METHODS AND EQUIPMENT FOR DETERMINING THE MOISTURE CONTENT AND RATE OF DRYING OF HAY IN THE FIELD AND IN THE MOW

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By

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PART I

MEASUREMENT OF THE MOISTURE CONTENT OF BALED HAY DURING MOW CURING BY MEASURING THE RESISTANCE OF FABRIC ABSORPTION UNITS

INTRODUCTION

Reason for the Investigation: A method was sought to quickly and accurately ascertain the moisture content of baled hay in the mow without sampling or disturbing the hay. As the curing process is essentially a process of moisture removal, the problem involved is one of measuring the moisture content of the hay and determining when it has reached a moisture content safe for storage.

In mow curing loose or chopped hay there is no reliable method for determining when the hay has reached the safe storage point. The usual procedure for checking the progress of the curing with a forced draft system is to shut off the fan or blower for several hours. If the hay "heats" during this time it indicates that the hay is not sufficiently dry and the drying process is continued. As it often happens, the drying process is stopped too soon resulting in spoilage and poor quality hay, or it is continued needlessly long resulting in inefficiency and higher drying costs. If such a method could be worked out it would be a welcome addition to the hundreds of users of hay driers now in operation and to the thousands that will be installed within the next few years.

Review of Literature: Electric conductivity methods have been used for detecting and measuring changes in the moisture content of more or less uniform materials. This method has been employed in measuring the change in the moisture content of ceramic clay in industry for a number of years. Direct resistance methods have also been used in foundries to measure the moisture in core sands. Conductivity measurements have never been successful in soil, however, because of the influence of compaction, texture, salt content, and temperature variations.

In 1940 Dr. G. J. Bouyoucos and Prof. A. H. Mick developed an electrical resistance method for the continuous measurement of soil moisture under field conditions. Errors caused by compaction, texture, and salt content were avoided by imbedding the electrodes in a material such as plaster of Paris.

Plaster of Paris is a very porous material, holding 68 percent of its dry weight of water when saturated. The pore spaces are of the proper size to facilitate capillary movement of water. It takes only a few seconds to saturate a plaster of Paris block with water. It also has an unusual property of expanding when setting, forming a very excellent contact with the electrodes.

The principle of the absorption block is that it establishes an equilibrium with the moisture in the soil and the electrical resistance of the absorption block varies inversely with the moisture that it contains. When placed in soil or water the block establishes equilibrium with the soil or water and soon becomes constant. If the soil is dry it absorbs only a little moisture, but if it is wet it absorbs a large amount. If the moisture content of the soil changes after equilibrium has been established, the block gains or loses moisture to re-establish equilibrium with the soil. The block thus follows any moisture changes that take place in the soil surrounding it. The moisture content of the block determines its electrical resistance. A change in the moisture content of the soil is reflected by a corresponding change in the moisture content of the absorption block and its electrical resistance. Temperature is the only factor which affects the electrical resistance of the plaster of Paris block outside of its moisture content.

As the moisture content of the block decreases, its electrical resistance increases and vice versa. A change of temperature affects the electrical resistance of the absorption block when the moisture content remains constant. This effect of temperature on the electrical resistance is relatively the same at all moisture contents. As the temperature increases the electrical resistance of the block decreases for a given moisture content. Thus at a constant temperature, the electrical resistance of the absorption block varies only with its moisture content. For accurate measurements the absorption block should be corrected for temperature.

An adaptation of the wheatstone bridge is used to make the resistance measurements. Since no satisfactory standard, portable, commercial unit was originally available, one was developed. The adapted bridge consists of:

1) A 2,000 cycle vacuum tube oscillator, powered by dry cell batteries, which supplies alternating current at high frequency, eliminating polarization and electrolysis errors;
2) A variable condenser to balance out the capacitance introduced by the absorption units and up to 200 feet of commercial strand rubber coated copper wire;
3) Variable resistance arms to increase the sensitivity, the proper combination of which is selected by multiplier switches;
4) A logarithmic potentiometric rheostat with a six inch dial as the graduated arm which is adjusted to get the final null point.

The bridge is used by making use of the sound characteristics of oscillating current. The circuit is tuned to the null point which is determined by listening with ear phones. A great contrast in tone volume which rapidly fades to a minimum level within an extremely narrow range, contributes to the ease in adjustment of the instrument. Ear phones are much less expensive and more satisfactory for field work than a "magic eye" assembly. Measurements may be made quickly, usually in less than a minute. The bridge has a range of 5,000,000 ohms. The high power output produces a loud signal which is in sharp contrast with the null point which is usually marked by total silence.

Three precautions must be observed in using absorption blocks:

1) The blocks should be saturated with distilled water when they are imbedded in the soil;
2) A close contact must exist between the block and the soil;
3) If quantitative data is desired, a sample of soil from immediately around the block must be reserved for use in calibration. However, for most practical purposes, standard absorption blocks need not be calibrated. In all soils the resistance readings may be directly interpreted, as the percentage of available water in all soils in approximately the same for any given resistance value.

Other investigators have confirmed the slope and general characteristics of the soil moisture-block resistance relationship. This relationship between the moisture in the soil and block resistance is basically one of free energy. In soil an arbitrary average resistance of 75,000 ohms has proved practical as an indicator of the maximum forces against which plants can obtain moisture. The resistance curve becomes asymptotic with respect to the percent of water in the soil. This represents the permanent wilting point with the soil containing 3 to 4 percent water. As the soil approaches the permanent wilting point, very small changes in the volume of total soil water are represented by relatively large changes in absorption block resistance. Rising resistance values indicate that the soil moisture is decreasing and that the portion remaining in the soil is held with correspondingly greater force. When the block resistance falls to a constant minimum level, or the curve becomes asymptotic with respect to resistance, the soil contains abundant water and may be even giving up gravatational water. A practical but arbitrary value selected for minimum resistance is about 600 ohms, representing about 13 percent water in the soil.

Two characteristics have limited the usefulness of the plaster of Paris type of absorption unit. One disadvantage is that it does not have a wide range of sensitivity. It measures only the so-called available water in the soil, or a range of soil moisture from about 3 to 13 percent. A unit was needed which would measure the entire soil moisture range from saturation to air-dryness. A second limitation, which has no significance in regard to measuring the moisture content of hay, is that plaster of Paris does not stand up in continuously saturated moisture environments.

In 1943 studies were started on the possibility of using various types of fabrics for absorption units. Colman, in 1946, suggested a soil moisture meter with a fiberglas absorption unit. Many kinds of fabric absorption units with both internal and external electrodes were investigated by Dr. G. J. Bouyoucos and Prof. A. H. Mick. Units with external electrodes gave satisfactory measurements of soil moisture in the laboratory, but they failed to correlate with the readings obtained in the field. The discrepancy was apparently due to external factors in the soil such as degree of compaction, texture, structure, salt content, and electrical lines of force. A constant known environment was needed around the electrodes.

The constant environment utilizing internal electrodes, together with the buffering action of gypsum is mainly responsible for the success of the plaster of Paris unit. A fabric unit was then developed embodying the internal electrode principle. It consists of two perforated, extremely thin nickle plates, or two pieces of fine monel screen acting as electrodes to which are silver soldered wire leads. These electrodes are separated by wrappings of nylon or fiberglas fabric. The whole assemblage is then placed in a perforated nickle case, pressed under high pressure, and the case mechanically fastened together. The case is perforated all over with square holes, $\frac{1}{4}$ inch between centers, and is 64 percent open. The absorbent thus has a large amount of exposure to the soil.

Nylon and fiberglas have about the same absorbent characteristics. Fiberglas is preferred for soil work, however, because it has a much greater buffering action.

Compared with plaster of Paris absorption blocks the fabric absorption unit is superior in the following ways:

1) It measures the entire range of soil moisture from saturation to air dryness;
2) It has very little lag in its response to moisture changes;
3) It will last longer under extremely wet conditions.

The fabric absorption unit also possesses the following disadvantages:

1) It is more inert and does not have the capacity to buffer changes in the salt concentration of the soil solution, but this is believed to be unimportant with regard to measuring hay moisture;
2) The wrapping of fabric around the screen electrodes makes the contact artificial and imperfect. In the plaster of Paris block the electrodes are perfectly imbedded and set, and if only a small area of surface is in contact with the soil, a fair index of soil moisture is obtained;

3) The outer case of metal tends to prevent a perfect contact between the soil and the absorption unit;

4) Fiberglas may absorb silt or react chemically with some soils.

The nylon and fiberglas absorption units seem to function on the same principle as the plaster of Paris blocks. The electrical resistance of a fabric absorbent varies with its moisture content. When the surrounding soil is wet, the unit resistances are low. As the soil dries out, the resistances increase. The magnitude of the resistance change depends on the physical and chemical characteristics of the absorbent material. Nylon and fiberglas are good absorbents and good capillary conductors, and equilibrium is readily established between moisture in the fabric and moisture in the soil.

The typical moisture curve indicated by the fabric absorbent units is somewhat irregular compared to the smooth curve obtained with the plaster of Paris absorption block. This irregularity is the result of the imperfect contact between the electrodes and the fabric; interference of the outer metal case in preventing perfect contact between the soil and the unit; chemical and physical properties of the soil; and transitions of the different forms of water.

Saturated soil conditions are marked by constant low resistance values in the vicinity of 50 to 200 ohms resistance. As air dry conditions are approached, the curves become asymptotic with respect to moisture content, generally in the vicinity of 1,000,000 ohms. As excess water disappears and the air begins to enter the soil pore space, most curves are marked by a critical point and further losses are marked by relatively large increases in resistance. The wilting point of soils with average salt concentration appears to be around 10,000 to 15,000 ohms as determined by the fabric unit in comparison with about 75,000 ohms determined by the gypsum block.

Temperature influences the resistance of the fabric unit at any given moisture content. For constant moisture content an increase in the temperature results in a decrease in the resistance value. However, the change in resistance between 70° and 90°F. is nearly negligible. At low moisture levels the error in terms of soil moisture percentage is about $\pm \frac{1}{2}$.

OBJECTIVES

To develop a method for determining the moisture content of baled hay without disturbing it while it is undergoing curing in the mow so that there will be a positive means of determining when the hay has reached a moisture content safe for storage.

STATEMENT OF THE PROBLEM

A way was sought to measure the moisture content of baled hay while it was being cured without disturbing it. The fabric absorption units developed by Dr. G. J. Bouyoucos and Prof. A. H. Mick appeared to have sufficient possibilities to warrant a performance test in hay.

APPARATUS AND EQUIPMENT

The experiment was carried out in the J. I. Case hay curing laboratory. See Fig. 1. Baled hay was mow dried by heated forced air, unheated forced, air, and natural draft ventilation. The laboratory is divided into six equal size compartments with one compartment being further subdivided into two equal parts, making a total of seven hay drying compartments in all. See Fig. 2 for the physical layout of the hay curing laboratory for the location and a brief description of the various drying tests. A centrally located instrument room made it possible to take all readings by remote control.

The equipment used in the investigation consisted of the following:

1) One special Wheatstone bridge. A self contained, portable, compact, high sensitivity instrument which is described in more detail under "Review of Literature";

Fig. 1. NORTHEAST VIEW OF J. I. CASE

HAY CURING LABORATORY

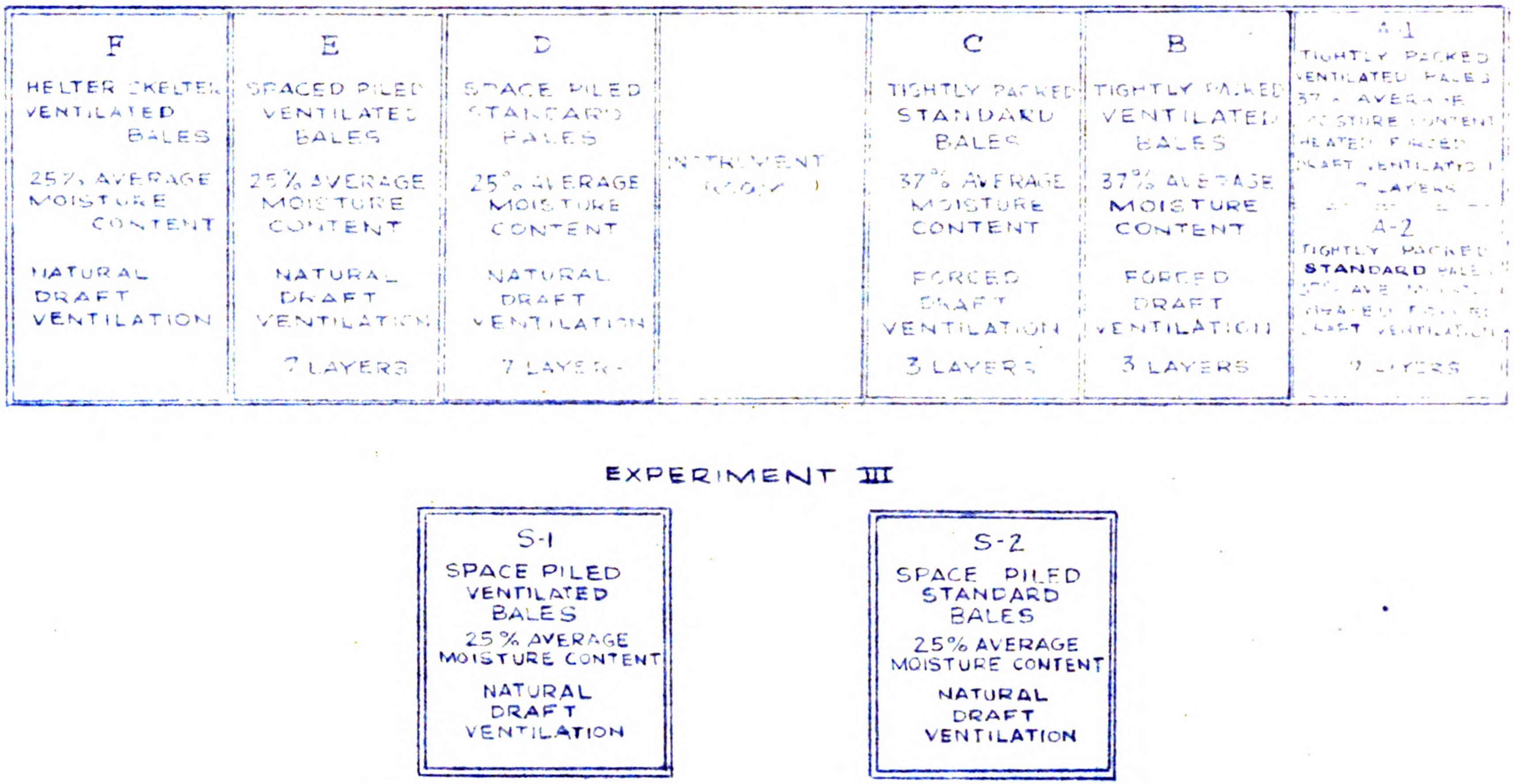


FIGURE 2 LOCATION of VARIOUS TESTS IN & AROUND THE HAY CURING LAB.

2) A Leeds and Northrup selector switch with 10 possible circuits attached to the top of an army signal corps communication jackbox;

3) Three army signal corps communications jackbox bottoms which completed the individual circuits to the possible positions for 30 fabric absorption units;

4) The necessary copper and constantan wire to connect the jackbox bottoms to the absorption units;

5) The fabric absorption units

   a) The first test was made using 12 external electrode nickle plate nylon seperated absorption units, and 4 external electrode nickle plate fiberglas separated absorption units. These 16 units were all that were available for the first test. Two internal electrode nickle plate fiberglas absorption units were also tried out independent of the remote control system.

   b) The second test was made using two of the 4 external electrode nickle plate fiberglas absorption units and the two internal electrode absorption units which were received too late to use.

The resistance bridge was connected to the master selector switch which in turn was connected through three jackboxes to the 30 absorption units. To take a resistance reading of any particular absorption unit, it was only necessary to plug into the proper jackbox and turn the master selector switch to the correct pole. The whole series of readings were taken by plugging into each jackbox in turn and turning the master selector switch to make contact with the desired absorption units. See Fig. 3 for a view of an operator taking remote control resistance readings.

Provision was made for three absorption units in each drying compartment and stack except for compartment "A" which was wired for six locations. The locations were staggered within each compartment so that moisture determination could be made in the lower, middle, and upper tiers of bales. See Fig. 4 for the 30 possible locations of the moisture content measuring units in the barn compartments and two stacks.

METHOD OF TESTING

Two separate tests were made on hay in an attempt to determine whether the resistance method of measuring the moisture content of hay has merit. The first test was made on first cutting hay using only 16 absorption units. Original plans called for 30 absorption units but they were not available for the tests.

First Test: While the 12 absorption units containing nylon absorbent were all basically the same, there were

Fig. 3. THE OPERATOR IS TAKING A RESISTANCE READING ON THE REMOTE CONTROL MOISTURE CONTENT MEASURING APPARATUS. THE MASTER SELECTOR SWITCH IS BEHIND THE BRIDGE AND THE GROUP OF THREE JACKBOXES IS TO THE LEFT.

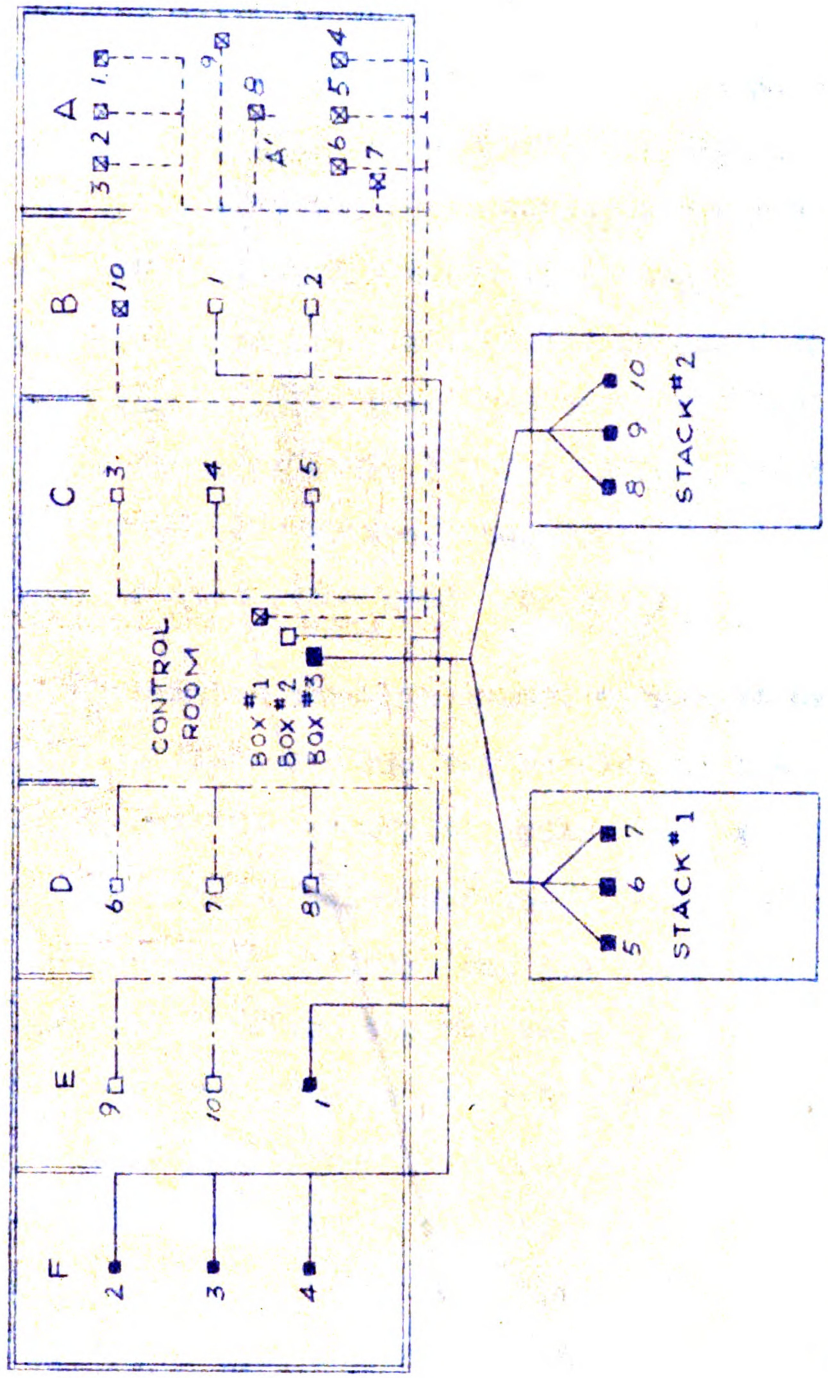


FIG. 4 THE LOCATION OF MOISTURE CONTENT MEASURING UNITS IN BARN COMPARTMENTS AND TWO STACKS.

three different styles based on the design and size of the nickle plate electrodes. See Fig. 5 for a photograph of the several types of absorption units used in the tests. Five of the absorption units were large in size, 1 7/8 by 3 inches, and had large holes, .45 of an inch square; four were small in size, 1 1/2 by 2 inches, and had large holes, .45 of an inch square; and three were large in size, 1 7/8 by 2 5/8 inches, and had small holes, .2 of an inch square. The four remaining units contained the fiberglas absorbent and were large in size, 1 7/8 by 3 inches with large holes, .45 of an inch square. See Table 1 for the location of the various absorption units for the first test .

Each absorption unit was inserted unmoistened into a test bale as the baled hay was stacked in the compartment. Where only one absorption unit was used it was put in the middle tier of bales and where two units were used one was placed in the middle, and the other was placed in either the top or bottom tier of bales. A special parting device was used to open the bales so that the absorption unit could be inserted into the center of the bale. See Fig. 6 for a picture of an absorption unit being placed in a test bale. The objective was to disturb the bale as little as possible so that the pressure exerted by the hay on the absorption unit would be the same as the pressure and density existing in the rest of the bale. A method was also desired which would not require opening

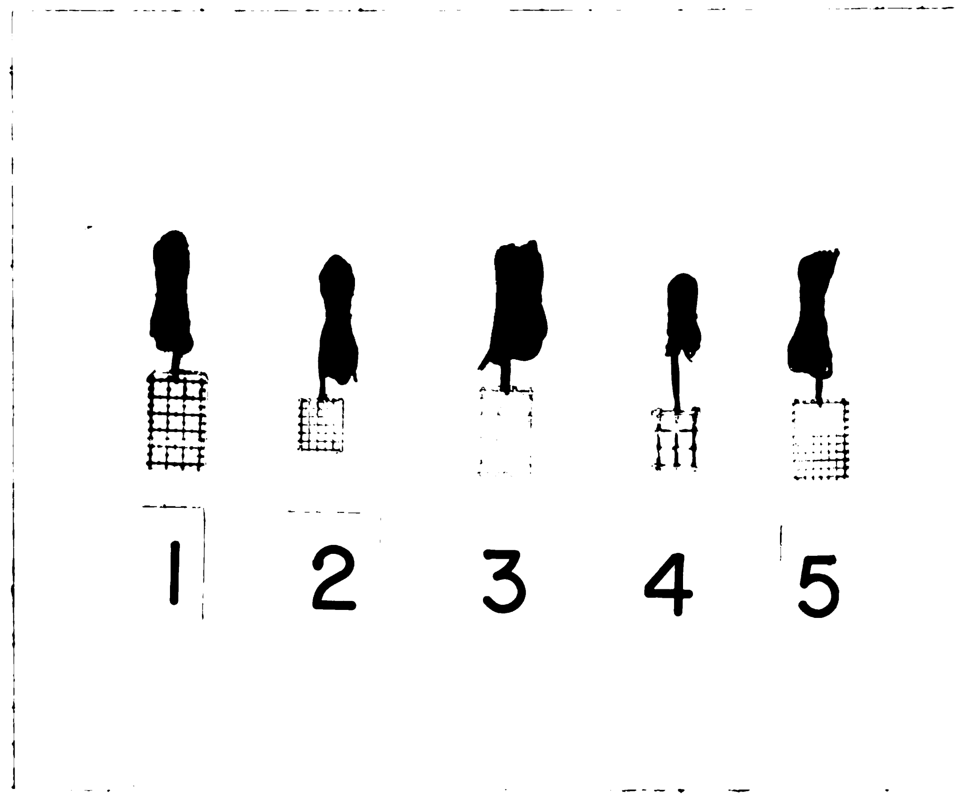


Fig. 5. SEVERAL TYPES OF ABSORPTION UNITS WHICH WERE TESTED. 1, FIBERGLAS, EXTERNAL ELECTRODE; 2, FIBERGLAS INTERNAL ELECTRODE; 3, 4, 5, NYLON EXTERNAL ELECTRODES.

Table 1. Types and Locations of Fabric Absorption Units Used in the First Test

Comp.	Box No.	Pole No.	Position in Comp.	Type	Description
A-1	1	2	Middle layer	Nylon external electrode	Large size, large holes
A-2	1	5	Middle layer	Nylon external electrode	Small size; large holes
		7	Bottom layer	Nylon external electrode	Small size, large holes
		8	Middle layer	Nylon external electrode	Large size, small holes
		9	Upper layer	Nylon external electrode	Small size, large holes
B	2	1	Middle layer	Nylon external electrode	Large size, small holes
		2	Upper layer	Fiberglas external elec.	Large size, large holes
C	2	3	Bottom layer	Fiberglas external elec.	Large size, large holes
		4	Middle layer	Nylon external electrode	Large size, large holes
D	2	7	Middle layer	Nylon external electrode	Large size, large holes
E	2	9	Bottom layer	Fiberglas external elec.	Large size, large holes
		10	Middle layer	Nylon external electrode	Large size, large holes
F	3	3	Middle layer	Nylon external electrode	Large size, small holes
S-1	3	6	Middle layer	Nylon external electrode	Large size, large holes
	3	7	Upper layer	Fiberglas external elec.	Large size, large holes
S-2	3	9	Middle layer	Nylon external electrode	Small size, large holes

Fig. 6. A FABRIC ABSORPTION UNIT BEING PLACED IN A TEST BALE

and reclosing the bale to save time. The densities of individual bales varied considerably, however, as shown by the Case Hay Drying Project report. The wide range in original bale density probably has more influence on the action of the absorption units than does the slight change in bale pressure due to the opening of the bale to insert the unit.

The first hay was harvested at an average moisture content of 26.5 percent and was stacked helter skelter in compartment "F" for drying by natural draft. All hay moisture contents are expressed on a wet basis unless otherwise stated. The resistance readings were taken beginning on June 26th and were recorded four times daily at 0400, 1000, 1600, and 2200 hours. Resistance readings for all tests were taken at these same hours.

On July 3rd hay at an average moisture content of 25.3 percent was placed in compartment "E" for drying by natural draft. Rain and inclement weather interfered with hay harvesting during the greater part of the first cutting tests so that it was very difficult to harvest hay at the desired moisture content. Farmers in this area had considerable difficulty making hay and much of it was finally abandoned in the field. The hay that went into compartment "E" and "F", for instance, had developed mold on the stems while still standing. For a discussion of the rate of drying of hay in the field see Part II of this report.

On July 7th hay baled for test in compartment "A-1" was a mixture of alfalfa and brome grass with an average moisture content of 33.5 percent and similar hay placed in compartment "A-2" had an average moisture content of 31.3 percent. heated forced air was used to dry the hay in both of these compartments. The test was completed on July 12th after five days of drying.

On the same day a mixture of alfalfa and grass hay with an average moisture content of 33.1 percent was placed in compartment "B" for drying by unheated forced draft. This test was completed on July 16th.

On July 8th similar hay at 35.7 percent average moisture content was put in compartment "C" for drying by unheated forced draft. Compartment "D" was filled on the same day with a mixture of alfalfa and grass hay at an average moisture content of 22.9 percent. These drying tests were completed on July 26th.

Two stacks were constructed outside of the hay laboratory for drying by natural draft means on July 9th. Stack "S-1" consisted of clover and grass hay at an average moisture content of 23.7 percent while stack "S-2" consisted of similar hay at an average moisture content of 26.0 percent. The drying tests were completed on July 28th.

The last of the first cutting, a mixture of clover and alfalfa was put into compartment "A-1" and "A-2" at an average moisture content of 30.5 percent and 30.1 percent respectively. The drying test was completed after eight days. During this second heated forced draft test two internal electrode fiberglas absorption units were tried in compartments "A-1" and "A-2" in the top layer of bales. The results were no more conclusive than those obtained from the external electrode absorption units. The test setup, however, was felt to be unsatisfactory and a second test was planned to determine whether the internal electrode absorption unit had possibilities for measuring the moisture content of baled hay.

Second Test: Only part of the compartments were used for the baled hay drying tests in the second cutting. Based on the results of the first tests, the nylon absorption units were discarded as being unsatisfactory. The fiberglas absorption units indicated some promise and two external electrode and two internal electrode absorption units of this type were used for the second cutting tests. One internal and one external electrode absorption unit were put in both compartments "B" and "C" which were both dryed by means of unheated forced draft. The two unmoistened absorption units were put in compartment "B" with an internal electrode absorption unit placed in the middle layer and an external electrode absorption unit placed in the upper layer of bales. The pre-saturated units were put in compartment "C" with the external electrode absorption unit placed in the middle layer and the internal electrode absorption unit placed in the upper layer of bales. See Table 2 for types and locations of these units.

Table 2. Types and Locations of Four Fiberglas Absorption Units Used in the Second Test

Comp.	Box No.	Pole No.	Position in Comp.	Type
B	2	1	Middle layer	Fiberglas internal electrode
		2	Top layer	Fiberglas external electrode
C	2	4	Top layer	Fiberglas internal electrode
		5	Middle layer	Fiberglas external electrode

The baled hay, a mixture of alfalfa and grass, was put into compartment "B" on August 4th at an average moisture content of 45.0 percent and into compartment "C" at an average moisture content of 40.0 percent. The resistance readings were taken beginning on August 4th and were completed on August 12th.

The resistance readings of the first test indicated that there was considerable lag on the part of the absorption units in establishing equilibrium with the baled hay when the absorption units were not pre-saturated before insertion in the test bale. For the second test two of the fiberglas absorption units were pre-saturated and compared with the two similar absorption units which were not pre-moistened before inserting into the test bales. Research in soil moisture testing had shown that it was necessary to saturate plaster of Paris blocks with distilled water before embedding in the soil. However, it was not believed necessary to saturate the fabric absorption units which are very hydroscopic. In hay, where a much less perfect contact is made between the moisture containing hay and the absorbent, it appears necessary to saturate the absorbent before inserting it in the hay whose moisture content is being measured.

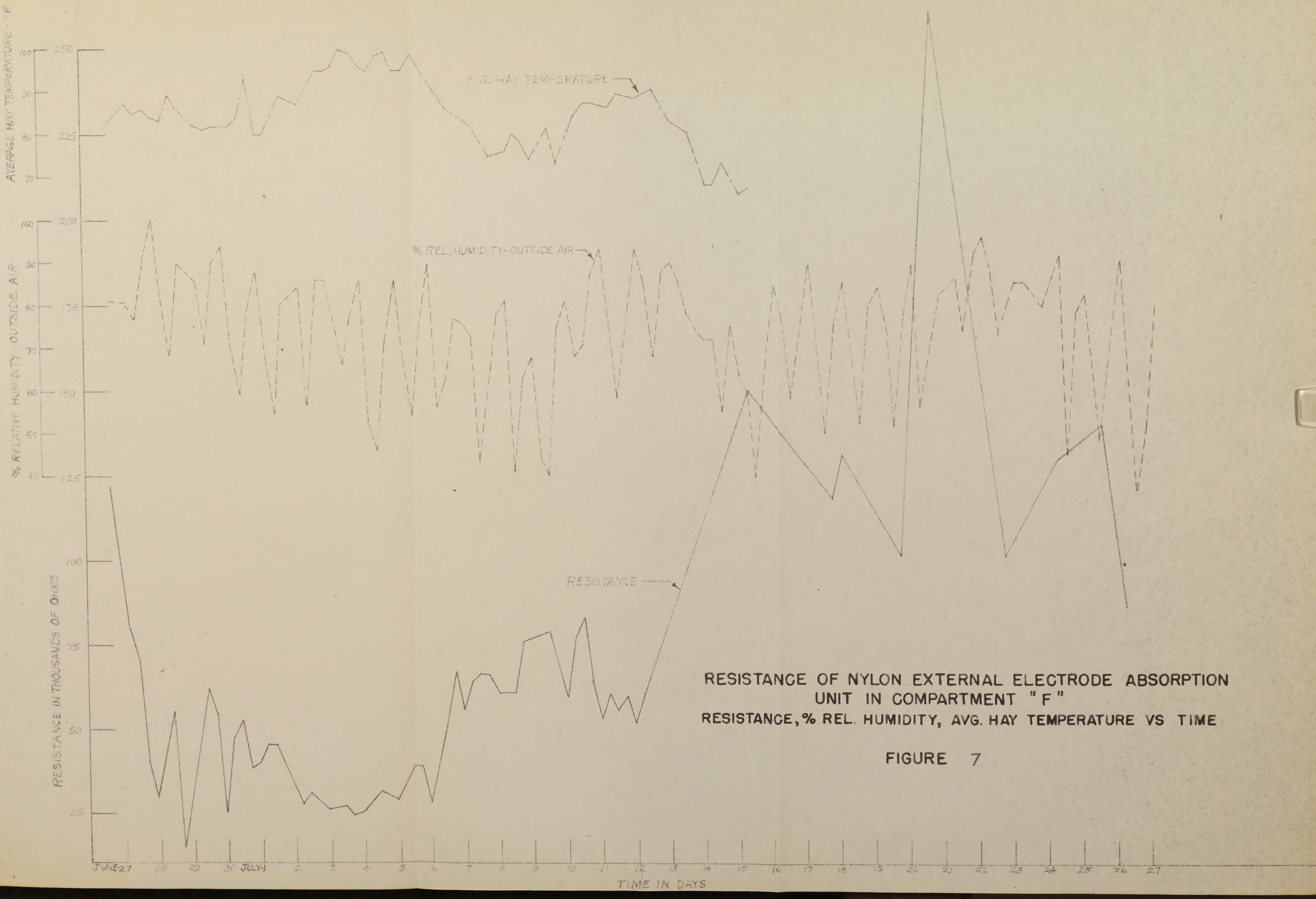
For the second test a non-portable assembled bridge for measuring resistance furnished by the Electrical Engineering Department was used to check the results of the portable bridge used in the first test. There was some doubt as to the accuracy of the resistance readings obtained with it, but the readings of both bridges in the second test were very similar showing that the portable bridge was reasonably accurate. With the pre-saturated absorption units there was very good agreement in resistance readings given by both bridges, while the resistance readings on the non-moistened absorption units showed some variance.

RESULTS AND DISCUSSION

First Test: Compartment "F" was filled helter skelter with a mixture of alfalfa and timothy at an average moisture content of 26.5 percent. After drying 13 days by natural draft the hay was removed with an average moisture content of 14.1 percent. One nylon external electrode absorption unit was placed in the middle layer of bales. Metabolic activity and considerable heating while curing had an unknown influence on the resistance of the absorption units. The high hay temperature reached 114°F. The resistance readings were greatly influenced by relative humidity during the test, increasing when the relative humidity decreased and decreasing when the relative humidity increased. The temperature also seemed to influence the resistance readings. After the absorption unit reached apparent equilibrium, low temperatures in general were characterized by higher resistance readings and high temperatures in general were characterized by lower resistance readings. See Fig. 7.

The resistance readings ranged mostly from 25,000 to 150,000 ohms. The moisture content of the hay evidently played only a minor role in determining the resistance readings. There was a general upward trend to indicate that the hay was drying out, but the readings were irregular and not very conclusive. There was no point in the curve which indicated that the hay had reached a safe storage condition as would have been indicated by a rapid and continuous increase in the resistance readings.

Compartment "L" was stacked seven layers deep with a mixture of alfalfa and grass baled hay. The hay was baled at an average moisture content of 25.3 percent and after curing 18 days by natural draft it was removed at an average moisture content of 14.8 percent. Like the hay in



RESISTANCE OF NYLON EXTERNAL ELECTRODE ABSORPTION UNIT IN COMPARTMENT "F"

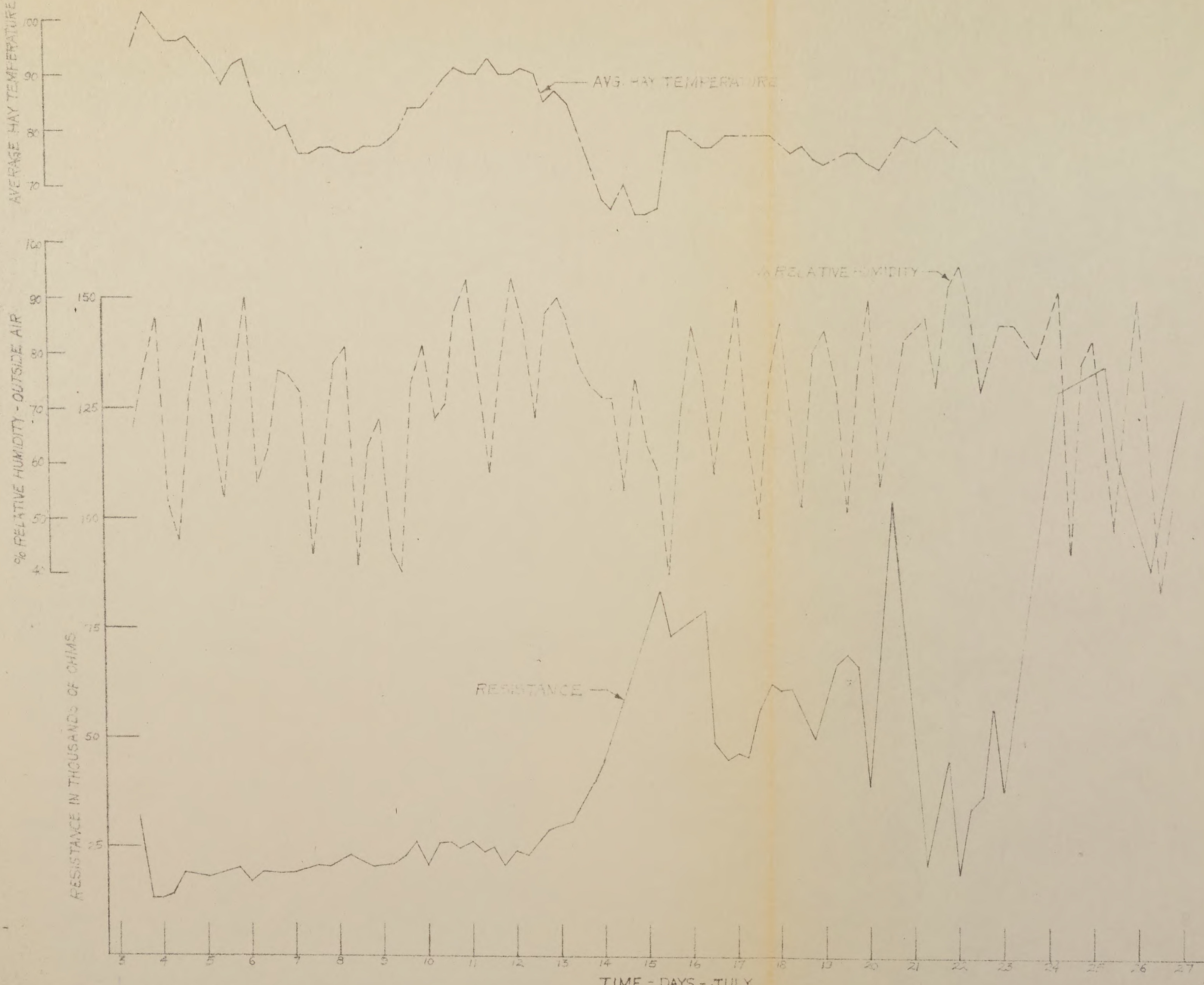
RESISTANCE, % REL. HUMIDITY, AVG. HAY TEMPERATURE VS TIME

FIGURE 7

compartment "F", this hay was made under adverse weather conditions and metabolic activity had begun while it was still in the field. The influence of these factors in comparison with the other factors of relative humidity, temperature, and moisture content on the resistance readings cannot be determined. The high hay temperature reached 132°F.

A fiberglas and a nylon external electrode absorption unit were placed in the bottom and middle layer of bales respectively. The nylon unit gave readings which were irregular and inconclusive. It took five days to reach apparent equilibrium and then after the 12th day a null point was not obtainable and the resistance was out of reach of the bridge. No curve was plotted for this absorption unit.

The fiberglas absorption unit gave fairly good resistance readings during the first part of the test ranging primarily between 12,500 and 135,000 ohms. See Fig. 8. It reached apparent equilibrium the first day and then started a gradual and quite regular climb indicating that the hay was drying out. After nine days of drying the resistance readings started to increase quite rapidly, but two days later the curve broke and started down. Very irregular fluctuations in resistance were recorded for the remainder of the test. Comparatively low temperatures marked the sharp increase in resistance readings. When the curve broke the temperature rose about 15 F. and remained



RESISTANCE OF FIBERGLAS EXTERNAL ELECTRODE ABSORPTION UNIT IN COMPARTMENT "E"

RESISTANCE, % RELATIVE HUMIDITY, & AVERAGE HAY TEMPERATURE VS TIME

FIGURE 8

fairly constant thereafter. During this period of rather constant temperature, the resistance readings apparently responded with marked lagging to the influence of relative humidity.

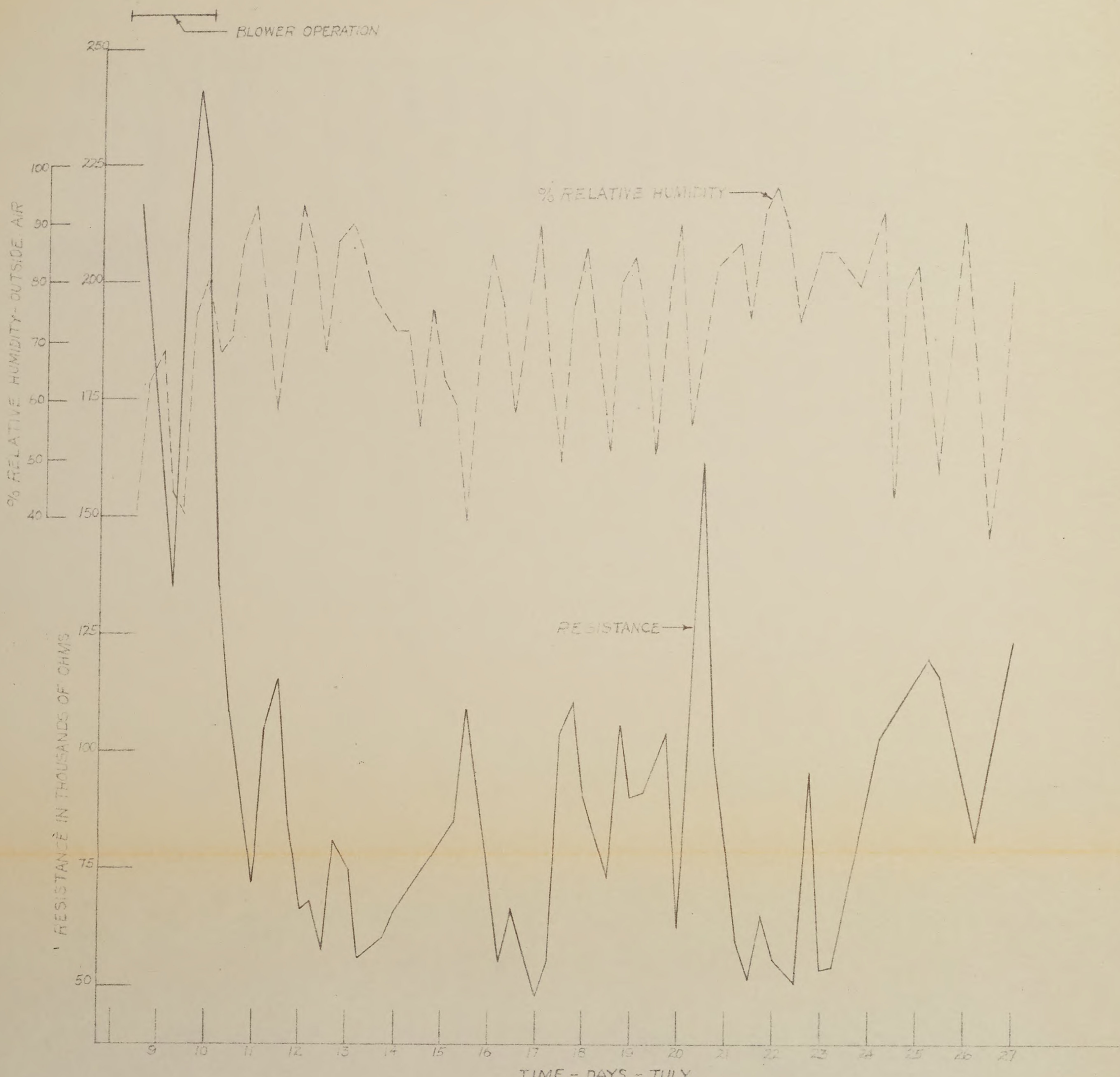
Hay in compartment "A-1" dried down to 20.1 percent average moisture content and hay in "A-2" dried down to 14.3 percent average moisture content after five days of drying by heated forced air. Insufficient data on resistance readings from the nylon and fiberglas absorption units located in these compartments prevent any analysis on the value of the resistance method of measuring the moisture content of baled hay while undergoing drying. The moisture content of the test bales after drying varied quite widely also, ranging from 4 percent to 29 percent. With some bales very dry and others comparatively high in moisture content, the effect of hay moisture content on the resistance readings could not be determined. The resistance readings that were obtained indicated a quite rapid and gradual increase but the curve did not become asymptotic to time to indicate that the hay had reached a condition of air dryness for safe storage condition. No curves were plotted for these absorption units.

Hay baled for tests in compartment "B" was a mixture of alfalfa and brome grass with an average moisture content of 33.1 percent. After drying by unheated forced air it was removed with an average moisture content of 12.8 percent. A nylon and a fiberglas external electrode absorption unit were checked in this compartment in the middle and upper layer of bales respectively. The resistance readings were very irregular tending to fluctuate through wide ranges of resistance values without apparent reason. The nylon and fiberglas absorption units both started out at a much higher range of resistance, about 500,000 ohms, and reached an apparent equilibrium two days later around 110,000 ohms resistance. From then on they acted very spasmodically, continually going up for a while and then dropping back near apparent equilibrium. After nearly two weeks of drying they even dropped down to resistance values lower than those obtained for the original apparent equilibrium. This was apparently the result of very high relative humidity during two days of rain. No good indication of drying was given. The fiberglas absorption unit did show a very general trend of increasing resistance to indicate drying during the first half of the test. No curves were plotted for either unit.

Mixed alfalfa and grass hay was put into compartment "C" at an average moisture content of 35.7 percent and removed after eight days of drying by unheated forced air at an average moisture content of 13.5 percent. A fiberglas and nylon external electrode absorption unit were located in the lower and middle layers of bales respectively. The resistance readings were again very irregular and while there was a slight general increase in the resistance readings there was a wide variation between individual readings. The hay certainly passed through the air dry stage, but there was no pronounced point at which the resistance readings began a rapid increase to indicate that the hay was air dry. The range of moisture content in the dried hay was from 11 percent to 17 percent. The resistance values were not plotted for the nylon absorption unit.

The resistance readings of the fiberglas absorption unit again seemed to respond to the changes in relative humidity. During the time the blower was on, the temperature was kept comparatively low and the resistance values were high. As soon as the blower was shut off the temperature increased and the resistance values decreased. From that time on the change in resistance values seemed to be a result of changing relative humidity. There was no pronounced reaction to temperature, but some low resistance values occurred at the peaks of the highest hay temperature. See Fig. 9 for graph of resistance values obtained from fiberglas absorption unit in compartment "C".

Compartment "D" was filled with alfalfa and grass mixture at an average moisture content of 22.9 percent. The bales were stacked seven layers deep and cured by natural draft over a period of 13 days. The average moisture content after curing was 13.1 percent. One external nylon absorption unit was located in this compartment in the middle layer of bales. The resistance readings were



RESISTANCE OF FIBERGLAS EXTERNAL ELECTRODE ABSORPTION UNIT IN COMPARTMENT "C"

RESISTANCE & % RELATIVE HUMIDITY VS TIME

FIGURE 9

irregular and indicated no clear cut trend of drying. Located deep in the center of the mow there was evidently considerable time lag before the resistance readings were affected by relative humidity or temperature. No curve was plotted for this absorption unit.

Clover and grass hay was baled at average moisture contents of 23.7 percent and 26.0 percent and used to construct stacks "S-1" and "S-2" respectively. Both stacks had an average moisture content of 14.5 percent after curing by natural draft for 18 days. A nylon and a fiberglas external electrode absorption unit were located in stack "S-1" in the middle and top layer of bales. One nylon absorption unit only was tested in stack "S-2" in the middle layer of bales. These nylon absorption units responded similarly to the other nylon units located in other compartments. There was no good indication of drying by constantly increasing resistance values. In general the results were unsatisfactory and form the basis for the conclusion that these units are not adaptable for measuring the moisture content of hay.

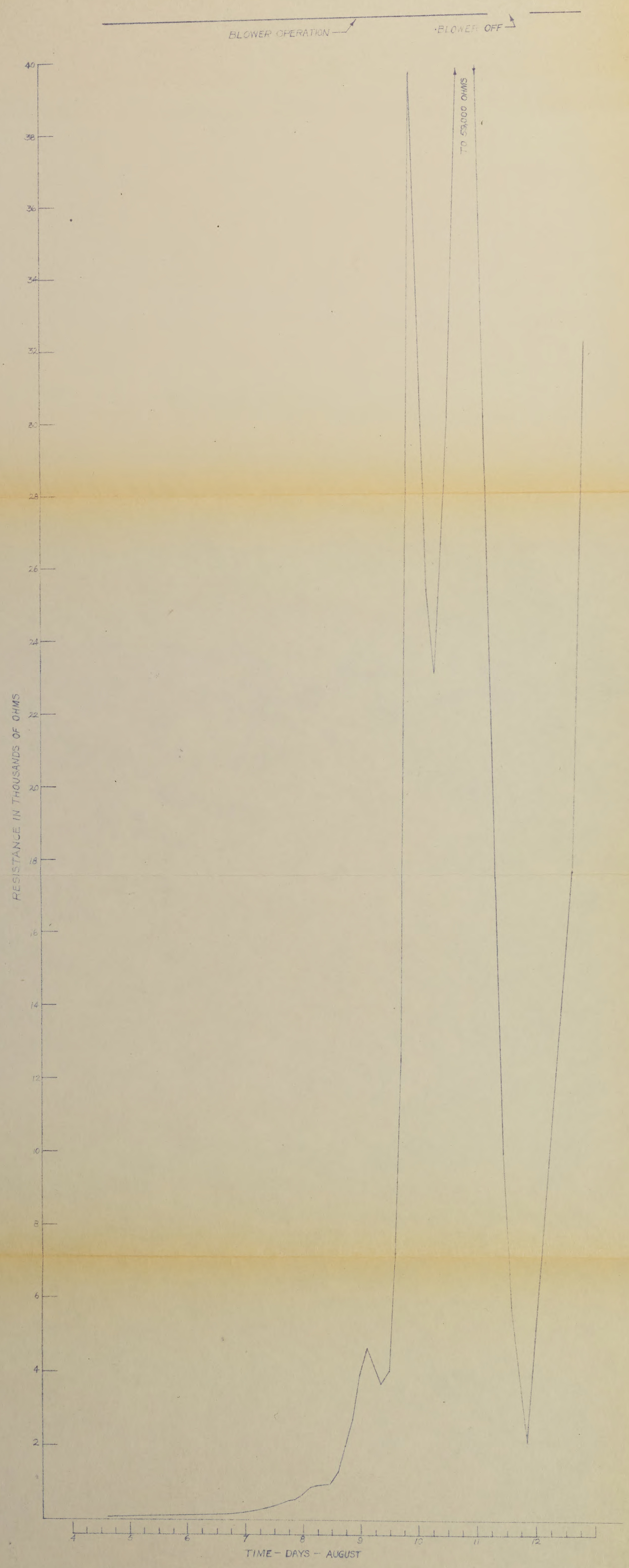
The resistance readings obtained from the fiberglas absorption unit were not much better and showed wide variance also. After the second day when apparent equilibrium was established, the resistance wavered up and down and showed no consistent increase to indicate that the hay was drying. In general higher resistance values were accompanied by lower temperatures and lower resistances by higher temperatures. At one time it rained for two days and the resistance dropped very low during that period. No curves were plotted for the resistance values.

All during the test considerable difficulty was had in isolating the null point to establish the resistance readings. Because of the scope and size of the hay drying project it was necessary to work several persons in shifts to take readings night and day. This contributed unknown errors where judgment was required in interpretation. The readings were not easy to take and in all probability were interpreted quite differently by each person. It usually took several minutes to take each reading. The null points were not as sharp and clear cut as usually experienced in taking soil moisture content resistance readings.

Second Test: Resistance readings were taken every three hours on four fiberglas absorption units in compartments "B" and "C" which were filled with three layers of baled alfalfa and grass hay. The hay in compartment "B" had an average moisture content of 44.5 percent when entering the compartment and an average moisture content of 10.5 percent when it was removed 11 days later. The hay in compartment "C" had an average moisture content of 45.8 percent when entering the compartment and an average moisture content of 13.5 percent when it was removed at the same time as the hay in "B". The blower was operated continually for 204 hours except for short periods of time when it was necessary to shut down for servicing the engine

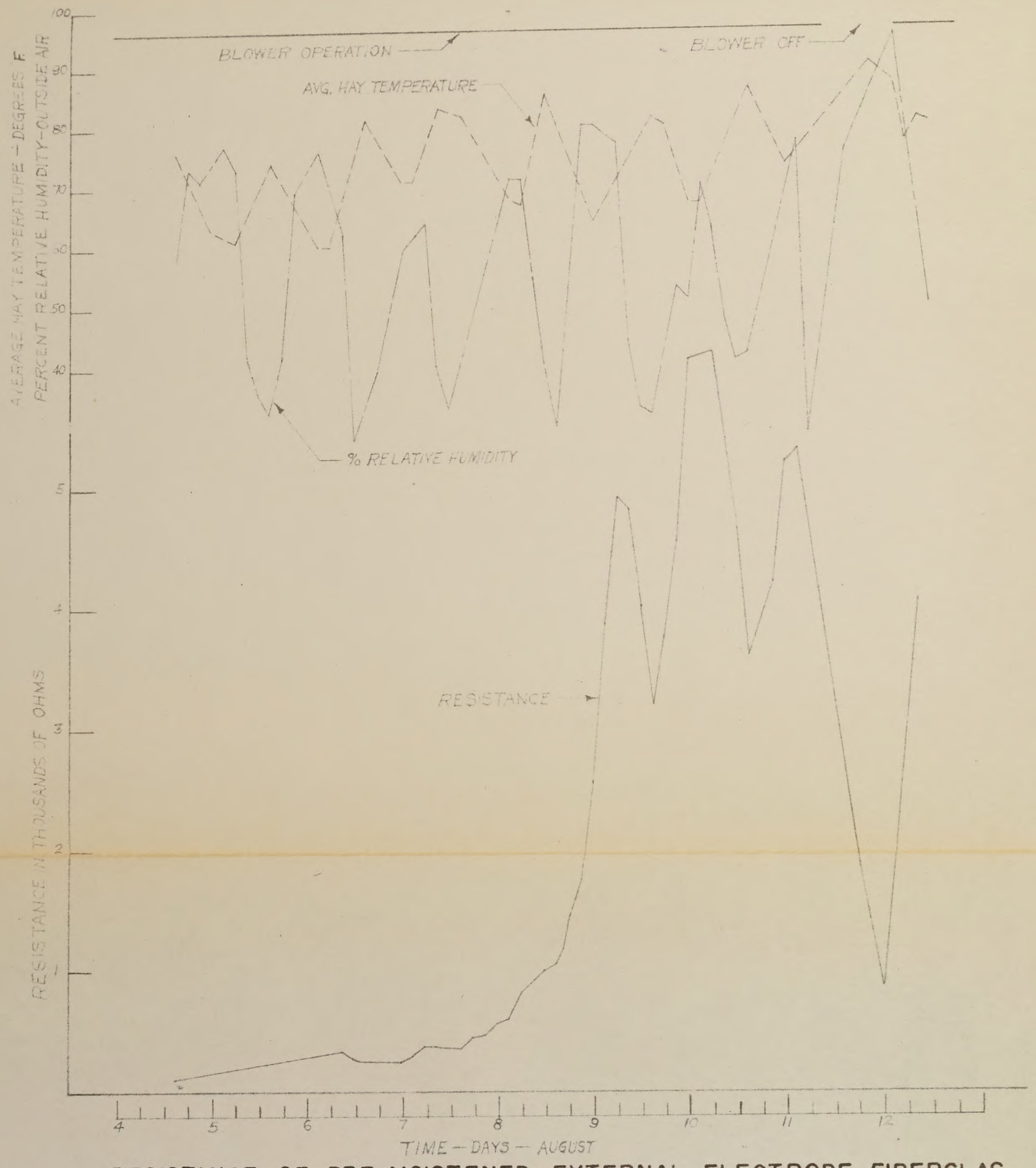
The two fiberglas absorption units which were saturated with distilled water before being inserted in the test bales, gave a very uniform resistance curve the first three days of blower operation. See Fig. 10 and Fig. 11. On the third day the resistance values began to increase more rapidly and gradually accelerated. On the fifth day there was a small break in the curves which was the result of high relative humidity accompanied by precipitation so that higher moisture content air was being blown into the compartment than was leaving the hay. Moisture was actually being deposited in the hay instead of being removed. This was indicated by a decrease in the resistance values. Being located in the middle and top layers of bales there was some lagging in the effect of the moisture addition on the resistance values.

The internal electrode fiberglas unit, see Fig. 10, recovered in 12 hours and the resistance curve became almost asymptotic with time to indicate that a critical point had been reached. In soil, saturated conditions are marked by constant low resistance values in the vicinity of 50 to 200 ohms resistance which were also obtained in the hay with the pre-saturated fiberglas units. As excess water disappears and the air begins to enter the soil pore spaces, soil resistance curves are usually marked by a



RESISTANCE OF PRE-MOISTENED INTERNAL ELECTRODE FIBERGLAS ABSORPTION UNIT IN COMPARTMENT " C "

FIGURE 10



RESISTANCE OF PRE-MOISTENED EXTERNAL ELECTRODE FIBERGLAS ABSORPTION UNIT IN COMPARTMENT " C "

RESISTANCE, % REL. HUMIDITY, & AVG. HAY TEMPERATURE VS TIME

FIGURE 11

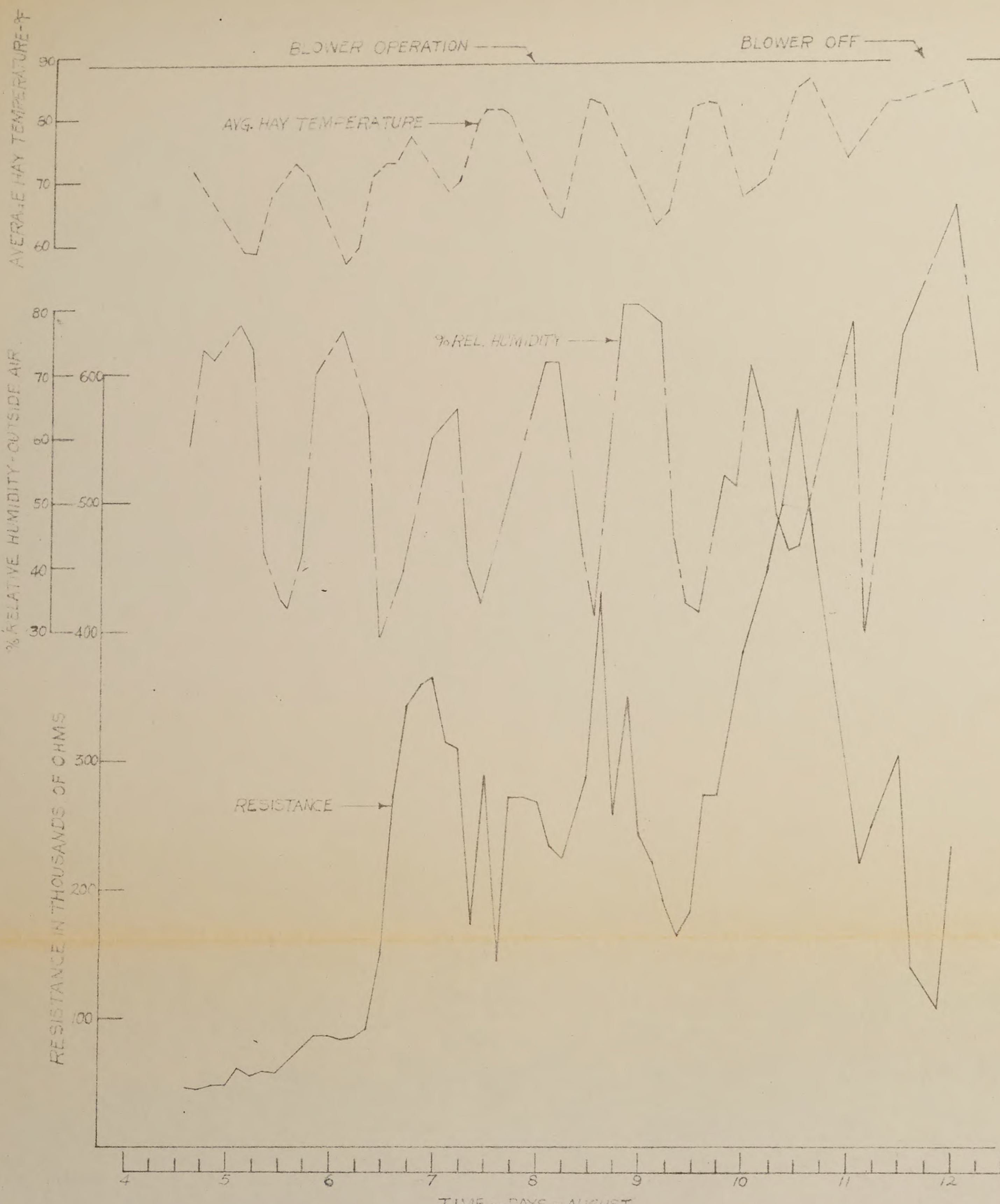
critical point and further losses are marked by relatively large increases in resistance. This is called the wilting point of soils and is shown by a resistance of 10,000 to 15,000 ohms by fabric absorption units. A similar response was obtained with the pre-saturated internal fiberglas absorption unit in hay. The resistance curve was marked by relatively large increases from 1,000 to 7,000 ohms and then increased rapidly to values well above 15,000 ohms. However, after going above 40,000 ohms the resistance curve of drying hay broke and began wavering up and down. The irregular changes in resistance were apparently not due to irregular changes in the hay moisture content because wet and dry bulb temperatures of both the entering and leaving air showed that moisture was continually being removed from the hay. However, the changes in resistance values were not without cause and the influencing effect must have come from the atmosphere surrounding the absorption unit. The only two known criteria are the relative humidity and the temperature.

When the blower was shut off on the 11th of August to check the progress of curing, the temperature and relative humidity immediately increased causing the resistance values to decrease markedly. They even dropped down to about 2,000 ohms resistance to suggest again that atmospheric conditions around the absorption unit were more influential than the actual moisture content of the hay in determining the resistance values of the absorption unit. When the blower operation was restarted the resistance values again increased as the temperature and relative humidity decreased.

The external electrode fiberglas absorption unit, see Fig. 11, reached 6,000 ohms resistance before the curve broke and began fluctuating. Irregular changes in moisture content were apparently not the cause of these irregular resistance readings, as was suggested above. During the time the blower was off the resistance values decreased and likewise increased when it was turned on again.

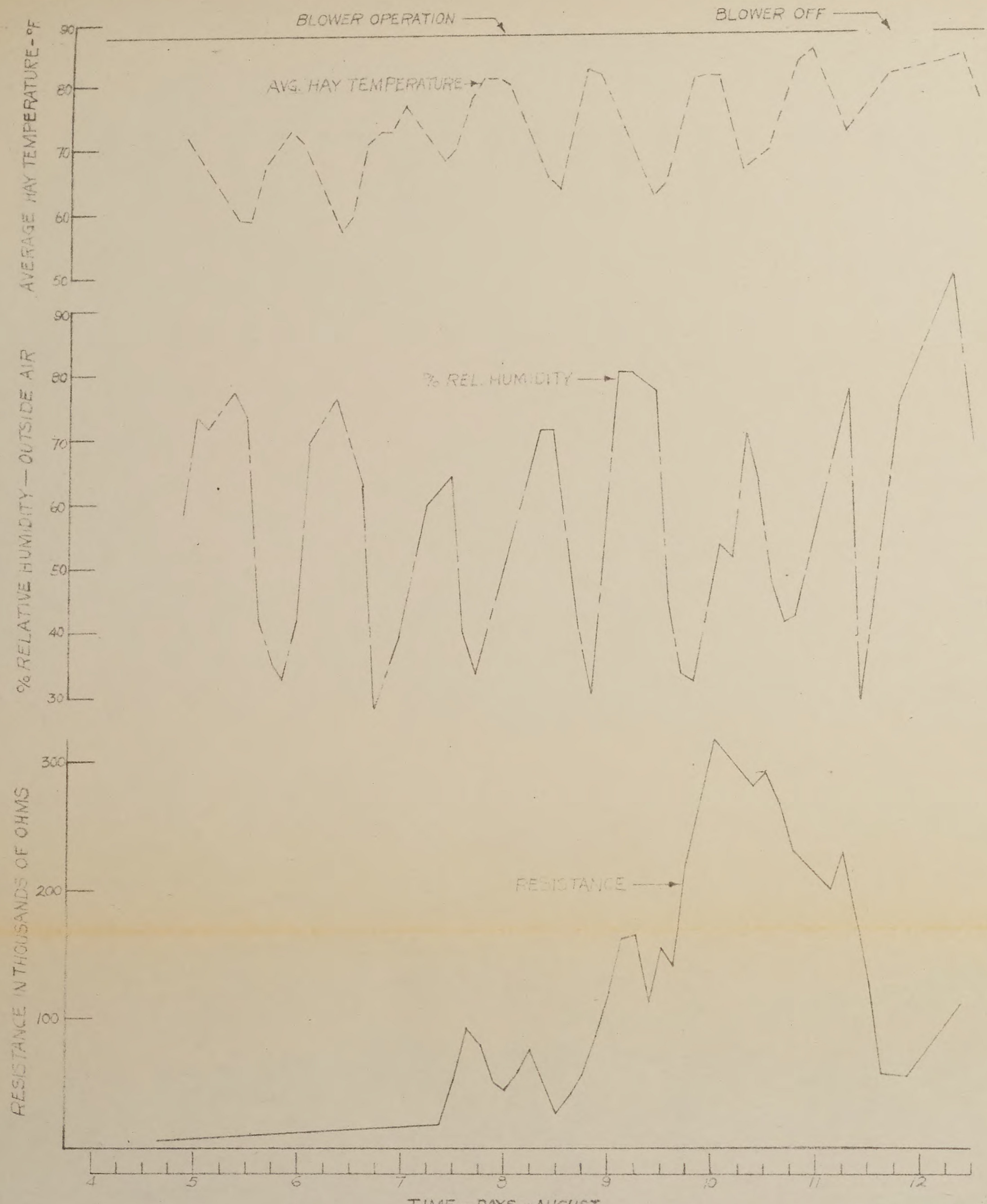
The non-saturated absorption units gave irregular readings similar to those obtained in the first test. The internal electrode unit gave resistance readings at a much higher range establishing apparent equilibrium at about 47,000 ohms and going as high as 570,000 ohms. See Fig. 12. This is considerably higher compared with the range of 45 to 60,000 ohms for the pre-saturated internal electrode unit. The non-saturated external electrode unit gave resistance readings ranging from about 7,000 ohms to 315,000 ohms as compared with a range of 100 ohms to 5,700 ohms for the pre-saturated external electrode unit. See Fig. 13. The external electrode unit showed less variance and a more gradual increase in resistance readings than did the internal electrode unit.

These few tests are at best only an indication, but they do suggest that fabric absorption units of the types



RESISTANCE OF UN-MOISTENED INTERNAL ELECTRODE FIBERGLAS ABSORPTION UNIT IN COMPARTMENT "B"
RESISTANCE, % RELATIVE HUMIDITY, & AVG. HAY TEMP. VS TIME

FIGURE 12



RESISTANCE OF UN-MOISTENED EXTERIOR ELECTRODE
FIBERGLAS ABSORPTION UNIT IN COMPARTMENT "B"
RESISTANCE, % REL. HUMIDITY, & AVG. HAY TEMPERATURE VS TIME

FIGURE 13

tested are not adaptable for measuring the moisture content of drying hay.

CONCLUSIONS

1) Fabric absorption units of the types used for measuring the moisture content of soil are not adapted to measuring the moisture content of hay.

2) The biggest factor contributing to their unsatisfactory operation is the lack of intimate contact between the moisture containing fibers and the absorbent of the absorption unit. At best this contact is very incomplete and artificial. The stems which contain most of the moisture form a very weak bridge for the conduction of the contained moisture to the absorbent of the unit. There are too few paths and they are very restricted and very indirect.

3) The nature of the absorption unit with its imperfect contact between the electrodes and the fabric, and with its outer metal case which interferes with perfect contact between the hay and the absorbent further decreases the chances of ever establishing anything like an intimate contact between the hay and the absorbent.

4) As the result of this poor contact the resistance readings tend to be influenced more by changes of relative humidity and temperature in the atmosphere which surrounds the absorption unit than by changes in the moisture content of the hay.

5) It is necessary to pre-saturate fabric absorption units before inserting them in the hay to be tested to establish a condition of equilibrium between the moisture containing hay and the absorbent. Although it was not tried, it is believed that pre-saturated nylon absorption units would have reacted similarly to the pre-saturated fiberglas absorption units.

6) In general higher temperatures will cause lower resistance values for a given absorption unit and lower temperatures will be characterized by higher resistance values.

7) In general for a given absorption unit the higher the relative humidity the lower will be the resistance values, and the lower the relative humidity the higher will be the values of resistance.

RECOMMENDATIONS FOR FURTHER STUDY

The fiberglas absorption units used in this study were experimental units still in the process of development. The internal electrode fabric absorption unit was designed to provide a constant environment around the electrodes so that the resistance of the unit would be unaffected by such factors as texture, compaction, chemical reaction with material being measured, and electric lines of force. With a constant environment the resistance of the electrodes would only be affected by the moisture content and the temperature of the environment.

It was later discovered by Dr. Bouyoucos, that a constant environment was not obtained in the first internal electrode fiberglas absorption units as a result of insufficient and improper contact between the fabric absorbent and the electrodes. A new technique in assembling is now being used to provide increased internal contact and to assure a more constant environment.

Dr. Bouyoucos has been receiving numerous requests for information regarding the use of the fabric absorption units to measure the moisture content of other materials besides soil. The improved internal electrode fiberglas absorption units should be retested in hay. However, in measuring the moisture content of material like hay, the biggest problem still is to get sufficient contact between the hay and the absorbent. Fluffy or expanding absorbents which would intermix and surround the hay would greatly increase the possibilities for successful measurement of moisture content of hay and similar poor contact materials. The improved fabric absorption units should be studied in chopped hay since it provides more intimate contact than does either baled or loose hay.

The use of these improved fabric absorption units to measure the moisture content of grains like wheat and rice should also be investigated.

PART II

FIELD DRYING RATES OF ALFALFA, ALFALFA AND BROME GRASS, AND JUNE CLOVER HAY IN THE SUMMER OF 1948

INTRODUCTION

The work that was done in moisture testing and the data herein presented was gathered in conjunction with hay drying experiments being made by the Agricultural Engineering Department of Michigan State College in cooperation with the J. I. Case Company of Racine, Wisconsin.

Any locality with diversified weather conditions presents a rather serious problem to the would-be hay maker. It is desirable to be able to make hay while the sun shines, but when it does not the farmer has to do the best he can to get his hay in under shelter in the best condition possible.

There are many factors, of course, which influence the rate at which hay dries or cures once it is cut down. The type of legume or grass and the percentage of each type in the composite sample if it is a mixture; the thickness, growth, succulence, and quality of stand; the kind and amount of weeds and foreign material if they are present; the stage of maturity at the time of cutting; the direction, nature, and velocity of the wind; the temperature of the air; the relative humidity of the air; the topography of the land; wind breaks; the occurrence of rain and/or dew; and the intensity and amount of sunshine and solar radiation which strike the hay, are all factors which affect the drying rate of hay.

OBJECTIVES

To determine the moisture content of various types of hays while drying under average weather conditions.

To plot the drying rates of these hays and to ascertain the average drying rate of common types of hay under usual weather conditions.

To determine which of the many variable factors that influence the drying rate of hay are the most important.

STATEMENT OF THE PROBLEM

The experiments were conducted during the 1948 hay harvesting season of central Michigan on the first and second cuttings of hay. The author's part consisted of taking moisture tests and of determining the drying rates of the hay. In experimental hay drying work it is necessary to eliminate as many of the variables as possible. It is not only important to know the moisture content of the hay undergoing test, but further to be able to harvest and bring it in for test at a predetermined moisture content.

Two methods were used in determining the moisture content of the hay. The first was the Doxter method used to spot check the moisture content of the hay in the field.

The results of this test indicated when the hay was ready to rake and when to begin the baling operation. The other method was the delayed oven drying method in which samples were collected and later dried overnight in a steam oven. The results of these tests were used to determine the reliability of the Dexter method and to plot the drying curves of the hay.

A brief description of a day's work program was as follows:

1) Map each day's cutting;
2) Start taking samples for oven drying as soon as the hay is cut;
   a) Check moisture content of each windrow every hour or when the hay is drying rapidly, check it every half hour;
   b) When time does not permit testing every swath or windrow, test every other one or a representative portion thereof;
3) Keep records of samples bagged for oven drying and those tested for moisture in the field. These records will include notations on location, time of cutting, sunshine, temperature, relative humidity, direction and velocity of the wind, and precipitation;
4) Keep the moisture content plotted for every 3rd or 5th windrow if possible;

a) Predict 50 percent stage and notify raker as to the time to begin raking;

b) Predict the time to begin baling for any predetermined baling range.

METHOD OF MAKING TESTS

In securing data for plotting the drying curves of the hay, samples were bagged and weighed in the field and later dried in the steam oven at 100°C. Precautions were taken to select an average portion of the field. As the drying rate was plotted against time and relative humidity, a cross section of half of the field was taken from which to collect the samples. Numbered signs were placed on each swath or windrow where the samples were to be taken. The signs were numbered from one to four in each series of a color. The different colors made it easy to differentiate between the several cuttings made in a large field over a period of several days. Consecutive samples were taken near the signs in order to get as accurate a picture as possible of the drying rate of similar hay. See Fig. 14.

It is not difficult to select a representative sample of hay from the swath as cut if it lies evenly on the ground and is fairly uniform in kind and texture of hay. When it is raked into the windrow, however, it is not quite so easy to get good representative samples. In taking a sample from the windrow, a portion was selected that was of average

Fig. 14. HAY SAMPLES BEING COLLECTED IN THE FIELD FOR OVEN DRYING IN ORDER TO DETERMINE THE MOISTURE CONTENT

size and density. A sample was taken from the center of the windrow being careful to secure hay from the top, middle, and bottom of the windrow. The average sample weighed between 100 and 200 grams and was of convenient size to insert in a 12 pound bag.

The bags were oven dried prior to their use and were taken out to the field in decicators to keep them dry. The tare weight ranged from 13 to 15 grams for the 12 pound bags and the movable face scales were set to read in terms of the net weight of the hay. Thus the sample was selected, bagged, and then weighed. The sample designation number and net weight were then marked on the bag and recorded on the data sheets. The samples were taken back to the Agricultural Chemistry drying oven at the end of each day and dried overnight at 100°C. The standard procedure is to dry for 24 hours, but in this case the samples were removed at the end of 15 hours in order to plot the drying curves for the previous day which were to be used to help predict the future drying rates of other hay. This also cleared the oven and made it possible to work out the moisture contents before going out into the field each morning. The error in computing the moisture content at the end of 15 hours of drying was very small because the loss of several additional grams of moisture change the percent of moisture content by usually less than 1.0 percent. To check this, samples were taken from a first cutting of alfalfa, brome grass, and timothy made on June 17.

They were selected from a representative portion of the field, bagged, weighed, and taken into the drying oven. The objective of the test was to determine the minimum amount of time that could be allowed for drying hay samples at 100°C. The samples were weighed at the end of 12, 24, and 48 hours respectively. The results that were obtained from a dozen samples selected at random are given in Table 1 in the Appendix. The percent moisture content is given on a wet basis. The results obtained in drying these and other samples indicated that a 12 hour drying period was sufficiently accurate in determining the moisture content of bagged samples. Only one sample was out of line with the other results. It was obviously in error.

Precautions were taken to see that the samples were not packed in the oven. They were placed on the shelves so that there was good air circulation around each one. Under these conditions samples dried very rapidly and uniformly and were taken out at the end of 12 to 15 hours without danger of having a few incompletely dried samples.

In making the drying curves the moisture content was plotted against time. On the average the samples were collected every hour. The moisture content of the selected samples, if they were representative, then gave a representative drying curve of the hay being studied. The relative humidity and precipitation were also entered on the chart. Since the East Lansing weather station was located within a few miles of all the harvesting operations, the percent of relative humidity and the precipitation rates were taken from their reports. The percent of relative humidity and temperature were also recorded on a Foxboro automatic clock driven recorder. The setting of this recorder was checked each morning with a sling psychrometer.

RESULTS AND OBSERVATIONS

<u>First Cutting</u>: The field data on hay drying was plotted on 10 to the inch graph paper. The percent of moisture content, the percent of relative humidity, and the inches of rainfall are plotted against time. The discussion which follows is based on the drying curves and weather conditions which prevailed at the time.

Fig. 15 illustrates the problem of weather conditions which are likely to confront the average farmer when he tries to field cure first cutting hay in central Michigan. The hay was a 20 acre field of alfalfa, brome grass, and some timothy. The field had a slope to the east and west. Unfavorable weather conditions in the form of rain, heavy dews, cloudiness, high relative humidity, and low temperatures are illustrated here and are of common occurrence during hay harvesting seasons.

In general, the lower the percent of relative humidity, the faster will be the drying rate for any given hay. Light precipitation in the form of rain or dew will slow down the drying rate of hay as is illustrated in Fig. 2 on the

FIGURE: 15 FIELD DRYING OF HAY SUPPLIED TO COMPARTMENTS F AND E WITH WEATHER CONDITIONS DURING THE PROCESS - MOISTURE CONTENT - REL. HUMIDITY AND RAINFALL VS TIME

18th, 19th, 21st, 23rd, and 27th of June. A heavy precipitation may halt and also reverse the drying process to add to the moisture content of the hay as it did on the 18th, 22nd, and 27th of June.

The drying rate for the hay varies considerably depending upon the weather and the type of moisture being evaporated. Freshly cut hay on a good drying day will dry quite rapidly because the first plant moisture is evaporated quite readily. When cut, legume hays have an average moisture content of about 75 percent on the wet basis or 300 percent on the dry basis. Unless otherwise stated, all moisture contents are given on a wet basis. For further discussion on the wet basis method of figuring moisture contents versus the dry basis method, see remarks in the conclusions. A large portion of this moisture is loosely held by the plant tissue and evaporates first. The last of the plant moisture evaporates at a slower rate because it is held tightly in the internal tissues of the plant.

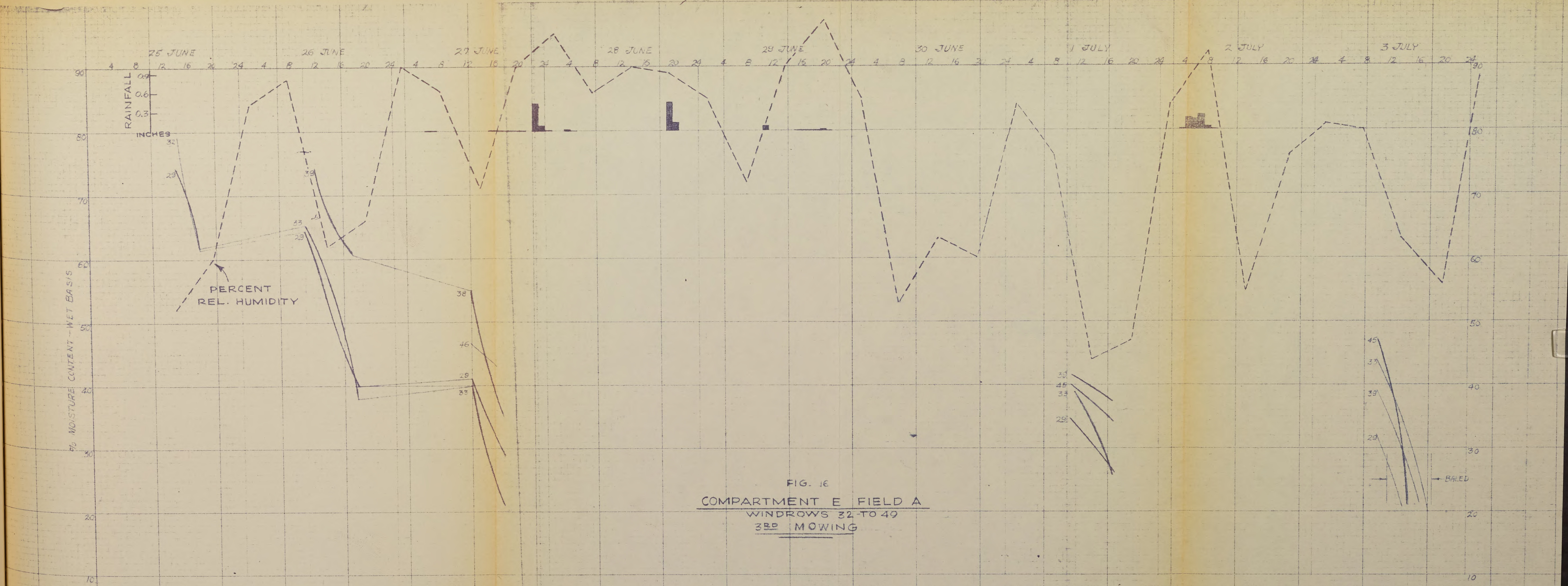
After cutting the first day, the moisture content of windrows 1 and 3 decreased at an average of 22.3 percent in seven hours or at an average rate of 3.2 percent per hour. Windrows 9 and 13, cut two hours later, decreased an average of only 9.5 percent in moisture content between the hours of 1 and 5 or at an average rate of 2.4 percent per hour. The drying rate starts slowly in the early morning, reaches its maximum rate in the early afternoon and tapers off in the late afternoon and early evening. Notice that the 17th was the only day in which the relative humidity went below 40 percent and all of the rest of the time it was above 50 percent.

The drying rate appears to be greater on the 20th, 23rd, and 24th of June. It is, however, the result of evaporation of moisture added by heavy precipitation, rather than the evaporation of plant moisture. On the 24th the moisture content is about where it was on the 13th of June. The moisture content dropped 17 percent in seven hours on the 25th, or at an average rate of 2.4 percent per hour. Again, on the 26th the relative humidity increased to above 60 percent and the drying rate slowed down to an average rate of 1.9 percent per hour. The 27th showed a further increase in relative humidity to greater than 70 percent and a further decrease in drying rate to an average rate of 1.7 percent per hour. A few windrows on the upland side of the field were baled on the 25th and the remainder of those through windrow 14 on the higher north and west slopes were baled on the 27th. Possibly a farmer would have been wise to bale on the 26th, but for the research tests the hay was desired with a moisture content of 25 percent and thus was timely baled after a light rain a day later at a moisture content of approximately 25 percent.

While the first mowing was getting ready for baling a third mowing was made on the 25th of June. See Fig. 16. The second mowing began to mold in the windrow and was deemed unfit for any tests. The rates of drying were faster than those of the first mowing which were drying out at a lower moisture content range. Again the rate of drying tended to decrease as the percent of relative humidity increased. On the 25th the drying rate averaged 4.2 percent per hour, on the 26th it was 2.9 percent per hour, and on the 27th it was 2.3 percent per hour. After rain and four more days of drying the moisture content of the hay on July 1st was no lower than it was on June 27th. The hay was finally baled on July 3rd after drying down to approximately 25 percent moisture content.

Field B, the second field mowed for the Case Hay Drying Experiment, was a five acre field with a general slope to the south. The hay in field "B" was a little more advanced in maturity and the original moisture content was lower than the moisture content in field "A". It varied from 66 to 70 percent in moisture content. See Fig. 17 for drying curves and weather conditions.

Even though the percent of relative humidity was quite high on July 5th a 10 mile per hour wind from the south east helped to speed up the drying rate. The average drying rate for the windrows was 3.7 percent per hour. On the second day the air was still and cloudy in the forenoon.



FIELD DRYING OF HAY SUPPLIED TO COMPARTMENT E WITH WEATHER CONDITIONS DURING THE PROCESS. MOISTURE CONTENT, RELATIVE HUMIDITY VS. TIME

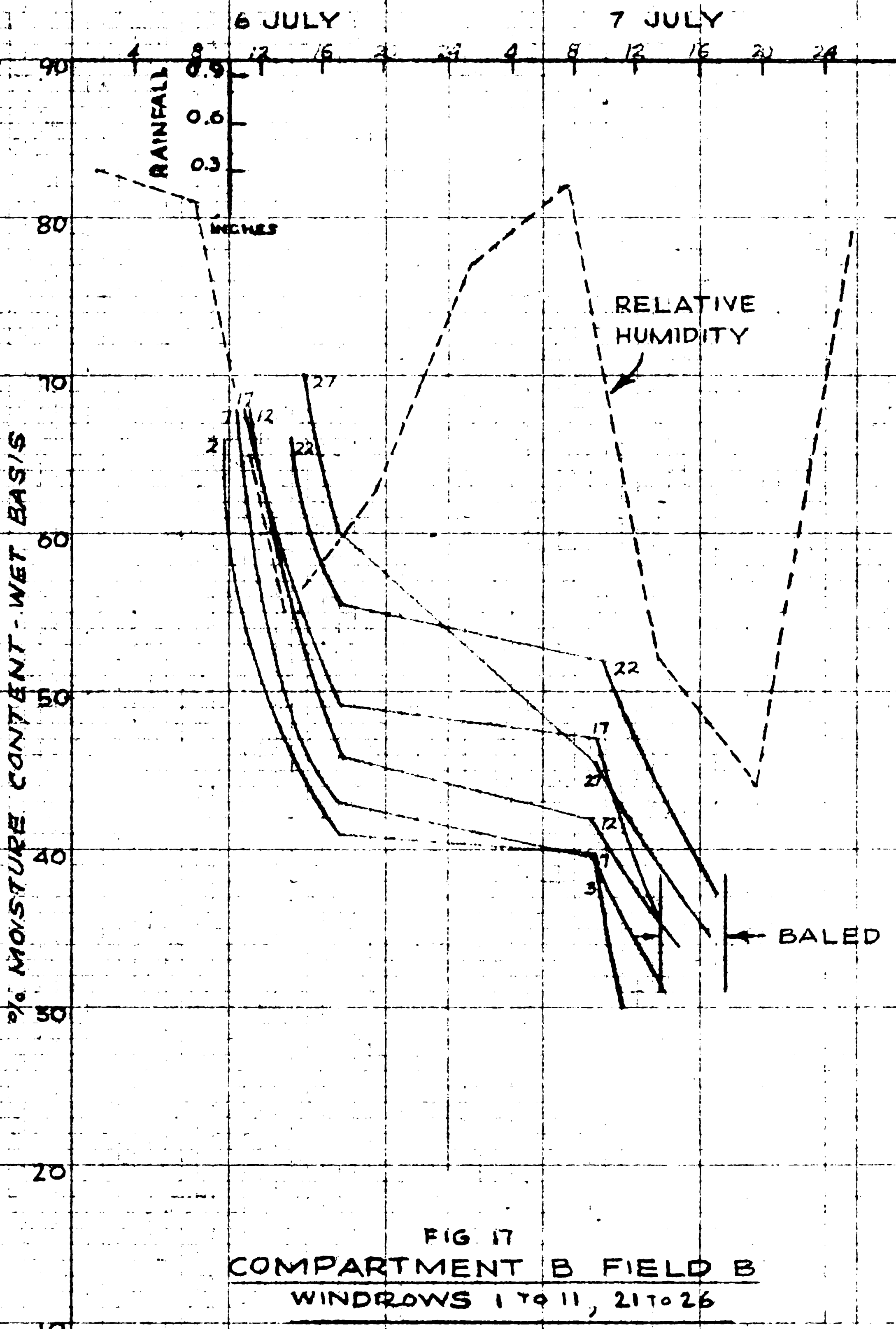


FIG 17

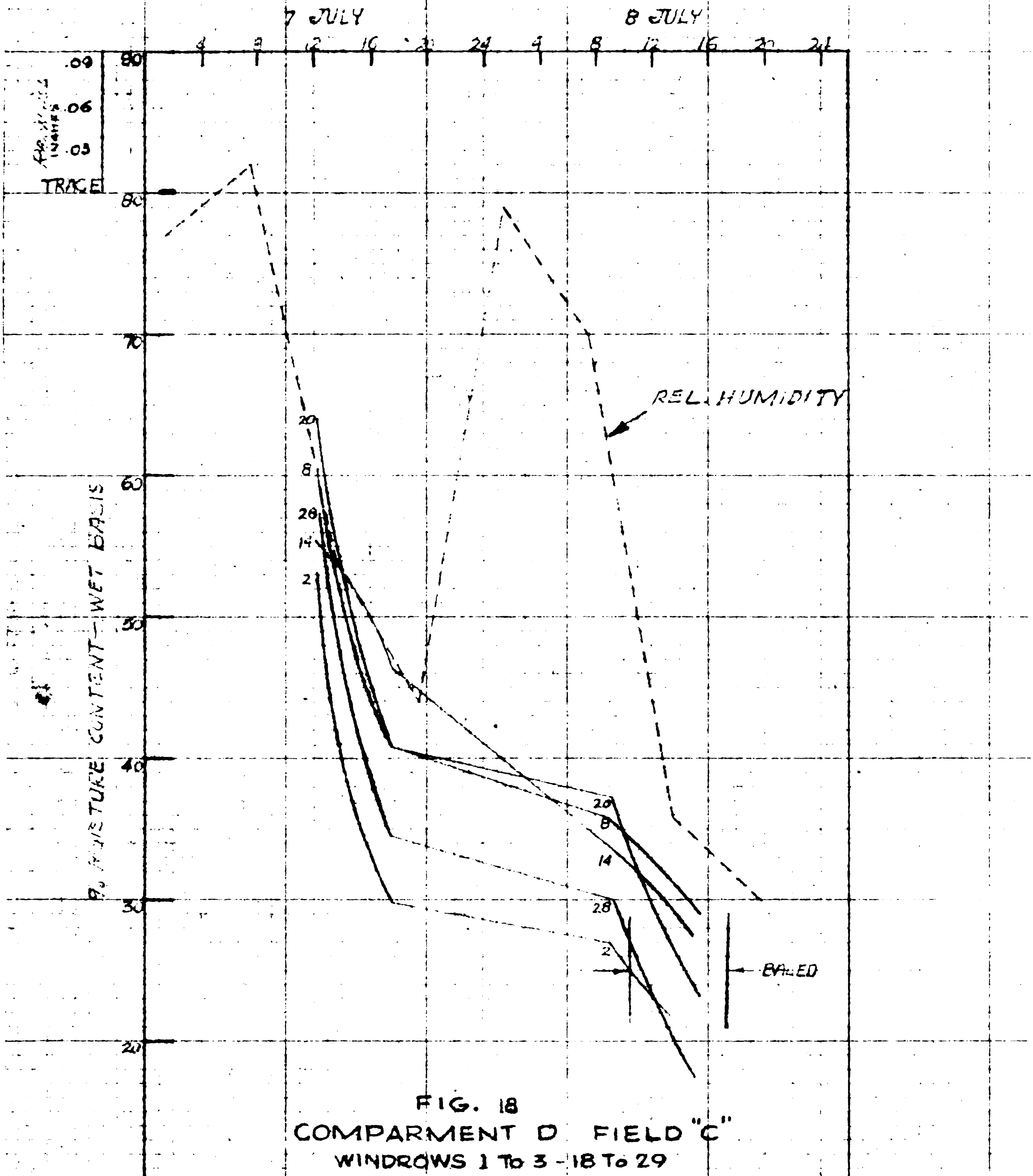
COMPARTMENT B FIELD B

WINDROWS 1 TO 11, 21 TO 26

FIELD DRYING OF HAY SUPPLIED TO COMPARTMENT B WITH WEATHER CONDITIONS DURING THE PROCESS MOISTURE CONTENT - REL. HUMIDITY AND RAINFALL VS TIME

Thus even though the relative humidity did drop below 50 percent later in the afternoon it did not affect the rate of drying which averaged 2.4 percent per hour. The hay was desired with a moisture content of 37.5 percent and the average moisture content when baled was 35 percent.

The third field cut was a seven acre field of alfalfa infested with quite a few large weeds. See Fig. 13 for drying curves and weather conditions for field "C". It was cut before the work was completed in field "B" and therefore no data was taken on the original moisture content of the hay or during the first few hours of drying. The hay dried rapidly in the afternoon, after the sun came out, at an average rate of 4.2 percent per hour. The second day the drying that was done took place in the morning prior to baling when the percent of relative humidity was quite high. The average rate of drying was only 1.6 percent per hour. The percent of relative humidity went below 40 percent in the afternoon and would have given a more rapid drying rate than that of the forenoon. An interesting example of drying took place in this field. The usual procedure is to begin raking the hay as it approaches a moisture content of 50 percent. However, if the hay is drying quite rapidly the last hay cut may lie long enough in the swath before raking so that it dries faster than the first cut hay which has its drying rate retarded by windrowing. On July 8th this is illustrated by



FIELD DRYING OF HAY SUPPLIED TO COMPARTMENT D WITH WEATHER CONDITIONS DURING THE PROCESS. MOISTURE CONTENT- RELATIVE HUMIDITY AND RAINFALL VS TIME.

windrows 20 and 23 which start out at a higher moisture content at the beginning of the day but dry faster down to a lower moisture content than the other windrows which have been cut longer. The hay was baled at 25 percent moisture content.

Field "D" was approximately a 20 acre field of good growth June clover which was in full bloom and advanced in maturity. The terrain was rolling to hilly. Only the north portion of the field with a slope to the north was used for tests. See Fig. 19 for drying curves and weather conditions.

The first three windrows were cut in the afternoon of July 7th and the remainder were cut the next morning. The original moisture content of the clover when cut averaged 72.3 percent. The drying curves on July 8th indicate the different drying rates that are likely to result from hays of varying original moisture contents. Notice that the higher moisture content hays have the fastest drying rates. Conversely the lower the moisture content of the hay the slower is the drying rate for any given set of weather and plant conditions. In this case the fastest drying rate was 5.8 percent per hour for windrow 20 and the slowest drying rate was 0.4 percent for windrow 3. The average rate of drying was 2.5 percent per hour for the first day and 2.2 percent per hour for the second day of drying. A heavy dew added moisture to the clover hay on the night of July 8th. The clover was baled the following

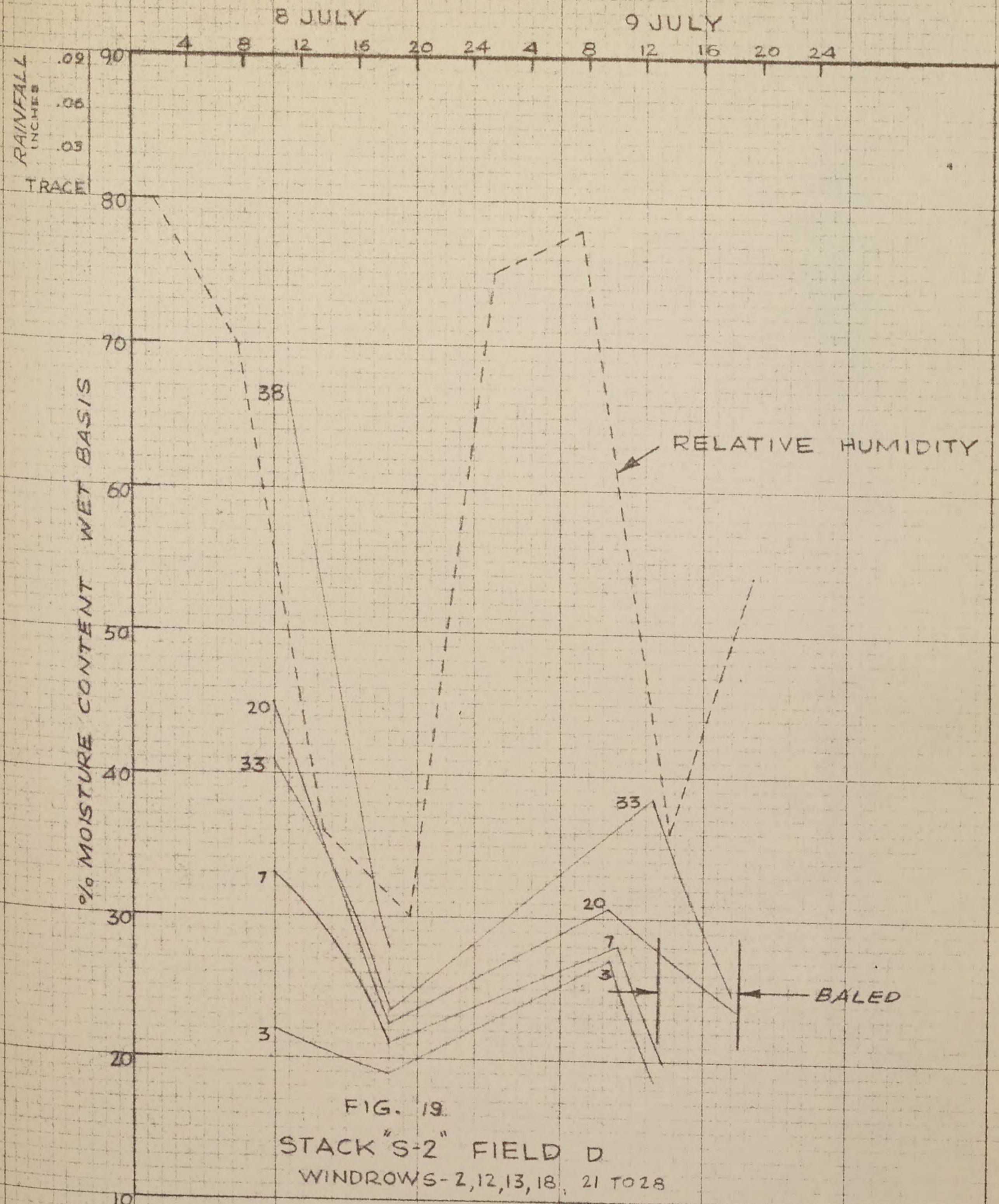


FIG. 19

STACK "S-2" FIELD D

WINDROWS - 2, 12, 13, 18, 21 TO 28

FIELD DRYING OF HAY SUPPLIED TO OUTSIDE STACK NO. 2 WITH WEATHER CONDITIONS DURING THE PROCESS. MOISTURE CONTENT - RELATIVE HUM. AND RAINFALL VS TIME day. The relative humidity was also higher on July 9th when the rate of drying was slower. Clover hay seems to be very simil r to alfalfa in moisture content and drying characteristics.

Field "H" completed the first cutting of hay. It was an eight acre field of alfalfa including a considerable number of thistles. See Fig. 20 for drying curves and weather conditions. This field received only a light precipitation so that the moisture content of the hay was increased only a small amount. The weather on the 12th and 13th of July was cloudy and overcast so that thedrying rate was only about 2.2 percent per hour the second day. The third day was more favorable drying weather with a bright sun, a clear sky, and a brisk breeze but with a rather high percent of relative humidity. The hay dried at an average rate of 2.7 percent per hour.

Second Cutting: The first field of the second cutting was mowed August 3rd. The first cutting on this field was made early and the second cutting was also made about two weeks earlier than in the other fields. See Fig. 21 for drying curves and weather conditions. Swaths 1 through 23 were mowed from 1500 to 2100 on the evening of August 3rd, and the remainder were mowed on the morning of August 5th. The alfalfa was short, fine, light in stand, and in the pre-bloom stage. The hay was unraked when the light precipitation fell so that it dried quickly and showed no

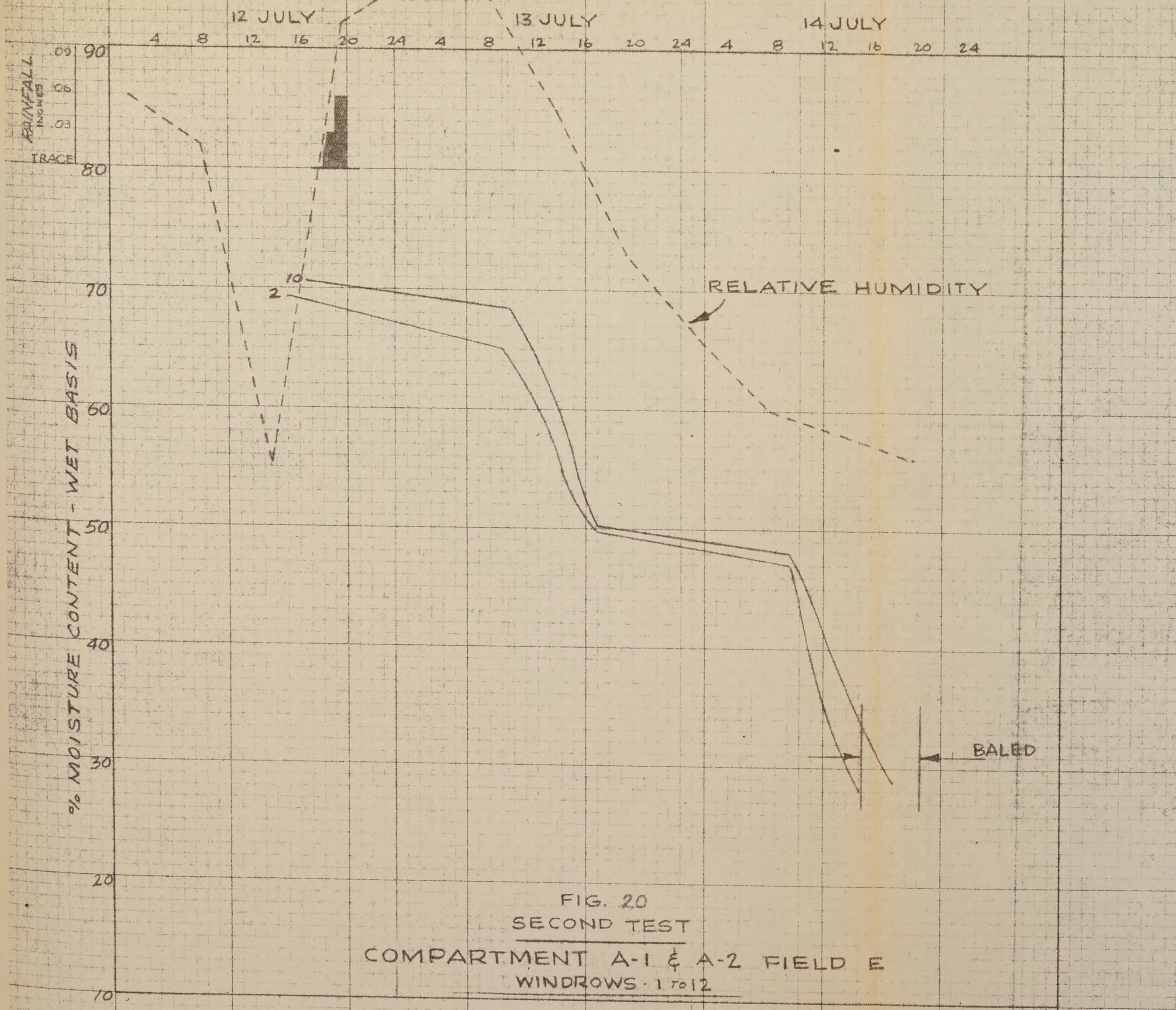


FIG. 20
SECOND TEST
COMPARTMENT A-1 & A-2 FIELD E
WINDROWS - 1 TO 12

FIELD DRYING OF HAY SUPPLIED TO COMPARTMENT A-1 AND A-2 WITH WEATHER CONDITIONS DURING THE PROCESS. MOISTURE CONTENT - REL. HUMIDITY AND RAINFALL VS TIME

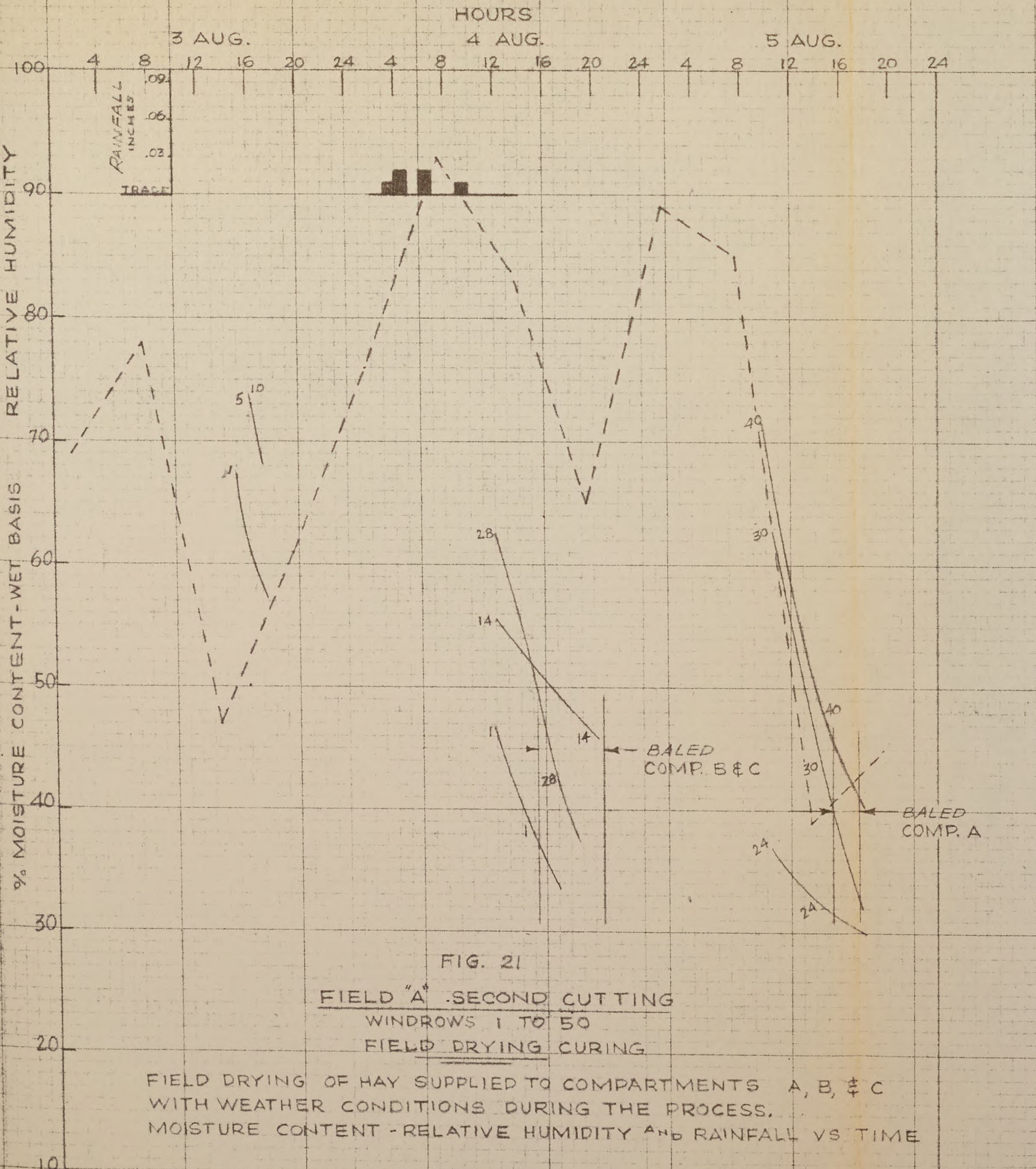


FIG. 21

FIELD "A" SECOND CUTTING
WINDROWS 1 TO 50
FIELD DRYING CURING

FIELD DRYING OF HAY SUPPLIED TO COMPARTMENTS A, B, & C
WITH WEATHER CONDITIONS DURING THE PROCESS.
MOISTURE CONTENT - RELATIVE HUMIDITY AND RAINFALL VS TIME

gain in moisture content. It dried at about an average rate of 2.5 percent per hour. Hay in windrows 30 to 50 that were cut on the 5th of August dried rapidly at the rate of 4.2 percent per hour, but the hay in windrow 24 which was cut two days earlier dried much more slowly at the rate of only about 1.0 percent per hour. This hay was baled on the afternoons of the 4th and 5th of August at an average moisture content of 45 percent and 40 percent respectively.

Very favorable drying weather the last of August dried the last of the second cutting alfalfa in almost record time. See Fig. 22 for drying curves and weather conditions. The hay in both fields "B" and "C" was cut one morning and was ready for baling 24 hours later. The hay was short, fine, light in stand, free of weeds, and not very succulent. Field "B" had an average moisture content when cut of about 68 percent while field "C" had an average moisture content of only 65 percent. A light breeze, bright sun, clear sky, and a low percent of relative humidity expedited the rate of drying. Field "B" dried at an average rate of 5.7 percent per hour with some of the last hay cut drying the fastest. Windrow 28 dropped 34.3 percent in five hours for an average rate of 6.9 percent per hours.

As has been noted the original moisture content of the alfalfa in field "C" was a little lower and that combined with warmer air temperatures and a little lower percent of relative humidity dried the hay down to a lower

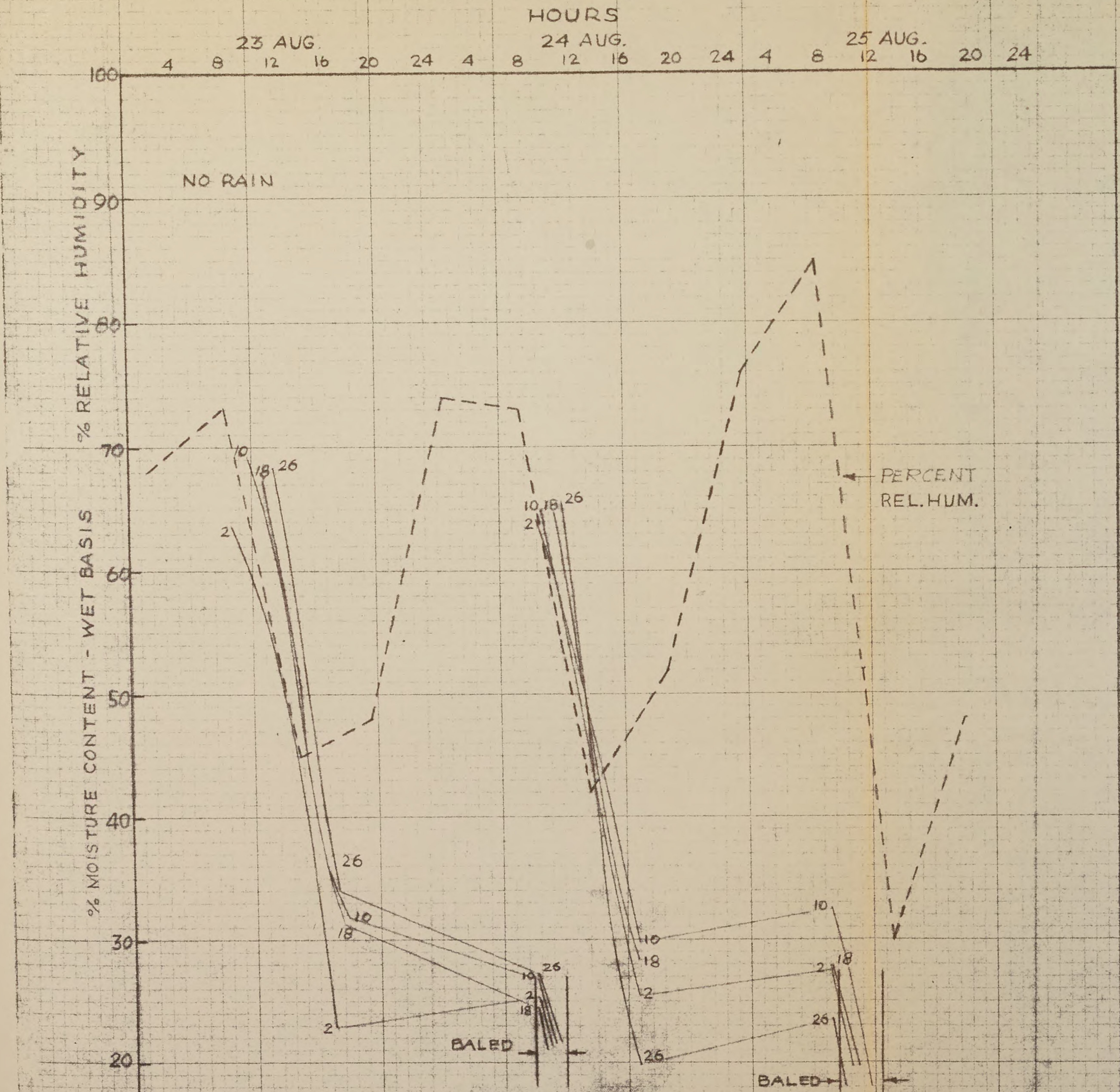


FIG. 22
FIELDS 'B' AND 'C' SECOND CUTTING
WINDROWS 1 TO 50
FIELD DRYING CURING

FIELD DRYING OF HAY SUPPLIED TO COMPARTMENTS D & E
WITH WEATHER CONDITIONS DURING THE PROCESS.
MOISTURE CONTENT - RELATIVE HUMIDITY AND RAINFALL VS TIME

moisture content but at a little slower rate. The average drying rate was 5.5 percent per hour but one windrow, number 26, dried down 45.5 percent in six hours or at an average rate of 7.6 percent per hour. The hay was baled at an average moisture content of 21.8 percent for field "B" and at 13.4 percent for field "C". The hay was drier than desired, but these records show how rapidly hay can dry under favorable weather conditions.

DISCUSSION

A farmer who wants his hay to reach a safe moisture content for storage will be most interested in the heavier and more luxuriant hay which dries the slowest, since, when that hay reaches the desired moisture content, all of the remaining hay will be safe to store.

It should be remembered too, that as hay matures, its moisture content decreases somewhat. Thus, mature hay with a moisture content around 65 percent to 69 percent will dry somewhat more quickly than more immature hay with a moisture content around 70 percent to 78 percent. Dry seasons, or a period of droughty weather several weeks before harvesting, will appreciably lower the original moisture content of the hay.

During a normal period of drying weather the maximum rate of drying takes place between the hours of 1100 and 1800. At this time the relative humidity is the lowest and the temperature is the highest. Hay that is cut early in the morning dries slowly at first when the relative humidity is high and the temperature is low. The drying rate accelerates in midmorning and reaches its maximum in midafternoon. The drying rate tapers off in late afternoon or about 1800 and comes to a standstill at sundown. During the night the hay may gain moisture if there is a dew and then it will again begin to dry out when the sun comes out the next morning.

Hay will also lose moisture more readily while drying from a moisture content of 75 percent down to 45 percent than it will in drying from 45 percent down to 15 percent. Thus the hay will dry more slowly as it decreases in moisture content.

During a normal season with favorable drying weather, a good stand of first cutting hay in central Michigan dried at about an average rate of 3 percent to 3.5 percent per hour during a nine hour day from 0900 to 1800. Thus under average conditions in early summer--relative humidity down to 45 percent during the day, air temperatures between 75°F. and 85°F. in the afternoon, and with a moderate breeze blowing--one might expect a good stand of alfalfa and brome grass hay to dry from a moisture content of 75 percent, when cut in the morning, to a moisture content of 43.5 percent to 48.0 percent at the end of nine good drying hours. If the mowing is stopped at 1300 then the last hay cut would dry only five hours. It would dry down to a moisture content of between 57.5 percent and 60.0 percent by the end of the day. The average moisture content of all hay mowed in one morning would then be about 52 percent at the end of the first day. The drying rates on the second and succeeding days in normal weather would be a little slower. A larger portion of the remaining moisture is held more tightly and less readily evaporated.

With light second cutting alfalfa it is possible to get much more rapid drying. The average rate of drying may be as high as 5 percent to 6 percent per hour and during optimum conditions for drying, some windrows may dry at a rate as high as 10 percent per hour for a few hours. Field "C", a light second cutting, was cut in the morning between the hours of 0900 and 1130. It had passed through a drought period for a month before cutting. By 1700 that first day it had dried down to an average moisture content of 26.3 percent. This meant that it had dried at an average rate of 5.5 percent per hour. The next morning it was baled from 0900 to 1220 and it had an average moisture content of 16.5 percent, with a range from 9.7 percent to 29.0 percent. The extremes in ranges were caused by patches of good and poor hay in the field. This hay dried so fast that even though the raking was started before most of the hay was down to 50 percent, it soon passed through this range and the last hay cut remained in the swath long enough for optimum drying so that it caught up with and passed the first cut hay in getting down to lower moisture contents. An interesting point is here brought out in that when the first cut hay is raked as it reaches 30 percent, and even though the raking progresses at about the same speed as the mowing, the hay which was cut later accelerates fast enough in its drying so that by the time it is raked it is catching up with the first cut hay. By the end of the day it is often drier than some of the hay which has been cut the longest. This condition can occur with almost any light stand of hay during good drying weather.

With a given kind of hay, in a given growth condition, on a given area of land, the farmer has only the factors of weather conditions to consider in harvesting that hay. Of these factors the amount and intensity of sunshine, precipitation, and wind are the most influential in slowing up or in speeding up the drying process. The relative humidity and the air temperature are dependent upon the aforementioned weather factors. They fluctuate quite rapidly and widely but alter the net drying rate of the hay to a much lesser degree. These two factors are inversely proportional, thus when the temperature rises the relative humidity decreases because the warmer air has a greater capacity for holding moisture. Again when the temperature decreases the percent of relative humidity increases.

With a given air temperature and percent of relative humidity, an increase in air movement reduces the air temperature and also the relative humidity of the atmosphere around the product which is undergoing drying. The moving air currents reduce the relative humidity by dispersing and lowering the concentration of moisture vapor which has accumulated after being released by the product undergoing drying. This allows more moisture to be evaporated to re-saturate the air and lowers the air temperature because it takes heat to evaporate water. It should also be noted that moisture laden air, or air with a higher specific humidity, will rise because it is lighter. This also tends to keep the concentration of vapor reduced around the plant undergoing drying.

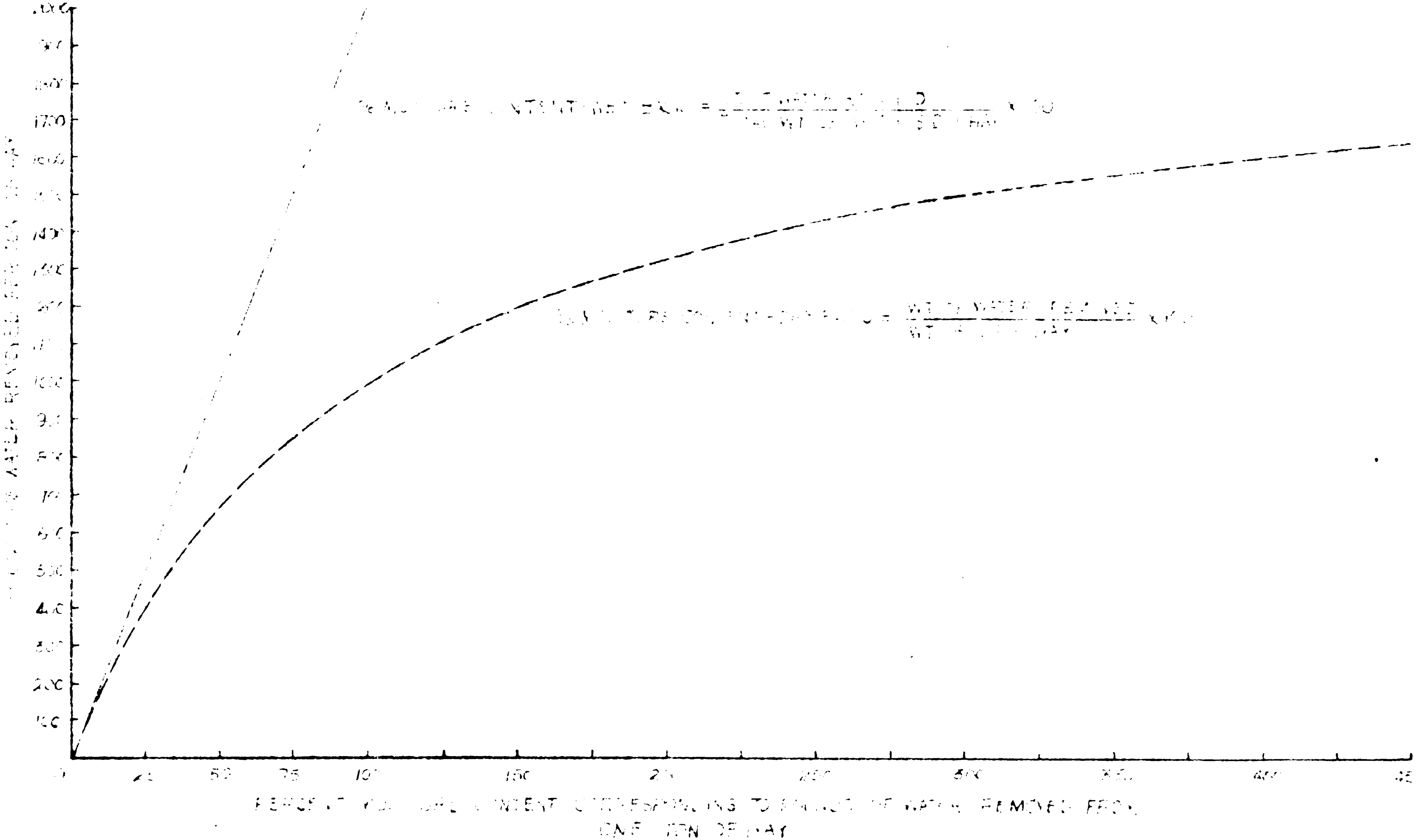
Optimum drying conditions for any given hay in a given condition would be continuous intense sunshine, resulting in a high air temperature and a low percent of relative humidity, and a brisk breeze to disperse the moisture that is evaporated.

The amount and intensity of the sunshine and solar radiation is a very important factor. Few people stop to realize how powerful the sun is as a drying agent. One reason is undoubtedly the way in which the percent of moisture content is stated--as on a wet basis instead of on a dry basis. Good alfalfa or mixed legume hay contains on an average about 75 percent moisture on a wet basis. However, on a dry basis this represents 300 percent moisture. Either way it is spoken of as a quantity of freshly cut green hay which weighs 2000 pounds, it will contain on an average about 500 pounds of dry hay matter with the remaining 1500 pounds being water. It is only when you speak of pounds of water removed on a dry basis that you appreciate what a truly remarkable drying agent the sun is. See Fig. 23 for a graphical comparison of percent moisture content on the wet basis versus the percent moisture content on the dry basis.

The wet basis method of describing moisture content is very misleading as the graph brings out. When 1500 pounds of water are removed from a ton of hay, the wet basis indicates that it is 75 percent of the total weight of the wet hay. However, we are not interested in this comparison of total moisture content with total wet weight of hay. What we should know is the percent of moisture in the hay as compared to the percent of dry matter. This is correctly given only by using the dry basis method for computing the percent of moisture content of hay.

CONCLUSIONS

1) During a normal season with favorable weather conditions, (relative humidity down to 45 percent during the day, air temperatures ranging between 75°F. and 95°F., and a moderate breeze blowing), a first cutting stand of good alfalfa and grass mixture hay might be expected to dry at an average rate of 3 percent to 3.5 percent per hour during the first day.
2) On the second and succeeding days the hay will dry at slightly reduced rates. As the hay dries, a larger



PERCENT MOISTURE CONTENT ON A WET BASIS COMPARED WITH PERCENT MOISTURE CONTENT ON A DRY BASIS

FIGURE 23

portion of the remaining moisture is held with correspondingly greater force.

3) Light second cutting alfalfa may dry more rapidly at rates as high as 5 percent to 6 percent per hour.

4) Because hay dries more rapidly in the swath than it does in the windrow, light second cutting hay which is cut last may lie longer in the swath or be subjected to more optimum drying conditions, so that by the end of the drying day it dries down to a lower moisture content than hay which was cut quite a while before it.

5) The sun has the most influence on the drying rate of hay. In normal weather, drying begins as soon as the sun comes up and stops when it goes down. The drying rate usually accelerates rapidly in midmorning and reaches its maximum in midafternoon. It tapers off in the late afternoon and the hay may begin to pick up moisture after sundown.

6) Precipitation in the form of dew or rain will retard and may reverse the drying process.

7) Air movement hastens the rate of drying by dispersing evaporated moisture.

PART III

DETERMINATION OF THE MOISTURE CONTENT AND THE DRYING RATE OF HAY IN THE FIELD BY THE EXHAUST OVEN METHOD OF DRYING

INTRODUCTION

The exhaust method of quick drying hay in the field makes use of the hot exhaust gases from an internal combustion engine. It was developed by Dr. S. T. Dexter of the Farm Crops Department, Michigan State College, in 1943. An automobile, truck, or tractor may be used but the heating is more uniform and there is less danger of burning or caramelizing the hay sample if the gases pass through a muffler before being used for drying. It takes from 16 to 18 minutes to dry a sample containing 50 percent or more moisture on the wet basis, from 12 to 14 minutes to dry hay with 30 percent to 45 percent moisture, and from 8 to 10 minutes to dry hay containing 20 percent to 30 percent moisture.

The sample of hay to be dried is put into a cylinder and connected to the end of the exhaust pipe. The temperature of the exhaust gases varies with the speed of the engine. Dexter states that 140°C. or 284°F. is the maximum temperature at which hay can be heated without caramelizing. Field trials showed this to be true. The effect of caramelization is to indicate higher moisture contents than really exsist. The Dexter method is useful for spot checking the moisture content of the hay in the field. By using this method the farmer can determine when the hay is ready to be raked and when it is ready to be baled. In the Case Hay Drying project for 1948 the hay was raked when it reached a moisture content of 50 percent on a wet basis. It was baled at various moisture contents ranging from 25 percent to 40 percent.

For purposes of research tests, the hay was desired at a certain moisture content. In any operation of any size whatsoever, this, at best, can only mean an average moisture content. In other words, it is usually necessary to start baling before the majority of the hay is down to the desired moisture content so that the hay will be passing through the range you desire while baling to give you a final average desired moisture content. It is not practical to stagger the mowing and raking to coincide with a continuous drying rate to give hay that would be at the desired moisture content as the baling progresses. There are too many factors involved which influence the original moisture content and the drying rate of the hay. The original moisture content is dependent upon the stage of maturity, the season, the soil, the presence or absence of weeds or other foreign material, and the variety and type of hay. The drying rate of a certain hay is dependent upon the original moisture content, the stand, the amount of leaves in proportion to stems, the topography of the field, the temperature of the air, the relative humidity of the air, the velocity of the wind, the amount and intensity of sunshine or clouds, the presence of windbreaks and location around the field, and the addition of more moisture by precipitation in the form of dews or rains. Crushing the stems as is done with the John Deere Haymaker will increase the drying rate by a third or more. For further information see Part IV of this report.

SAMPLE SELECTION

The hardest part, by far, of making moisture tests of any kind is in selecting samples which are representative of the hay to be tested. The field should be appraised before beginning to take any samples. If the field is level or very nearly so, and the stand of hay is even throughout and free of weeds and foreign material, then it is quite easy to select a cross section of the field which will be representative. On the other hand, if the topography of the field is quite uneven there will be high areas which will probably have a lighter stand of hay and which will dry more quickly because of more favorable sun and wind action, and there will be low areas which will probably have a more luxuriant growth and which will dry more slowly because they do not receive as much drying action from the sun and wind. The presence of windbreaks, trees, and buildings may temper the action of the wind and produce similar results. The percent of relative humidity may build up in the low areas on very still days or in areas sheltered from the wind. As the sun evaporates the moisture from the hay, it builds up the concentration of moisture immediately around the stems and leaves of the plants and as the concentration increases the drying rate decreases somewhat. The wind is needed to disperse this concentration of moisture in order to obtain the maximum rate of drying of the hay.

APPARATUS AND EQUIPMENT

The Dexter method is simple enough so that any farmer can make the equipment, or have it made by a tinsmith, and run the test. The equipment consists of the exhaust oven in three main parts: a funnel shaped adapter made of light galvanized sheet metal and which fits onto the exhaust pipe or onto an extension of flexible exhaust tubing; a cylinder made of aluminum which fits into the large end of the adapter and which makes up the main body of the oven; and an inner split cylindrical wrap made of aluminum into which the hay is placed before being inserted into the main cylinder. See Fig. 24 for sketch of component parts and method of assembling. It is expected that this equipment will be available for purchase very shortly.

Other equipment needed includes: a 500 gram scale graduated in grams and with a movable face so that the tare weights of the aluminum cylinder can be deducted from the reading to give the net weight of the hay sample directly; a thermometer which reads at least 180°C. or 360°F.; a clip board with data sheets; and leather gloves for handling the hot cylinders during the drying process.

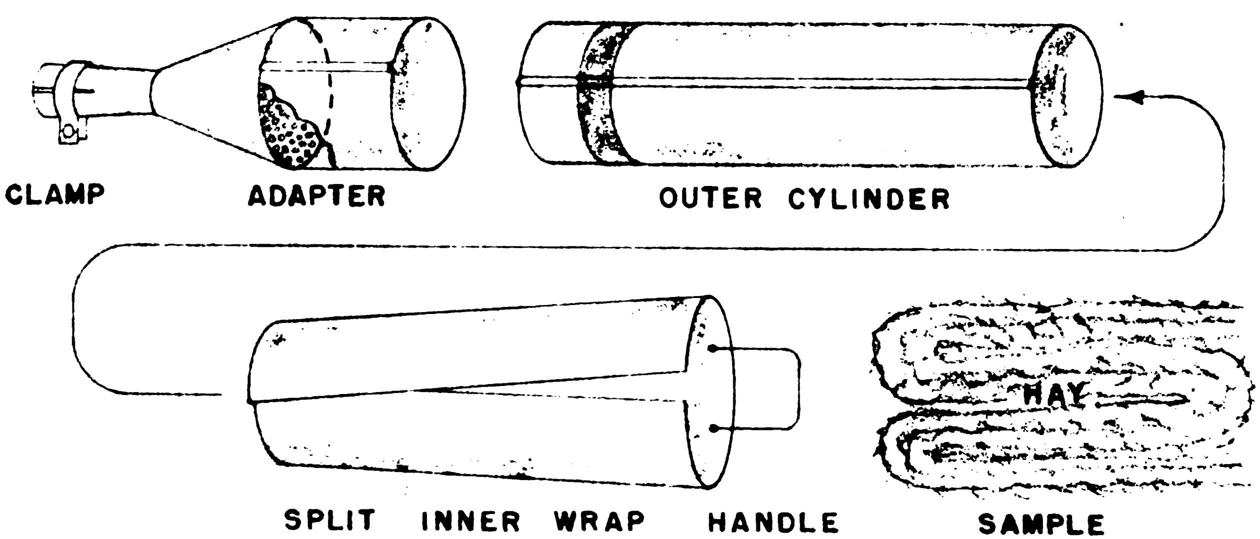


Fig. 24. COMPONENT PARTS OF THE EXHAUST OVEN

On such tractors as the Ford it may be desirable to extend the exhaust pipe with a piece of flexible tubing so as to bring the oven up behind the tractor seat in a more convenient and vertical position. A box or small platform can also be bolted on behind the tractor seat to which the end of the flexible tubing and the adapter can be fastened. The scales can then be set in the box and after the sample has been selected, the entire testing operation can be run by the operator without moving from the tractor seat. As thermometers are easily broken, a safe place should be provided to keep them from being broken when not in use. The scales are also rather sensitive and should be reasonably level to give accurate results. A small swivel joint platform can easily be built which makes it possible to level the scales by means of a small plumb bob. This is a very helpful aid when operating on rolling terrain.

On tractors such as the International and Case the oven can be mounted directly on the short exhaust pipe above the muffler, or a piece of flexible tubing can be used to bring the oven back toward the controls of the tractor. This puts the oven at a lower level where it will be easier to read the thermometer, weigh the sample, and conduct the test in general. In this way the tractor controls are convenient to reach and the scales can usually be set on the tractor before the seat so that they are also convenient to the operator. If the oven is mounted directly above the manifold in place of the exhaust, very careful attention must be given to engine speed adjustment to prevent burning or caramelizing of the sample. Lower engine speeds will be needed to give the maximum drying temperature as in comparison to the engine speed of the Ford tractor. See Fig. 25 for picture of exhaust oven drying test being made with a Case tractor.

Most automobiles, small trucks, and one plow tractors have about the same size exhaust pipes, or about 1 1/2 to 2 inches in outside diameter. The larger two plow tractors usually have a 2 to 2 1/2 inch exhaust pipe as on the Farmall H and Case RC. Before making up the oven equipment, the farmer should determine which engine he can most conveniently use and adapt the oven to it.

A short piece of two inch pipe can be brazed on the end of the flexible tubing so that it can easily be slipped on and off the exhaust pipe to make the oven quickly detachable from the machine. An inch or two of coarse steel wool is also packed into the adapter against the screen to shield out sparks and to divide and distribute the flow of hot gases evenly over the enlarged area of the adapter.

If a 500 gram scales is used, the combined weight of the completed split inner wrap and the outer cylinder should be kept between 250 and 300 grams. This leaves between 200 and 250 grams as the maximum size sample that can be weighed on the scales. During the drying process the outer cylinder,

Fig. 25. THE EXHAUST OVEN DRYING TEST

BEING MADE WITH A CASE TRACTOR

and split inner wrap containing the hay, is reversed every few minutes to dry the hay uniformly from both ends of the sample. To make it easier to keep track of the drying process, a colored band is painted around one end of the outer cylinder. Then if the banded end is always inserted first into the adapter it is easy to remember when to reverse the cylinder for more uniform drying or when to take it out for weighing.

A wire handle can also be attached to the split inner wrap to make it easier to remove it from the inside of the outer cylinder. The split inner wrap and outer cylinder should be made out of light weight aluminum sheeting to keep the weight as low as possible. The adapter can be made out of heavier 18 gauge galvanized sheet metal. The end that slips over the exhaust pipe can be split so that an adjustable clamp can be used to fasten it on securely.

After the equipment has been made and installed on the engine, the operator should allow the engine to warm up and then check the temperature of the exhaust gases coming through the empty oven. After several trials with hay in the oven, the operator should have a fairly good idea as to how fast the engine should be operated to get certain temperatures in the hay sample. In actual practice it will usually be found that the engine can be operated faster at first when moisture is being driven off rapidly because the evaporation of moisture cools the gases. With samples of 30 percent moisture content or more the engine can be operated at a rather fast speed continuously for the first four minutes or more, but it then must be slowed down as the moisture content decreases. For example, on a Ford or Ferguson tractor with a flexible tubing extension, high moisture content hay can be dried for the first four to eight minutes at about 2/3 throttle, but then as the hay dries out and the temperature begins to climb, the throttle must be reduced to 1/2 or more. The engine should be throttled at all times so that the temperature is kept just below 140°C. or 243°F.

METHOD OF TESTING

Following is given a suggested procedure to follow in running the exhaust oven drying test.

Select a representative sample which will weigh between 100 and 200 grams. A little experience will enable one to judge this quite effectively. Fold the hay into a loose bundle about eight inches long, or just a little shorter than the split wrap. The bundle of hay should be of such size that it will fill the split inner wrap and require a little pressure to squeeze it together when inserting it into the main cylinder. A little trick may be utilized here to keep the hay from sliding in and out as it dries and shrinks. When inserting the hay into the split wrap, hold onto the bottom ends of a few stems and put them between the edges of the split cylinder. This will then hold the hay in place even after it has dried out and it will not be necessary to pack the sample in tightly. The hay must be held in place in the cylinder in order to insert the thermometer without pushing the hay down into the opposite end of the cylinder. Care should be taken to keep the sample fairly loose and open at the ends, especially where it is folded. Dense and tightly packed ends make it hard to dry out the middle of the hay sample and increase the changes of caramelizing the ends.

After the hay sample has been placed inside the split wrap, insert it into the outer cylinder. Make sure that the hay does not stick out of the ends of the outer cylinder. Set the tare weight of the outer cylinder and split inner wrap on the scale by moving the scale face. Place the filled inner wrap and cylinder on the scale and record the net weight of the wet hay sample.

It is presumed that the tractor has been running and that the exhaust pipe is hot. Insert the paint banded end into the adapter on the end of the exhaust pipe and open the throttle on the tractor about 2/3. At the end of one minute, pull the cylinder out of the adapter and insert the opposite end into the adapter. Continue to reverse ends at the end of each succeeding minute thereafter. It usually takes about four minutes to heat up the hay if it has 30 to 40 percent moisture. Hay that has a higher or lower moisture content will require a little more or a little less time respectively to come up to the proper drying temperature. Check the temperature of the hay during the third and fourth minute and decrease the engine speed if the temperature is very near the 140°C. mark. Weigh the hay at the end of four minutes. For high moisture content hay, weigh again at the end of eight minutes and record. Weigh every two minutes thereafter or whenever the painted band is down. For low moisture content hays, weigh the second time at the end of six minutes and every two minutes thereafter or whenever the painted band is down. Whenever the hay sample is weighed it cools off, so after it is again inserted into the adapter, race the engine for about 15 or 20 seconds to bring the hay back up to the desired drying temperature and then reduce the engine speed to hold it just below 140°C.

Watch the weights as the drying proceeds and when the change in weight does not exceed more than one for five grams, the hay sample can be judged as dried. See Fig. 26 for a sample data sheet and record of several days exhaust oven drying tests. When drying high moisture content hays, 35 percent or more, the tendency will be to not dry them completely. A good example of this is shown by samples $B_1$9N1 and B_1 24N1 in Fig. 26. Also, when drying hay with a moisture content of less than 35 percent the tendency will be to dry them too much or to caramelize them. In either case the percent of error should not exceed one or two percent.

FIELD "B" DATE August 23 HAY Alfalfa

SAMPLES DRIED BY EXHAUST OVEN IN THE FIELD

TIME	SAMPLE NO.	NET WT. IN GRAMS AFTER MINUTES OF DRYING IN OVEN WET	4"	6"	8"	10"	12"	14"	16"	18"	20"	DIFF.	% MOISTURE WET BASIS	REMARKS
1330	$B_2$2N1	198	188		167		151		139	121	118	80	45.5	
1445	$B_1$9N1	142	135		119		107	102	96			46	32.4	Damp Center
1600	$B_1$24N1	87	75		64		58		55			32	36.8	
August 24 Field "B" and "C"														
0850	$B_2$2N1	128	110		99		96	94				34	26.6	
0930	B_2CS1	118	102		93		89	89				29	24.6	
1130	$C_1$2S1	134	122		95		76	66	64			70	52.2	
1500	$C_1$4S1	131	115		100		90	88				43	32.8	
August 25 Field "C"														
0745	$C_2$4S1	117	93		84	84	84					33	28.2	
0815	$C_2$26S1	87	70	68	67	67						20	23.0	
0830	$C_2$14N1	105	88	84	80	80	80					25	23.8	

Fig. 26. SAMPLE DATA SHEET AND RECORD OF SEVERAL DAYS EXHAUST OVEN DRYING TESTS

RESULTS

To check the accuracy of the exhaust oven test for drying hay, a large sample was selected out of the swath or windrow, and after being thoroughly mixed, it was divided into two parts. The moisture content of one part was determined by exhaust oven in the field and the other part was bagged, weighed and later dried in the steam oven. For a comparison of results obtained in drying similar samples with the exhaust oven in the field and with the steam oven for 15 hours, see Table 3.

Table 3. Comparison of Hay Samples Exhaust Oven Dried With Samples Steam Oven Dried

Sample No.	Percent Moisture Content*		Percent Deviation Exhaust Dried from Steam Dried
	Exhaust Oven Dried	Steam Oven Dried	
$B_1$2N1	45.5	47.3	- 1.8
$B_1$9N1	32.4	42.4	-10.0
$B_1$24N1	36.8	39.3	- 2.5
$B_2$2N1	26.6	25.3	+ 1.3
B_2CS1	24.6	23.1	+ 1.5
$C_1$2S1	52.2	54.0	- 1.8
$C_1$4S1	32.8	33.2	- 0.4
$C_2$4S1	28.2	27.5	+ 0.7
$C_2$26S1	23.0	23.4	- 0.4
$C_2$14N1	23.8	22.1	+ 1.7

* Percent Moisture Content on the Wet Basis

These figures show that the exhaust oven method of field testing hay for moisture content is both practical and helpful for determining the percent of moisture in hay with reasonable accuracy. The biggest error is likely to be in the operator's judgment. The length of time that the sample should be run to be dried is best taught by experience. Without a thermometer it is very hard if not impossible to maintain the proper temperature for maximum drying without danger of burning or caramelizing the sample.

A season's work in checking moisture contents of hay will soon convince any one that they cannot accurately tell the moisture content of hays by merely looking and feeling of them. After a season's experience a person can make fairly good estimates of the moisture content without testing, but there are always cases when he judges wrong. Most farmers have a very poor conception of what the moisture content of hay is when cut and at any time during drying. Farmers at the 1948 grass days guessed everything but the correct moisture content in most cases. Michigan has a reputation for variable weather which changes rapidly and it has a profound influence on the drying rate of hay. By running just a few samples a farmer can determine when it is time to rake and when his hay is safe to be baled.

CONCLUSIONS

1) The exhaust oven test enables a farmer to determine the moisture content of hay in the field.
2) It is sufficiently accurate if moderate precautions are taken by the operator.
3) It can be used on equipment available on most farms.
4) The technique does not require a great deal of experience and can be self taught.
5) The equipment is simple and the outlay for it costs very little.
6) The accurate determining of the moisture content of hay takes much of the guesswork out of haymaking.

Some disadvantages of the exhaust oven test are:

1) The test takes 10 to 15 minutes to run one sample.
2) The test may tie up a tractor or other equipment needed for some other job.
3) The test requires reasonably good judgment in selecting and testing the sample.
4) The wind may be bothersome while weighing samples. A portable windbreak would be a very useful device in providing a sheltered place for weighing.

PART IV

COMPARISON OF THE DRYING RATE OF CRUSHED VERSUS UNCRUSHED ALFALFA HAY

INTRODUCTION

A study was made in the late summer of 1948 on the drying characteristics of crushed hay versus uncrushed hay. The experiment was conducted on the Kellogg Farm near Battle Creek, Michigan, which is a part of the Michigan State College Experiment Station.

A John Bean Haymaker was purchased for the farm in 1947 and it was used in making all of the hay during the 1948 season. Clover, alfalfa, and alfalfa brome grass hays were harvested. The farm superintendent, Mr. McCrary, stated that he thought it was the best quality hay they had ever made. He said that two factors stood out with the use of the haymaker:

1) A shorter curing period which in good drying weather enabled them to cut hay down one day and to bring it in on the following day;
2) A better quality hay because of the resulting brighter green color and the retention of almost 100 percent of the leaves.

Mr. McCrary further stated that he thought the time required for curing and drying the hay was shortened by 1/3 to 1/2 as compared to the time required for drying the hay when harvested with conventional haymaking equipment.

Good drying weather, consisting of a relatively high temperature, a low percent of relative humidity, and a breeze, is a factor which is most essential for rapid hay curing and drying. The time during which all of these conditions occur simultaneously and in optimum intensities for rapid hay drying is relatively short and infrequent in occurrence.

Crushing the hay expedited the evaporation of the moisture from the stems and leaves and may help overcome in part less favorable weather conditions as they affect hay drying and curing in the field.

OBJECTIVES

The experiment was conducted to determine to what extent crushing shortens the drying time of alfalfa hay. The moisture content of hay on a wet basis should be 20 percent for safe storage without additional natural or artificial drying. Thus the time that it takes hay to dry down to this range is the critical period and the one in which the farmer is interested.

A second objective was to determine how much windrowing retards the drying of crushed and uncrushed hay. The drying rate of both the crushed and uncrushed hay was compared under three different conditions:

1) Raked immediately after cutting;
2) Raked at the time the hay reached approximately the 50 percent moisture content level on the wet basis;

3) Left unraked.

A third objective was to determine if it was better to mow in the morning, in the late afternoon, or whether it made any appreciable difference.

APPARATUS AND GENERAL TEST CONDITIONS

The machine used for cutting and crushing was a seven foot cut John Bean Haymaker with a pressure of about 1200 pounds per square inch between the crushing rollers. See Fig. 27 for a view of the Haymaker in action. A side delivery rake was used for windrowing. A sling psychrometer was used to check the relative humidity and temperature. The samples were weighed on a 500 gram spring scale with a movable face.

The hay which was used in the test was a third cutting of pure alfalfa. The previous two cuttings were made early but very little precipitation fell after the second cutting was made in late June. This combined with the light sandy nature of the soil provided inadequate moisture for growth over most of the field. The rolling topography of the land, however, produced lower lying pockets or hollows in which a fairly good growth took place. It was on two of these areas of about 1/2 acre a piece that hay was selected for the tests. The hay averaged 15 inches high in test area no. 1, and 13 inches high in test area no. 2. The hay was in the pre-bloom stage and very succulent.

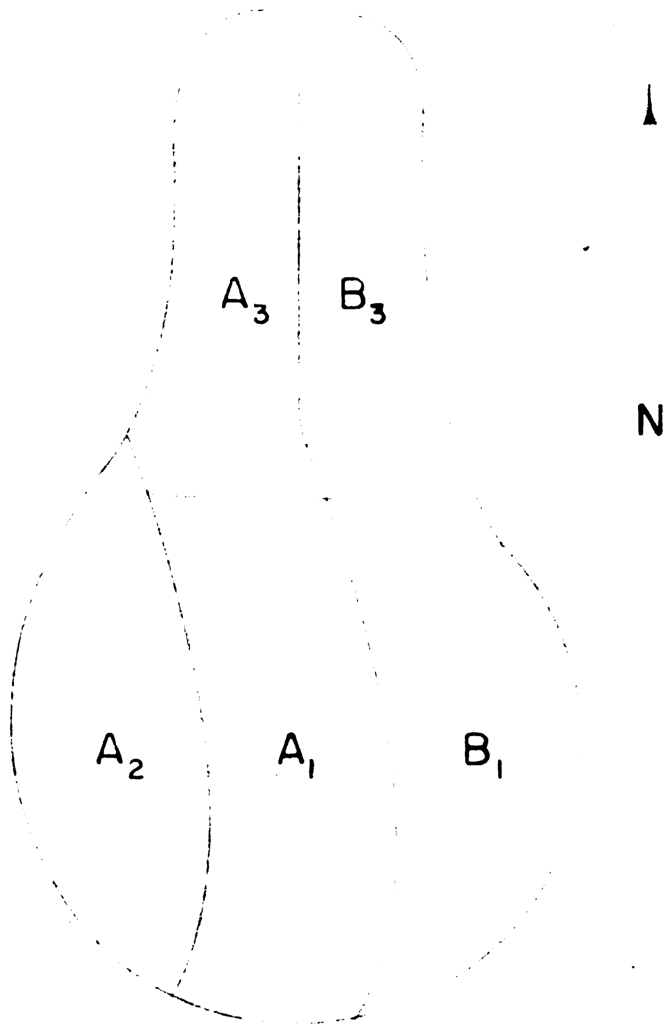
Fig. 27. THE JOHN BEAN HAYMAKER WHICH WAS USED FOR CRUSHING THE HAY

METHOD OF TESTING

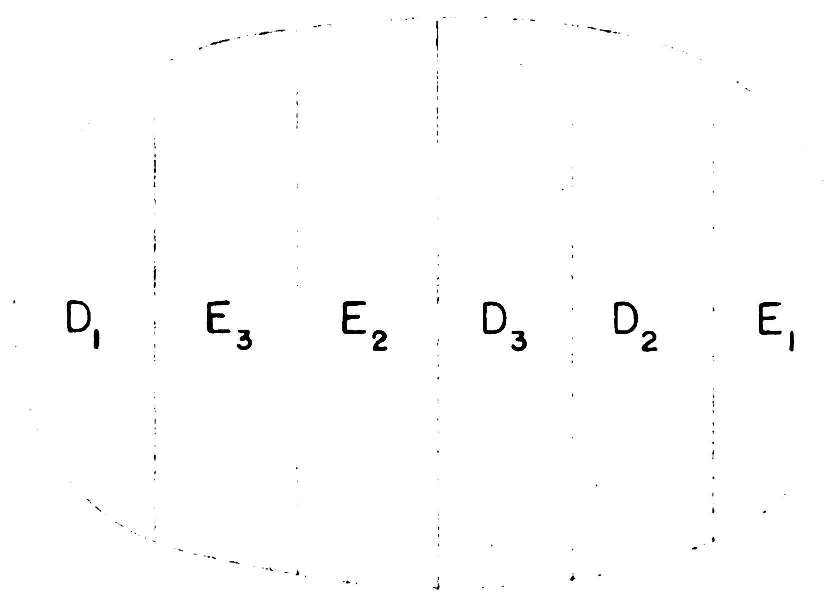
The original plan was to cut two identical areas of hay and hope for similar weather conditions on successive days in order to get a comparison of the drying rates. The first test area was to be cut early in the morning or as soon as the dew had evaporated. In the second test area the hay was to be cut late that same afternoon and allowed to dry the next day.

The morning the tests were to start the sky was completely overcast. There was a heavy dew so the hay on test area number 1 was not cut until 1100 hours. Also, because of the nature of the pockets of hay which were selected for the tests, it was not possible to cut two identical areas in shape or in size of hay.

The hay in test area number 1 was in a long, rather narrow strip extending north and south and it was divided into sections lengthwise. See Fig. 23 for sketch of test areas. The roller crusher mechanism was elevated and the east side was cut first without being crushed. The roller crusher was then lowered and the west side was cut and crushed. The moisture content of the crushed and uncrushed hay was then checked under three different conditions; one-third of that which was cut was raked immediately, one-third was raked when it reached an estimated moisture content of 50 percent, and one-third was left unraked. The uncrushed hay was not checked under condition number 2, raking



TEST AREA "1"



TEST AREA "2"

FIGURE 2[illegible]

after the hay reached the 50 percent moisture content level, because of insufficient hay.

Representative samples of hay were selected from windrows or swaths of the various conditions at one-half hour intervals until 1700 hours. The hay in test area 2 was cut at 1715 hours. Being oval in shape, the plot was divided into six sections, with the swaths cut perpendicular to the long axis. Samples of hay for the comparative tests under the three conditions were taken from similar areas to try to give greater likeness for better comparative results. See sketch in Fig. 23.

From 1700 until 2400 hours samples were taken at one hour intervals. The second day when samples were taken from two areas which were about one-fourth of a mile apart, the samples were taken at one hour intervals all during the day. The samples were carefully selected, bagged, marked, and weighed as they were taken. The movable face on the scales was set so that the net weight of the hay was given each time a sample was weighed. The samples were then brought back to the college and steam oven dried at 100°C. for 24 hours. A second weighing then gave the information needed to calculate the moisture content.

See Fig. 1 in the Appendix for a sample data sheet and record of the drying rate of crushed and uncrushed alfalfa.

LIMITATIONS AND OBSERVATIONS

The first day the test was started was not a good drying day. The sky was cloudy and overcast until about 1400 and the relative humidity remained above 50 percent except for about two hours in the afternoon. Heavy dews were also precipitated on the nights of August 29th and 30th.

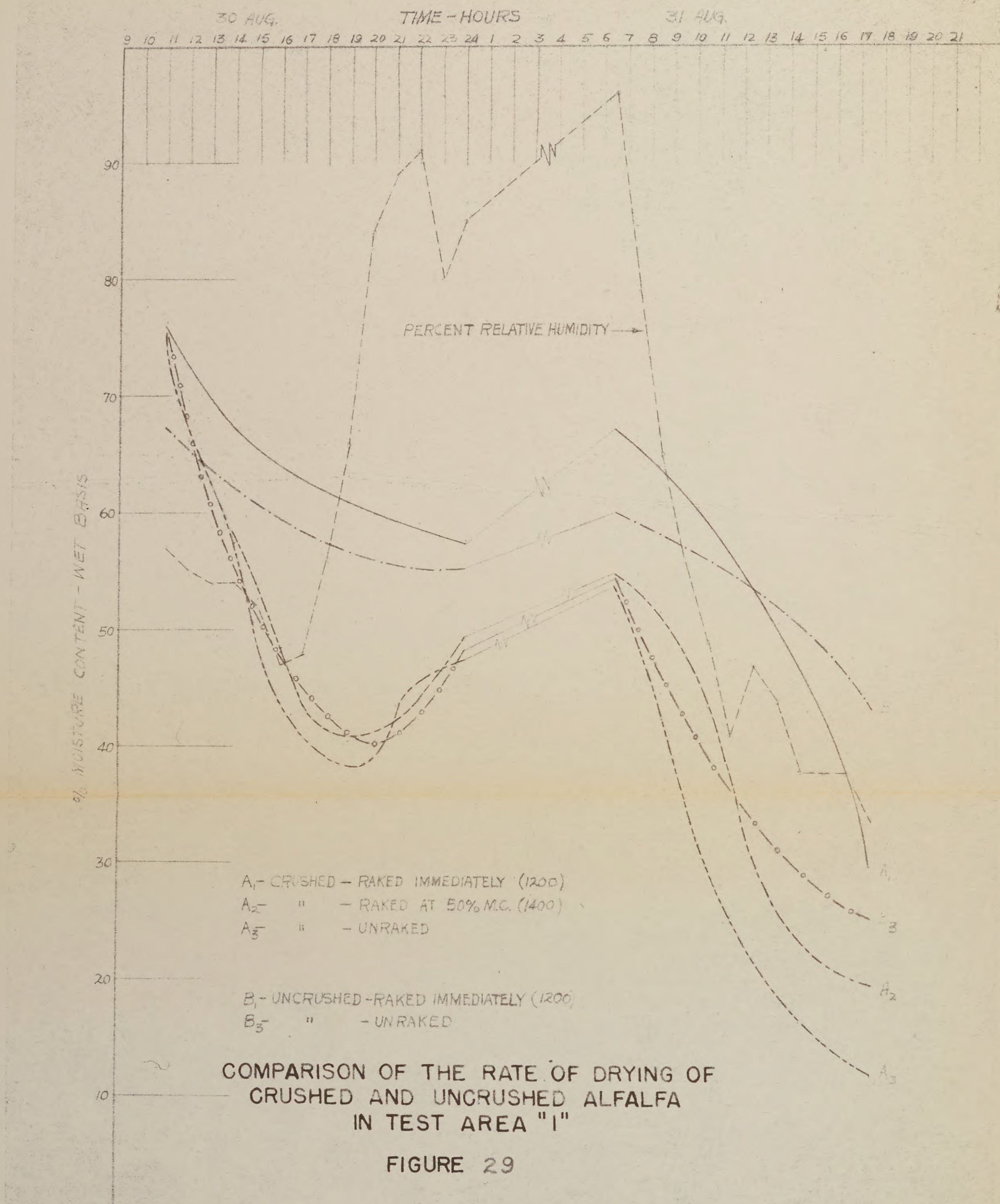
The alfalfa in test area 1 varied quite extensively in growth. Around the edges of the pocket it was considerably shorter, less succulent, and thinner in stand than in the center areas. The samples throughout the test, however, were selected from the windrows and swaths in the center areas. The alfalfa in test area 2 was not as uniform as was desired for the test, but it did have more growth, more even density of stand, and a more advanced stage of maturity than that in test area 1. The above reasons would suggest that the study should be repeated again under more favorable conditions. The study should also be made on a first or second cutting as they are used mostly for hay and as the third cutting is often nullified by drought or used for pasture.

The variance in thickness of stand and in height presented no problems in plain mowing, but it did affect the crushing operation. When the hay was short and light in stand, it did not feed through the crushing rollers. It was estimated that from 5 to 50 percent of the mowed hay dropped off or passed under the crushing rollers instead of passing through them when the stand was poor to fair. Again when the stand was fair to good, but the alfalfa was short, fine, and succulent, it passed through the roller crushers but tended to hang up on the scraper, which cleans the lower roller, and drop off in bunches. The bunching of this freshly crushed and matted hay does retard its rate of drying but to a lesser degree than that which is raked immediately into windrows. This indicates that as far as the mechanical operation of the crusher is concerned it is necessary to have a good stand of forage which is not too short, immature, or succulent.

RESULTS

<u>Test Area 1</u>: For a comparison of the drying rate of crushed versus uncrushed hay in test area 1, see graph in Fig. 23.

Under condition 1, raked immediately after cutting and/or crushing, the uncrushed hay had a lower original moisture content. This was due to the position of the hay in the test area. See Fig. 23. Evidently the hay on the southeast side was less succulent than the rest. The crushed hay dried out more than the uncrushed hay, or about a third faster. Notice that as the relative humidity increases above 50 percent the drying rate slows down and even reverses in the evening. A very heavy dew precipitated the night of August 30th so that the hay gained moisture



COMPARISON OF THE RATE OF DRYING OF CRUSHED AND UNCRUSHED ALFALFA IN TEST AREA "I"

FIGURE 29

and was literally "wringing wet" the next morning. Overnight the crushed hay picked up more moisture than did the uncrushed hay.

The second day was a fairly good drying day with a clear sky, a bright sun, a light breeze during part of the day, and a low relative humidity which dropped down to 34 percent in the late afternoon. The crushed hay dried over twice as fast as did the uncrushed hay. Without a heavy dew the crushed hay would not have taken on as much moisture at night and would probably have dried out even faster the second day. The uncrushed hay dried from 67 percent down to 30 percent moisture content in 11 hours or at the rate of 1.5 percent per hour. The crushed dried from 80 percent down to 43 percent moisture content in 11 hours or at the rate of 3.4 percent per hour.

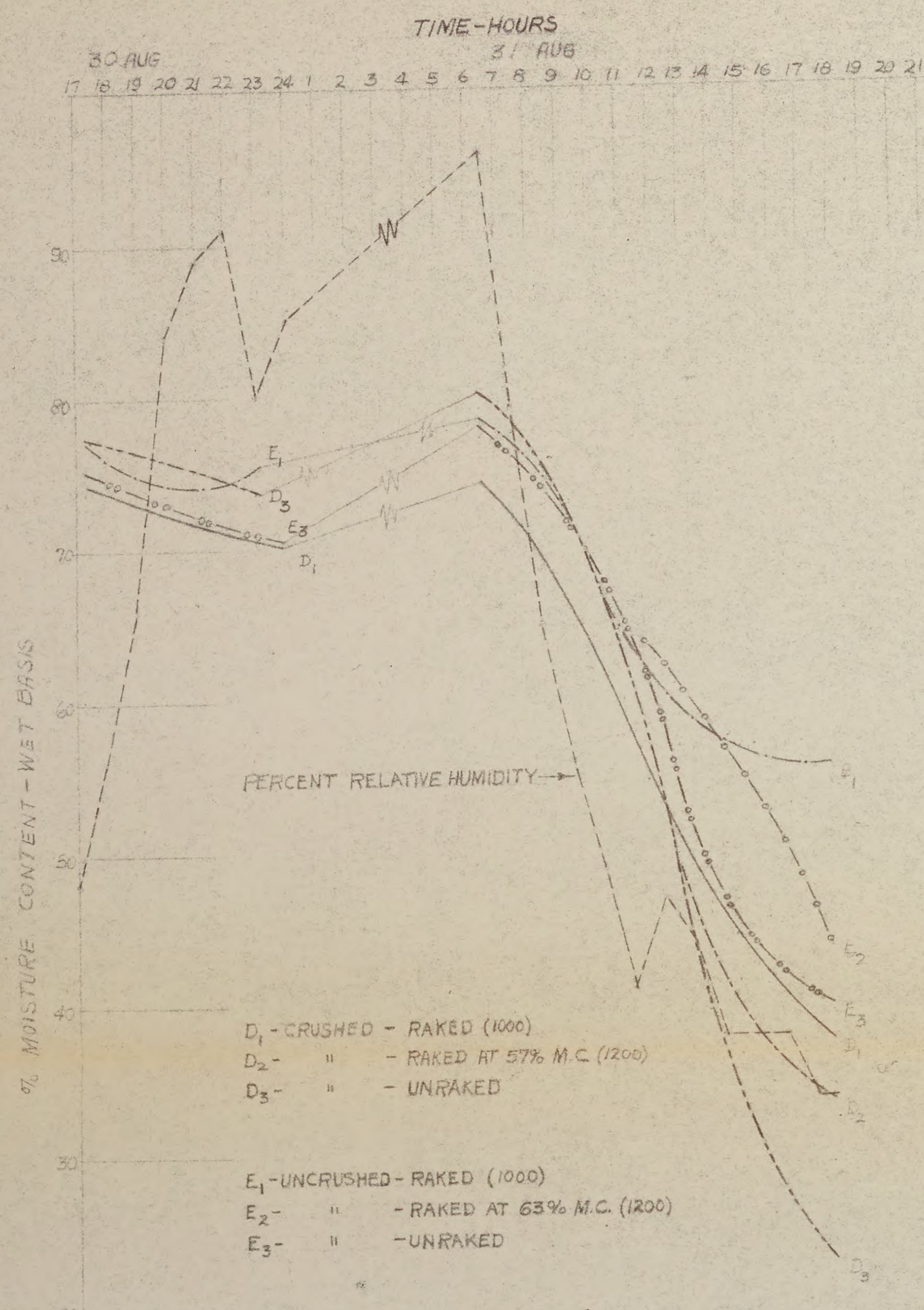
Under condition 2, raked when the hay approached a moisture content level of 50 percent, there was no comparative test between crushed and uncrushed hay suitable for the test. Raking the crushed hay as it approached 50 percent moisture content did retard the drying rate somewhat the first day of drying. The spread in drying rate gradually widened the second day. Notice that the drying rate slowed down markedly soon after the relative humidity started to increase. About 1900 hours the hay in condition 2 started to take on moisture and increased the moisture content by 8 percent by 2400 hours. The second day the moisture content was decreased from 55 percent to 20 percent in 11 hours or at the rate of 3.2 percent per hour. A_2 is a typical drying curve and it follows the path of the relative humidity curve. In the morning when the relative humidity is high, the rate of drying is low. As the relative humidity drops the rate of drying increases and it reaches its maximum rate at midday or a little later. As the relative humidity starts to increase, the rate of drying slows down, and may stop altogether and reverse in the evening.

Under condition 2, unraked, the crushed and uncrushed hay showed little difference in drying rate until late in the afternoon of the first day. They reached an equilibrium in drying at about 1930 hours and then increased in moisture content. The second day the moisture content of the crushed and uncrushed hay was approximately the same at the beginning of the day due to the addition of moisture during the night. The crushed hay dried out more rapidly and reached a moisture content of 25 percent six hours before the uncrushed hay. The drying rate of the crushed hay was almost half again as fast as the uncrushed hay. The uncrushed hay dried from 54 percent down to 25 percent moisture content in 11 hours or at the rate of 2.6 percent per hour. The crushed hay dried from 54 percent down to 12 percent moisture content in 11 hours or at the rate of 3.8 percent per hour.

Test Area 2: Comparison of the drying rate of crushed versus uncrushed hay in test area 2. See graph in Fig. 30 for the drying curves of the hay under all three conditions.

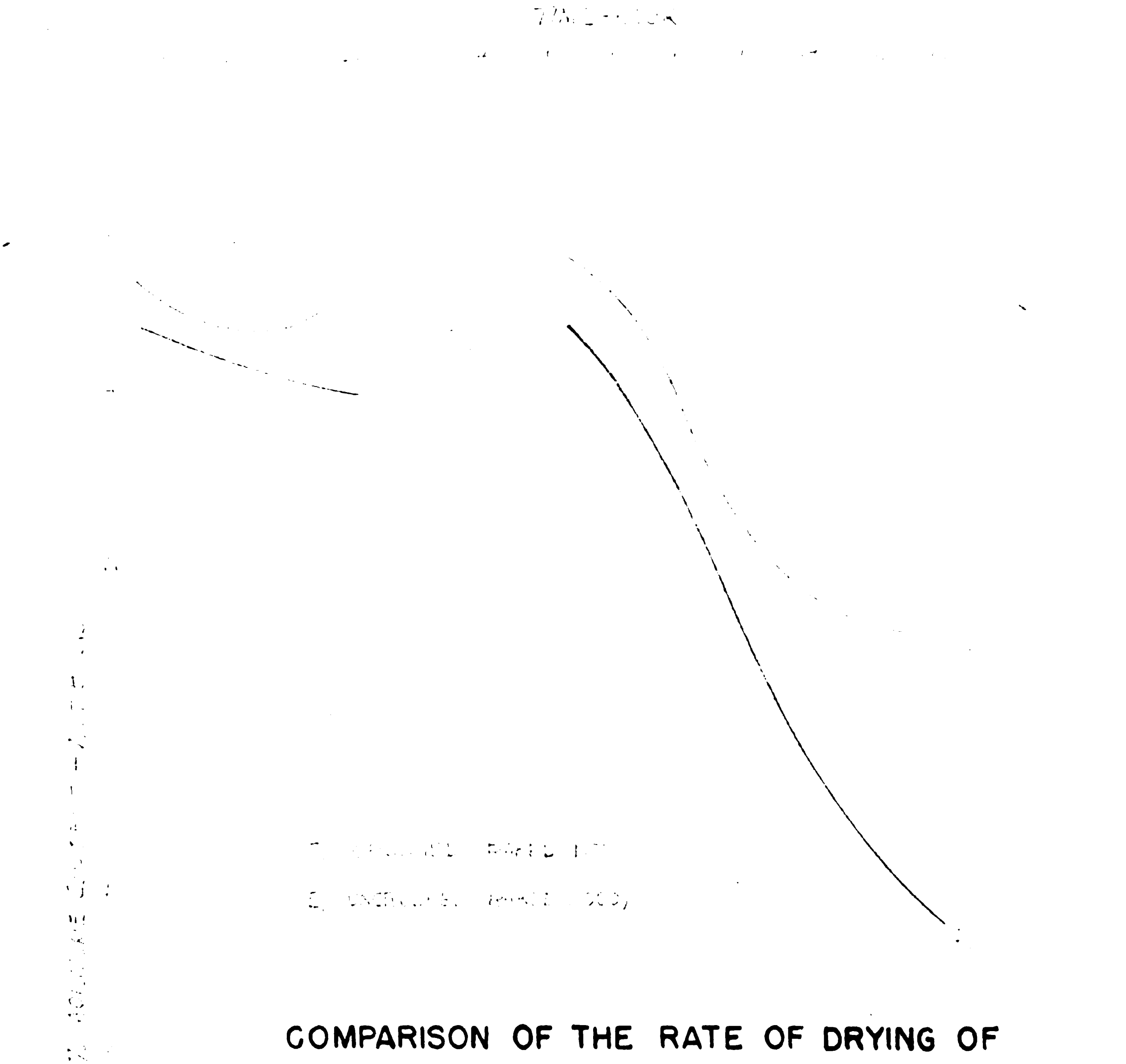
Under condition 1, cut the evening before and raked as soon as the dew evaporated the next morning, the crushed hay had a lower original moisture content than did the uncrushed hay. See Fig. 31. The first evening very little drying took place. Overnight the crushed hay gained a little moisture. The second day the uncrushed hay decreased 23 percent in moisture content in 11½ hours or at the rate of 2 percent per hour. The crushed hay decreased 36 percent in moisture content in 11 hours or at the rate of 3.3 percent per hour. The crushed hay thus dried over half again as fast as the uncrushed hay. For a better comparison the test should have been continued another day or until the uncrushed hay reached a moisture content of 30 percent or less.

Under condition 2, to be raked when the moisture content reached 50 percent, the hays were raked a little prematurely. The uncrushed hay was raked about 1½ hours too soon or when it had 63 percent moisture content. See Fig. 32. The crushed hay was raked when it was approximately 57 percent moisture content which was one-half hour too soon at the rate it was drying. In the six hours following, the uncrushed hay dried from 63 percent down to 44 percent



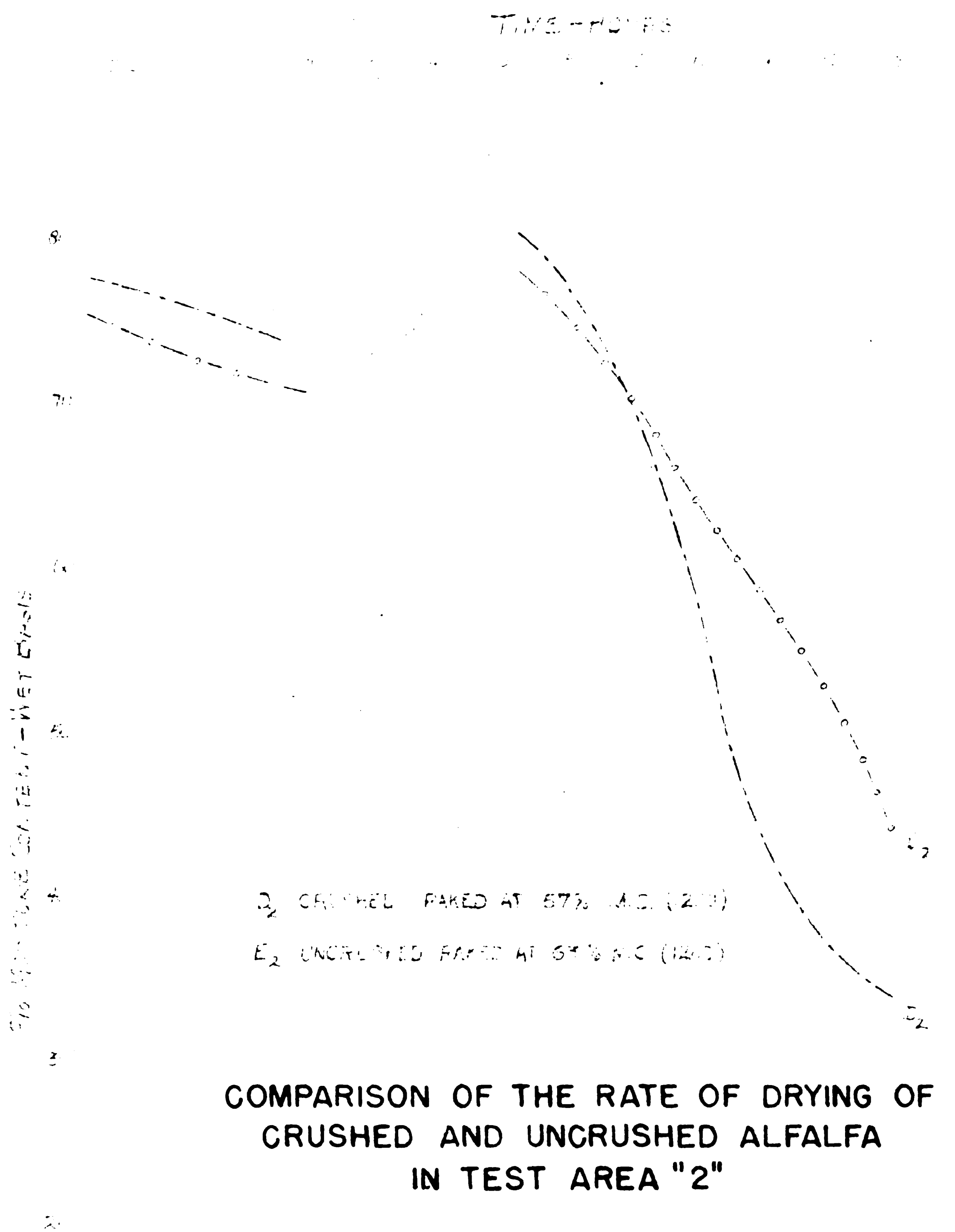
COMPARISON OF THE RATE OF DRYING OF CRUSHED AND UNCRUSHED ALFALFA IN TEST AREA "2"

FIGURE 30



COMPARISON OF THE RATE OF DRYING OF CRUSHED AND UNCRUSHED ALFALFA IN TEST AREA "2"

FIGURE 31



COMPARISON OF THE RATE OF DRYING OF CRUSHED AND UNCRUSHED ALFALFA IN TEST AREA "2"

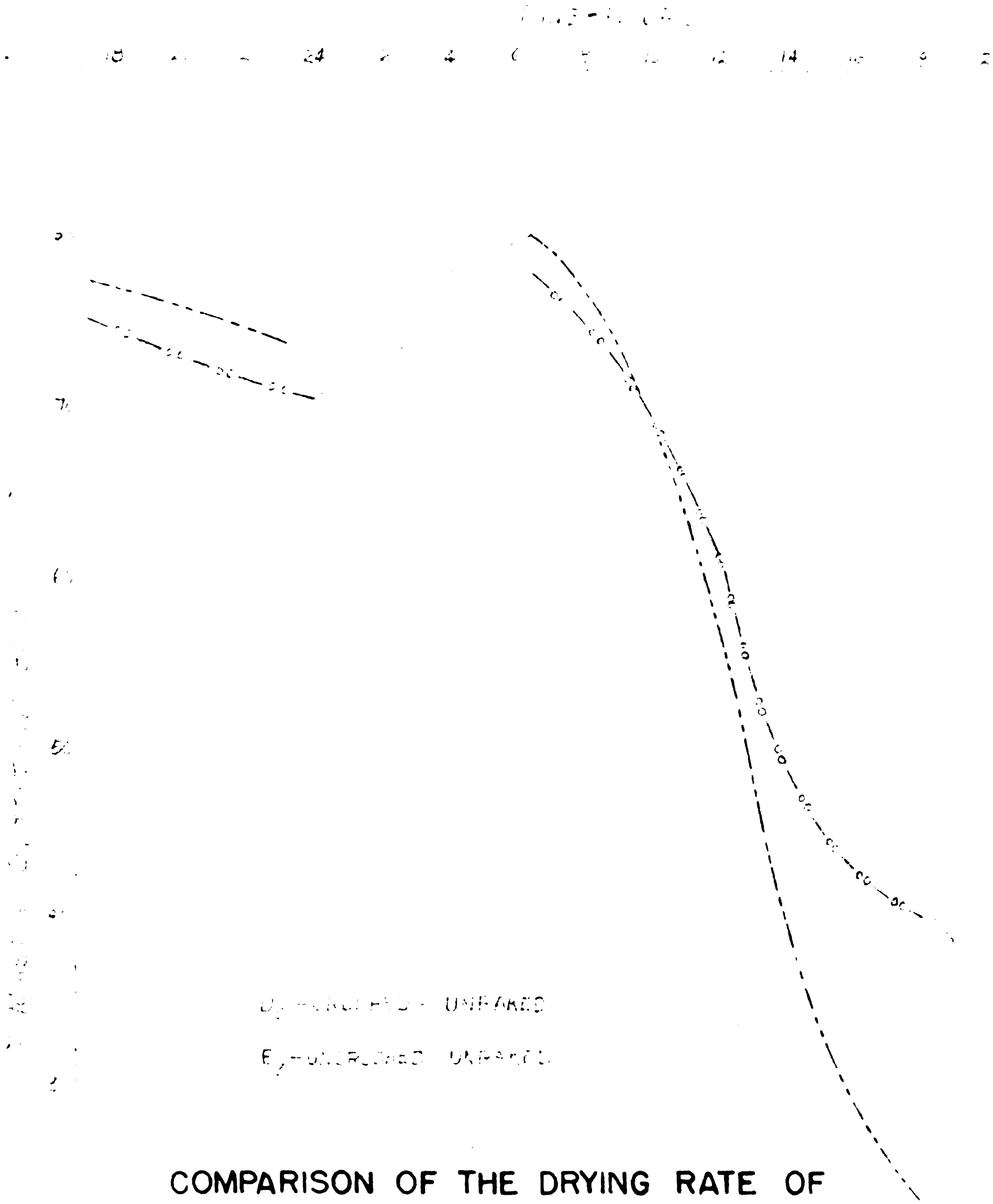
FIGURE 32

moisture content, or at a rate of 3.2 percent per hour. During the same time the crushed hay dried from 57 percent down to 34 percent, or at a rate of 3.8 percent per hour. Immediate or delayed windrowing will retard the rate of drying of crushed or uncrushed hays. In this study the windrows were small, indicating that the effect would be more pronounced with larger windrows.

Under condition 3, hays unraked, the uncrushed hay was drier originally than the crushed hay. See Fig. 33. The first evening very little drying took place while the relative humidity was high and on the increase. The drying rate was about the same in both cases. The uncrushed hay gained a little more moisture overnight. On the second day the drying rate of the uncrushed hay was less than the crushed hay going from 73 percent down to 40 percent moisture content in 11½ hours or at a rate of 3.3 percent per hour. The crushed hay dried from 80 percent down to 23 percent moisture content in 11½ hours or at a rate of 5.0 percent per hour.

DISCUSSION

Even though the test conditions were not too favorable, the results of the study show that crushing does reduce the drying time of alfalfa hay by a third or more. The lower the moisture content level to which the hay is dried the greater is the percent reduction in drying time to be gained by crushing the hay. Crushing cracks open the stems, but



COMPARISON OF THE DRYING RATE OF
CRUSHED AND UNCRUSHED ALFALFA
IN TEST AREA "2"

FIGURE 33

does not actually squeeze but the very smallest amount of moisture from the hay. By crushing, and exposing the inner tissues and cells of the leaves and stems to the drying action of the sun and air, the process of drying is speeded up. The internal moisture in the uncrushed stem is the last to be given up, but when it is cracked open it tends to dry from the inside out as well as from the outside in. A much larger surface is exposed to evaporation also, so that drying can take place more rapidly. Thus a smaller amount of internal moisture, tightly held and insulated, is left to be evaporated in the last stages of drying.

In general, immediate or delayed windrowing will slow down the drying rate of either crushed or uncrushed hay as compared to the drying rate of unwindrowed crushed or uncrushed hay. The results also indicate that uncrushed hay is retarded more in drying by windrowing than is crushed hay.

It is not possible to recommend the cutting of hay either in the morning or in the late afternoon or evening by the results of this study. Many factors enter into the picture to cause each set of conditions to be solved separately.

With favorable weather conditions and hay that is not too succulent and in the proper stage of maturity, it appears that a second or third cutting of hay can be cut and crushed one morning and taken in the afternoon of the following day with a moisture content below 30 percent. If the hay were not crushed the time for drying would be at least half again as long.

In test area 1 in spite of the facts that the hay was immature and highly succulent, that it was not good drying weather the first day, that the hay was not cut until 1100 because of the unfavorable weather conditions, and that the moisture content of the hay was increased overnight by a heavy dew, the crushed hay raked at 53 percent moisture content was down to 20 percent moisture content at the end of $1\frac{1}{2}$ days of drying.

There seem to be no advantage in cutting hay in the late afternoon or evening when heavy dews are precipitated as the hay may have a higher moisture content the following morning than when it was cut the evening before. During good drying weather without dews it may be possible to cut the hay in the evening and then take it in early the second day of drying.

CONCLUSIONS

1) Crushing reduces the drying time by a third or more.
2) The lower the moisture content level to which the hay is dried, the greater is the reduction in drying time to be gained by crushing hay.
3) Crushing cracks o en the stems to increase the effective area from which evaporation takes place, but apparently does not squeeze out any appreciable amount of moisture.

4) The hay crusher does not operate satisfactorily in light, rather short stands of hay.

5) Windrowing immediately decreases the drying rate of uncrushed hay by about one-third.

6) Windrowing immediately decreases the drying rate of crushed hay by about one-fifth, thus indicating again, the superior drying characteristics of crushed hay.

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APPENDIX

TABLE 1. COMPARISON OF SAMPLE WEIGHTS AFTER DRYING 12, 24, AND 48 HOURS.

SAMPLE	NET WT.	WET WT. AT END OF 12 HRS	24 HRS	48 HRS	% MOISTURE AT END OF 12 HRS	24 HRS	48 HRS	VARIATION IN % MOISTURE AFTER 12 HRS DRYING COMPARED WITH 24 HRS	WITH 48 HRS
A-1	326	103	101	102	68.4	69.0	68.7	-0.6	-0.3
A-2	309	87	87	85	71.9	71.9	72.5	0.0	-0.6
A-3	328	81	79	79	75.3	75.9	75.9	0.0	-0.6
A-4	328	83	82	81	74.7	75.0	75.3	-0.3	-0.6
A-5	310	79	79	80	74.5	74.5	74.2	0.0	+0.3
A-6	303	105	107	102	65.3	64.7	66.3	+0.6	-1.0
A-7	309	118	126	117	61.8	59.2	62.1	+2.6	-0.3
A-8	300	106	107	107	64.7	64.3	64.3	+0.4	+0.4
A-9	322	104	102	105	67.7	68.3	67.4	-0.6	+0.3
A-10	314	84	83	83	73.2	73.6	73.6	-0.4	-0.4
A-11	316	101	101	99	68.0	68.0	68.7	0.0	-0.7
A-12	320	90	90	90	71.9	71.9	71.9	0.0	0.0

FIELD KELLOG AREA "1" DATE AUG. 30,1948 HAY ALFALFA-THIRD CUTTING*

SAMPLES BAGGED FOR STEAM OVEN DRYING

TIME CUT	SWATH NO.	TIME	SAMPLE NO.	NET WEIGHT-GRAMS WET	DRY	DIFF.	% MOISTURE WET BASIS	RELATIVE HUMIDITY	WEATHER AND REMARKS
1100	1	1100	B_1-1	198	65	133	67.2	57.0%	Temp. 65°F, cloudy
1103	2	1105	A_1-1	212	53	159	75.0		and overcast
1106	3	1200	B_1-2	197	71	126	64.0	55.0%	Temp. 69°F
1109	4	1205	A_1-2	220	56	164	74.5		
1112	5	1230	B_1-3	162	56	106	65.4		
1115	6	1235	A_1-3	173	52	121	70.0		
		1300	B_1-4	163	65	98	60.1	54.0%	Temp. 72°F, hazy
		1305	A_1-4	188	53	135	71.7		but clearing on
		1330	B_1-5	174	67	107	61.5		the north west
		1335	A_1-5	197	66	131	66.5		
		1400	B_1-6	215	83	132	61.3	54.0%	Temp. 74°F, hazy
		1405	A_1-6	203	67	136	67.0		
		1430	B_1-7	171	66	105	61.4		Bright sun and
		1435	A_1-7	182	68	114	62.7		clear sky
		1500	B_1-8	184	71	113	61.4	52.0%	Temp. 78°F
		1505	A_1-8	199	66	133	66.8		
		1530	B_1-9	183	73	110	60.1		
		1535	A_1-9	194	76	118	60.8		
		1600	B_1-10	225	91	134	59.5	47.0%	Temp. 81°F, Bright
		1605	A_1-10	206	71	135	65.5		sun, scattered
		1630	B_1-11	209	85	124	59.3		clouds
		1635	A_1-12	205	61	144	70.2		
		1700	B_1-13	228	98	130	57.0	48.0%	Temp. 78°F
		1705	A_1-13	209	70	139	66.5		
		1800	B_1-14	179	79	100	55.9	56.0%	Temp. 73°F
		1805	A_1-14	185	74	111	60.0		
		1900	B_1-15	212	88	124	58.5	66.0%	Temp. 68°F, clear
		1905	A_1-15	203	59	144	71.0		sundown
		2000	B_1-16	203	93	110	54.2	84.0%	Temp. 62°F
		2005	A_1-16	194	85	109	56.2		
		2100	B_1-17	259	102	157	60.6	89.0%	Temp. 58°F
		2105	A_1-17	206	83	123	59.7		
		2200	B_1-18	212	87	125	59.0	91.0%	Temp. 55°F
		2205	A_1-18	251	94	157	62.5		Moderate breeze
		2300	B_1-19	283	126	157	55.5	80.0%	Temp. 62°F
		2305	A_1-19	283	99	134	57.5		
		2400	B_1-20	224	101	123	54.9	85.0%	Temp. 60°F
		2405	A_1-20	251	106	145	57.8		
August 31	Second day	0630	B_1-21	268	112	156	58.2	96.0%	Temp. 55°F, Clear,
		0635	A_1-21	271	87	184	67.8		sun-up, still
		0730	B_1-22	270	105	165	61.1	79.0%	Temp. 61°F, clear
		0735	A_1-22	237	107	130	54.9		Bright sun
		0830	B_1-23	214	105	109	51.0	65.0%	Temp. 68°F
		0835	A_1-23	248	84	164	57.7		
		0930	B_1-24	188	78	110	58.6	56.0%	Temp. 73°F
		0935	A_1-25	220	79	141	64.0		
		1030	B_1-25	236	98	138	58.5	49.0%	Temp. 77oF
		1035	A_1-25	239	81	158	66.0		
		1130	B_1-26	214	96	118	55.2	41.0%	Temp. 82°F
		1135	A_1-26	165	87	78	47.3		
		1230	B_1-27	207	90	117	56.5	47.0%	Temp. 78°F, Light
		1235	A_1-27	183	85	98	53.6		breeze, bright
		1330	B_1-28	149	74	75	50.3	44.0%	Temp. 79°F
		1335	A_1-28	169	84	85	50.3		
		1430	B_1-29	148	86	62	41.9	38.0%	Temp. 80°F, Strong
		1435	A_1-29	175	87	88	50.3		breeze
		1530	B_1-30	185	88	97	52.4	38.0%	Temp. 80°F
		1535	A_1-30	130	67	63	48.5		
		1630	B_1-31	142	82	60	42.2	38.0%	Temp. 80°F
		1635	A_1-31	156	94	62	39.7		
		1730	B_1-32	181	103	78	43.1	34.0%	Temp. 76°F
		1735	A_1-32	131	92	39	29.5		
		1800						34.0%	Temp. 74°F

*Key: Raked Immediately, A_1= Crushed hay, B_1= Uncrushed hay.

Fig. 1. SAMPLE DATA SHEET AND RECORD OF RATE OF DRYING OF CRUSHED AND UNCRUSHED ALFALFA HAY RAKED IMMEDIATELY

ROOM USE ONLY