# FACTORS INFLUENCING THE NATURAL FIELD DRYING OF ALFALFA HAY

by

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# INTRODUCTION

For the past several years, there has been considerable interest in improving the quality of hay. This is extremely important because no single crop in the United States is grown so generally as hay. There are two general factors that contribute to low quality hay. One of these is the stage of maturity at which the hay is cut. This is usually quite easily controlled. The other factor is the deterioration in quality between the time the crop is cut and the time it is put into permanent storage. Weather factors such as exposure to sunlight and bleaching by rain are considered the primary causes of deterioration. This is due to the fact that these factors affect bacteria and enzyme action.

In order to obtain optimum quality hay, it is usually considered desirable to minimize the time between cutting and storage. Various methods and machines are now used to prepare hay for storage. One is to dehydrate and pellet the hay immediately after cutting it. Another method is to partially field dry the hay and then finish drying it in storage by passing natural or heated air through it. A third method is to increase the rate of field drying. This is done by conditioning the hay. A combination of accelerated field drying and drying in storage is also used. Mowing, conditioning and raking can be combined into a single field operation to reduce the time needed for haying.

Hay conditioning will be defined here as the process which bruises or ruptures the plant stem either during the cutting operation or immediately after cutting. This allows the moisture in the stem to dissipate faster.

All of these methods have certain objectionable features. Dehydrating and pelleting require an investment well above that which can be afforded by the average farmer. Also, tests have shown that roughage in the form of pellets alone is not satisfactory for ruminating animals. (8) The moisture content of hay must be lowered from an initial 70-80 per cent to about 40-50 per cent before forced air drying can be started. Thus, the hay will be exposed to the weather elements for a time. While increasing field drying rates reduces the chances of weather damage, it does not eliminate it. The machines that combine operations may reduce the total time in a large operation between initial cutting and final storage. The actual time, though, between cutting and storage of a particular location is usually increased, because these machines windrow the hay immediately rather than leave it in the swath for a period of time.

The average farmer must rely on field drying in part or entirely to reduce the moisture content of hay for safe storage. In order to accelerate the natural field drying, the hay is conditioned.

There are now three types of machines generally used to do this. One of these is the crusher. This is a machine with two relatively smooth rolls. The rolls are usually both metal, both rubber or one rubber and one metal. By passing the forage between the rolls, the entire length of the stem is split open. Another type of machine is the crimper. This is a machine with two fluted metal rolls. The fluted rolls mesh and crack or break the forage stems at intervals, usually every $1\frac{1}{2}$ - $2\frac{1}{2}$ inches, as they pass through the rolls. The third type of hay conditioning machine is the flail chopper and horizontal rotary cutter, both of which depend on the rotating action of the rotars to bruise the plant stems.

There was a movement for some time, particularly in the northeastern states, to store all hay in the form of haylage or grass silage. This appears to have lost favor with many farmers because they believe that higher milk production is obtained from hay.

The common method of producing hay for many years was to mow it, rake it into a windrow at about 30-40 per cent moisture and put it into storage either as loose hay or in bales at 20-25 per cent moisture. Today, this has been altered in many cases. Often a crusher or crimper is pulled behind the mower to reduce drying time. Another method is to use a 10 to 16 foot windrower with conditioning attachment. This takes up to twice as wide a cut as the conventional mower and performs the three operations of cutting, conditioning and raking all in one operation.

The horizontal blade rotary cutting machine performs the same functions as the windrower and takes up to a 12 foot swath. The flail chopper with its series of swinging hammers which rotate in a vertical plane is another machine that performs the three operations in one pass over the field. This machine is usually limited to a five foot cut but it may put two or three swaths together into a single windrow. Machines which mow, condition and windrow all in one operation do retard drying as compared to hay which is mowed, conditioned and left in the swath for a while before raking.

There is considerable need to learn more about the various factors that influence the drying rate of hay and consequently what effect these have on the quality of the final product. This is especially true of legumes such as alfalfa, the principle hay crop in Kansas.

Another factor that needs considerable exploration is the available weather data. Up to this time there has been very little information available as to the probability of rainfall on a particular day. Nor has there been much information as to the possible number of successive rain-free days at any particular time. Some of this information is now becoming available and needs to be set up in a form that is usable to the farmer.

## PURPOSE

The purpose of this work was to investigate some of the factors that influence the field drying rate and consequently the quality of alfalfa hay by comparing the hay produced by various commercially manufactured hay conditioning machines. Factors of special interest to be investigated include the effect of soil moisture, soil temperature, hay temperature and crushing force on the rate of drying. The use of weather data was also investigated.

## REVIEW OF LITERATURE

### Hay Conditioning

Hay conditioning is not a new idea. Zink (35) of Kansas, Bainer (2) of California and Jones (15) of Mississippi all reported on the developments of hay conditioners in the early 1930's. Zink (35) said that there was a practical application for the mower crusher under Eastern Kansas conditions. Jones (15) states that a difference of 4 percent in moisture content between crushed and uncrushed alfalfa hay at the end of a ten-hour period is hardly sufficient to justify crushing. Following this early work, very little was done on the development of hay conditioning for a number of years.

In the late 1940's and early 1950's, there was a general revival of interest in hay conditioning.

In the 1960 Yearbook of Agriculture, Hukill, Saul and Feare (33) state the following about haying methods and machines:

> Hay conditioners, such as crushers and crimpers, make it possible for the sun to reduce hay moisture to 40 per cent in less time. This reduces field drying time and speeds up haymaking. It results in better hay. Hay conditioners are not essential, but they reduce field

drying hazards. Windrowers that deliver freshly cut hay immediately to a windrow slow down field drying. Freshly windrowed hay may not drop to 40 per cent moisture for several days. During this time, enzymes, oxidations, and weathering losses are sure to reduce quality too much. Direct windrowing machines, therefore, are not universally recommended for making hay.

In certain areas of the country particularly in the western states, windrowers are a very popular haying machine.

Until recently, most work done with hay conditioning was with the use of crushers. Among the earliest machines were mower-crushers built by Zink (35), Cushman (2) and Jones (15).

Tests conducted by Zink (35), Jones (15), Milne (24), Bruhn (7), Ramser (27), Luttrell (22) and Zachariah (34) all show that crushing accelerates drying of various crops by about 25-50 per cent. Bruhn also states that atmospheric conditions and density of the crop affect the drying rate and comparative performance of various machines. These and other factors that influence the performance of hay conditioners are still receiving considerable attention by engineers, animal husbandry specialists and others. Bruhn (7) has done considerable work to study the effects of roll pressure, roll speed, roll diameter, multiple crushing and delayed crushing.

He has shown, for example, that under a particular set of conditions alfalfa hay will dry to 20 per cent in eight hours when crushed with a pressure of 30.4 pounds per linear inch of crushing roll. When using 7.9 pounds per inch the hay dries to only about 32 per cent in the same length of time.

The word pressure here as in much of the literature covering hay crushers is erroneously used. Since the cross sectional area of the material in contact with the rolls is not known, the crushing force is all that is usually measured. Hereafter, the term force will be used unless a pressure is definitely indicated.

Multiple crushing was done by passing the hay through the rolls, two and three times through a single pair of rolls and through two pair of rolls. In seven hours, hay, crushed three times by a single pair of rolls, was reduced to a 10 per cent moisture content. That crushed twice was at 13 per cent and single crushed hay was reduced to 19 per cent moisture. Uncrushed hay had reached a moisture content of only 35 per cent. Multiple crushing through a double pair of rolls shows similar results. There was a decided advantage though, in having the second set of a double set of rolls run at a slightly slower speed than the first set.

Increasing the peripheral speed of the rolls in relation to the ground speed up to a point also increased the drying rate. Tests were conducted with speed ratios of 1.22:1, 1.46:1, 2.31:1 and 3.44:1. The two highest ratios showed no difference in the drying rate.

Pedersen and Buchele (26) have also done considerable work on factors influencing the drying rate of hay. Their tests included the effect of soil moisture, effect of a plastic sheet under a hay swath, degree of crushing and effect of time of cutting. Alfalfa hay was used for all tests.

Soil moisture studies were conducted in the laboratory. Soils with moisture contents of 4.3 and 15 per cent dry weight basis were used. Crushed and uncrushed hay was dried on each of the two soils. In each case, half of the hay was laid directly on the exposed soil and half had a plastic sheet placed between the hay and soil. The drying rate of the hay on the dry soil, both with and without the plastic sheet, and on the wet soil with the plastic sheet was about the same. The hay exposed to the wet soil dried much slower. Crushed hay, though, dried faster than the uncrushed hay with all the treatments.

In order to make better use of the available solar energy, hay was dried on black polyethylene, transparent polyethylene, and on the ground. Hard crushed, normal crushed and uncrushed hay was used. Hard crushed hay on black polyethylene reached 20 per cent moisture in four hours; on transparent polyethylene it reached 20 per cent moisture in 6.5 hours. Both crushed and uncrushed hay on the ground took over 56 hours to reach 20 per cent moisture. By using polyethylene, it was possible to dry in one day a layer of hay equal to 7.2 tons of 20 per cent hay per acre.

The degree of crushing was varied by changing the clearance between the rolls rather than by changing the pressure applied to the rolls. Clearances of 0.005 in., 0.0125 in., 0.0250 in., 0.0500 in., and 0.1000 in., were used. A clearance of less than 0.015 in. was required in order to have hay dry to a 20 per cent moisture content in one day.

Hay was cut between 9 a.m. and 5 p.m. at two hour intervals. It was hard crushed and dried on black polyethylene. Only the hay cut at 9 a.m. dried to a safe storage level in one day.

Boyd (5) used three conditioners in his tests. They were a crimper, crusher and flail-type forage harvester. Both alfalfa-clover and timothy-brome mixtures were used in the tests. His conclusions were that the flail cut hay dried faster than hay conditioned by the other two methods. Field losses were greater, though, with the flail cut hay. The flail chopper left a longer stubble than a mower which accounted for part of the field losses. Because the flail chopper produced a shorter cut, there were greater raking and baler pickup losses.

To date, most of the work reported shows that conditioning in it various forms does definitely increase the drying rate of most forages. There are many interrelated factors though that have not been thoroughly explained. Also, what effect does this have on the quality of the hay?

## Hay Quality

Very little work has been reported previously concerning hay quality as affected by conditioning. It is known that much of the food value in alfalfa hay is in the leaves. Adams (1) gives the following figures:

> We found that over 65 per cent of the protein in legumes, especially alfalfa, is in the leaves and that approximately 80 per cent of the fat is in the leaves. Therefore, more than 70 per cent of the total food value in alfalfa is in the leaves.

It is also known that under conventional haying methods, the leaves in alfalfa hay dry much faster than the stems. Thus, the high value leaves are subject to shatter and losses. Richardson (28) has the following to say:

> Eighty per cent of the plant's crude protein is in the leaves. With careful handling and most favorable conditions, 15 per cent of the leaves are left in the field. Under less favorable conditions 60 per cent of the leaves may be wasted.

Miller (23) has the following to say about decomposition of hay after it is cut:

> Conservation of values is an objective in all processing operations. Hay making can properly be classified as a processing operation of very great economic importance. Naturally, we want to conserve all the elements of nutrition in the finished product as nearly as possible at the same level as they were in the living plant before it was cut loose from the ground. The decomposition of organic matter due to microorganisms after life has ceased to exist is well known. The decomposition continues more or less rapidly depending on conditions, until reduction is complete or until it is terminated by conditions under which microorganisms cannot carry on their life processes.

Miller further states that there are four treatments that will stop the decomposition: refrigeration, chemical, canning and dehydration. Of these, dehydration is the one commonly used in hay making.

The preceding statements indicate that it is desirable to have the drying or dehydration transpire as quickly as possible and also that it be as uniform as possible. In other words, the stem should dry as quickly as the leaves to minimize leaf loss.

Jones and Palmer (15, 16, 17, 18) have done considerable work in studying the physiological reactions of alfalfa after it has been cut. It is well known that large quantities of water transpire through the leaves of living plants. On this basis, they make the following statement:

> It then seems logical to conclude that if the normal flow of water through the vascular bundles to the stomatal chambers for evaporation could be retained without any serious check after plants are cut, the possibilities for more rapid and economical curing of forage plants would be expected.

On the basis of some calculations they made, if hay is cut on a day favoring rapid transpiration, it would reach field-cured stage within one hour's time. This assumes that it could be handled in such a manner as to prevent serious harm to the factors concerned in the natural process of transpiration.

Some tests were conducted in which the leaves were stripped from alfalfa plants. The drying rate of the stripped plants was compared with that of whole plants. The results indicated that for the first ten hours, the loss of moisture was greatest from the plants where the leaves were attached. After that time, the drawing power of the leaves had been diminished to such a degree that the rate of moisture loss became greatest in the case of the stripped plants. Windrowing or raking the hay within two hours after cutting caused the stomats of the leaves to remain open for a longer period of time. This in turn produced a faster drying rate over hay left in the swath. Bruhn (7) on the other hand shows that windrowing or raking the hay immediately after cutting reduces the drying rate to an impracticably low level. Thus, as in most field research it must be realized that local conditions have to be taken into account.

It is known that to produce an optimum quality hay product, it is necessary to dry it as quickly as possible. It has now also been determined that two things aid in maintaining the drying rate at a fast pace. One is to keep the stomata in the leaves open as long as possible to keep natural transpiration working. The other possibility is to condition the hay so that plant cells are exposed directly to the air and evaporation can take place without the water having to move long distances through the plant itself. The question then is; which of the present day methods best perform these functions and thereby produces the best hay?

The ultimate result in a hay quality test must be determined with feeding trials. Kepner et al (20) reported in 1960 on some feeding tests conducted with sheep. Crimped, crushed and non-conditioned hay was fed. The first test showed a significant difference at the five per cent level in favor of the crushed hay. In two subsequent tests, the results could not be repeated. The final conclusion was that the first test was a chance event and that over all there was no significant difference in favor of either the conditioned or the non-conditioned hay.

Tests with dairy cows at the Pennsylvania Agricultural Experiment Station (20) showed no difference between crushed and unconditioned hay when milk production and body-weight changes were the criteria.

Stoddard (30) has also conducted tests with dairy cows, using windrowed-conditioned hay and unconditioned hay. The conditioner on the windrower was a crimper. Hay from the two treatments was fed to individual cows in alternate periods of three or four weeks each. The entire test lasted 147 days. On the basis of anticipated production, the cows produced about five per cent more milk while being fed the windrowed-conditioned hay.

In general, the tests to date are of limited value and quite inconclusive. The California tests were conducted with only two sheep per pen for each treatment. The results of the Utah dairy trials are based on anticipated milk production. This is an estimated and not a measurable standard.

## Weather Data Correlation

The only study previously reported on the correlation of weather data with various haying methods was done in Missouri by Borgman and Brooker. (4) They used climatological data recorded by the United States Weather Bureau at six locations. An "open haying day" was defined as any day in the haying season (May through September) during which there was less than 0.10 inch total precipitation, 70 per cent or more of possible sunshine, and less than 1.0 inch total precipitation the preceding day. The conventional field curing process was considered to require three consecutive "open haying days". Conventional field curing combined with conditioning was considered to require two "open haying days". The general conclusions were stated as follows:

> The chances of making good hay are materially increased by reducing the number of days required for the process. In general, the chances of making good hay in

one day are at least double those of making good hay in three days. If the weather forecasts are studied before cutting, the increased accuracy of the one day forecast over the three day forecast would further enhance the chances in favor of making hay in one day. This same line of reasoning can be applied to the process requiring two days of good weather when the chances for this process are compared with either one day or three day processes.

## PROCEDURE AND EQUIPMENT

### Comparative Drying and Quality Tests

Three alfalfa hay cuttings were used to compare the drying rates and quality of the hay produced by various conditioning treatments. All three crops were cut at the Agronomy Farm 3 miles northwest of Manhattan, Kansas. The first test was conducted with third cutting hay on August 7 and 8, 1961. The second test was conducted with fourth cutting hay on October 3 and 4, 1961. The third test was conducted with first cutting hay on May 17 and 18, 1962. While the first cutting was not as rank and dense due to dry weather conditions, as is often encountered, it was nevertheless heavy enough to provide good variation from the third and fourth cuttings used the previous year.

The hay drying tests were conducted in a similar manner in all three tests. Test plots were selected to be as nearly uniform as possible. Initial cutting time of each swath for each treatment was noted. Two or three replications were made of each treatment. Cutting started in the morning as soon as the dew was dried off. Samples of each of the hay treatments were then picked up every hour during the day and every two hours at night. Nighttime was considered as 8 p.m. to 6 a.m.

In studying a product as variable as hay, careful consideration must be given to sampling techniques. Kepner et al (21) outlines two procedures that are commonly used in making a drying rate determination.

One method is to take a section of a windrow and put it on a tray where it is left and periodically weighed throughout the drying period. This has the advantage of being simple, requiring little labor and allowing frequent weighings. The disadvantages are that the hay has been disturbed and therefore does not represent true field drying conditions and that relatively few samples are taken and thus may present a distorted picture of the entire test.

The other method is to take periodic samples at random locations. These are weighed when taken and then oven dried. The advantages of this method are that the samples are taken from actual undisturbed field conditions and a relatively large number of samples are usually taken thus giving more representative results. The disadvantages are the greater amount of work required to collect the samples and the amount of space and time required for oven drying. The randomized samples will tend to produce more erratic data.

The method of collecting periodic samples was used for all tests. A complete cross section of each swath or windrow was included in each sample. The samples were put in paper bags and immediately weighed on a balance set up near the sampling area. Most of the samples weighed from one to four pounds depending on the moisture content and width of cut included in the swath or windrow. All samples were picked up at random locations to take into account field variations. Sampling was completed just prior to baling in each case. Since all treatments were not drying at the same rate, some were usually over dry and some not dry enough when baled.

After the field testing was completed, all hay samples were brought to the laboratory to be oven dried. Drying was done with an electric oven at 100 - 105° C for 24 hours. Moisture content was then calculated on a wet weight basis. By noting the time when each sample was picked up and weighed, it was possible to determine the elapsed time between cutting and sample pickup. Thus, a uniform basis was established on which to compare drying rates.

Ambient temperature and relative humidity were determined at the same intervals as the hay samples were taken. This was done with a sling psychrometer. Dry bulb temperatures were read directly. Relative humidity was determined from a psychrometric chart by using the dry bulb and wet bulb temperature readings.

Periodic samples were taken to the Biochemistry Laboratory for protein and carotene analysis. For the first trial, two samples per day were taken from each treatment, one in the morning and one in the afternoon. The first sample was taken immediately after the hay was cut and the final sample just prior to baling. Three samples per day were collected during the second trial. During the last trial, samples for chemical analysis were taken at only two times, immediately after cutting and just prior to baling.

During the second trial about eight tons of hay were produced by each of the treatments to be used by the Department of Animal Husbandry for beef feeding trials.

During the first two trials, soil moisture and temperature were determined at each location where a hay sample was collected for the hay moisture determination. A soil probe was used to take the soil samples. Three samples to a depth of three inches were taken at each location and mixed in a container. These samples were weighed immediately after collection to get an initial or wet weight. After the conclusion of each trial, they were taken to the laboratory and oven dried for 24 hours at 100 - 105° C. Moisture content was then determined on a dry weight basis.

The soil temperature was measured with an iron-constantan thermocouple and read with a potentiometer. For the initial test, the probe was made so the thermocouple would penetrate the soil about 1/4 inch. This proved to be too weak structurally and was, therefore, not too satisfactory. For the second test, the thermocouple was altered so it would measure only soil surface temperature. Temperatures in all cases were measured under undisturbed hay swaths or windrows.

During the last test, air temperature in the hay was measured. An iron-constantan thermocouple and a potentiometer identical to those used in measuring soil temperatures were used to measure the air temperatures. The temperature was measured in the middle of the hay swath or windrow as nearly as possible. Again, a measurement was made at each time and location that a hay moisture determination sample was taken.

Six haying methods were used to determine relative drying rates and quality of the hay. The methods were first the conventional method of mowing, raking at 30-40 per cent moisture and baling for storage. Hereafter, this will be referred to as the "control". A second method consisted of conditioning the hay with a smooth roll crusher. A third method was to condition the hay with a fluted roll crimper. A fourth method was the use of a self-propelled windrower with conditioner. The fifth method was a horizontal rotary cutter. The sixth method was similar to the control except that the hay was raked immediately after cutting. Two mower swaths or about a 13 foot width were raked together. This method will be referred to as "mow and rake".

All mowing for the control, crimped, crushed and mow and rake treatments was done with a conventional seven foot tractor mounted mower. Raking was done with a side delivery rake.

The crusher (Plate I) had a one-foot diameter steel roll on top and an eight-inch diameter hard rubber bottom roll. The bottom roll had spiral grooves to aid in picking up the hay from the swath. The rolls had a positive gear and chain drive from the tractor PTO. They were geared in such a manner that the peripheral speeds of both rollers were the same. The peripheral speed of 1542 ft/min. was three to four times as fast as the ground speed.

The crimper (Plate I) had the conventional fluted meshing steel rolls. Both the crimper and crusher were the same width as the mower and followed the mower one round after cutting.

The rotary cutter (Plate I) took a twelve-foot cut and windrowed the hay after cutting. Two horizontal four-bladed rotars with a tip speed of 12,138 ft/min. were used. The hay was brought into a center windrow where it was split by a divider.

The self-propelled windrower (Plate I) also took a twelve foot cut. After the hay was brought to the center, it was run through a combination crusher-crimper. The lower roll was a smooth hard rubber roll with spiral grooves similar to that used on the crusher. The upper roll consisted of a series of evenly spaced one-inch diameter bars. The net effect was similar to a crimping action. Both rolls had an eight-inch diameter and ran at the same speed, about 1000 ft/min. This was also about three times as fast as ground travel.

## EXPLANATION OF PLATE I

Fig. 1. The crimper used in field tests.

Fig. 2. The crusher used in field tests.

Fig. 3. The rotary windrower used in field tests.

Fig. 4. The self-propelled windrower used in field tests.

PLATE I

Fig. 1

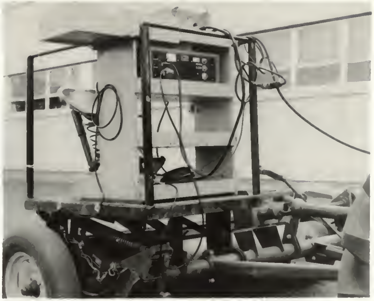


Fig. 2


Fig. 3

Fig. 4

## Field Crusher Force Trials

Because the crusher is the most popular of the various hay conditioners, two additional trials were conducted with it. Both the crushing force and feeding rate were varied. The drying rate was determined under these various treatments.

The same crusher was used for these trials as previously described in the drying rate and quality trials. The upper roll is located on a cam which in turn is pressure loaded by two coil springs. This creates the crushing force between the two rolls.

A pair of links (one on each side) was replaced with specially constructed links on which strain gages were bonded. (Plate II) The cross sectional area of the steel bar where the strain gages were mounted was .16 $in.^2$. The gages used had the following specifications: Type A-5, gage factor 1.98±1 per cent, resistance 120±.2 ohms. One gage was located on each of the four sides of the links (Fig. 1) to eliminate bending moments. All gages were covered with waterproof wax. The two links plus two temperature compensating gages were combined into a four arm wheatstone bridge. (Fig. 2)

The wheatstone bridge was connected to a Brush amplifier and recording oscillograph. (Plate II) Power was supplied by a portable generator mounted on the tractor. (Plate II)

The links were calibrated by subjecting them to known loads with a hydraulic press. Calibration was carried out from 0 to 4000 pounds in increments of 500 pounds. The calibration curve is shown in Plate III.

EXPLANATION OF PLATE II

Fig. 1. The field crusher strain gage link.

Fig. 2. The amplifier and recorder-instruments used in strain measurements.

Fig. 3. The portable generator used to supply power for strain measuring instruments.

PLATE II

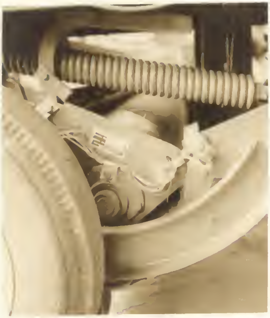


Fig. 1

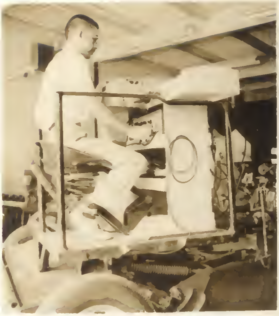


Fig. 2

Fig. 3

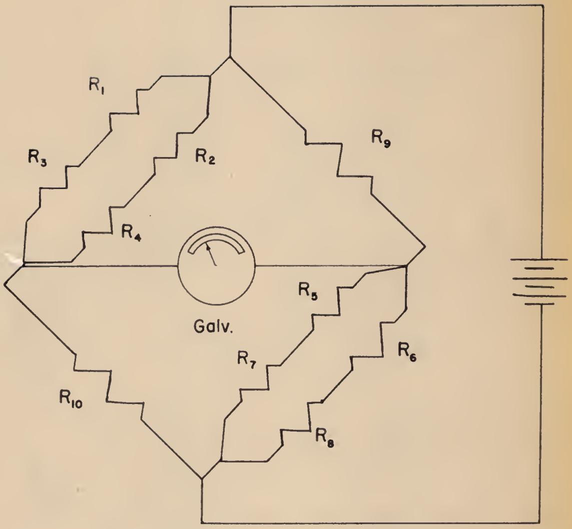



Fig. 1. A schematic diagram of the strain gage wiring as used on the field crusher. $R_1$, $R_2$, $R_3$, and $R_4$ are the gages in one link and $R_5$, $R_6$, $R_7$, and $R_8$ are the gages in the other link. $R_9$ and $R_{10}$ are temperature compensating gages.

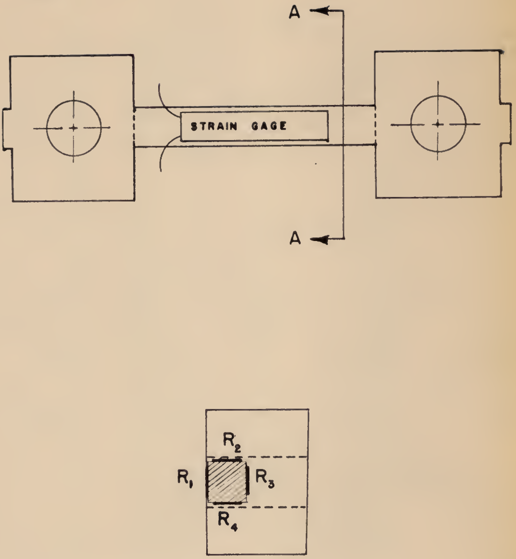
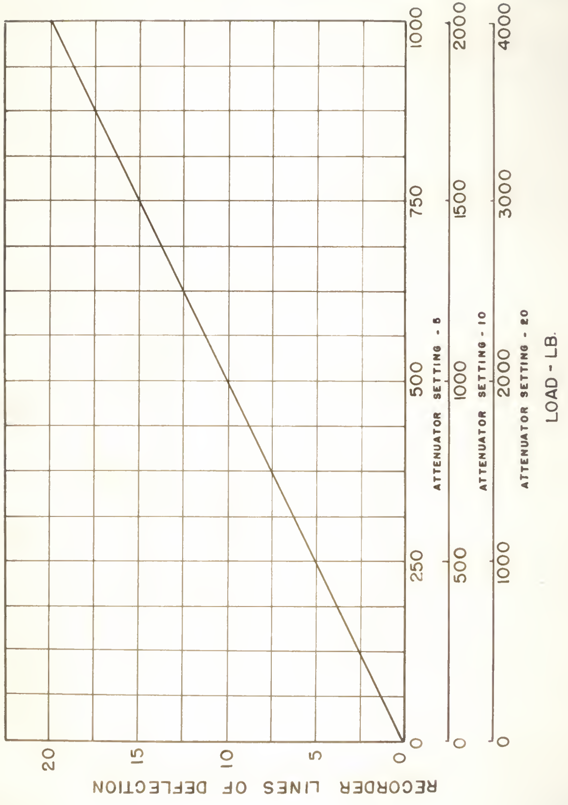



Fig. 2. A diagram of the field crusher strain gage link showing the locations of the four active gages.

## EXPLANATION OF PLATE III

The calibration curve for the strain gages used on the field crusher.

PLATE III


RECORDER LINES OF DEFLECTION
0
5
10
15
20
ATTENUATOR SETTING - 5
0
250
500
750
1000
ATTENUATOR SETTING - 10
0
500
1000
1500
2000
ATTENUATOR SETTING - 20
0
1000
2000
3000
4000
LOAD - LB.

Crushing pressure was determined by applying three different initial pressures on the pressure springs and using four different feeding rates with each pressure. The pressure was determined by tightening the threaded rods that held one end of the springs, 4, 12 and 20 rounds. These will be referred to as low, medium and high pressures. Four tractor speeds 2 gear, 1.3 mph; 4th gear, 2.0 mph; 6th gear, 4.0 mph; 8th gear 6.0 mph. were used to vary the feeding rates. This gave a total of 12 treatments.

Because of the dynamic unbalance in the crushing rolls, considerable vibration was apparent even when no load was applied. An average of the maximum and minimum points was therefore taken as the pressure for each test. Plate IV shows samples of the traces obtained from one of the tests.

Hay samples were again collected and weighed to determine hay moisture content and in turn the drying rate of each of the treatments. Samples were collected approximately every four hours during the day.

## Static Laboratory Crushing Pressure Trials

The force that was measured between the crushing rolls was not a good criteria to determine the degree of crushing. In order to determine the actual pressure required to crush a single stem of alfalfa hay, the laboratory crusher, shown in Plate V, was built. This consisted essentially of two 8½ inch diameter steel rolls, eighteen inches long.

## EXPLANATION OF PLATE IV

The oscillograph recordings of the field crusher force measurements.

Fig. 1. High pressure
Attenuator setting - 20
Speed - 1.3 miles/hour

Fig. 2. Low pressure
Attenuator setting - 5
Speed - 4.0 miles/hour

PLATE IV

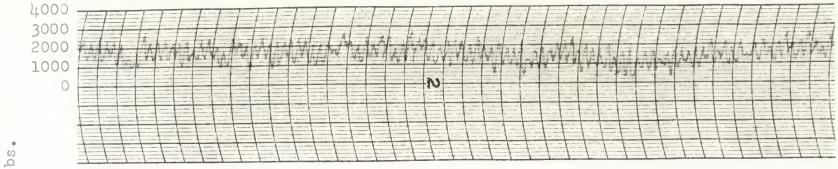



Fig. 1

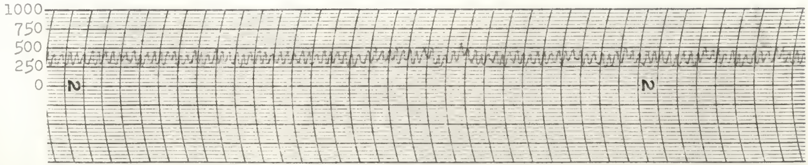



Fig. 2

EXPLANATION OF PLATE V

Fig. 1. The laboratory crusher used to determine the crushing pressures of individual alfalfa stems.

Fig. 2. The laboratory crusher strain gage link.

Fig. 3. Lowering the top roll to apply a crushing force on an alfalfa stem.

Fig. 4. The instrumentation used to measure the force required to crush an alfalfa stem.

PLATE V

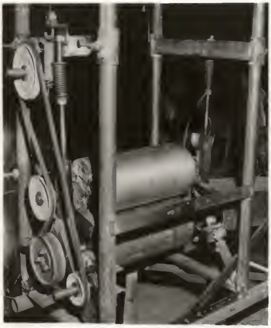


Fig. 1

Fig. 2

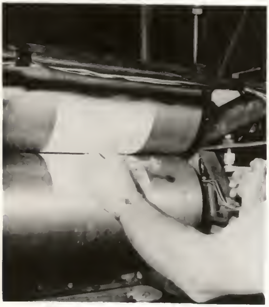


Fig. 3

Fig. 4

The bottom roll was suspended on each end by a $\frac{1}{4}$-inch diameter steel rod. Strain gages were bonded on these rods in the same manner as used on the field crusher (Plate V). These gages had the following specifications. Type A-12, gage factor $2.08\pm1$ per cent, resistance $120.0\pm.2$ ohms. The top roll was suspended by a rod on each end. These could be spring loaded to apply a force if the weight of the roll was not enough. It was also possible to regulate the clearance between the two rolls and the force applied by the top roll by adjusting a screw located under the horizontal arm at each end of the top roll. (Plate V).

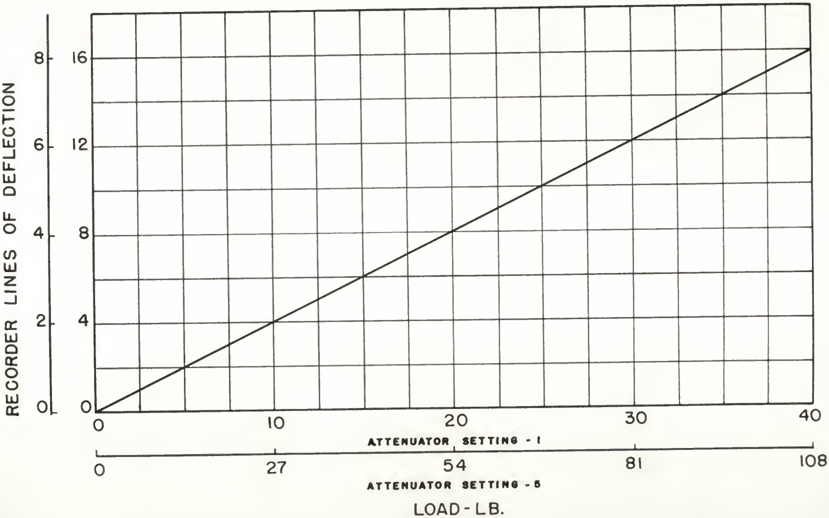
The gages were calibrated by applying a series of known weights. Plate VI shows the calibration curve.

For the tests, the rolls were covered with a sheet of white paper. (Plate V) The fresh cut alfalfa stems were dipped in food coloring. When crushed, the dye left an imprint on the paper showing the area that had been crushed. (Plate VII) All crushing was performed with static rolls (no rotational motion). The area of the imprint was measured with a planimeter. Dividing this area into the force measured by the strain gages produced the crushing pressure for each stem. A cross section of the stem at the point of maximum crushing was photographed. (Plate VIII)

## EXPLANATION OF PLATE VI

The calibration curve for the strain gages used on the laboratory crusher.

PLATE VI


RECORDER LINES OF DEFLECTION
0
2
4
6
8
0
4
8
12
16
0
10
20
30
40
ATTENUATOR SETTING - 1
0
27
54
81
108
ATTENUATOR SETTING - 5
LOAD - LB.

EXPLANATION OF PLATE VII

The imprint of the area of the alfalfa stems Fig. 2-6 shown on Plate XVIII that was crushed.

Fig. 1. Area - 0.10 $in^2$

Fig. 2. Area - 0.24 $in^2$

Fig. 3. Area - 0.28 $in^2$

Fig. 4. Area - 0.19 $in^2$

Fig. 5. Area - 0.04 $in^2$

PLATE VII

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

EXPLANATION OF PLATE VIII

Cross sections of alfalfa stems - 14 X magnification.

Fig. 1. Uncrushed stem

Fig. 2. Crushing force - 7.5 lb.
Crushing pressure - 75 psi

Fig. 3. Crushing force - 25 lb.
Crushing pressure - 105 psi

Fig. 4. Crushing force - 101 lb.
Crushing pressure - 360 psi

Fig. 5. Crushing force - 74 lb.
Crushing pressure - 390 psi

Fig. 6. Immature stem
Crushing force - 5 lb.
Crushing pressure - 125 psi

PLATE VIII

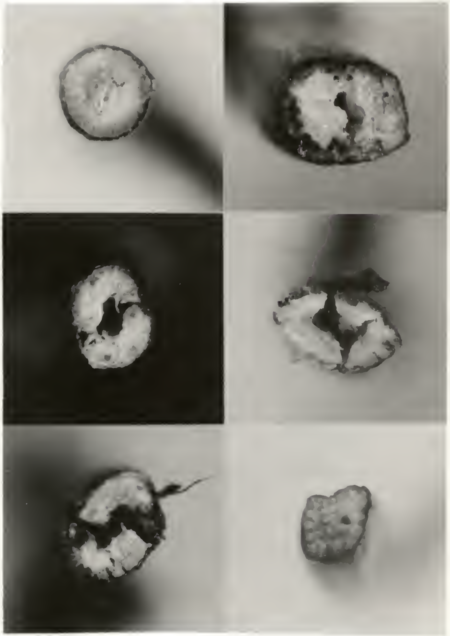


Fig. 1 (top) Fig. 2 (top)

Fig. 3 (middle) Fig. 4 (middle)

Fig. 5 (bottom) Fig. 6 (bottom)

# RESULTS

## Comparative Drying and Quality Trials

Trial One - Third Cutting. After the hay and soil samples had been dried and moisture content calculated, the results were plotted on graphs. (Plates IX, X, XI) Hay moisture content was calculated on a wet weight basis. Moisture content of the soil samples was calculated on a dry weight basis.

The hay moisture content was plotted versus elapsed time. Soil moisture and soil temperature were plotted against clock time. These two items proved to be not as critical as the hay drying rate.

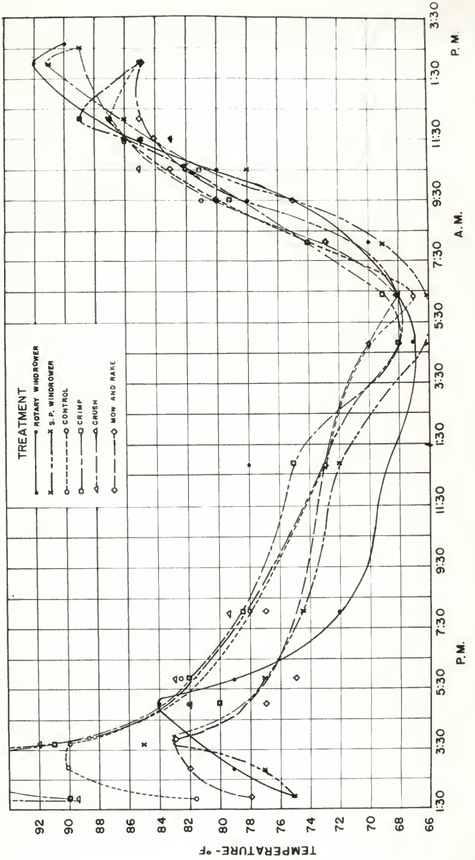
The next step was to make a statistical analysis and determine the interrelated effects of the various treatments used and the qualities measured.

A two-way analysis of variance was made on data for the soil moisture, soil temperature and protein and carotene contents to determine the effects. In these analyses, the effects of time and treatment were considered. In all of these analyses, the hypotheses tested were: Ho: the means of the treatment (time) effects are equal vs. Ha: the means of the treatment (time) effects are not equal. An analysis of co-variance was used in analyzing the hay drying rate. In this, the hypotheses were: Ho: the slopes (elevations) of the drying rate curves are equal vs. Ha: the slopes (elevations) are not equal.

## EXPLANATION OF PLATE IX

Soil temperature under the hay windrows and swaths versus time for the first trial - third cutting, August 7 and 8, 1961. Not shown on the graph is the fact that at 2:45 p.m. the first day, the soil under the crushed hay reached a maximum temperature of 102° F and the soil under the crimped hay reached a maximum temperature of 98° F.

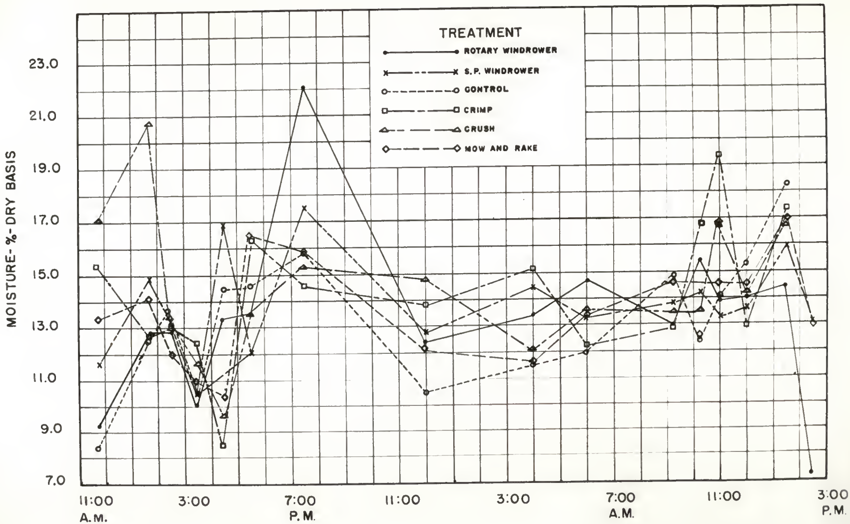
PLATE IX


TREATMENT
ROTARY WINDROWER
S.P. WINDROWER
CONTROL
CRIMP
CRUSH
MOW AND RAKE
TEMPERATURE - °F
92
90
88
86
84
82
80
78
76
74
72
70
68
66
1:30
3:30
5:30
7:30
9:30
11:30
1:30
3:30
5:30
7:30
9:30
11:30
1:30
3:30
P.M.
A.M.
P.M.

## EXPLANATION OF PLATE X

Soil moisture content under the hay windrows and swaths versus time for the first trial - third cutting, August 7 and 8, 1961.

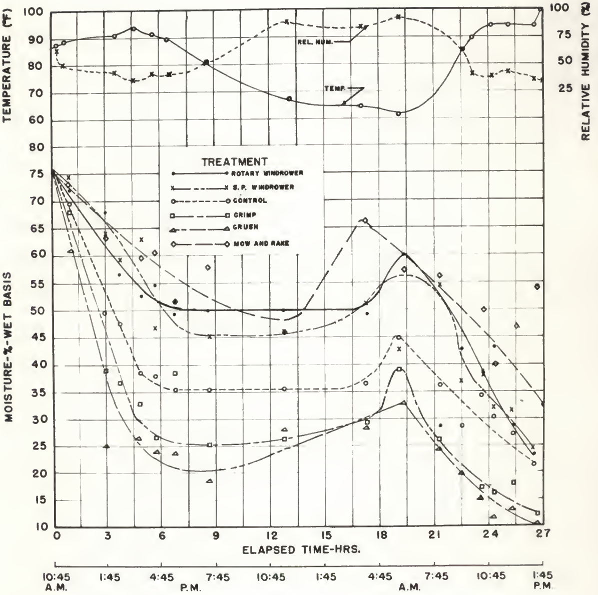
PLATE X


TREATMENT
ROTARY WINDROWER
S.P. WINDROWER
CONTROL
CRIMP
CRUSH
MOW AND RAKE
MOISTURE-%-DRY BASIS
23.0
21.0
19.0
17.0
15.0
13.0
11.0
9.0
7.0
11:00 A.M.
3:00
7:00 P.M.
11:00
3:00
7:00 A.M.
11:00
3:00 P.M.

EXPLANATION OF PLATE XI

Hay moisture content of the various treatments and ambient temperature and relative humidity versus elapsed time for the first trial - third cutting, August 7 and 8, 1961.

PLATE XI


TEMPERATURE (°F)
RELATIVE HUMIDITY (%)
REL. HUM.
TEMP.
TREATMENT
ROTARY WINDROWER
S. P. WINDROWER
CONTROL
CRIMP
CRUSH
MOW AND RAKE
MOISTURE-%-WET BASIS
ELAPSED TIME-HRS.
10:45 A.M.
1:45
4:45
P.M.
7:45
10:45
1:45
4:45
A.M.
7:45
10:45
1:45 P.M.

As can be seen in Plate X, the data obtained in the soil moisture samples were quite erratic. The F test showed that the estimated mean due to the various treatments was non-significant ($p > .10$). This indicated that there was not enough evidence to detect that the hay in one treatment gained or lost more moisture than that in another treatment due to the soil moisture. There was a significant difference, ($p < .01$) though, in the estimate of the mean due to the time effect. The trend was towards an increase in moisture. Since there was no precipitation during this time, indications are that the soil must have picked up moisture from the hay.

The analysis of the soil temperature measurements showed a significant difference among the means for both time and treatments effects ($p < .01$). An LSD for the treatment effect gave evidence that the soil under the treatments where the hay was immediately windrowed (mow and rake, rotary windrower and self-propelled windrower) had a significantly lower temperature than the soil under the hay from the other three treatments. Table 1 shows the treatment means of the soil moisture and soil temperature analyses.

For the results of the chemical analyses, (Table 2) two separate statistical analyses were conducted. This was due to the number of samples collected from each of the treatments. Only three samples were taken from the three windrowed treatments. Four samples were taken from the other three treatments. One analysis was, therefore, made with three samples from six treatments and one analysis with four samples and three treatments. The analysis for protein showed that in the first instance, there was a nonsignificant difference ($p > .10$) due to time but a significant difference ($.05 < p < .10$) due to treatments. An LSD showed the crimped, crushed and rotary windrower treatments to have a nonsignificant difference and the control, crimped, mow and rake, rotary windrower and self-propelled windrower treatments to have a nonsignificant difference (Table 2). In the second analysis with the data from the control, crimped and crushed treatments, there was a nonsignificant difference ($p > .10$) due to treatment. The hypotheses were that the protein of the hay produced by one treatment was equal to the protein of the hay produced by all other treatments and that the protein level of the hay was uneffected by time. Under the conditions of this trial, the null hypothesis of no treatment effect can be rejected in the case of crushed versus mow and rake and crushed versus self-propelled windrower. This indicates that the crushing treatment has an adverse effect on protein content as compared to the mow and rake or the self-propelled windrower treatments. The second analysis also showed a significant difference ($.01 < p < .025$) in protein content due to time. This could indicate two possibilities. One is that the swathed hay loses protein with time while the windrowed hay does not. The other possibility is that protein is lost at a rate high enough to be significant during the initial hours immediately after cutting.

Table 1. Results of the soil moisture and soil temperature tests for the first trial - third cutting hay.

| Soil Moisture | | | | | | |
|---|---|---|---|---|---|---|
| Treatment | Crushed | Crimped | Self-propelled windrower | Mow and rake | Rotary windrower | Control |
| Soil moisture Mean - % | 14.41 | 14.18 | 13.82 | 13.56 | 13.29 | 13.28 |

| Soil Temperature | | | | | | |
|---|---|---|---|---|---|---|
| Treatment | Crushed | Crimped | Control | Rotary windrower | Mow and rake | Self-propelled windrower |
| Soil temperature Means - °F | 82.1 | 81.7 | 80.7 | 78.5 | 77.7 | 77.3 |
| LSD - 2.55 | | | | | | |

For the carotene content similar hypotheses were tested: carotene content was not changed by treatment or time effects. In the first analysis of three treatments (control, crushed and crimped) and four samples per treatment, there was a nonsignificant difference ($p > .10$) of the means due to treatment effect but a significant difference ($p < .01$) due to the time effect. In the analysis of six treatments and three samples per treatment, there was a significant difference due both to time ($p < .01$) and treatment ($.01 < p < .025$) effects. The LSD test showed that the hypothesis of no treatment effect could be rejected for the crush versus the other treatment methods. The analysis showed a lower carotene content for the crushed

Table 2. Protein and carotene content of first trial - third cutting alfalfa hay. Hay was cut between 10:20 and 10:50 a.m.

| Protein Content - % | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Treatment | | | | | | | |
| Date | Time | Control | Crimped | Crushed | Mow and rake | Rotary windrower | Self-propelled windrower | Means: Three Treatments | Means: Six Treatments |
| Aug. 7 | 11:00 a.m. | 17.32 | 17.25 | 17.96 | | | | 17.51 | |
| Aug. 7 | 3:45 p.m. | 16.94 | 16.85 | 15.56 | 16.81 | 16.70 | 16.79 | 16.45 | 16.61 |
| Aug. 8 | 8:15 a.m. | 17.53 | 16.50 | 16.29 | 17.40 | 16.69 | 17.76 | 16.77 | 17.03 |
| Aug. 8 | 2:00 p.m. | 15.66 | 15.53 | 13.61 | 17.72 | 15.98 | 17.75 | 14.93 | 16.04 |
| Mean - three samples | | 16.71 | 16.29 | 15.15 | 17.31 | 16.46 | 17.43 | | |
| Mean - four samples | | 16.86 | 16.53 | 15.86 | | | | | |

Treatment LSD - 1.29 (six treatments)

Table 2. Protein and carotene content of first trial - third cutting alfalfa hay. Hay was cut between 10:20 and 10:50 a.m. (concl.).

| Carotene Content - mg/100 gr. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Treatment | | | | | | | |
| | | | | | | | | Means | |
| Date | Time | Control | Crimped | Crushed | Mow and rake | Rotary windrower | Self-propelled windrower | Three Treatments | Six Treatments |
| Aug. 7 | 11:00 a.m. | 25.33 | 22.33 | 25.42 | | | | 24.36 | |
| Aug. 7 | 3:45 p.m. | 10.71 | 13.71 | 9.00 | 11.02 | 11.49 | 11.90 | 11.14 | 11.30 |
| Aug. 8 | 8:15 a.m. | 10.21 | 8.29 | 6.73 | 8.51 | 8.72 | 9.34 | 8.38 | 8.62 |
| Aug. 8 | 2:00 p.m. | 6.73 | 6.16 | 3.62 | 8.56 | 5.93 | 5.93 | 5.50 | 6.16 |
| Mean - three samples | | 9.19 | 9.39 | 6.45 | 9.36 | 8.71 | 9.06 | | |
| Mean - six samples | | 13.22 | 12.62 | 11.19 | | | | | |

Treatment LSD - 1.99 (six treatments)

treatment. Probably the reasons this was detected in the second instance, but not in the first, was because the initial carotene content was essentially the same. This would tend to bring the means closer together than would be true in the second instance where the initial conditions were eliminated. The fact that the loss of carotene due to the time effect was detected, only confirmed what was generally known.

It must be remembered that a very small sample size was used with these chemical analyses. Conclusions based only on this one trial are, therefore, quite open to question. For this reason, it was decided that the next trial should include a larger number of samples for chemical analyses.

The hay drying rate analysis was broken into two sections; one during the first day and another during the second day. The analyses were made during the approximate periods when the drying rate slopes were negative. This limitation was established for several reasons. One was that primary interest was focused on the drying rate and not the nighttime moisture pickup that is usually experienced in this area. Another reason was that samples for chemical analyses were always taken when drying was positive. Third, was the fact that sample size picked up during the night was very small and therefore chances of obtaining valid results were limited.

The first set of samples collected immediately after cutting began was taken from only three of the six treatments. This meant that the analysis of co-variance started with a complete set of samples taken approximately one hour after the hay was cut. Since the slopes of the drying rate changed from negative to positive at different times the first evening, it was difficult to determine a uniform breaking point. Consequently, two analyses were made, one using five samples (six hours elapsed time) and one using seven samples (nine hours elapsed time) from each treatment. The first alternative hypothesis, that the slopes were not the same, ($p > .10$) was not shown in either instance. The second alternative hypothesis, that the elevations were different, was shown to be true in both instances ($p < .01$). The fact that this is possible when the difference in the slopes was nonsignificant probably is due to the fact that the analyses started with the data taken approximately an hour after the hay was cut. This indicates that there was a difference in the slope during the first hour or that the drying rate was a curvilinear function. Hay drying rate results are shown in Table 3.

The Students "t" test was used between adjusted means to determine which of the elevations were significantly different. In the analysis of the data from the first day, there was not enough evidence ($p > .10$) to detect a difference between the three windrowed treatments. In all other paired comparisons between treatments, there was a significant difference. This was true for both the five sample per treatment analysis and the seven sample per treatment analysis.

A Bartlett's test was conducted to determine the validity of the hypothesis that the residual variances were equal for the

Table 3. Hay drying rate results of the first trial - third cutting alfalfa hay.

First Day

| Treatment: | Control | Crimped | Crushed | Mow and rake | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|---|
| Slope | | | | | | |
| -7 samples: | -4.09 | -4.26 | -4.40 | -2.15 | -3.23 | -4.04 |
| -5 samples: | -7.59 | -9.04 | -8.27 | -3.17 | -4.61 | -5.59 |

Mean Elevation Differences 1/

| | | | | | |
|---|---|---|---|---|---|
| Rotary windrower | Self-propelled windrower | Mow and rake | Control | Crimped | Crushed |

Second Day

| Treatment: | Control | Crimped | Crushed | Mow and rake | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|---|
| Slope - 7 and 8 samples: | -2.70 | -3.64 | -2.97 | -2.06 | -3.02 | -2.87 |
| Slope - 6 to 8 samples: | -2.70 | -3.24 | -2.97 | -2.06 | -3.95 | -2.87 |

Mean Elevation Differences

| | | | | | |
|---|---|---|---|---|---|
| Mow and rake | Rotary windrower | Self-propelled windrower | Control | Crimped | Crushed |

1/ Underlined treatments indicate no significant difference.

various treatments. There was not enough evidence ($p > .05$) to reject this in any of the analyses performed on data from this drying trial either for the first day or the second day.

For the drying rates of the second day, again, two analyses were performed on the data. The first analysis included the last seven samples ($6\frac{1}{2}$ hours elapsed time) from the windrowed treatments and six from the swathed treatments. Because the windrowed treatments were slower in arriving at a moisture content safe for storage there was time to take an extra sample from each of these.

There were two points in the data from the second day that seemed to be completely out of reason. These might have been experimental errors or they might have been due to mechanical errors that were never realized. One of these was an exceptionally low value in the rotary windrowed treatment. The other was an exceptionally high value in the crimped treatment. This last analysis was repeated with these two points removed. Their influence, though, was not of such a magnitude as to influence the results.

As mentioned above, there was not enough evidence to reject the hypothesis that the variances were equal even when the data included the extreme points. Again, by using an F test, there was not enough evidence to reject the hypotheses ($p > .10$) that the slopes were equal. The F test did detect a significant difference though in the elevation means ($p < .01$).

Using the t test, there was not enough evidence to reject the hypothesis of equal elevation ($p > .10$) means between the crushed and crimped treatments, between the self-propelled windrower and control treatments, or between the self-propelled windrower and rotary windrower treatments. Between the control and rotary windrower treatments, there was evidence to reject the hypothesis of equal means ($.05 < p < .10$).

Comparing the results of the first days drying with the second days drying, there are indications that the crushed treatment picked up more moisture during the night than the crimped treatment. Also, the control and mow and rake treatments picked up more moisture than the self-propelled windrower or rotary windrower treatments.

Trial Two - Fourth Cutting. Most of the analyses performed on the data of this trial were done similar to that of the first trial. Plates XII, XIII, and XIV show the plots of soil temperature, soil moisture and hay moisture.

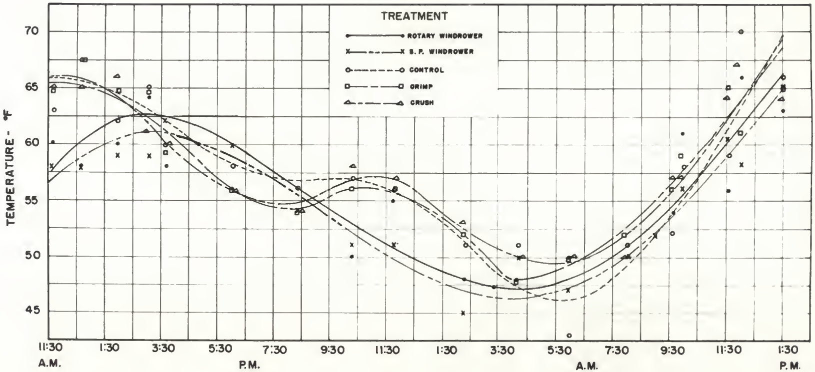
Using the F test, the soil temperature measurements again showed a significant difference in the means of both time ($p < .01$) and treatment ($p < .01$) effects. The LSD, as in the last trial, showed that the windrowed treatments had a significantly lower temperature than the swathed treatments.

The results of these soil temperature tests indicated that the temperature measured was probably related directly to the hay temperature and the ambient temperature. This accounts for the significant difference in means of the time effects. The soil temperature curves (Plate XII) were very similar to the ambient temperature curve (Plate XIV). The fact that the treatments in both tests had lower temperature than the swathed treatments can be explained by the physical setup. The windrowed hay was placed in a highly concentrated location. This provided for better detection of the evaporative cooling. Also, the sun was not able to penetrate to the soil and heat it as readily under

EXPLANATION OF PLATE XII

Soil temperature under the hay windrows and swaths versus time for the second trial - fourth cutting, October 3 and 4, 1961.

PLATE XII

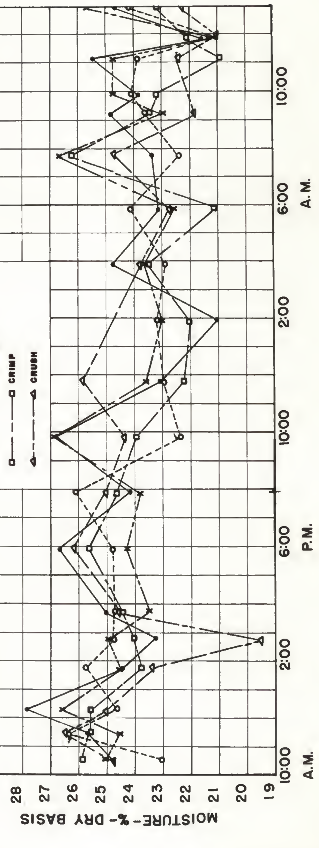


TREATMENT
ROTARY WINDROWER
S. P. WINDROWER
CONTROL
CRIMP
CRUSH
TEMPERATURE - °F
70
65
60
55
50
45
11:30 A.M.
1:30
3:30
5:30
7:30
9:30
11:30
1:30
3:30
5:30
7:30
9:30
11:30
1:30
P.M.
A.M.
P.M.

## EXPLANATION OF PLATE XIII

Soil moisture content under the hay windrows and swaths versus time for the second trial - fourth cutting, October 3 and 4, 1961.

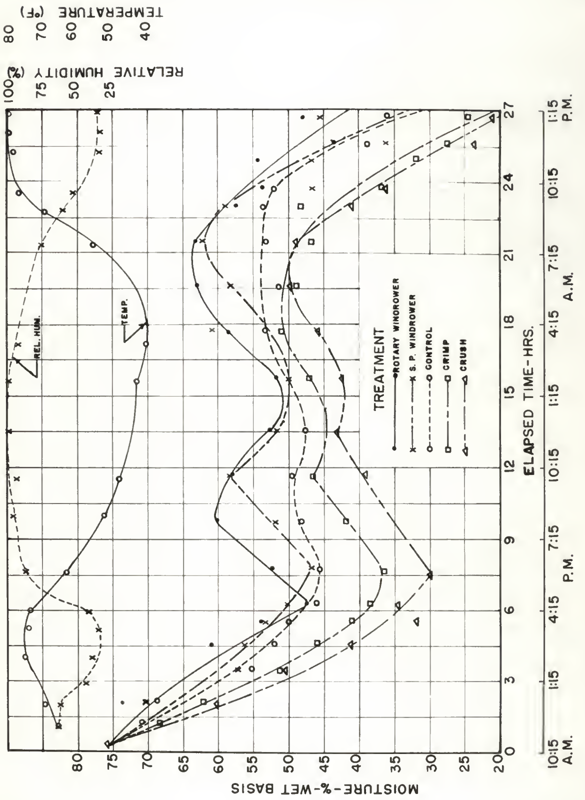
PLATE XIII


TREATMENT
ROTARY WINDROWER
S. P. WINDROWER
CONTROL
CRIMP
CRUSH
MOISTURE-%-DRY BASIS
28
27
26
25
24
23
22
21
20
19
10:00
A.M.
2:00
6:00
P.M.
10:00
2:00
6:00
A.M.
10:00

## EXPLANATION OF PLATE XIV

Hay moisture content of the various treatments and ambient temperature and relative humidity versus elapsed time for the second trial - fourth cutting, October 3 and 4, 1961.

PLATE XIV


TEMPERATURE (°F)
80
70
60
50
40
RELATIVE HUMIDITY (%)
100
75
50
25
MOISTURE-%-WET BASIS
80
75
70
65
60
55
50
45
40
35
30
25
20
ELAPSED TIME-HRS.
0
3
6
9
12
15
18
21
24
27
10:15 A.M.
1:15
4:15
7:15 P.M.
10:15
1:15
4:15
7:15 A.M.
10:15
1:15 P.M.
REL. HUM.
TEMP.
TREATMENT
ROTARY WINDROWER
S. P. WINDROWER
CONTROL
CRIMP
CRUSH

the windrowed hay as under the swathed hay. On the basis of these conclusions, it was decided that in the next trial it would be desirable to measure the air temperature in the center of the windrow or swath instead of at the soil surface.

The soil moisture data analysis also showed results similar to that obtained in the previous trial. The F test showed a significant difference in the means due to time effects ($p < .01$) but there was not enough evidence to detect a difference ($.05 < p < .10$) in the means due to treatment effects. Again, the data (Plate XIII) was very erratic. In this instance, there was a moisture decrease in the soil during the testing period. This is probably due to the fact that the soil was wetter during this trial than during the previous trial. This indicates that there is a point above which the soil moisture is a detriment and below which it is an asset in increasing the drying rate. Table 4 shows the soil temperature and soil moisture results.

Because neither test showed an interrelated treatment effect with the soil moisture, it was decided to discontinue this particular measurement on the next trial.

Protein and carotene content data (Table 5) were also analyzed as in the previous trial. In the protein data analysis, the F test showed a significant difference ($.01 < p < .025$) in means due to time effects. There was not enough evidence to detect a difference ($p > .10$) of the means due to treatment effects. The data, though, is not indicative of the fact that protein is primarily lost in the early hours after cutting as seemed to be

Table 4. Results of the soil temperature and soil moisture tests for the second trial - fourth cutting hay.

Soil Moisture

| Treatment: | Rotary windrower | Self-propelled windrower | Control | Crimped | Crushed |
|---|---|---|---|---|---|
| Soil moisture Means - % | 24.40 | 24.31 | 23.89 | 23.70 | 23.10 |

Soil Temperature

| Treatment: | Crushed | Crimped | Control | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|
| Soil temperature Means - °F | 58.6 | 58.3 | 58.1 | 56.3 | 55.3 |

LSD - 1.66

indicated by the results of the first trial. Probably the protein loss is due to chemical changes in the early hours and leaf loss during the later hours.

In analyzing the carotene content data, the F test showed a significant difference in the means due to both time (p  .01) and treatment ($.025 < p < .05$) effects. Again, the time effect was expected because there is a carotene loss due to enzyme action that takes place when hay is exposed to the sun. There was not enough evidence to reject the hypothesis of no treatment effect ($p > .10$) among the following groups: control, rotary windrower and self-propelled treatments; control, crimped and rotary windrower treatments; crimped and crushed treatments.

In order to determine whether the carotene loss was in reality a function of treatment effect, the results were analyzed

Table 5. Protein and carotene content of second trial - fourth cutting alfalfa hay. Hay was cut between 10:15 and 10:30 a.m.

Protein Content - %

| Date | Time | Treatment: Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower | Mean |
|---|---|---|---|---|---|---|---|
| Oct. 3 | 10:25 a.m. | 17.21 | 17.98 | 17.09 | 18.31 | 17.68 | 17.65 |
| Oct. 3 | 2:05 p.m. | 17.18 | 17.40 | 17.24 | 16.63 | 16.82 | 17.05 |
| Oct. 3 | 4:30 p.m. | 17.76 | 17.43 | 17.36 | 18.24 | 17.34 | 17.63 |
| Oct. 4 | 8:00 a.m. | 17.74 | 16.58 | 17.39 | 18.29 | 18.35 | 17.67 |
| Oct. 4 | 10:15 a.m. | 16.41 | 15.90 | 16.33 | 16.89 | 17.02 | 16.51 |
| Oct. 4 | 1:00 p.m. | 17.98 | 17.77 | 17.28 | 16.08 | 16.97 | 17.22 |
| | Mean | 17.38 | 17.18 | 17.14 | 17.36 | 17.41 | |

Carotene Content - mg/100 gr.

| Date | Time | Treatment: Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower | Mean |
|---|---|---|---|---|---|---|---|
| Oct. 3 | 10:25 a.m. | 18.87 | 15.16 | 13.80 | 20.21 | 18.88 | 17.38 |
| Oct. 3 | 2:05 p.m. | 16.38 | 16.72 | 15.15 | 13.57 | 13.21 | 15.01 |
| Oct. 3 | 4:30 p.m. | 16.31 | 16.30 | 14.75 | 14.63 | 17.15 | 15.83 |
| Oct. 4 | 8:00 a.m. | 12.37 | 8.76 | 9.63 | 13.10 | 14.51 | 11.67 |
| Oct. 4 | 10:15 a.m. | 10.53 | 9.04 | 8.79 | 11.92 | 12.54 | 10.56 |
| Oct. 4 | 1:00 p.m. | 10.05 | 8.86 | 8.39 | 9.41 | 11.40 | 9.62 |
| | Mean | 14.08 | 12.47 | 11.75 | 13.81 | 14.62 | |

LSD - 1.92

from another direction. The hypothesis used here was that with the moisture and carotene means for each treatment adjusted to the same time basis, that carotene loss and moisture loss were related. A linear regression line was calculated for each treatment for the drying period of each day. (Plate XV) The moisture, time relationship was taken from these new data. Using an F test there was not enough evidence ($p > .10$) to reject the hypothesis. Thus, while the hay from certain treatments loses carotene at a faster rate than hay from other treatments, the same treatment also accelerates drying. If hay from the various treatments is put into storage at an equal moisture content, the carotene content should also be equal at that time. This is not to say that there is a cause and effect relation between moisture loss and carotene loss. Much more likely is the probability that certain factors that cause a loss of one either directly or indirectly cause a loss of the other.

The hay drying rate data were also analyzed as in the first trial. The data from the first eight samples (7 3/4 hours elapsed time) per treatment were used for the first day's analysis. The F test showed a significant difference ($p > .10$) in both the slope and the elevation means of the drying rate curves. Table 6 shows the results of the hay drying rate data.

A confidence interval ($p > .10$) was placed on the slope for each of the treatments. There was a significant difference between the crushed treatment and the control, rotary windrower and self-propelled windrower treatments. There was not enough

EXPLANATION OF PLATE XV

Derived regression curves of hay moisture versus elapsed time for the second trial - fourth cutting, October 3 and 4, 1961.

PLATE XV

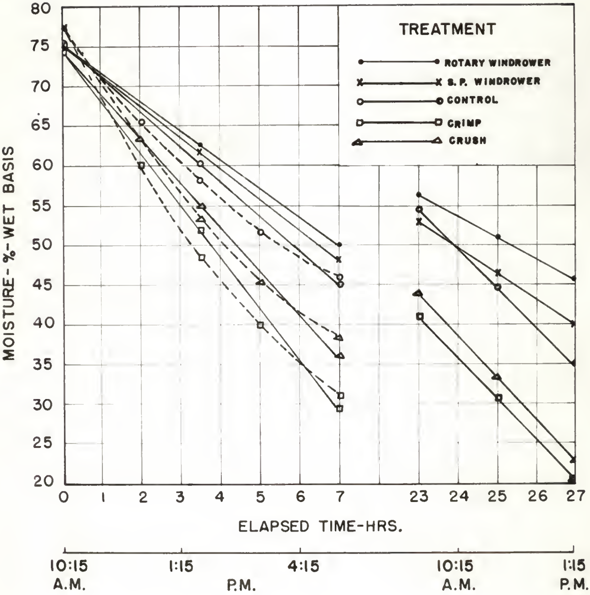

TREATMENT
ROTARY WINDROWER
S. P. WINDROWER
CONTROL
CRIMP
CRUSH
MOISTURE - % - WET BASIS
80
75
70
65
60
55
50
45
40
35
30
25
20
0
1
2
3
4
5
6
7
23
24
25
26
27
ELAPSED TIME-HRS.
10:15 A.M.
1:15
4:15
P.M.
10:15 A.M.
1:15 P.M.

Table 6. Hay drying rate results of the second trial - fourth cutting alfalfa hay.

First Day

| Treatment: | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|
| Slope - 8 samples: | -0.073 | -0.091 | -0.108 | -0.061 | -0.065 |
| - 7 samples: | -0.071 | -0.086 | -0.104 | -0.060 | -0.064 |

Mean Slope Differences (8 Samples)

<u>Control</u> <u>Rotary windrower</u> <u>Self-propelled windrower</u> <u>Crimped Crushed</u>

Mean Elevation Differences

<u>Control</u> <u>Rotary windrower</u> <u>Self-propelled windrower</u> <u>Crimped</u> <u>Crushed</u>

Second Day

| Treatment: | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|
| Slope: | -0.084 | -0.090 | -0.088 | -0.046 | -0.056 |

Mean Elevation Differences

<u>Rotary windrower</u> <u>Self-propelled windrower</u> <u>Control</u> <u>Crimped</u> <u>Crushed</u>

evidence to reject the hypothesis of equal slopes between any other treatment combinations.

The difference in elevation means was tested by the multiple comparison t test again. There was not enough evidence ($p > .10$) to reject the hypothesis of equal means between the control, rotary windrower and self-propelled windrower treatments, or between the crushed and crimped treatments. There was some discrepancy because there was not enough evidence to reject the hypothesis of equal slopes between the crushed treatment and the control, rotary windrower and self-propelled windrower but there was a significant difference in the elevation means of the crushed treatments and these other three treatments. Looking at the curves of Plate XIV, it is evident that the slopes and means are probably different.

In order to check on the possibility of a curvilinear trend during this first day's drying, the analysis was repeated with the data of the first hour eliminated. This produced an analysis similar to that used in the first trial. As in the first trial, this resulted in a significant difference ($p > .10$) in elevation means but a nonsignificant difference ($.05 < p < .10$) in the slopes. Again, this indicated the curvilinear trend. In the determination of the difference in elevation means, the results were the same as when the first hour was included.

A computor program was set up to determine if a second degree polynomial would fit the data better than a straight line. For the two windrowed treatments there was not enough evidence ($p > .10$) to show significance in the quadratic term. The quadratic equation was a better fit, though, for the swathed treatments. Table 7 shows the equation for the linear and polynomial regression lines and correlations of each.

Table 7. Equation of linear and polynomial regression lines and correlations of each for the first days hay drying rate second trial, fourth cutting.

| Treatment | Equation: Straight Line | Equation: Quadratic | Correlation |
|---|---|---|---|
| Rotary windrower | $Y = 75.90-3.76X$ | | 0.8137 |
| S. P. windrower | $Y = 75.43-3.92X$ | | 0.9500 |
| Control | $Y = 75.43-4.39X$ | | 0.9401 |
| | | $Y = 78.99-.1201X+.000098X^2$ | 0.9701 |
| Crush | $Y = 74.68-6.50X$ | | 0.9411 |
| | | $Y = 79.41-.1756X+.0001437X^2$ | 0.9712 |
| Crimp | $Y = 74.14-5.47X$ | | 0.9552 |
| | | $Y = 78.70-.1536X+.0001317X^2$ | 0.9909 |

The analysis using the hypothesis of equal slopes and equal means was performed also on data of the second day. Again, there was not enough evidence to detect slope difference ($p > .10$) but there was a significant difference ($p < .01$) in the elevation means. Differences in the elevation of the crimped and crushed treatments were not detected nor were differences in the elevation of the curves of the control, rotary windrower and self-propelled windrower treatments detected.

The Bartlett's tests were used again to determine if there was a significant difference in the variance. On the data of the first day, there was nonsignificant difference ($p > .10$). On the second day, there was a significant difference

($.05 < p < .10$). The difference was probably due to the high value of the self-propelled windrower treatment mean square. Again this was probably experimental error.

There was a phenomona which occurred during the night that remains unexplained. This is the dip in the hay moisture curves at about the 12th to 15th hour after cutting. The ambient temperature and relative humidity data show no significant change during that time. There was no observed change in the slight breeze that was blowing. Also, it was a clear night with no change in the cloud cover.

Feeding Trials. The Department of Animal Husbandry used hay from this cutting to conduct feeding trials. Ten heifer calves with an initial weight of about 400 pounds were put into each of the five lots. The hay was fed free choice for 98 days. The heifers were also fed 3.4 pounds of rolled sorghum grain per head per day. The calves in the lot that were fed crushed hay had a significantly lower average daily gain than the calves in the other four lots.

This can probably be explained by the fact that the crushed hay dried somewhat faster than the hay from the other treatments. Both the raking and baling were done somewhat late for optimum operation, causing a high leaf loss. This, consequently, lowered the feeding value of the crushed hay.

<u>Trial Three - First Cutting</u>. Procedures in this trial were altered somewhat from the previous two trials. Samples for chemical analyses were taken only at the beginning and end of

the test. No soil moisture samples were taken. Temperatures were recorded in the center of the windrow or swath instead of at the soil surface. An increased number hay drying samples were taken.

The hay temperature data were analyzed in the same manner as soil temperature data in the previous trials. As in the previous soil temperature results, there was a significant difference in the hay temperature due both to time ($p > .01$) and treatment ($p > .01$) effects. The change in temperature due to time somewhat followed the change in ambient temperature. The initial temperatures in the swathed treatments were somewhat higher than the ambient temperature. This is probably because temperatures were of necessity measured very close to the earth. The black soil is a good solar energy absorber causing an increase in temperature close to the soil above that of the ambient temperature. The rapid reduction of the initial temperature can be explained by evaporative cooling. After that, ambient temperature and solar radiation are the predominant factors again causing the rise in temperature during the afternoon and subsequent reduction in temperature at night. The variation in temperatures after midnight and continuing throughout the second day is primarily due to the variations in ambient conditions. During that time, there were alternate clear and cloudy periods and considerable variation in the amount of wind. As can be seen, there is a variation in the response of the various treatments. The general break in the temperature at 1:30 p.m. the second day was due to a strong wind combined with a trace of rain. Plate XVI is the graph showing hay temperature versus time. Table 8 shows the statistical results.

Table 8. Results of the hay temperature tests for the third trial - first cutting hay.

| Treatment: | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|
| Hay temperature Mean - % | 79.2 | 77.1 | 79.1 | 74.1 | 75.2 |
| LSD - 2.52 | | | | | |

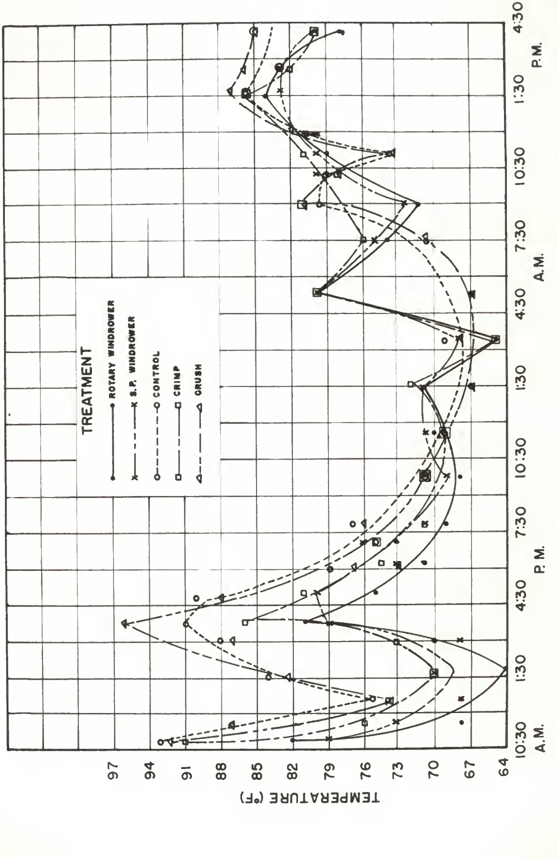
With an LSD, significance of treatment effects was determined. There was not enough evidence to reject a difference in means among the following combinations of treatments; rotary windrower and self-propelled windrower treatments; crimped and self-propelled windrower treatments; control, crimped and crushed treatments.

Because of a considerable difference in the point where the first days hay drying rate curves flattened (Plate XVII) out in the evening it was decided to make two analyses of this period. The first used the data from 12 samples (eight elapsed hours) per treatment and the second analysis used 14 samples (ten elapsed hours) per treatment. The F test ($p < .01$) showed a significant difference in both the slopes and elevation means for both analyses. Using a confidence interval, there was not enough evidence from the 12 samples analysis to detect a difference

## EXPLANATION OF PLATE XVI

Hay temperature versus time for the third trial - first cutting, May 17 and 18, 1961.

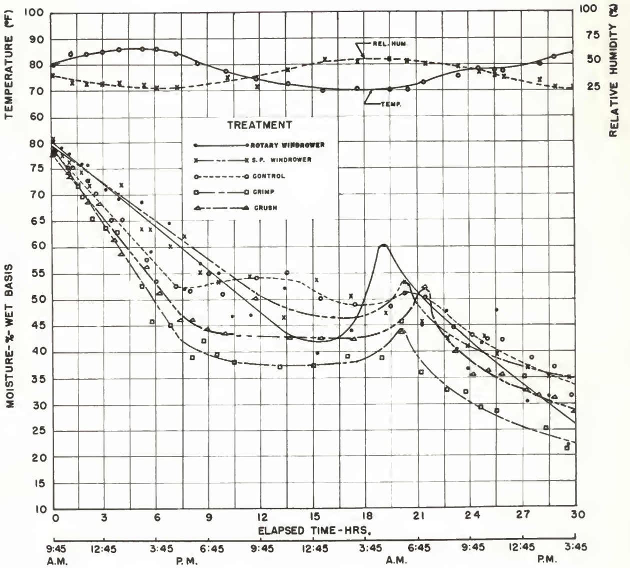
PLATE XVI


TREATMENT
ROTARY WINDROWER
S.P. WINDROWER
CONTROL
CRIMP
CRUSH
TEMPERATURE (°F)
97
94
91
88
85
82
79
76
73
70
67
64
10:30
1:30
4:30
7:30
10:30
1:30
4:30
7:30
10:30
1:30
4:30
A.M.
P.M.
A.M.
P.M.

## EXPLANATION OF PLATE XVII

Hay moisture content of the various treatments and ambient temperature and relative humidity versus elapsed time for the third trial - first cutting, May 17 and 18, 1961.

PLATE XVII


TEMPERATURE (°F)
RELATIVE HUMIDITY (%)
REL. HUM.
TEMP.
TREATMENT
ROTARY WINDROWER
S.P. WINDROWER
CONTROL
CRIMP
CRUSH
MOISTURE-%-WET BASIS
ELAPSED TIME-HRS.
9:45 A.M.
12:45
3:45 P.M.
6:45
9:45
12:45
3:45 A.M.
6:45
9:45
12:45
3:45 P.M.

($p > .10$) in the slopes of the following combinations: control and crushed treatments; control and rotary windrower treatments; rotary windrower and self-propelled windrower treatments. In the 14 sample analyses there was not enough evidence to detect a difference ($p > .10$) in the slopes of the following combinations: crimped and crushed treatments; control and crushed treatments; control, rotary windrower and self-propelled windrower treatments.

The multiple comparison test was unable to detect a mean elevation difference ($p > .10$) in either analysis between the crimped and crushed treatments and between the two windrowed treatments. The analysis using data from the 12 samples was probably more accurate because of the premature reduction in slope of several of the treatments. It will be noticed that the line for the crimped and crushed treatments cross. This probably accounts for the fact that a difference in slope could be detected but a difference in elevation could not be detected. Table 9 shows the statistical results.

For the second day's drying, there was a nonsignificant difference ($p > .10$) in the slope but the F tests showed a significant difference ($p < .01$) in the elevation. Multiple comparison tests produced the following results. There was a nonsignificant difference ($p > .10$) in the mean elevation of the following combinations: control and self-propelled windrower treatments; crushed, rotary windrower and self-propelled windrower treatments.

Table 9. Hay drying rate results of the third trial - first cutting of alfalfa hay.

First Day

| Treatment | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|
| Slope-14 samples | -3.05 | -4.55 | -3.76 | -2.94 | -2.74 |
| -12 samples | -3.68 | -5.16 | -4.20 | -3.23 | -2.68 |

Mean Slope Difference (14 Samples)

| Crimped | Crushed | Control | Self-propelled windrower | Rotary windrower |
|---|---|---|---|---|

Mean Slope Difference (12 Samples)

| Crimped | Crushed | Control | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|

Mean Elevation Differences (14 Samples)

| Crimped | Crushed | Control | Self-propelled windrower | Rotary windrower |
|---|---|---|---|---|

Mean Elevation Differences (12 Samples)

| Crimped | Crushed | Control | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|

Second Day

| Treatment | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
|---|---|---|---|---|---|
| Slope | -1.85 | -1.33 | -2.29 | -2.57 | -1.29 |

Mean Elevation Differences

| Control | Self-propelled windrower | Rotary windrower | Crushed | Crimped |
|---|---|---|---|---|

The crusher was set to produce the very minimum pressure in order to see if this would have any effect on the quality, especially carotene content. The final results (Table 10) were not consistent enough to show a definite trend. While comparatively speaking, the crushed treatment dried slower during this trial it still showed the lowest carotene content in the samples taken just prior to baling. On the other hand, the samples taken the following day from the bales, place it highest in the amount of carotene content.

The Bartlett's test showed that there was a significant difference ($.05 < p < .10$) in sampling variance during the second day due to a high mean square value for the rotary windrower treatment. This machine had been altered since the last trial by using a larger divider to produce a more pronounced division of the windrow. This is in turn caused more variation in the windrow size due to bunching. By the second day, the smaller sections were definitely drying faster than the larger sections.

Table 10. Results of the protein and carotene content analysis for the third trial - first cutting of alfalfa hay.

Protein Content - %

| Date | Time | Treatment | | | | |
|---|---|---|---|---|---|---|
| | | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
| May 17 | 10:30 a.m. | 16.50 | 15.57 | 16.08 | 16.28 | 16.17 |
| May 17 | 10:30 a.m. | 15.92 | 14.51 | 15.52 | 15.44 | 15.53 |
| May 18 | 4:30 p.m. | 17.18 | 15.85 | 15.96 | 18.22 | 17.43 |
| May 19 | Taken from | 15.90 | 14.03 | 14.64 | 16.87 | 13.74 |
| May 19 | bales | 18.54 | 14.19 | 14.07 | 16.43 | 14.18 |

Carotene Content - mg/100 gr.

| Date | Time | Treatment | | | | |
|---|---|---|---|---|---|---|
| | | Control | Crimped | Crushed | Rotary windrower | Self-propelled windrower |
| May 17 | 10:30 a.m. | 11.35 | 11.22 | 13.39 | 9.23 | 9.37 |
| May 17 | 10:30 a.m. | 17.63 | 11.54 | 11.99 | 9.70 | 9.69 |
| May 18 | 4:30 p.m. | 6.51 | 7.08 | 5.99 | 6.51 | 7.65 |
| May 19 | Taken from | 3.95 | 6.12 | 3.83 | 5.03 | 5.87 |
| May 19 | bales | 3.64 | 5.48 | 4.46 | 4.85 | 8.80 |

## Crushing Force and Feeding Rate Variation

Two trials were performed at different locations in order to replicate the tests. In both cases, a light third cutting of alfalfa hay was used. In the first instance, there was a yield of 0.665 tons/acre and in the second, a yield of 0.875 tons/acre.

A two way analysis of variance was performed on this data. In the first trial, there was a significant difference ($p < .01$) due to treatment effect. The LSD showed a lack of evidence to differentiate among the various treatments. Table 11 shows the results of the two trials.

Low pressure gave a range of 300 to 675 pounds force on the crushing rolls. The medium crushing pressure resulted in a range of 400 to 1200 pounds force. High pressure gave a range of 1050-1650 pounds force. As can be seen from Table 11, in all cases the force increased as the feed rate increased. Thus, for optimum results the density of the crop must be taken into account. In the first trial, the results show that the fastest drying is accomplished by using a medium to high pressure crushing force and a low feeding rate. Slowest drying comes from the treatment with the low pressures. This is about what one would normally expect.

This test was repeated in a second trial. There was considerable difficulty with the instrumentation during the trial, which resulted in some delay between treatments and erratic

Table 11. Results of crushing pressure and feeding rate variation trials.

First Trial

| Load on Crusher rolls-lb. | Speed mph | Hay feeding rate-lb./min. |
|---|---|---|
| 300 | 1.3 | 23 |
| 750 | 1.3 | 23 |
| 1100 | 1.3 | 23 |
| 375 | 2.0 | 35 |
| 925 | 2.0 | 35 |
| 1250 | 2.0 | 35 |
| 425 | 4.0 | 70 |
| 1050 | 4.0 | 70 |
| 1375 | 4.0 | 70 |
| 450 | 6.0 | 105 |
| 1200 | 6.0 | 105 |
| 1650 | 6.0 | 105 |

Mean Treatment Differences

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Speed-mph: | 4.0 | 6.0 | 1.3 | 6.0 | 2.0 | 2.0 | 6.0 | 4.0 | 4.0 | 1.3 | 1.3 | 2.0 |
| Pressure: | low | low | low | med | high | low | high | high | med | med | high | med |
| Hay Moisture: Mean - %: | 55.38 | 54.88 | 52.93 | 51.75 | 51.30 | 50.39 | 50.12 | 49.84 | 49.60 | 46.61 | 46.61 | 46.15 |

LSD - 3.75

Table 11. Results of crushing pressure and feeding rate variation trials (concl.).

| Second Trial | | |
|---|---|---|
| Load on Crusher rolls-lb. | Speed mph | Hay feeding rate-lb./min. |
| 350 | 1.3 | 30 |
| 400 | 1.3 | 30 |
| 1050 | 1.3 | 30 |
| 400 | 2.0 | 46 |
| 500 | 2.0 | 46 |
| 1050 | 2.0 | 46 |
| 575 | 4.0 | 92 |
| 750 | 4.0 | 92 |
| 1250 | 4.0 | 92 |
| 625 | 6.0 | 138 |
| 900 | 6.0 | 138 |
| 1450 | 6.0 | 138 |

results. Also, it will be seen that there is not as much difference between the low and medium crushing force as in the first trial. For these reasons, there was a nonsignificant difference $(.05 < p < .10)$ among treatments.

## Crushing Pressures

Plate VIII shows the cross sections of alfalfa stems after applying various crushing pressures and forces. Fig. 1 shows an uncrushed stem as a control. Fig. 2 shows the results of a crushing pressure of 75 psi (7.5 pound force). Fig. 3 shows a stem crushed with 105 psi (25 pound force). Fig. 4 shows a stem crushed with a pressure of 360 psi (100 pound force). Fig. 5 shows another stem crushed with 390 psi (75 pound force). These last four stems were quite mature. As a comparison, Fig. 6 shows a very immature stem crushed at 125 psi (5 pound force). Plate VII shows the area of each of the crushed stems that was in contact with the rolls. From this it can be seen that pressure is probably a better criteria to use than force. Note the results of Fig. 2 and 3 and Fig. 4 and 5.

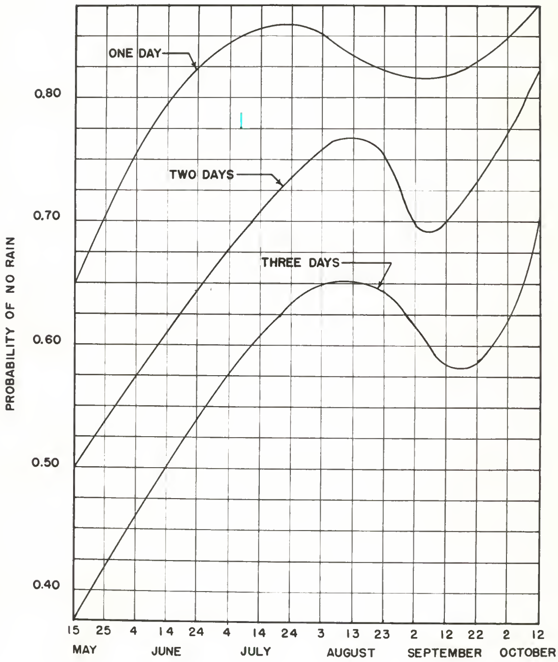
## Weather Data

It was decided that three successive rain free days are sufficient to provide for hay drying regardless of the treatment used. Plate XVIII shows the probability of no rain for one

EXPLANATION OF PLATE XVIII

The probability of no rain for one, two and three successive dry days during the haying season.

PLATE XVIII


ONE DAY
TWO DAYS
THREE DAYS
0.80
0.70
0.60
0.50
0.40
PROBABILITY OF NO RAIN
15 25 4 14 24 4 14 24 3 13 23 2 12 22 2 12
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER

day, two successive days and three successive days from May 15 to October 13. These are based on a record of 58 successive years of rainfall data from the Manhattan, Kansas Weather Bureau Station No. 2. No rain is defined as .10 inch or less. This is a criteria established by the University of Missouri.

It is usually conceded that rain will lower the quality of hay crop. It has been noted previously that increased exposure time will increase carotene loss. After a rain the hay must usually be handled one or more extra times to provide sufficient drying. This increases leaf loss where most of the nutrients are located. Knowing the probability of rain free days then gives the operator some idea of the risk he is taking with the use of the various equipment now available for cutting, conditioning and windrowing hay.

## SUMMARY AND CONCLUSIONS

Protein and carotene are good indicators of alfalfa hay quality. Among the various treatments used in these tests, there seems to be very little protein loss which indicates that leaf loss due to the various treatments is about the same. Rate of carotene loss is definitely affected by the treatments. This, though, correlates closely with moisture loss so that in general, if the hay is handled correctly, the carotene level will be about equal from the various treatments at the time of baling.

Because of the slow drying rate and therefore increased chance of getting rained on, raking immediately after mowing is not considered a good method of haying.

Since hay is a hygroscopic material, moisture is picked up at night. If hay requires more than one day to dry to safe storage levels, the amount of moisture pickup at night must be considered in the overall drying picture. Thus, any advantage that the crushed treatment gains over the crimped treatment in accelerated drying the first day is lost the first night. Both treatments will reach a moisture level sufficient for safe storage at about the same time the second day. Similarly, the first day's advantage of an unconditioned treatment over the rotary and self-propelled windrower treatments is lost the first night. Since all three of these treatments invariably require two drying days under northeastern Kansas conditions, the hay produced by all three will be dry enough to bale at about the same time.

Since the drying rate of all the treatments was essentially the same the second day, baling time is largely determined by the drying rate during the first day and the amount of moisture pickup during the night. These two factors will determine the moisture content when drying starts the second day. One of the primary reasons for similar drying rates on the second day is that the swathed treatments were raked into the windrow early the second day. This meant that during the second day all treatments could be considered windrowed.

Crushing and crimping definitely accelerate drying over nonconditioning and windrowing. Under favorable conditions, it is possible to dry hay to 20 per cent moisture wet basis in one day by crushing.

Net crushing force on a set of crushing rolls is a function of both the applied force and the feeding rate. A net force of about 15 lb/in of roll length provides the maximum drying rate in a light alfalfa crop.

It must be remembered that all of these conclusions are based on tests conducted with commercial machines. With the exception of the crimper, the same machine was used for a particular treatment in each of the trials. It is entirely possible that the results would have been somewhat different had a different manufacturer's machine been used for a particular treatment. The machines used, though, were quite representative of the industry.

Some visual criteria have now been established to determine actual crushing pressures. Forces can vary a great deal with the same results. Thus, the pressure should be a much better criterion to determine the degree of crushing.

Dry day probability curves show the improved probability of getting hay into storage with no rain damage if drying can be accomplished in one rather than two or three days. Manhattan, Kansas data shows an increased probability of about 20 per cent of one rain free day over two successive rain free days and an improvement of 35 per cent of one day over three days.

Continued testing with beef cattle feeding trials by the Department of Animal Husbandry will provide more information on the quality of the hay produced by various hay conditioning treatments.

## ACKNOWLEDGEMENTS

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# FACTORS INFLUENCING THE NATURAL FIELD DRYING OF ALFALFA HAY

by

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For the past several years, there has been considerable interest in improving the quality of hay. There are two general factors that contribute to low quality hay. One of these factors, the stage of maturity at which the hay is cut, is usually quite easy to control. The other, and more difficult, factor to regulate is the deterioration in quality between the time the crop is cut and the time it is put into storage.

There are several different types of commercially manufactured hay conditioning machines now available. The use of these is one approach toward producing a better quality hay. Some of the factors that influence the hay drying rate and consequently the quality of alfalfa hay produced by several of these machines were investigated.

The treatments used were a smooth roll crusher, a fluted roll crimper, a self-propelled windrower, a horizontal blade rotary windrower, the control and the mow and rake. The mow and rake consisted of raking two mowed swaths together immediately after cutting. The control was mowed and raked in the conventional manner.

The mow and rake treatment was eliminated after the first trial. The other five treatments were compared during three trials or hay cuttings. The third and fourth cutting of alfalfa hay of one year and the first cutting the following year were used. All trials took place at the KSU Agronomy Farm.

Hay samples of each treatment were taken periodically to determine the moisture content and the protein and carotene content.

During the first two trials data were also collected on soil moisture and soil temperature under the windrows and swaths. During the third trial the temperature was measured in the center of the hay windrow or swath. Throughout the trials ambient temperature was measured and the relative humidity was determined.

Soil moisture has some effect on the drying rate of hay. A moisture content above 20% retards drying; below 20% it aids the drying.

Soil temperature is primarily affected by the ambient conditions and the evaporative cooling of the hay. Consequently, it had no noticeable effect on the hay drying rate. The hay temperature appears to be much more closely associated with the drying rate.

There is no significant difference in the quality of the alfalfa hay produced by the various treatments. Loss of protein is about the same for each treatment. Loss of carotene follows very closely the loss of moisture. Thus, the carotene content is about the same at baling time for each of the treatments.

The Department of Animal Husbandry used hay from the fourth cutting to conduct feeding trials. Hay from each of the five treatments was fed to a group of ten heifer calves for 98 days. The calves in the lot that were fed crushed hay had a significantly lower average daily gain than the calves in the other four lots.

Because both raking and baling of the crushed hay were done somewhat late for optimum operation, there was a high leaf loss. This, consequently, lowered the feeding value of the crushed hay.

Additional feeding trials are to be conducted. These will provide more information on the quality of the hay produced by various hay conditioning treatments.

There is considerable difference in the drying rate of the various treatments the first day. The drying rate of swathed hay follows a curvilinear function while the windrowed hay follows a straight line function. The second day there is no significant difference in the drying rate of any of the treatments. Much of this can be accounted for by the fact that early in the second day the swathed hay was raked.

Dry day probability curves show the improved probability of getting hay into storage with no rain damage if drying can be accomplished in one rather than two or three days. Manhattan, Kansas data shows an increased probability of about 20% of one rain free day over two successive rain free days and an improvement of 35% of one day over three days.

Because the crusher is the most popular of the various hay conditioners, two additional trials were conducted with it. Both the crushing force and feeding rate were varied. The drying rate was determined under these various treatments. A low force and medium feeding rate provides slowest drying. Medium to high force and a slow feeding rate provides the fastest drying rate. Strain gages were used to measure the crushing forces. The feeding rate was varied by changing the groundspeed of the crusher.

The force that was measured between the crushing rolls was not a good criteria to determine the degree of crushing. A laboratory crusher was built to determine the pressure required to crush a single alfalfa stem. The force applied was again measured with strain gages. To measure the area in contact with the rolls, the stems were dipped in food coloring. This left an imprint on paper that covered the rolls. The area of the imprint was measured with a planometer. Thus, the actual pressure could be determined.

After being crushed, the stems were cut at the point of maximum crushing and the cross section was photographed. The photographs showed that the amount of crushing correlated much closer with the applied pressure than with the applied force.