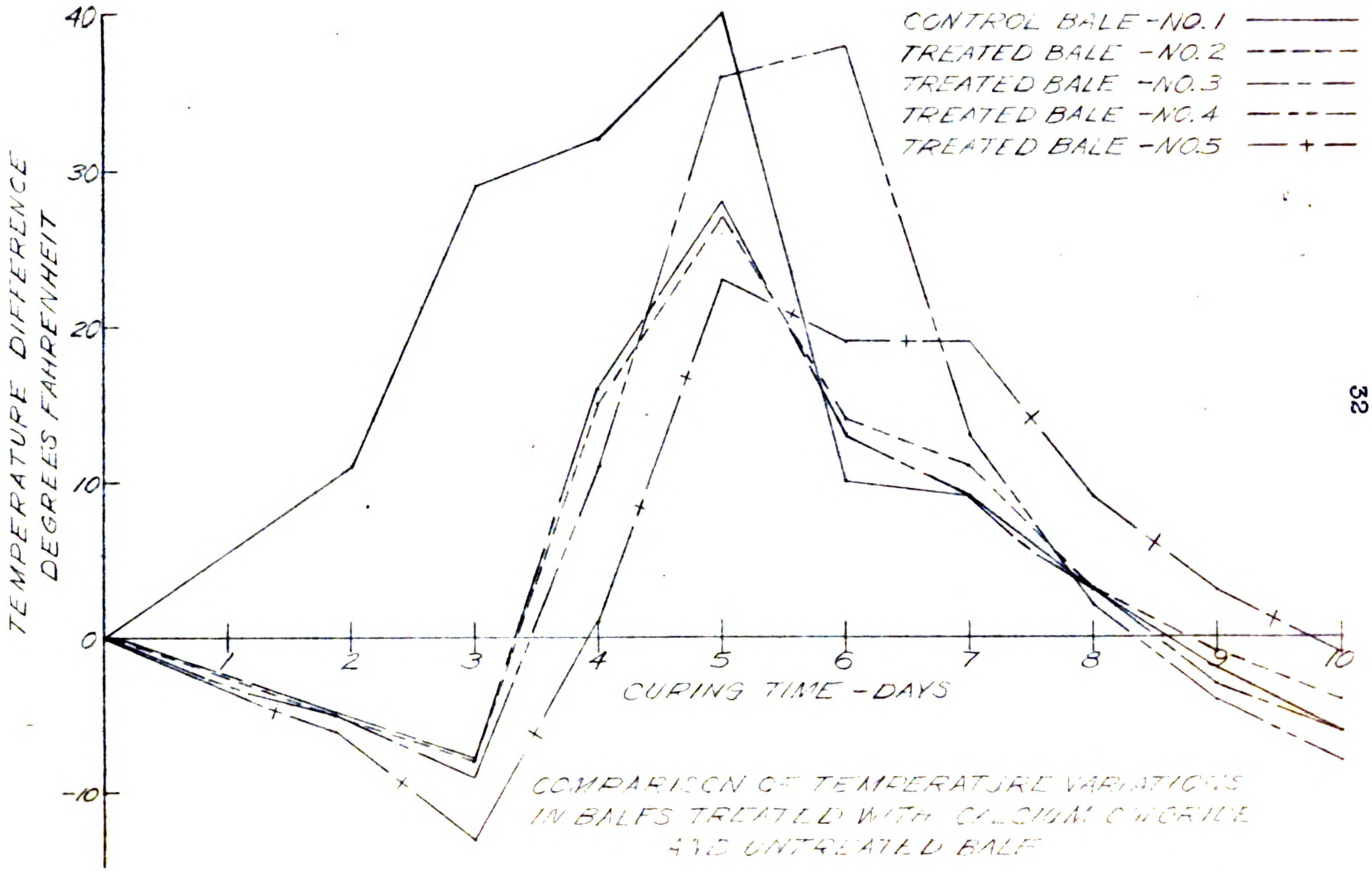
The third test also verifies what other workers have found. "Salt added to moistened alfalfa hay will inhibit bacterial growth, and will delay but not prevent mold develop-

TABLE IV

Calcium Chloride -- Baling Data

Test Bale Number	Hay Weights Dry	Hay Weights Wet	M.C.*	Length of Curing Period (Days)	Condition of Hay after Curing
1 (Control)	3.6	4.8	40	10	Very moldy
2	3.8	4.7	34	10	Very moldy
3	3.4	4.3	37	10	Moldy, but less than the rest of the bales in the test
4	3.4	4.7	43	10	Very moldy
5	4.2	5.5	38	10	Very moldy

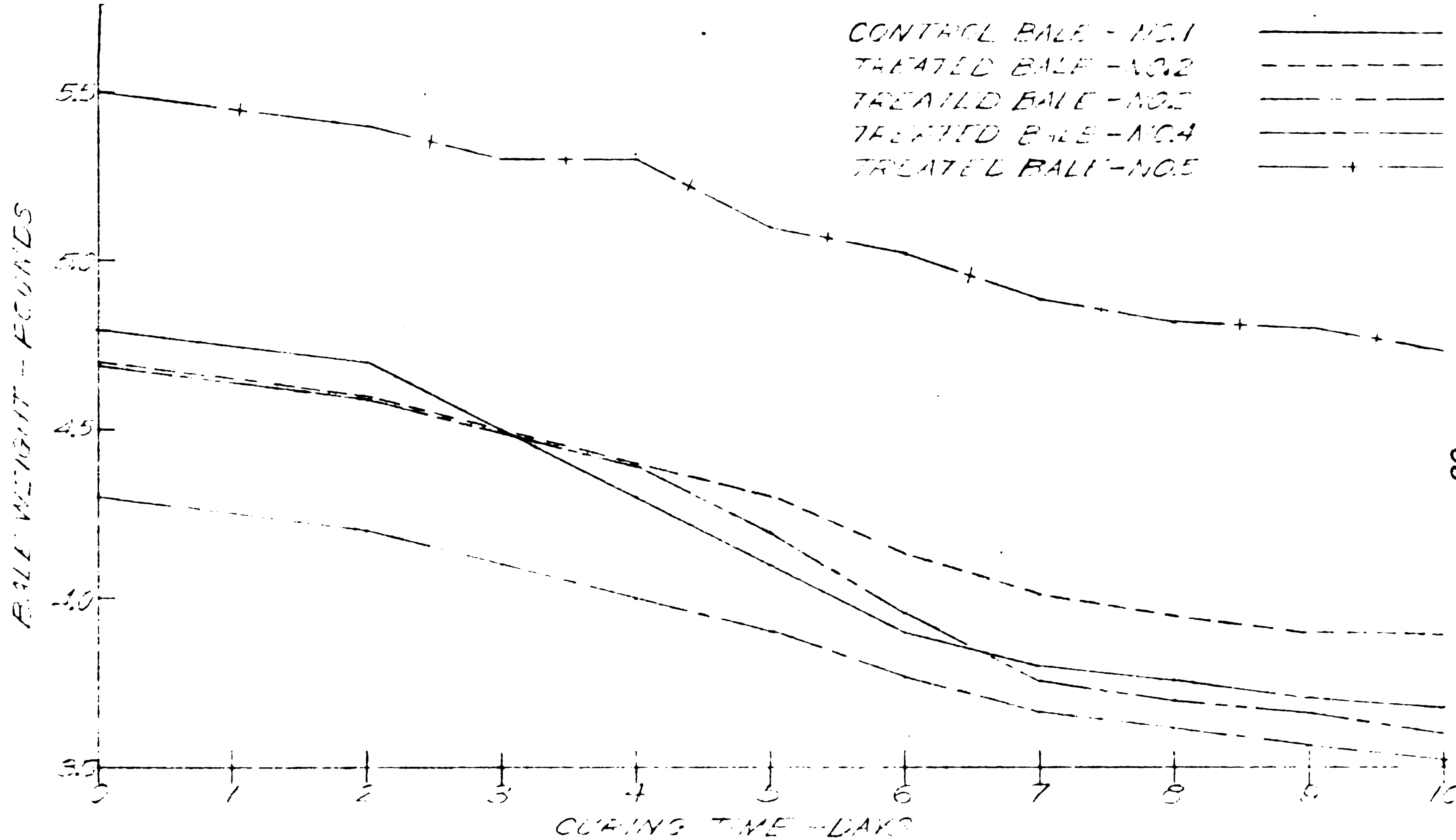
*Moisture content in percent (wet basis).



COMPARISON OF TEMPERATURE VARIATIONS
IN BALES TREATED WITH CALCIUM CHLORIDE
AND UNTREATED BALE

FIG. 6

APRIL, 1951



COMPARISON OF RATE OF WEIGHT LOSS IN TEST BALES
TREATED WITH [illegible] AND [illegible] BALE

FIG. 7

[illegible]

ment."[10]

The temperature curves indicate that mold and bacterial action were delayed, but the peak temperatures were reached at approximately the same time in the treated bales and the untreated bale. This temperature change could only be caused by micro-organism action within the bale, since there could be no respiratory action in fully-cured hay.

A five-tenths percent solution of Dowicide A, with Triton as a wetting agent, was used to treat the hay in the fourth test. The hay used for this test, was obtained from the same storage bale as the hay that was treated in the previous test. During the spraying process, it was noticed that Dowicide A was somewhat insoluble in the concentration used. This insolubility seemed to be a property of the compound, but could have been increased by the low temperature of the water that was being used as a solvent.

The baling data, for the fourth test, is listed in Table V, while the temperature difference curves and test bale weight curves are plotted in Fig. 8 and Fig. 9.

The results of the fourth test indicate that Dowicide A inhibits the growth of mold for a period of time, but does not kill the mold organisms. After 21 days of curing, the treated hay showed small patches of mold; but after the 35-day period, the treated hay was quite badly molded.

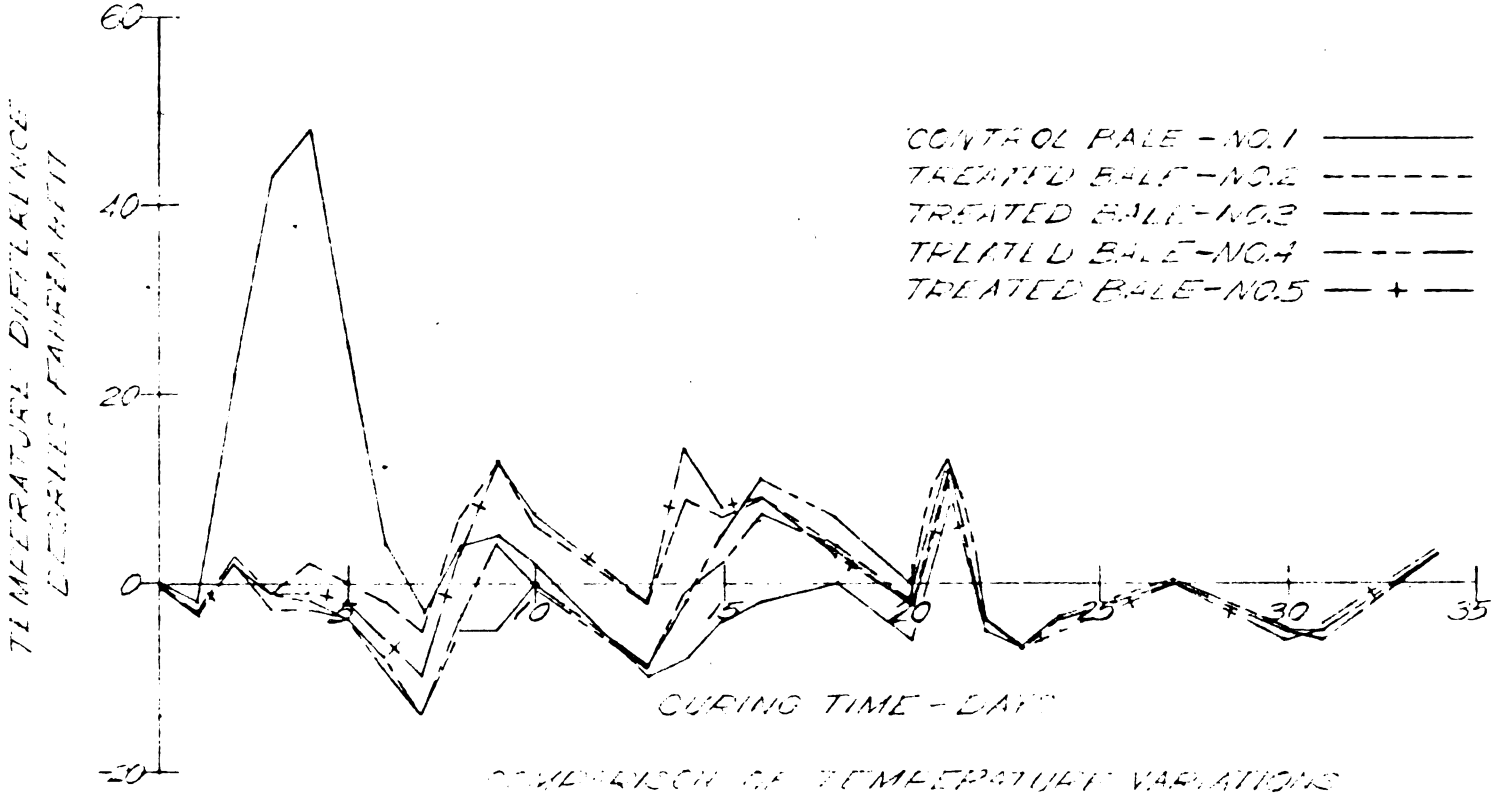
The temperature difference curves that were plotted for the Dowicide A treatment can be used only to indicate

TABLE V

Dowicide A -- Baling Data

Test Bale Number	Hay Weights		M.C.*	Length of Curing Period (Days)	Condition of Hay after Curing
	Dry	Wet			
1 (Control)	3.1	5.3	53	21	Very moldy
2	3.4	4.8	44	21	Small mold patches and some mustiness
3	3.7	4.7	36	35	Moldy, but less than control bale
4	3.9	4.9	37	35	Scattered mold
5	4.2	5.4	37	35	Very moldy

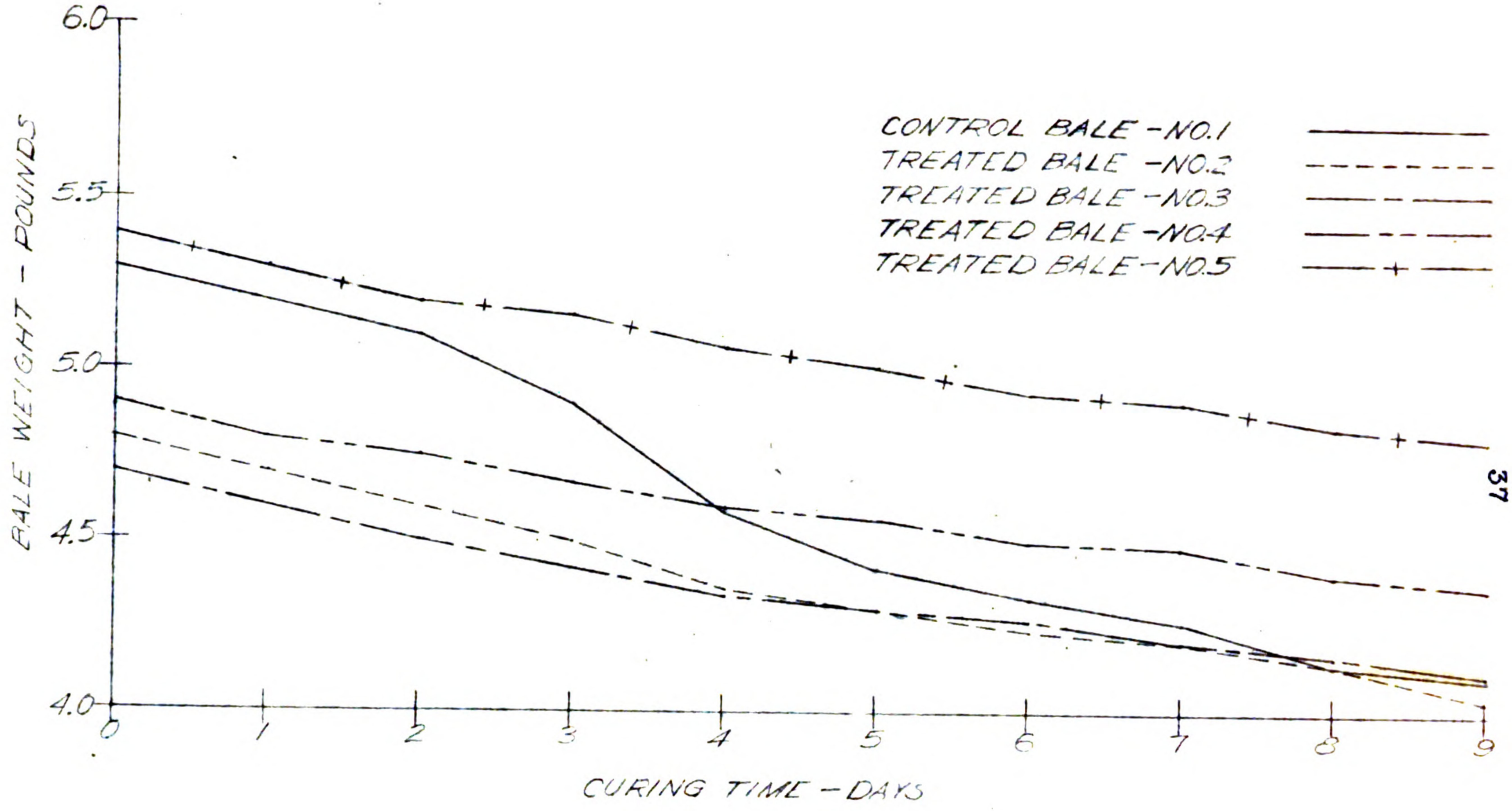
*Moisture content in percent (wet basis).



COMPARISON OF TEMPERATURE VARIATIONS
IN BALES TREATED WITH DOW [illegible] A AND
UNTREATED BALES

FIG. 8

MAY, [illegible]



COMPARISON OF RATE OF WEIGHT LOSS IN TEST BALES
TREATED WITH DOWICIDE A AND UNTREATED BALE

FIG. 9

MAY, 1951

a trend, because of the irregularity of the curves. The curves would seem to indicate alternate heating and cooling of the test bales, but a part of this variation is undoubtedly due to a time lag between changes in air temperature and corresponding changes at the center of the bale.

At the points where the curves fall below the zero point on the chart, it must be assumed that the cause was evaporation of moisture from the hay, together with the temperature time lag. The curves show, in addition, that the untreated test bale underwent a much greater change in temperature at an earlier point in the curing period than did any of the treated bales. A study of Fig. 9 also shows a much faster rate of moisture loss in the untreated bale, than in the test bales containing hay that was treated with Dowicide A.

The fifth test of this series, and the final laboratory test, was run on good-quality storage hay, using Dowicide B as a mold inhibitor. A five-tenths percent solution of the compound was used, with five drops of Triton as a wetting agent. The baling data for this test are shown in Table VI and the temperature difference curves and bale weight curves are plotted in Fig. 10 and Fig. 11, respectively.

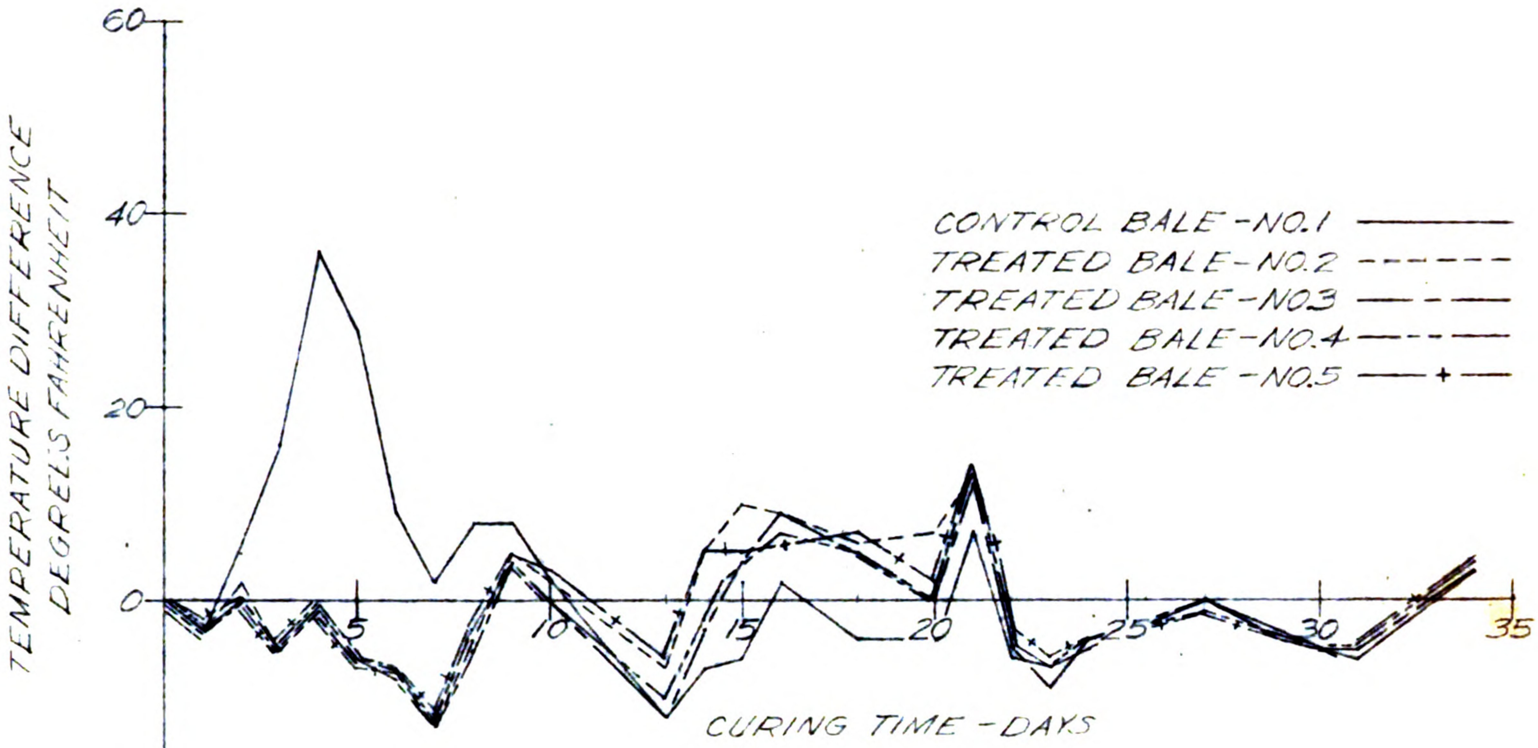
The temperature difference curves and bale weight curves that were plotted for the fifth test are very similar to the corresponding curves that were plotted in the test using Dowicide A as a mold inhibitor. The results of this test

TABLE VI

Dowicide B -- Baling Data

Test Bale Number	Hay Weights		M.C.*	Length of Curing Period (Days)	Condition of Hay after Curing
	Dry	Wet			
1 (Control)	3.5	4.6	39	35	Very moldy
2	4.1	5.3	38	21	Scattered mold patches, most of bale has good color and pleasant odor
3	4.0	5.2	39	35	Hay is good quality, with slight trace of visible mold and mustiness.
4	4.2	5.1	33	35	Bale dry, with no mold
5	4.0	5.4	41	35	Bale dry with no mold. Hay has very pleasant odor.

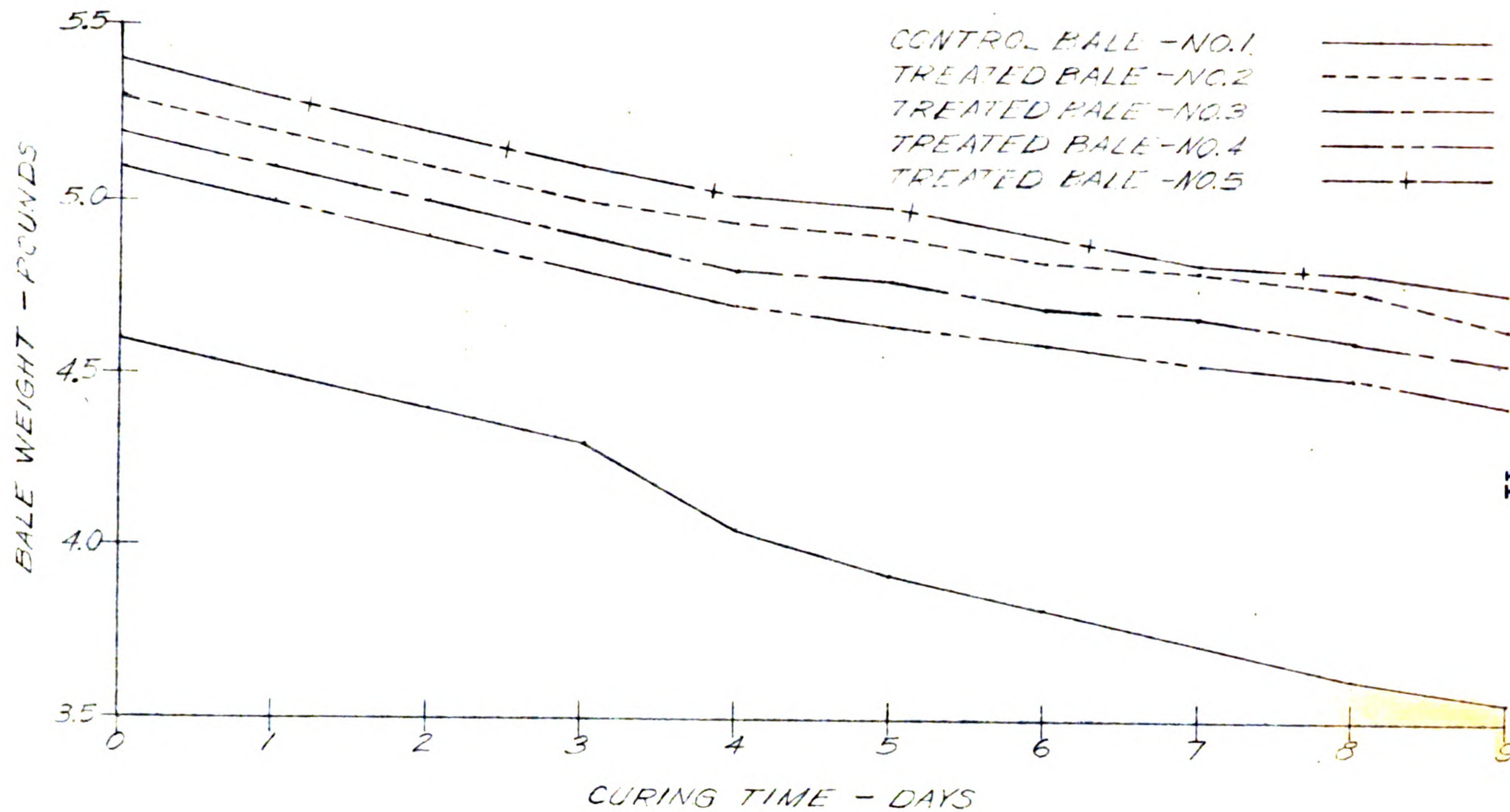
*Moisture content in percent (wet basis).



COMPARISON OF TEMPERATURE VARIATIONS
IN BALES TREATED WITH DOWICIDE B
AND UNTREATED BALES

FIG. 10

MAY, 1951



COMPARISON OF RATE OF WEIGHT LOSS IN TEST BALES TREATED WITH DOWICIDE B AND UNTREATED BALE

FIG. 11

MAY, 1951 J.F.

also indicate that Dowicide B may have better fungicidal properties than the other compounds tested, since mold growth was prevented for a long enough period to allow two of the test bales to become thoroughly dry. The test data seem to give no explanation for the trace of mold that was found in two of the treated bales. Therefore, it was assumed that lack of complete coverage when spraying was the cause of the scattered mold patches. This variation might also have been caused by differences in the storage hay that was used in the test.

Conclusions

The laboratory tests indicated that the following compounds were most effective in preventing mold growth in hay.

1. DHA and DHAS had very similar mold-inhibiting qualities, but the final test of DHAS was rather inconclusive because of the poor quality of the hay that was treated. Both compounds had good mold-inhibiting properties, but only for a limited period of time. In effect, they had micostatic rather than fungicidal properties.

2. The results obtained from the Dowicide A tests may have failed to give a true indication of its value as a mold inhibitor because of the insolubility characteristic of the compound. This difficulty might have been overcome by the use of a different type of solvent. The test results

indicated that Dowicide A has good mold-inhibiting qualities, but is similar to DHA and DHAS in that it exhibits mycostatic properties.

3. The most promising results were obtained from the use of Dowicide B. The test data compared quite closely with that obtained from the test on Dowicide A, but Dowicide B exhibited much better fungicidal properties. The test results indicated that the mold organisms were either killed or reduced in potency to a point where growth was no longer possible.

In addition, several miscellaneous conclusions were drawn from the laboratory tests.

1. There is a definite correlation between the amount of temperature change and the amount of mold growth.

2. Mold control is more difficult in poor-quality hay, or in hay that has been badly weathered in the field, than in high-quality hay.

3. There is a close correlation between the rate of moisture loss and the amount of temperature variation. When high bale temperatures are reached, the rate of moisture loss is much greater.

FIELD TESTS

Objectives

The general objectives of the field tests were to determine which chemical compounds, of those selected for field tests, were most effective in the prevention of mold in baled hay, and to determine the most effective methods and rates of application for these compounds.

Statement of the Problem

All of the compounds selected for field tests had fungicidal properties. Therefore, it was decided that complete coverage of the hay was necessary when the compounds were applied. This could best be accomplished by application of the compounds in liquid spray form.

The chemical compounds were obtained in the salt form and all were reasonably soluble in water. Though other solvents might have been more effective, water was used because it is low in cost and readily available.

Since it was necessary to apply additional water to the hay by the spraying method, it was evident that this application had to be made at a point in the field operation where the excess moisture would least affect the drying and curing of the hay.

The hay was to be baled at a high initial moisture content, so it was not feasible to add the water to the hay entering the bale chamber. Since good coverage was necessary, it also seemed inadvisable to spray the hay while it was curing in the swath or windrow. The only alternative was to apply the liquid spray to the standing hay just before it was mowed. At this point in the operation, the free moisture would be removed from the hay almost immediately, with no adverse effect on the hay. In addition, this method would be more desirable from a practical viewpoint because the sprayer could be mounted just ahead of the mower cutter bar, with both machines powered by the same tractor.

To effectively control mold by the spraying method, it was necessary to use compounds with relatively low vapor pressures. Volatile compounds would soon be reduced to a state of ineffectiveness by the sun and wind during the curing process of the hay.

Equipment

1. Tractor with mounted sprayer, as shown in Fig. 12. The sprayer had a ten-foot boom, with one nozzle plugged to obtain a seven-foot spraying width.
2. Tractor with mounted mower, as shown in Fig. 13. The mower was power take-off driven and mowed a seven foot swath.
3. Side delivery rake (Fig. 14).

Tractor-mounted Sprayer in Operation

Fig. 12

Tractor-mounted Mower in Operation

Fig. 13

Side-delivery Rake in Operation

Fig. 14

4. Tractor and automatic twine-tie pickup baler, shown in Fig. 15.
5. Hay laboratory containing temperature recording equipment.
6. Miscellaneous equipment: hay wagons, mixing equipment for chemicals, power units for hauling hay, etc.

Test Procedure

Each test compound was weighed to obtain the desired concentrations. Each compound, together with a wetting agent, was placed in the sprayer tank and thoroughly mixed by agitation from the pump by-pass return hose.

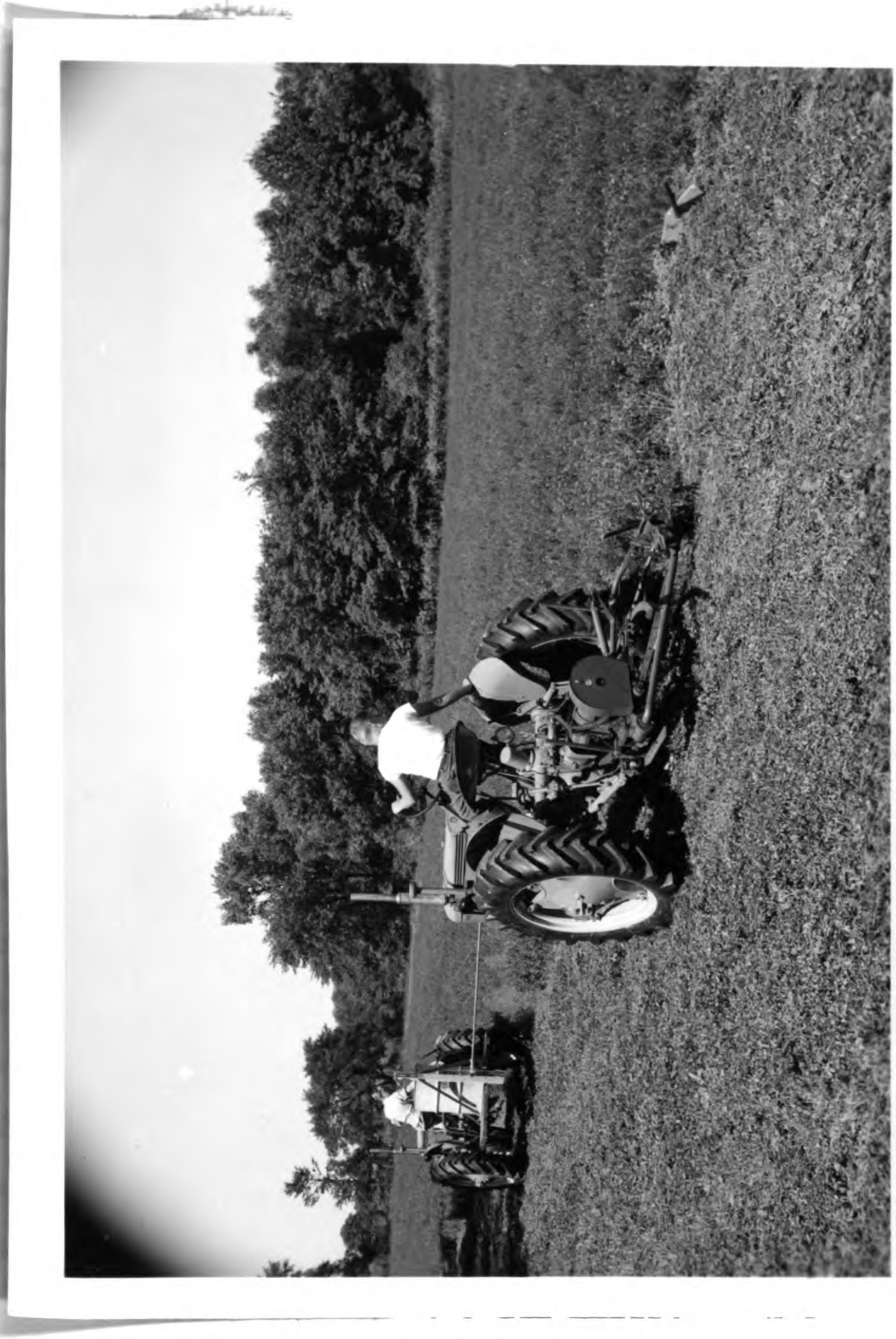
The spraying and mowing operations were carried on simultaneously, with the mowing tractor closely following the tractor carrying the sprayer, as shown in Fig. 16. The ground speed of the sprayer and the pressure applied to the nozzles were regulated to obtain complete coverage, but to prevent any waste due to excess application of the solution.

After spraying and mowing the desired amount of hay, the hay was allowed to dry to a moisture content of approximately fifty percent (wet basis), at which time it was raked with a side delivery rake. When raking, the direction of travel was the same as when mowing, but the ground speed was determined by the drying rate of the hay.

The hay was allowed to dry in the windrow until a mois-

Baler in Operation

Fig. 15



Sprayer and Mower in Operation

Fig. 16

ture content of approximately thirty percent (wet basis) was reached. At this time baling was started, at the point in the field that was first mowed. The baling operation was completed as quickly as possible in an attempt to obtain hay of a uniform moisture content.

Moisture samples were taken at regular intervals, during baling, disregarding the location in the field. The resulting random samples were used to determine the average moisture content of the hay. The wet samples were dried in an electric oven, at controlled temperatures, to obtain the moisture contents. Throughout the remainder of this test, moisture contents are listed on the wet basis unless otherwise stated.

The test bales were placed in the hay laboratory immediately after baling and copper-constantan thermocouples were inserted to the center of selected bales. Bale temperatures were manually recorded from a Brown ten-point potentiometer. A number of temperature readings were recorded for each stack of test bales. Temperature readings were taken twice each day, at 8:00 A.M. and 8:00 P.M. Because bale temperatures rise slowly and decrease slowly, it was decided that more frequent readings were not necessary. The average of the recorded temperatures was listed as the average daily bale temperature of the stack.

The test bales were left in storage until the temperature records indicated that the heating cycle was finished. When the bale temperatures returned to normal, laboratory tests had indicated that mold and bacterial action had been completed. The bales were then removed from storage and inspected for mold growth. Moisture samples were taken upon removal from storage to determine the average moisture content of the hay.

Results and Discussion

First Cutting

Before regular field tests were started, a preliminary test was run to calibrate the sprayer, and to check the proposed testing method. The compounds tested were DHA, Dowicide A, and Dowicide B. A quantity of untreated hay, equal to the amount baled for each treatment, was used as a test control lot.

The calibration trial indicated that the best coverage was obtained at a ground speed of 1.2 miles per hour and a sprayer pressure of 100 pounds per square inch. At this speed and pressure, the rate of application of the chemical solution was approximately 48 gallons per acre.

The chemical compounds were dissolved in water to form a one percent concentration (by weight), while the wetting agent (Alconal detergent) was added at the rate of one-tenth percent of the weight of the water.

At the time of baling, the average moisture content was approximately 37 percent, which was too high to expect complete mold control. Three bales were obtained from each treatment, and were inspected after a three-week curing period with the following results:

Control:

1. Some visible mold, very musty.
2. No visible mold, musty.
3. No visible mold, slightly musty.

DHA:

1. No visible mold, musty.
2. No visible mold, slightly musty.
3. No visible mold, musty.

Dowicide A:

1. No visible mold, slightly musty.
2. No visible mold, slightly musty.
3. No visible mold, musty.

Dowicide B:

1. No mold or mustiness.
2. A few scattered patches of mold, most of bale good.
3. Very slightly musty in one-half of bale.

The preliminary test indicated that the proposed method of testing would prove satisfactory. However, the sprayer nozzles should have been somewhat larger in order that the normal ground speed of mower could be more closely approximated. The test further indicated that coverage might have been somewhat less than was desired.

There were no significant differences between the treated and untreated hay in two of the preliminary test lots, but the hay treated with Dowicide B seemed to show definite evidence of mold control. Upon visual inspection, the bales treated with Dowicide B contained much less mold than did the control bales.

The first full-scale field test was run near the end of the first cutting of hay. The alfalfa hay was quite badly lodged, with weeds about one and one-half feet above the hay. Since it was necessary to adjust the spray boom to a height above the weeds, some wind drift of spray and possible irregular coverage resulted.

In addition to testing the selected chemical compounds, the first tests were used to compare two types of wetting agents. A compound called Methocel Paste had been obtained, which was supposed to act as a binder in holding the solution on the hay. In addition, it had the usual properties of a detergent. Alconal detergent was the second wetting agent to be used in the comparison.

Methocel Paste was used in the treatment at the rate of one-half pint in each 25 gallons of water and one-fourth pound of Alconal detergent was used in the same quantity of water. Dowicide A and Dowicide B were used for the treatment at the rate of five pounds in each 50 gallons of water. Each treatment was divided into two 25-gallon lots to permit the comparison of detergents.

The hay was treated and mowed in the afternoon and had wilted slightly by the end of the day. The weather was partly cloudy, with a light wind that blew in occasional gusts. The temperature was approximately eighty degrees Fahrenheit throughout the afternoon. The following day was overcast, with very high humidity and occasional light showers. A hard shower occurred during the evening that was undoubtedly hard enough to wash part of the chemicals from the hay. The third day was cloudy, warm, and humid, with some sunshine and a light breeze during the afternoon. The hay was raked during the morning of the fourth day at a moisture content of thirty-five to forty percent. The hay was drying very slowly, but was baled late in the afternoon and placed in storage.

Because the treating process was rather slow, the treatments were run in two series of tests. The compounds tested in the second series were Dowicide 2S and DHAS. As Dowicide 2S is quite insoluble in water, it was necessary to mix it with a caustic before placing it in the water. The caustic was used in a concentration of two-tenths pound per pound of Dowicide 2S. The caustic was first dissolved in a small amount of water and then mixed with the desired quantity of the compound. Dowicide 2S was used in a concentration of approximately one percent, or five pounds in fifty gallons of water. Methocel Paste was used as a wetting agent and binder, in a concentration of one pint in fifty gallons of water. The DHAS treatment was made up of DHAS and Methocel Paste in the same concentrations as were used in the Dowicide 2S treatment. Because DHAS was very expensive and not readily available, only half as much hay was treated as in the other three tests. The DHAS compound seemed rather insoluble and tended to plug the intake screen to the pump. Because the tractor was being operated in low gear, it was necessary to increase the speed of the tractor by about one-third to maintain the spraying pressure at one hundred pounds per square inch.

The hay was sprayed in the morning of a hot, partly-cloudy day. A moderate wind was blowing, with occasional forceful gusts during the DHAS treatment. The amount of wind, together with the increase in ground speed, indicated that rather doubtful results could be expected from the test of DHAS. Raking was completed in the morning of the following day. The weather was hot and clear throughout the day. The two test lots were baled in mid-afternoon and placed in storage.

In the first field test, the bales corresponding to the hay in the moisture samples were tagged, and records kept for these bales. (Tables VII through XI). The temperature curves (Fig. 17) were plotted by the same method as the corresponding curves in the laboratory tests.

The results of the field test indicated that the

TABLE VII

Control--Sample Test Bale Record

Sample No.	Bale Weight Before Storage	Bale Weight After Storage	M.C.* Before Storage	M.C.* After Storage	Condition of Hay After Curing
264	39	33.5	21.9	15.6	No mold or must
200	45	42	23.2	19.3	Slightly musty
266	52	47.5	23.2	23.3	Musty
39	50	46.5	20.6	--	No mold
112	48	43.5	19.5	18.4	No mold
100	50	46.5	21.5	16.6	No mold
110	53	49	22.0	--	Slightly musty
Average	48.2	44.2	21.7	18.6	

*Moisture Content (wet basis) in percent.

TABLE VIII

Dowicide A -- Sample Test Bale Record

Sample No.	Bale Weight Before Storage	Bale Weight After Storage	M.C.* Before Storage	M.C.* After Storage	Condition of Hay After Curing
Alconal Detergent:					
157	60	55	20.8	19.1	Slight trace of mustiness
59	56	52	28.8	19.2	Very slight trace of mustiness
132	51	46.5	19.8	17.9	No mold
255	52	49	22.0	18.8	Slight trace of mustiness
Methocel Paste:					
139	57	54	17.3	--	No mold
102	56	51.5	19.3	20.6	No mold
105	51	48.5	20.5	18.4	No mold
Average	54.7	51.0	21.0	19.0	

*Moisture Content (wet basis) in percent.

TABLE IX

Dowicide B--Sample Test Bale Record

Sample No.	Bale Weight Before Storage	Bale Weight After Storage	M.C.* Before Storage	M.C.* After Storage	Condition of Hay After Curing
Alconal Detergent:					
111	58	50	23.2	18.8	Musty
253	54	48.5	22.6	21.5	Very musty
117	60	52.5	20.5	19.4	Slightly musty
252	54	51.5	26.3	21.9	Slightly musty
Methocel Paste:					
159	61	52	25.6	17.7	Musty
247	57	52.5	22.1	22.6	Slightly musty
76	59	49.5	26.5	19.3	Very musty
Average	57.6	51.0	24.0	20.2	

*Moisture Content (wet basis) in percent.

TABLE X

Dowicide 2S--Sample Test Bale Record

Sample No.	Bale Weight Before Storage	Bale Weight After Storage	M.C.* Before Storage	M.C.* After Storage	Condition of Hay After Curing
4	55	47.5	31.5	21.8	Scattered visible mold
32	50.5	46	28.6	21.7	No mold
34	50	45	22.3	20.6	Musty
18	61	51	32.7	21.6	Some visible mold
50	49	45.5	24.2	18.3	No mold
124	58	54	22.2	15.3	No mold
Average	54.0	48.1	26.9	19.9	

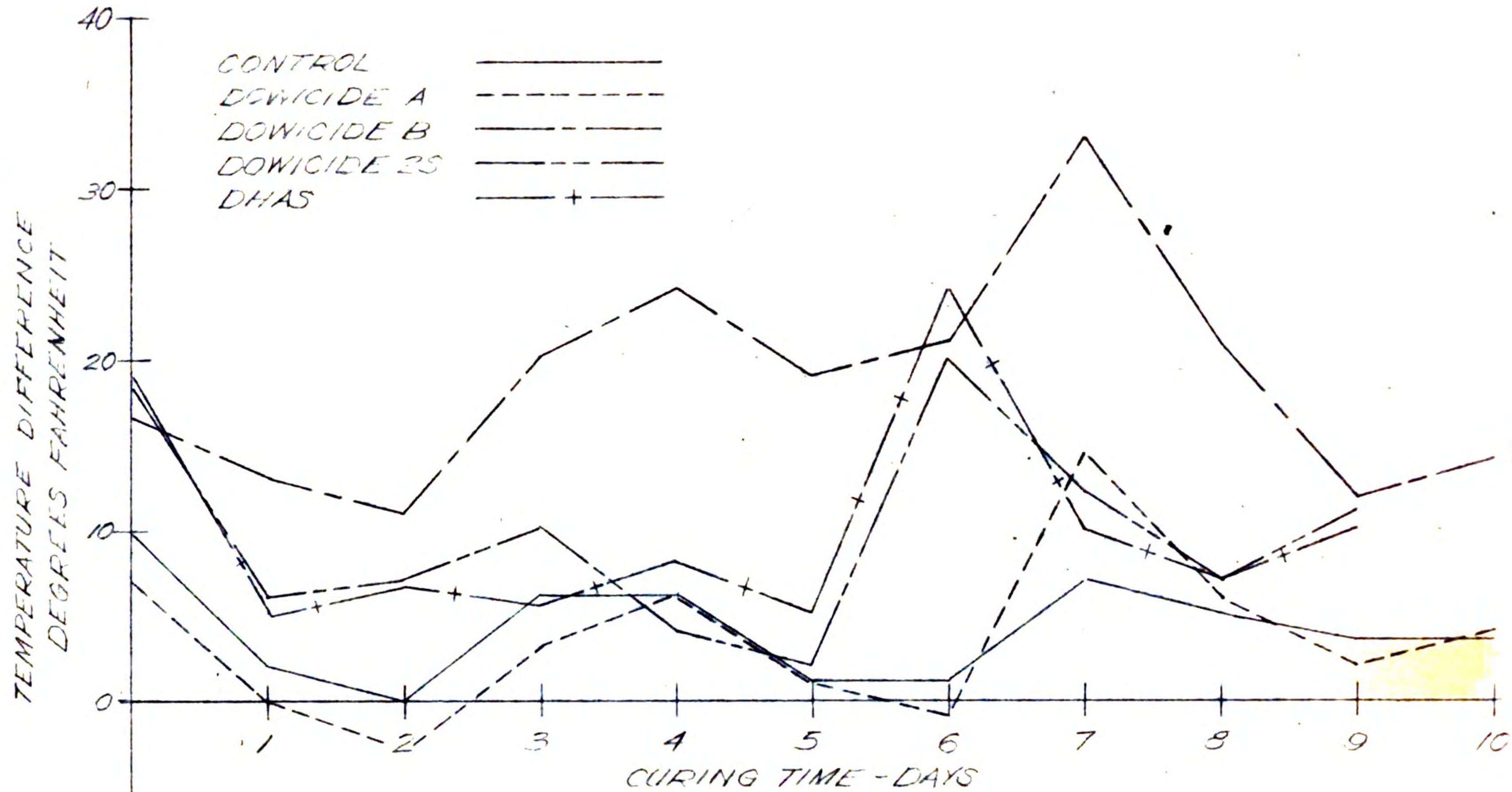
*Moisture Content (wet basis) in percent.

TABLE XI

DHAS--Sample Test Bale Record

Sample No.	Bale Weight Before Storage	Bale Weight After Storage	M.C.* Before Storage	M.C.* After Storage	Condition of Hay After Curing
19	59.5	53	27.8	25.3	Musty
16A	55	46.5	29.5	22.2	Musty
11	60	54.5	27.8	23.6	Musty - scattered visible mold
Average	58.2	51.3	28.4	23.7	

*Moisture Content (wet basis) in percent.



COMPARISON OF TEMPERATURE VARIATIONS IN
TREATED AND UNTREATED TEST BALES
FIRST CUTTING

AUG. 1951 BR

FIG. 17

Dowicide A and Dowicide B treatments were rendered practically valueless by the rainstorm that occurred during the field curing period. In addition, the moisture content of the hay at the time of baling was too low to definitely prove the value of the treatment.

The amount of mold found in the bale should vary directly with the moisture content,[6] but this did not seem to hold true for the tests of Dowicide A and Dowicide B. It must be concluded that the variations were largely due to the differences in the amount of the compound that was washed from the hay. In some instances, the treatment seemed to have a definite effect on the amount of mold growth, but in others, no effect was evident.

The field curing conditions were much better during the test of Dowicide 2S and DHAS. The data, that were recorded for this test, indicate that Dowicide 2S was quite effective in controlling mold, in hay with a moisture content below thirty percent. The results indicate that DHAS was less effective than Dowicide 2S, but probably inhibited mold growth to some extent. Normally, mold growth can be expected, in untreated baled hay, at any moisture content above twenty percent.

Results and Discussion

Second Cutting

Before the second cutting tests were started, larger nozzles were obtained for the sprayer. This permitted an increase in spraying speed to approximately three miles per hour, or more nearly the normal operating speed of the mower. The operating pressure of the sprayer was increased to 120 pounds per square inch to aid in compensating for the increase in ground speed and to obtain better distribution of the spray.

Following a procedure similar to that used for the first-cutting tests, the tests were divided into two groups. The first series of tests consisted of a control test lot, a test lot treated with Dowicide A, and a test lot using Dowicide B. The second series was composed of a control lot, and test lots using Dowicide 2S and DHAS for treatments.

Spraying and mowing were started in the morning of a cool, clear day. A light wind, with occasional gusts, caused some drifting of the spray, but not enough to affect coverage. Both Dowicide A and Dowicide B were used in concentrations of approximately one percent, with Methocel Paste as a wetting agent in a concentration of three-fourths pint in fifty gallons of water. The hay wilted rapidly and was raked during the afternoon. The following morning was warm and clear, drying the hay rapidly. The hay was baled early in the afternoon and immediately placed in storage.

The second series of tests was started two days later. The weather was warm and clear with a slight breeze. Dowicide 2S was mixed with potassium hydroxide to increase its solubility in water. The caustic was used in a concentration of one pound for each four pounds of Dowicide 2S. Both Dowicide 2S and DHAS were mixed with water in concentrations of slightly less than one percent, with Methocel Paste as a wetting agent.

The hay treatment was completed during the morning and the hay was raked in the afternoon. A hard shower occurred on the following morning and the weather remained cloudy all day. The third day was cloudy and humid, but the hay dried sufficiently to permit baling late in the afternoon. The bales were placed in storage and temperature readings started.

Random hay samples were taken in much the same manner as during the first cutting tests, except that no bales were tagged to correspond to the samples. The samples were used to obtain average moisture contents, but the second cutting tests were organized for statistical analysis, eliminating the need for tagged bales. The average moisture contents of the test lots were:

Control - 1	32.7%
Dowicide A	29.2%
Dowicide B	32.3%

Control - 2	32.1%
Dowicide 2S	31.4%
DHAS	35.6%

The statistical analysis of the second cutting test results was based on the percentage of bales containing no mold. Therefore, it was necessary to inspect all of the test bales and record the condition of the hay. These data are listed in Table XII and Table XIII. Because of the varying degrees of mustiness, it was necessary to differentiate between the bales that were excessively musty and those that contained only a little mustiness. A slight trace of mustiness was not considered to be harmful to the palatability or feeding value of the hay. The statistical analysis is found in Appendix I. Group II, Dowicide 2S and DHAS, could not be analyzed statistically because of the small number of bales in each test lot. Only a limited amount of hay was available for this final test group.

The results of the second-cutting field tests indicate that Dowicide A and Dowicide B were significantly effective in preventing mold in hay. The statistical analysis shows that Dowicide B was very effective in mold prevention and that Dowicide A was also well above the significant level. However, there was no significant difference between the Dowicide B and Dowicide A treatment.

When the second-cutting test results are compared with those of first-cutting, it must be concluded that the second

TABLE XII

Test Bale Inspection Results

Second Cutting

Group I

Control

Bale	Condition
1	Extremely musty - no visible mold
2	Extremely musty - no visible mold
3	Extremely musty - no visible mold
4	Very musty
5	Very musty
6*	Slightly ensiled - no mold
7	Musty
8	Very musty
9*	One-half musty - one-half no mold
10	Musty
11*	One-half bale slightly ensiled, no mold - one-half musty
12	Musty
13	Very musty
14	Musty
15	Very musty
16	Extremely musty
17	Extremely musty
18	One-half extremely musty, one-half musty
19	Very musty
20	Musty and slightly ensiled
21	Musty
22	One-half musty, one-half very musty
23	Musty
24	Very musty
25	One-half musty, one-half very musty
26	Very musty
27	Extremely musty
28	Extremely musty
29	Very musty
30	Very musty

*No mold.

TABLE XII (cont.)

Dowicide A

Bale	Condition
1	Very musty
2	Very musty
3	Extremely musty
4	Very musty
5*	Slightly ensiled but no mold
6*	Slightly ensiled but no mold
7	Musty
8	Very musty
9*	One-half bale musty, one-half slightly ensiled but no mold
10	Musty
11*	Slightly musty
12	Musty
13	Very musty
14*	No mold - one end musty
15*	No mold
16	One-half musty, one-half slightly musty
17*	One-half musty, one-half no mold
18*	One-half musty, one-half slightly ensiled but no mold
19*	Slightly musty
20*	Slightly musty
21	Musty
22	Musty
23	Very musty
24*	Slightly musty
25	One-half slightly musty, one-half musty
26	Musty
27*	Very slightly musty
28	Musty
29	Very musty
30*	No mold

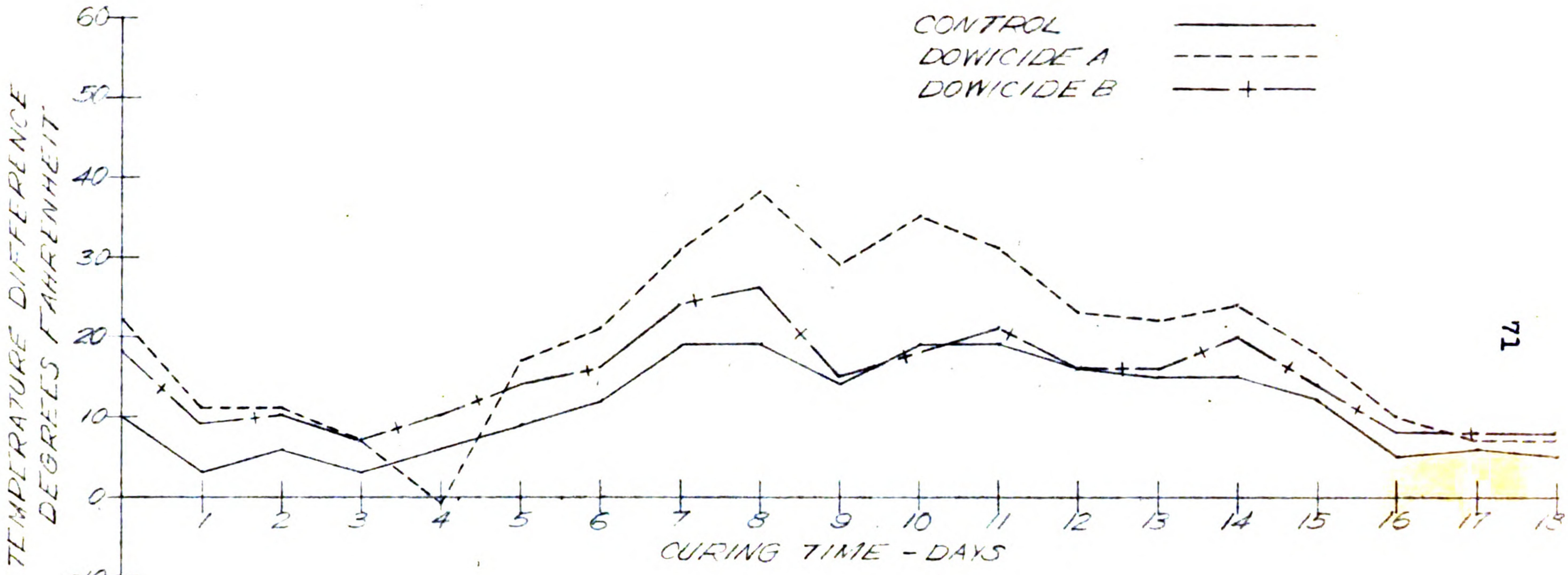
*No mold.

TABLE XII (cont.)

Dowicide B

Bale	Condition
1*	Slightly musty
2*	Extreme end of bale slightly musty, rest of bale no mold
3*	Slightly musty
4	One-half slightly musty, one-half musty
5*	No mold
6*	One-half slightly musty, one-half no mold
7*	No mold
8	Musty
9	Very musty
10*	No mold - one end slightly musty
11*	No mold
12	Musty
13*	No mold
14*	One end slightly musty, rest of bale no mold
15*	Slightly musty
16*	Slightly ensiled but no mold
17*	Very slightly musty
18*	Very slightly musty
19*	No mold
20	Musty
21	Musty
22*	No mold
23*	One end of bale musty, rest no mold
24*	Slightly musty
25	Musty
26*	No mold
27	Musty
28	Musty

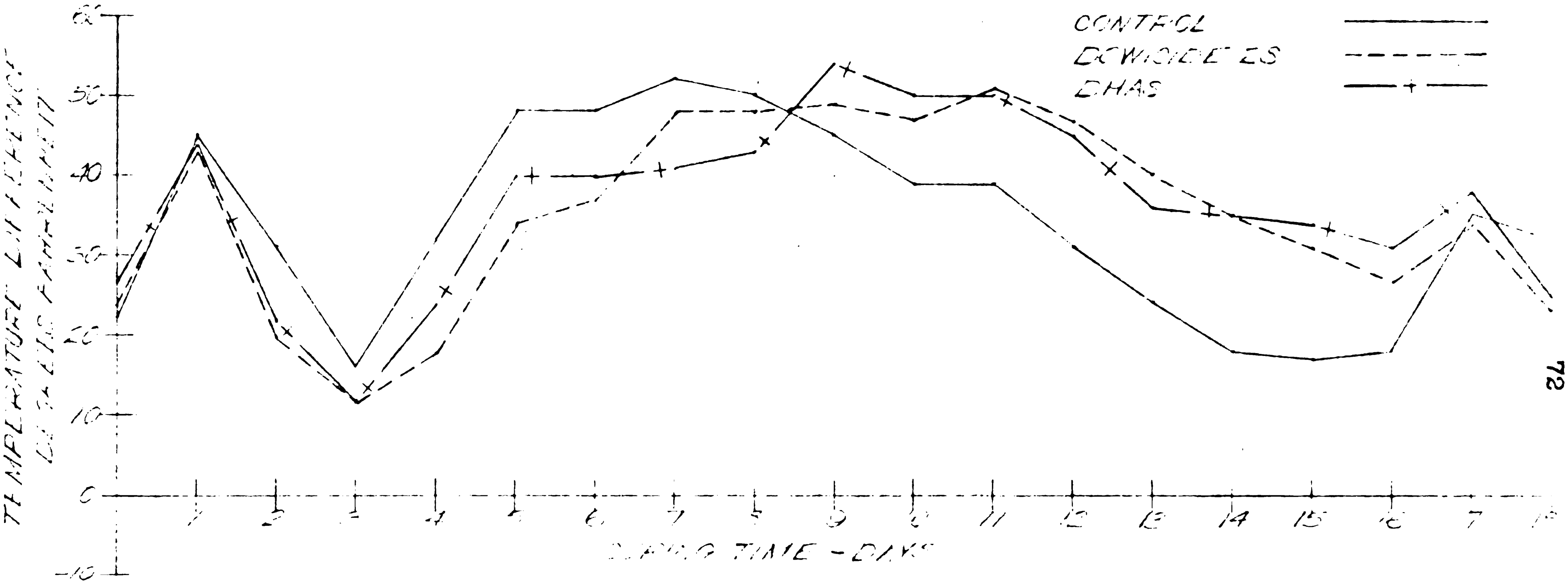
*No mold.



COMPARISON OF TEMPERATURE VARIATIONS
IN TREATED AND UNTREATED TEST BALES
SECOND CUTTING

FIG. 18

AUG., 1951 SR



COMPARISON OF TEMPERATURE VARIATIONS
IN TREATED AND UNTREATED TEST PILES
SECOND CUTTING

FIG. 19

TABLE XIII

Test Bale Inspection Results

Second Cutting

Group II

Control

Bale	Condition
1	Extremely musty
2	Musty
3	Musty
4	Very musty
5	Musty
6	Musty
7	Very musty
8	Very musty
9	Extremely musty
10	Musty
11	Extremely musty
12	Extremely musty

Dowicide 2S

1	Musty
2	Musty
3	Musty
4	Musty
5	One-half musty - one-half slightly musty
6	Very musty
7	Musty
8	Musty
9	Musty
10	Musty
11	One-half musty, one-half slightly musty

TABLE XIII (cont.)

DHAS

Bale	Condition
1	Extremely musty
2	Extremely musty, some visible mold
3	Extremely musty, some visible mold
4	Extremely musty
5	Extremely musty
6	Extremely musty

group of tests was adversely affected by the rainstorm during the field-curing period. There was very little difference between the hay treated with Dowicide 2S and the untreated hay. This condition could have been caused by the washing of the chemicals from the hay. The test of DHAS showed no control of mold, but may have been influenced by the higher moisture content of the hay.

Field Test Conclusions

1. Dowicide 2S partially prevented mold growth, but needs further testing. Possibly a better method of mixing could be found to increase its solubility in water.

2. Of the compounds tested, Dowicide B was most effective. Test results indicated, however, that rain would wash the deposited compound from the hay and reduce its effectiveness.

3. Dowicide A was effective in preventing mold growth, though slightly less than Dowicide B. Statistical analysis of the test results showed no significant difference in mold control between Dowicide A and Dowicide B.

4. DHAS was ineffective in controlling mold growth. The compound appeared to be somewhat insoluble in water, which may have reduced its effectiveness when applied as a spray.

CONCLUSIONS

1. The manufacturer stated that DHA and DHAS had very similar mold-inhibiting qualities. The laboratory tests indicated that DHA was more effective in controlling mold growth than DHAS, but DHA was unavailable for field tests. DHAS was ineffective, both in laboratory and field tests.

2. Dowicide 2S was reasonably effective in preventing mold formation, but needs further testing. Even when mixed with a caustic, the compound was somewhat insoluble, which reduced its effectiveness when sprayed.

3. Though laboratory tests gave inconclusive results with Dowicide A, field tests indicated that the compound had good mold-inhibiting qualities. A statistical analysis of the field test results showed no significant difference between Dowicide A and Dowicide B.

4. The most promising results, both in laboratory and field tests, were obtained from the use of Dowicide B. The test data indicated that Dowicide B was quite similar to Dowicide A, but Dowicide B exhibited much better fungicidal properties.

5. Test results indicated that mold control is more difficult in poor-quality hay.

6. There is a close correlation between the rate of moisture loss and the amount of temperature variation in

the bale. When high bale temperatures are reached, the rate of moisture loss is much greater.

RECOMMENDATIONS FOR FURTHER STUDY

1. Using the present test compounds, an additional check should be made on variations in spraying concentrations and methods of rendering some of the compounds more soluble.

2. Further exploration of the wide field of available fungicidal compounds.

3. Test the application of the compounds in the dry state. The powder might be applied using very fine particles in a high velocity stream of air.

4. Investigate the application of the test compounds at a different point in the haying operation. This application might be made at the feed table or bale chamber of the baler.

5. Investigate the use of the mold-inhibitor treatment and the hay crusher in combination. The sprayer could be mounted on the tractor that provides the power for the hay crusher unit.

APPENDIX
I

Statistical Analysis of Second Cutting Bale Curing Data:

1. Comparison of Dowicide A treatment and Control test lot.

$$p_1 = \frac{3}{30} = 0.100 \qquad p_2 = \frac{13}{30} = 0.434$$

$$\sigma p_1 = \sqrt{\frac{(0.1)(0.9)}{30}} \qquad \sigma p_2 = \sqrt{\frac{(0.434)(0.566)}{30}}$$

$$\sigma(p_1 - p_2) = \sqrt{\frac{1}{30}\left[(0.1)(0.9) - (0.434)(0.566)\right]}$$

$$= 0.106$$

$$t = \frac{0.434-0.100}{0.106} = 3.15$$

2. Comparison of Dowicide B treatment and Control test lot.

$$p_1 = 0.100 \qquad p_2 = \frac{19}{30} = 0.633$$

$$\sigma(p_1 - p_2) = \sqrt{\frac{1}{30}\left[(0.1)(0.9) - (0.633)(0.367)\right]}$$

$$= 0.104$$

$$t = \frac{0.633 - 0.100}{0.104} = 5.12$$

APPENDIX
I (cont.)

3. Comparison of Dowicide A and Dowicide B treatments.

$$\sigma_{(p_1 - p_2)} = \sqrt{\frac{1}{30}\,(0.246 - 0.232)}$$

$$= 0.126$$

$$t = \frac{0.633 - 0.434}{0.126} = 1.58$$

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