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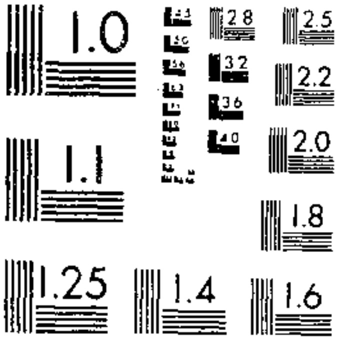

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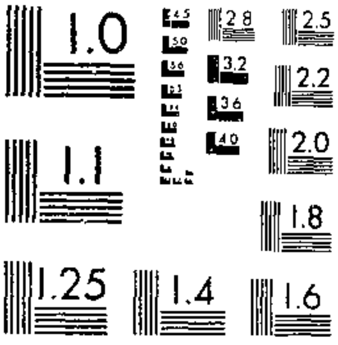

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QUALITY OF ALFALFA HAY IN RELATION TO CURING PRACTICE

By T. A. KIESSELBACH, *Agronomist*, and ARTHUR ANDERSON, *Assistant Agronomist, Nebraska Agricultural Experiment Station* [1]

CONTENTS

INTRODUCTION

The essential characteristics of high-grade alfalfa hay have been summarized by Parker (*8, p. 2*) [2] as consisting of "purity, a high percentage of leaves, clinging foliage, green color, and pliable stems." Other qualities that are stressed by the United States hay standards include freedom from mustiness and moldiness. It is commonly recognized that hay possessing the highest feed value and commanding the maximum market price conforms to the above specifications. The purpose of the investigations herein reported has been to determine the manner and extent to which the quality of the hay may be influenced by the mode of curing and to establish the basic principles of good curing practice.

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[1] In cooperation with the Bureau of Plant Industry and the Bureau of Agricultural Economics, United States Department of Agriculture. Acknowledgments are made to A. J. Pieters, of the Office of Forage Crops and Diseases, Bureau of Plant Industry, for assistance in planning these investigations; to E. C. Parker, E. O. Pollock, and W. H. Hosterman, of the Division of Hay, Feed, and Seed, Bureau of Agricultural Economics, for personally inspecting and establishing the commercial grades of the hay; and to Supt. W. E. Lyness, J. O. Culbertson, and Austin Goth, of the Nebraska station farm, for assisting with the detailed labor connected with the experiments. The protein determinations were made under the direction of J. C. Russel, of the College of Agriculture, University of Nebraska. Acknowledgment is also given F. E. Mussehl for the unpublished results from feeding artificially dried alfalfa to chickens.

[2] Italic numbers in parentheses refer to Literature Cited, p. 25.

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It was believed that these principles might be most effectively determined by contrasting the effects of a rather wide range of opposing conditions which may be subject to the control of the hay producer. As a result of this procedure a number of practices have been included which appear self-evidently undesirable, but whose outcome serves to emphasize the advantages of more favorable treatments.

The various tests were designed to determine the effects of (1) immediate compared with delayed raking, (2) size of windrow, (3) turning the windrow after partial curing, (4) direction of windrow, (5) direction of raking with respect to direction of cutting, (6) type of rake, (7) time of cutting during the day, and (8) cocking immediately and after various degrees of curing. Supplementary studies were made of the effects of the speed of curing and of rain upon the protein content, and of the manner in which moisture escapes from the stems during the curing process.

One of the important considerations in regions where curing hay is subject to damage from rain is to follow a practice which shortens to a minimum the interval between cutting and storage and yet is conducive to good quality. Accordingly, the progressive rate of curing under various treatments was also determined.

REVIEW OF LITERATURE

The literature previous to 1926 on hay-curing practices has been reviewed by the writers (*5*) in another publication. A number of references appearing since that date are here included.

Steenbock, Hart, Elvehjem, and Kletzien (*11, p. 439*) conclude that—

> The antirachitic properties of hays are related to their exposure to sunlight. * * * Clover hay excessively weathered was reduced in antirachitic action as compared with hay less exposed to dew and rain. * * * There remains no question of the advisability of "making hay when the sun shines."

Mason (*7, p. 13*) with reference to artificially dried hay, says:

> It makes a beautiful bright-green hay, much greener than western sun-cured hay, and much superior in feeding value, as it runs from 18 to 23 per cent protein as against 14½ per cent in the western hay.

The Wisconsin Agricultural Experiment Station (*9, p. 42*) states:

> Accumulated experimental evidence secured this year by Messrs. Hart and Steenbock indicates that the antirachitic properties of plant tissues are directly related to their exposure to the sun. Hay cut without exposure to sunlight and cured in the dark away from sunlight has no antirachitic property.

Russell (*10, p. 296*) concludes that—

> Alfalfa leaves from plants dried by artificial heat, by the Mason process, were found to contain at least seven times as much vitamin A as the leaves from hay that was cured in the field so that the greater part of its green color was lost.
>
> The sample which contained the larger amount of vitamin A was green as compared with the brownish green color of the field-cured sample.
>
> The leaves of the artificially cured plants contained only a small amount of the antirachitic vitamin.
>
> When the alfalfa was dried in the sun, without exposure to dew or rain, there was an increase in the antirachitic potency of the leaves, but it was accompanied by a decrease in vitamin A content.

The Michigan Agricultural Experiment Station (*1, p. 356–357*) reports:

Special investigations were begun regarding methods of curing hay. It was shown that hay cured in loose windrows dried down much more uniformly than where it was partially cured in the swath. When cured in the windrows, the leaves and stems lose moisture at about the same rate while the hay cured in the swath shows a divergence of as much as 10 per cent in moisture content between the leaf and stem, the leaves drying rapidly while the stems retain much moisture. This condition causes loss of leaf and often times spoilage in the mow.

Cox and Megee (*2, p. 46–48*) state:

In curing alfalfa, follow a method that will conserve the leaves and produce hay of bright green color. To do this, it is necessary that the leaves and stems dry out so that the per cent of moisture will be about the same in each. When alfalfa is cured in the swath, the leaves lose their moisture very rapidly, while the stems lose their moisture very slowly, resulting in brittle, crumbling leaves that shatter off very easily while the stems are still comparatively green. This method produces a hay of poor quality. Heavy yields of hay are difficult to cure in the swath. The upper part will dry out and leaves shatter easily while the lower part will be very slow to lose its moisture.

Curing in the windrow allows the stems and leaves to dry down together. When the hay is heavy, the windrows may be turned, greatly facilitating the curing. After a rain, the windrows may be turned with the side-delivery rake and curing hastened. In using the side-delivery hayrake, the hay may be raked immediately after cutting, or may be allowed to remain in the swath two or three hours before raking. The hay should be raked into a loose, open swath[1] before the leaves have lost sufficient moisture to become brittle. The left-hand side-delivery rake is advantageous in that it operates in the opposite direction to the course of the mower. The left-hand rake works against the tops of the plants instead of the newly cut butts, throwing a majority of the leafy tops toward the center of the windrow, thus aiding in the conservation of the leaves through better curing.

The Iowa Agricultural Experiment Station (*3, p. 29*) reports:

The best quality of alfalfa hay is secured normally by windrowing shortly after it has been cut. The process may be hastened a little by permitting the hay partially to dry out in swath before windrowing.

Experiments show that the leaves help "pump" water out of the stems. This principle is made more effective when the hay is windrowed. The environment naturally plays an important rôle. To standardize practices, the evaporating environment has been given particular attention. Aeration is important in hay storage.

Parker (*8, p. 8*) has stated:

Essential points to consider are (1) facilitating rapid evaporation of a large part of the moisture in the newly mown hay by exposing it to sun and wind in the swath, where the rate of evaporation is faster than in the windrow, bunch, or cock, and (2) performing the operations of raking and windrowing while the hay is tough and the leaves are not easily shattered.

The rapid evaporation of moisture and the preservation of leafiness and color are jointly accomplished in the most practical manner when the hay is wilted for a short time in the swath and then either windrowed with the side-delivery rake or cocked to complete the evaporation of moisture to that degree where the hay may be stored or baled. * * *

EXPERIMENTAL WORK

PLAN OF CURING TESTS

CHARACTER OF PLOTS

A comparatively uniform 12-acre alfalfa meadow located on the experiment station farm at Lincoln, Nebr., was used for these investigations. This meadow was in its prime, yielding at the rate of 4.5 tons per acre in 1928 when these tests were made.

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[1] "Windrows" evidently meant.

A large number of curing practices were compared. (Table 1.) Forty-eight plots (fig. 1) approximately one-fifteenth of an acre in size were required for each test. By dividing the meadow into three series and harvesting those successively at approximately weekly intervals during each of three crops, it was possible to undertake nine duplicate tests. Because of rain interference or other unavoidable factors only six of these, or portions thereof, materialized satisfactorily for inclusion in this report. Although the first three tests differed somewhat with respect to the maturity of the alfalfa when cut, the succeeding tests were harvested at approximately the half-bloom stage.

48	42	36	30	24	18	12	6
47	41	35	29	23	17	11	5
46	40	34	28	22	16	10	4
45	39	33	27	21	15	9	3
44	38	32	26	20	14	8	2
43	37	31	25	19	13	7	1

FIGURE 1.—Relative location of the alfalfa plots, experiment station farm, Lincoln, Nebr.

TABLE 1.—*Treatments applied to alfalfa during the curing process, and arrangement of the plots*

Treatment	Plot numbers raked with—	
	Side-delivery rake	Sulky rake
Hay cut at 9 a. m.:		
Raked immediately after cutting into—		
Small windrows	1	8
Medium windrows	2	9
Large windrows	3	10
Medium windrows, turned after 4 hours	4	11
Medium windrows, placed in small cocks after 4 hours	5	12
Medium windrows, placed at once in small cocks	6	
Medium windrows, placed at once in large cocks	7	
Raked 4 hours after cutting into—		
Small windrows	13	20
Medium windrows	14	21
Large windrows	15	22
Medium windrows, turned after 4 hours	16	23
Medium windrows, placed in small cocks after 4 hours	17	24
Medium windrows, placed at once in small cocks	18	
Medium windrows, placed at once in large cocks	19	
Medium windrows (extending from north to south)	44	45
Medium windrows (raked opposite to direction of mowing)	39	42
Medium windrows (raked with direction of mowing)	40	41
Medium windrows (raked crosswise to direction of mowing)	43	46
Raked 8 hours after cutting into—		
Medium windrows	25	28
Medium windrows, placed at once in small cocks	26	
Medium windrows, placed at once in large cocks	27	
Raked 24 hours after cutting into—		
Medium windrows	29	32
Medium windrows, placed at once in small cocks	30	
Medium windrows, placed at once in large cocks	31	
Raked when field cured into medium windrows	33	34
Raked when overcured into—		
Medium windrows (in morning when damp)	35	36
Medium windrows (in afternoon when dry)	37	38
Hay cut at 1 p. m.: Raked 4 hours after cutting into medium windrows	47	
Hay cut at 5 p. m.: Raked 16 hours after cutting into medium windrows	48	

MOWING, RAKING, AND COCKING

The area comprised within each test was approximately 225 by 800 feet. (Fig. 2.) Mowing (from east to west) was started at 8 a. m., and two hours were usually required to cut over this area with two 5-foot machines. All raking was done with either a standard left-hand side-delivery rake or a sulky rake. Hay raked immediately after cutting was usually in the windrow within 15 minutes. The first operations on the first day of any test were therefore completed shortly after 10 o'clock. For the purpose of simplification in compiling the data, all tests are considered as having begun at 9 a. m., which was midway during this period of getting the tests under way.

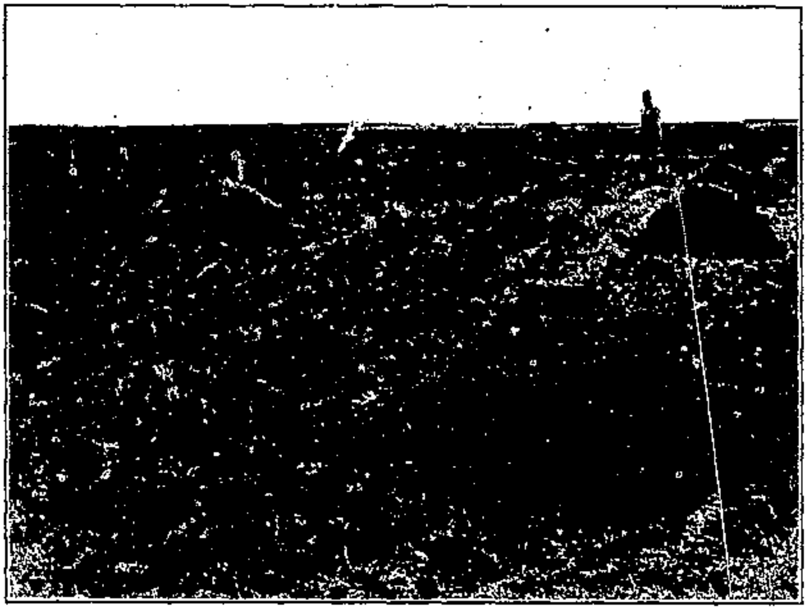

FIGURE 2.—General view of the alfalfa meadow in which the hay-curing tests were made. This field produced at the rate of 4.5 tons of cured hay per acre during the season of 1928. In the foreground are shown small-sized cocks made at the rate of 120 per acre. At the distant right are large cocks, of which there were 60 per acre. In the background various combinations of swath and windrow curing are being compared

Except as otherwise stated, the side-delivery rake followed the direction of mowing, and the sulky rake went crosswise to the swath. (Fig. 3.) This procedure was followed in order to maintain windrows comparable in size and direction, thus making possible direct comparisons between the two types of rakes. Studies conducted in connection with these tests have indicated that direction of windrows or direction of raking with respect to the mower swath were not factors in the rate of curing or in the quality of hay resulting. The windrows were approximately 85 feet long with 2, 4, and 8 mower swaths in the small, medium, and large windrows, respectively. Except in the size-of-windrow comparison, however, all windrows contained 4 mower swaths or their equivalent. Thus the maintaining of such procedure with both types of rakes permits a direct comparison between type of rake and quality of hay produced and the time required for curing.

In the case of the cocked hay, 4 small and 2 large cocks were made from each medium-sized windrow, or 8 and 4 cocks per plot. In making these cocks the hay was forked over by hand and the cocks well rounded as a protection against the weather.

At the time the hay on each plot was considered sufficiently cured for storage it was forked over twice. Such treatment was intended to mix the hay for sampling and to simulate the amount of handling that hay receives under average farm conditions. Hay with a moisture content of 25 per cent was considered field cured. Since there was no way of determining the moisture content in the field, it was necessary to rely on observation and experience in deciding when the hay had reached a cured condition. Moisture determinations that followed revealed the true moisture content.

SAMPLING FOR MOISTURE AND QUALITY DETERMINATIONS

At the time the hay in each plot was pronounced field cured, three composite samples of approximately the indicated weights were taken as follows: (1) A 5-pound sample, which was immediately run

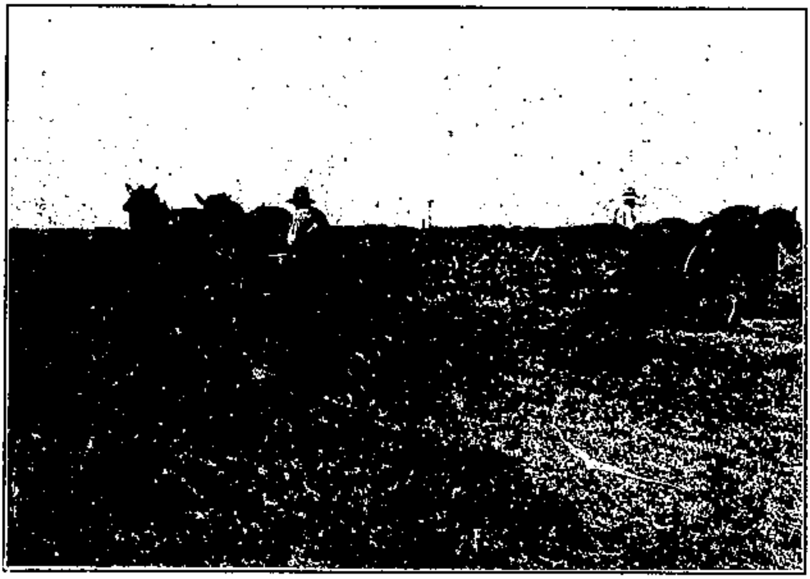

FIGURE 3.—Standard types of hayrake used in these curing studies. At the right is a sulky rake; at the left, a side-delivery rake

through a hand feed cutter and reduced to a 500-gram sample for moisture determination; (2) a 300-gram sample for relative leaf and stem determination on a moisture-free basis; and (3) a 7-pound sample stored in a 15 by 17 by 19 inch carton for official grading.

The samples selected for moisture determination were cut into lengths of approximately one-half inch by means of a hand feed cutter to facilitate mixing and reducing. The time occupied by this entire operation of sampling and reduction seldom exceeded 15 minutes. During this time the samples were protected from undue exposure.

The box samples from any one crop were graded according to the official United States hay standards soon after completion of the third test of each crop. In addition to the factors ordinarily considered in grading hay, the texture or condition of the stems was scored numerically as follows: 1, Pliable; 2, medium hard and brittle; 3, hard and brittle; and 4, very hard and brittle.

A rough separation was first made of the leaf-stem samples. This was followed later by a more careful separation of the stems from the leaves. After moisture-free weights had been taken, the leaves and stems were mixed, ground, and reduced for protein determinations. The percentage of leaves as determined in these separations was used as the leafiness factor in reporting the final grade.

The grade of hay as reported in the tables is based on the average of grade factors given for the individual tests. Where a sample grade resulted in individual tests, the frequency of such occurrence is reported.

In addition to the sampling already mentioned, composite samples approximating 3 pounds of cured hay were taken at stated intervals (9 a. m., and 1 and 5 p. m.) from a number of plots during the first three days of four different tests, in order to measure comparative curing rates. These samples were run through a hand feed cutter in the field and reduced to 500 grams for moisture determination.

PRESENTATION OF DATA

Because of the variability of weather conditions, the inability to determine the moisture content of the hay in the field, and the limitations of the sampling methods, it seems desirable to base conclusions and interpretations with reference to the field-curing studies on average results rather than on individual tests. Experiments were started on June 6, 13, and 18; July 11, 16, and 23; and August 14, 21, and 27. Because of excessive rain in the case of tests begun on June 6 and 18 and July 16, these have not been included in the general averages. Comparable results pertaining to direction of raking with respect to mower swath were secured only for the tests beginning July 23 and August 14 and 21.

DETERMINATIONS OF INITIAL BASIC LEAFINESS AND PROTEIN

In order to study the effect of various curing practices upon the changes in quality due to the mechanical loss of leaves, it seemed essential to have an initial determination of leafiness, free from shattering, to serve as a basis for comparisons. Accordingly, two representative samples were collected at random for analysis at the time of cutting. One of these was immediately dried in the drying oven for moisture determination and later analysis. The other was spread out thin on a canvas in the hay barn for slow curing and freedom from leaf loss. The average results for both types of samples are reported in Table 2. The samples that cured slowly in the shade averaged 48 per cent leaves and 18.8 per cent protein, while those cured rapidly had 47.3 per cent leaves and 19 per cent protein.

TABLE 2.—*Quality and composition of alfalfa hay when cured under shelter to avoid losses from exposure*

[Average of six tests] [1]

Character of sample	Quality [2]						
	Stems	Color	Leaves	Protein			Grade
				Hay	Leaves	Stems	
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Slowly cured	1.0	72	48.0	18.8			1
Rapidly cured			47.3	19.0	27.49	11.39	1

[1] These are basic results from hay free from leaf shattering and weather damage. Any deviation therefrom in succeeding tables may be attributed to the field-curing procedure.

[2] All specific data in these quality notes in this and subsequent tables are averages for the duplicate tests. The commercial grade is based on the averages for the specific quality values. The color values are estimates. The percentage of leaves is on a moisture-free, total-weight basis. The numerical values of stems are straight averages which have the following significance: 1, Pliable; 2, medium hard and brittle; 3, hard and brittle; 4, very hard and brittle; L., leafy; Exl., extra leafy. S and a superior number following indicate the sample grade and its frequency.

Any reductions below these figures in the leafiness or protein content of the hay cured by various practices may be ascribed as due primarily to mechanical loss of leaves.

IMMEDIATE RAKING COMPARED WITH PARTIAL SWATH CURING

For comparison with immediate raking after cutting, alfalfa was retained in the swath before raking for periods of 4, 8, and 24 hours, and until completely cured. All comparisons were made with both side-delivery and sulky rakes, and medium-sized windrows containing four mower swaths were used throughout. The results, together with those pertaining to the question of overcuring discussed later, are summarized for the six duplicate tests in Table 3.

TABLE 3.—*Effect of immediate and delayed raking with side-delivery and sulky rakes upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of raking and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Side-delivery rake	82	22	2.3	53	40	17.4	2 L
Sulky rake	78	22	2.0	53	40	17.3	2 L
Average	80	22	2.2	53	40	17.3	2 L
Raked 4 hours after cutting:							
Side-delivery rake	60	24	2.2	61	40	17.1	1
Sulky rake	59	23	2.2	61	41	17.2	1
Average	60	24	2.2	61	41	17.2	1
Raked 8 hours after cutting:							
Side-delivery rake	54	25	2.0	59	41	17.4	2 L
Sulky rake	50	26	2.0	60	42	17.3	1
Average	52	26	2.0	60	42	17.4	1
Raked 24 hours after cutting:							
Side-delivery rake	54	25	2.0	60	40	17.0	1
Sulky rake	50	26	2.2	61	42	17.6	1
Average	52	26	2.1	61	41	17.3	1
Raked when field cured:							
Side-delivery rake	42	27	2.2	56	39	16.5	2
Sulky rake	42	26	2.0	56	38	16.4	2
Average	42	27	2.1	56	39	16.5	2
Raked when overcured:							
With dew on—							
Side-delivery rake	66	21	2.2	47	41	17.3	2 L
Sulky rake	66	21	2.2	45	43	17.6	2 L
Average	66	21	2.2	46	42	17.5	2 L
With dew off—							
Side-delivery rake	66	20	2.5	45	36	16.1	2
Sulky rake	66	20	2.3	43	35	16.2	2
Average	66	20	2.4	44	36	16.2	2

[1] For explanation of quality factors see Table 2, footnote 2.

The percentages of leaves and protein were not materially affected, whether raking was immediate or delayed for various intervals up to 24 hours. The color of the hay was considerably lowered, however, by immediate raking, which reduced the speed of drying and resulted in prolonged exposure in the field. Accordingly, the hay that was

FIGURE 4.—Combined swath and windrow curing. In the right foreground is shown a medium-sized windrow containing four mower swaths; at the left are small-sized windrows containing two mower swaths

raked immediately graded only No. 2, while all degrees of partial swath curing up to a 24-hour period resulted in grade No. 1. (Fig. 4.) Delay of raking until the alfalfa was fully cured in the swath shortened the period required but reduced the hay quality to grade No. 2 because of lessened color and leafiness.

EFFECT OF OVERCURING IN SWATH

In conjunction with the studies of partial swath curing reported in the preceding discussion, part of the forage was permitted to lie in the swath for an entire day after reaching the cured stage. Part of it was then raked in the forenoon while still tough with dew, and the other portion was raked after the dew had dried off. The effect of such overcuring, as shown in Table 3, was a decided loss in color; and when the raking was delayed until the dew had dried off, the leaf loss through shattering became pronounced. Both lots of hay that were overcured in the swath graded only No. 2 because of the undue field exposure.

EFFECT OF SIZE OF WINDROW

Hay was raked into small, medium, and large windrows with both types of rakes immediately and four hours after cutting. These windrows contained 2, 4, and 8 mower swaths, respectively. The medium and large windrows were made with the side-delivery rake by rolling the hay over as necessary. The results are summarized in Table 4.

As an average for both types of rake, 64, 80, and 92 hours were required, respectively, for hay raked into small, medium, and large windrows immediately after cutting to reach a field-cured condition. In the parallel test where 4 hours of swath curing preceded windrowing, 50, 60, and 71 hours were required for the small, medium, and large windrows, respectively. The size of windrow did not materially influence the quality of hay in any respect. Marked differences in quality might result, however, from the retarded curing in large windrows in case of unfavorable weather.

TABLE 4.—*Effect of size of windrow and type of rake upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of raking, type of rake, and size of windrow	Field-cured hay						
	Hours required	Moisture content	Quality[1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:							
Side-delivery rake—		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Small windrow	64	24	2.0	54	41	17.4	2 L
Medium windrow	82	22	2.3	53	40	17.4	2 L
Large windrow	94	27	2.2	53	44	18.3	2 L
Average	80	24	2.2	53	42	17.7	2 L
Sulky rake—							
Small windrow	63	25	2.2	54	41	17.2	2 L
Medium windrow	78	22	2.0	53	40	17.3	2 L
Large windrow	90	27	2.0	53	43	18.4	2 L
Average	77	25	2.1	53	41	17.6	2 L
Raked 4 hours after cutting:							
Side-delivery rake—							
Small windrow	50	26	2.3	61	40	16.8	1
Medium windrow	60	24	2.2	61	40	17.1	1
Large windrow	71	23	2.2	63	40	17.3	1
Average	60	24	2.2	62	40	17.1	1
Sulky rake—							
Small windrow	50	24	2.2	60	40	17.1	1
Medium windrow	59	23	2.2	61	41	17.2	1
Large windrow	71	24	2.2	63	41	17.3	1
Average	60	24	2.2	61	41	17.2	1
Grand average							
Raked immediately after cutting:							
Small windrow	64	25	2.1	54	41	17.3	2 L
Medium windrow	80	22	2.2	53	40	17.4	2 L
Large windrow	92	27	2.1	53	44	18.4	2 L
Average	78	25	2.1	53	42	17.7	2 L
Raked 4 hours after cutting:							
Small windrow	50	25	2.3	61	40	16.9	1
Medium windrow	60	24	2.2	61	41	17.2	1
Large windrow	71	24	2.2	63	41	17.3	1
Average	60	24	2.2	62	41	17.1	1

[1] For explanation of quality factors see Table 2, footnote 2.

Owing perhaps to a longer exposure in the field, hay raked immediately after cutting retained but 53 or 54 per cent of its color, regardless of windrow size, and was therefore placed in grade 2. Hay raked four hours after cutting had 61 per cent or more color and was placed in grade 1.

There was no significant effect of the type of rake when windrows of equal size were compared except that in the case of the hay raked immediately after cutting the curing was somewhat more rapid when the sulky rake was used.

EFFECT OF TURNING WINDROW WHEN PARTIALLY CURED

The effect of turning the windrows four hours after raking was studied in connection with hay raked immediately after cutting and also with hay swath cured for four hours before raking. The results are summarized in Table 5. The tests were duplicated with both types of rake.

TABLE 5.—*Effect of turning of windrow after four hours of windrow curing upon quality of alfalfa hay and time required for curing*

[Average of 6 tests]

Time of raking and turning, and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality[1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:							
Side-delivery rake—		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Windrows turned after 4 hours	68	25	2.2	58	41	17.7	2 L
Windrows not turned	82	22	2.3	53	40	17.4	2 L
Sulky rake—							
Windrows turned after 4 hours	60	25	2.2	58	41	17.6	2 L
Windrows not turned	78	22	2.0	53	40	17.3	2 L
Average (both types of rake):							
Windrows turned after 4 hours	64	25	2.2	58	41	17.7	2 L
Windrows not turned	80	22	2.2	53	40	17.3	2 L
Raked 4 hours after cutting:							
Side-delivery rake—							
Windrows turned after 4 hours	56	24	2.2	58	40	17.3	2 L
Windrows not turned	60	24	2.2	61	40	17.1	1
Sulky rake—							
Windrows turned after 4 hours	55	25	2.2	59	41	17.6	2 L
Windrows not turned	59	23	2.2	61	41	17.2	1
Average (both types of rake):							
Windrows turned after 4 hours	56	25	2.2	59	41	17.5	2 L
Windrows not turned	60	24	2.2	61	41	17.2	1

[1] For explanation of quality factors see Table 2, footnote 2.

When both tests are averaged, turning the windrows of hay raked immediately after cutting reduced the length of the curing period by 16 hours. Where four hours of swath curing had preceded the raking, the turning of windrows shortened the curing period only four hours.

The color of the hay was somewhat benefited by turning the windrow in the case of immediate raking. This was probably due to a decided shortening of the curing period. There were no other significant variations as a result of the method of handling. In no case did turning the windrow raise the commercial grade.

RELATION OF DIRECTION OF WINDROW TO CURING

After four hours of swath curing, hay was raked with the side-delivery and sulky rakes into medium-sized windrows that extended from east to west and from north to south. The side-delivery rake followed the direction of mowing, and the sulky rake went crosswise to the mower swath in both instances. These tests were planned to determine the effect, if any, that the direction of windrow exposure might have on hay quality and curing rate. It was believed that such a difference in exposure with reference to prevailing wind and sun might affect the rate of drying. The results are summarized in Table 6.

TABLE 6.—*Effect of direction of windrow upon quality of alfalfa hay and time required for curing*

[Average of five tests]

Direction of windrow and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
		Per cent		*Per cent*	*Per cent*	*Per cent*	
Windrows extending from east to west:							
Side-delivery rake	61	23	2.2	63	40	16.9	1
Sulky rake	60	23	2.2	63	41	16.9	1
Average	60	23	2.2	63	41	16.9	1
Windrows extending from north to south:							
Side-delivery rake	59	25	2.2	62	44	17.5	1
Sulky rake	59	25	2.4	64	42	17.2	1
Average	59	25	2.3	63	43	17.4	1

[1] For explanation of quality factors see Table 2, footnote 2.

In an average of five duplicate tests there was no indication that the direction of windrow with either type of rake is a factor in rate of curing or in quality of the final product. All lots of hay produced graded No. 1.

DIRECTION OF RAKING IN RELATION TO MOWER SWATH

Tests were made to determine what effect raking at various directions with respect to the mower swath might have on rate of curing and quality. Hay was raked against the heads (following the mower), with the heads (opposite the mower), and crosswise to the swath, with both types of rake. The data are reported in Table 7. In an average of the three tests, beginning July 23 and August 14 and 21, there was practically no difference in the time required to reach a field-cured condition or in the quality factors of leafiness and protein content in response either to direction of raking with respect to the mower swath or to the type of rake. The color percentage ranged from 60 to 67, but the variation bore no apparent relation to the method of curing. All lots of hay graded No. 1.

TABLE 7.—*Effect of direction of raking with respect to mower swath upon quality of alfalfa hay and time required for curing*

[Average of three tests]

Direction of raking and type of rake	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
		Per cent		*Per cent*	*Per cent*	*Per cent*	
Side-delivery rake:							
With direction of mowing	57	22	2	60	43	17.1	1
Opposite to direction of mowing	57	19	2	65	44	17.8	1
Crosswise to the mowing	58	20	2	67	44	17.7	1
Sulky rake:							
With direction of mowing	57	22	2	63	44	17.5	1
Opposite to direction of mowing	57	20	2	60	43	17.0	1
Crosswise to the mowing	58	19	2	60	43	17.1	1

[1] For explanation of quality factors see Table 2, footnote 2.

EFFECT OF TYPE OF RAKE

It will have been noted that all of the curing practices reported in Tables 3 to 7 were conducted in duplicate with the two standard types of rake—side delivery and sulky. With few exceptions it made no important difference which rake was used. In a number of cases somewhat less time was required for hay to cure when windrowed with the sulky rake. This may have been due to the fact that the sulky rake left the windrow somewhat wider than, and therefore not quite so deep as, the windrow made by the side-delivery rake.

In general both types of rake gave practically equal results with respect to moisture content, color, leafiness, and protein percentage of the hay when equal-sized windrows were compared. It is obvious, however, that striking differences in curing rate and quality may be

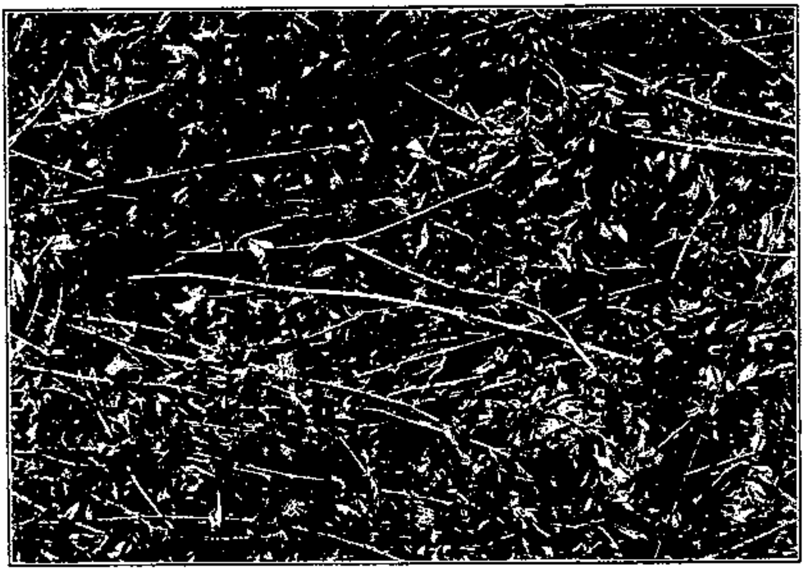

FIGURE 5.—Surface view of alfalfa hay in a typical windrow made by a side-delivery rake. In comparative studies the type of rake did not materially influence either the percentage of leaves exposed at the surface or the rate of moisture loss from the forage

expected when the small windrows commonly made with the side-delivery rake are compared with the large windrows usually made by the sulky rake in farm practice. Examination of the forage in the windrows disclosed no material differences with respect to the percentage of exposed leaves in relation to rake type. (Fig. 5.)

TIME OF CUTTING DURING DAY IN RELATION TO CURING

Special cuttings of hay were made at 1 and 5 p. m. during each test for comparison with the hay cut at 9 a. m. as to quality and time required for curing. All hay in this comparison was raked into medium-sized windrows with a side-delivery rake. The hay cut at 1 p. m. was raked at 5 p. m. and that cut at 5 p. m. at 9 o'clock the following morning.

TABLE 8.—*Effect of cutting at various times during the day upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of cutting and raking	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Hay cut at 9 a. m.:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Raked immediately	82	22	2.3	53	40	17.4	2 L
Raked after 4 hours	60	24	2.2	61	40	17.1	1
Raked after 8 hours	54	25	2.0	59	41	17.4	2 L
Hay cut at 1 p. m., raked after 4 hours	59	25	2.0	67	43	17.2	1
Hay cut at 5 p. m., raked after 16 hours	54	26	2.2	63	42	17.1	1

[1] For explanation of quality factors see Table 2, footnote 2.

These results together with those for hay cut at 9 a. m. and raked immediately, and four and eight hours after cutting are shown in Table 8. In an average of the six duplicate tests, there was no marked difference with respect to quality and time required for curing except that the hay raked immediately after cutting required 22 to 28 hours longer for curing and was materially reduced in color.

RELATION OF COCK CURING TO HAY QUALITY

In order to study the effect of cock curing on hay quality and the time required for curing, hay was raked in medium-sized windrows and cocked immediately after cutting, and 4, 8, and 24 hours after cutting. Small and large cocks (eight or four cocks per plot) were made in all cases. In addition, small cocks were made following four hours of windrow curing where hay had been raked immediately, and four hours after cutting. For comparison the average results for windrowed hay (Table 4) are also included. The data are reported in Table 9.

TABLE 9.—*Effect of immediate and delayed raking and cocking upon quality of alfalfa hay and time required for curing*

[Average of six tests]

Time of raking and cocking and size of cock	Field-cured hay						
	Hours required	Moisture content	Quality [1]				
			Stems	Color	Leaves	Protein	Grade
Raked immediately after cutting:		*Per cent*		*Per cent*	*Per cent*	*Per cent*	
Medium windrow	80	22	2.2	53	40	17.4	2 L
Cocked at once—							
Small cock	185	24	2.2	46	40	17.0	2 L-S[2]
Large cock	246	22	2.0	38	41	17.2	2 L-S[2]
Cocked after 4 hours [2]—							
Small cock	182	20	2.0	50	41	17.2	2 L-S[2]
Raked 4 hours after cutting:							
Medium windrow	60	24	2.2	61	41	17.2	1
Cocked at once—							
Small cock	177	19	2.2	54	40	17.6	2 L-S[2]
Large cock	224	21	2.0	51	42	17.3	2 L-S[2]
Cocked after 4 hours [2]—							
Small cock	177	19	2.2	53	41	17.6	2 L-S[2]
Raked 8 hours after cutting:							
Medium windrow	52	26	2.0	60	42	17.4	1
Cocked at once—							
Small cock	145	21	2.2	58	42	17.4	2 L-S[2]
Large cock	172	23	2.0	53	41	17.5	2 L-S[2]
Raked 24 hours after cutting:							
Medium windrow	52	26	2.1	61	41	17.3	1
Cocked at once—							
Small cock	150	20	2.2	54	42	17.5	2 L-S[2]
Large cock	160	24	2.0	52	40	17.1	2 L-S[2]

[1] For explanation of quality factors see Table 2, footnote 2.
[2] Results for the 2 types of rakes are averaged.

As an average of the six tests, the cocked hay required from two and one-half to three times as long to become field cured as comparable hay cured in medium-sized windrows. The color of the cocked hay ranged from 38 to 58 per cent, compared with 53 and 61 per cent for windrowed hay. The latter averaged grade 1 except that which was raked immediately after cutting, which fell into grade 2 because of too low color. On the other hand, all cocked hay (as an average) fell into grade 2 because of color, and into Sample grade 25 times out of 60 because of a moldy or musty condition. Every method of cock curing resulted in one or more moldy samples during the six tests. Differences in leafiness were not significant, and in all cases they averaged sufficiently high for grade 1 hay.

The cock-cured hay as a whole was better than the windrowed hay in 1 test out of 6. In a total of 60 comparisons between windrowed and cocked hay, the latter graded higher than windrowed hay 13 times and lower 31 times.

EFFECT OF TURNING HAY EXPOSED TO EXTERNAL MOISTURE

A number of comparisons were made in the tests beginning June 18 and August 14 wherein a portion of the hay on a number of plots was turned or scattered following exposure to rain. As an average of 33 comparisons, including both windrows and cocks (Table 10), the hay that was turned or scattered became dry in 159 hours after cutting, compared with 187 hours for hay that was not disturbed. There were 9 and 13 Sample grades, due to a moldy or musty condition, among the turned and unturned hay, respectively. Differences in color, leaf composition, and protein content did not appear significant.

TABLE 10.—*Effect of turning and scattering partially cured windrowed and cocked hay, after exposure to external moisture, upon its quality and the time required for drying*

Treatment	Number of plots averaged	Field-cured hay					
		Hours required	Moisture content	Quality[1]			
				Color	Leaves	Protein	Grade
Tests beginning June 18:							
Windrows—			*Per cent*	*Per cent*	*Per cent*	*Per cent*	
Turned	15	167	19	40	34	16.5	2
Not turned	15	186	20	39	33	16.3	2
Cocks—							
Scattered	4	192	19	40	34	16.5	$2-S^{1}$
Not scattered	4	300	25	41	36	16.7	$2-S^{3}$
Tests beginning August 14:							
Windrows—							
Turned	2	131	15	43	38	17.0	$2-S^{3}$
Not turned	2	131	15	40	38	16.9	$2-S^{3}$
Cocks—							
Scattered	12	142	13	44	36	16.2	$2-S^{5}$
Not scattered	12	159	19	53	38	16.5	$2-S^{7}$
Averages:							
Windrows and cocks—							
Turned	33	159	16	42	35	16.4	$2-S^{9}$
Not turned	33	187	20	43	36	16.5	$2-S^{13}$

[1] For explanation of quality factors see Table 2, footnote 2.

EFFECT OF RAIN ON PROTEIN CONTENT

It seemed of interest to determine what effect exposure to rain might have on the quality of alfalfa hay aside from actual leaf loss. It was possible to select 21 lots of hay from the tests beginning June 18, July 11, and August 14 which had not been exposed to much rain and an equal number of samples of practically the same leaf content but which had been exposed to more than 1 inch of rain. The results as averaged in Table 11 show that the hay that had been rained on, although exposed much longer in the field with a resulting lower color value, had slightly more protein than hay not exposed to rain.

TABLE 11.—*Comparative quality of alfalfa hay that has been exposed to rain and equally leafy hay not so exposed*

Number of comparisons	Exposed to rain	Field-cured hay					
		Hours required	Moisture content	Quality [1]			
				Color	Leaves	Protein	Grade
Tests beginning June 18:			*Per cent*	*Per cent*	*Per cent*	*Per cent*	
14	No	74	28	48	36.8	16.9	2
14	Yes	161	23	40	36.4	17.0	2
Tests beginning July 11:							
5	No	54	31	57	39.2	17.9	2
5	Yes	136	31	32	39.2	18.0	3
Tests beginning August 14:							
2	No	44	17	65	38.0	16.4	1
2	Yes	131	15	40	38.0	16.8	S[2]
Averages:							
21	No	57	25	57	38.0	17.1	2
21	Yes	153	23	37	37.9	17.5	2-S[2]

[1] For explanation of quality factors see Table 2, footnote 2.

EFFECT OF ARTIFICIAL DRYING

In conjunction with these field-curing studies, the Bureau of Public Roads of the United States Department of Agriculture cooperated in determining the effect of artificial drying upon the quality of alfalfa hay. These results as published elsewhere (Hurst and Kiesselbach (*4*)) are summarized in Table 12 to contrast rapid drying with field curing and prolonged drying.

As an average of 12 lots of hay which were dried with heated air, it required 2¾ hours to reduce the hay to 21 per cent moisture. This hay graded No. 1, extra leafy, averaged 20.4 per cent protein, retained 67 per cent of its color, and had pliable stems.

TABLE 12.—*Effect of the rapidity of drying upon the quality of alfalfa hay*

Mode of drying	Number of samples	Cured hay						
		Hours required	Moisture content	Quality [1]				
				Stems	Color	Leaves	Protein	Grade
			Per cent		*Per cent*	*Per cent*	*Per cent*	
Artificially dried	12	2¾	21	1	67	52	20.4	1 Exl.
Field cured	8	41	25	1.5	60	48	19.5	1
Cured indoors	1	127		1	65	52	20.9	1 Exl.

[1] For explanation of quality factors see Table 2, footnote 2.

In contrast, eight comparable samples which were cured in the field required 41 hours to reach a moisture content of 25 per cent. This hay averaged grade No. 1, 19.5 per cent protein, 60 per cent color, and medium hard stems.

One sample which was cured indoors required 127 hours for drying, graded No. 1 extra leafy, 20.9 per cent protein, 65 per cent color, and had pliable stems.

The field-cured hay and the sample that was cured indoors were cut on July 23. The field-cured hay remained four hours in the swath prior to being raked into medium-sized windrows where curing was finished. The artificially dried hay was cut from adjacent plots during the period of July 24 and 28 and was removed immediately to the drying equipment.

These data suggest that the three methods of curing produced hay of almost identical quality. The slightly lower leaf and protein content of the field-cured hay was doubtless due to mechanical loss of leaves, since it is safe to assume that even the best method of field curing is likely to result in some loss of leaves.

Quantities of the artificially dried and of the field-cured hay from the above experiment were supplied to the poultry husbandry department of the Nebraska Agricultural Experiment Station for comparison in feeding to young chickens. The leaves from both lots of hay were fed to two groups of 35 chicks each in connection with a basal ration low in vitamin A. Differences in growth due to feeding the alfalfa cured under these two extreme conditions were not significant.

RELATION OF LEAFINESS OF CURED HAY TO PROTEIN CONTENT

It is generally considered that approximately three-fourths of the protein of alfalfa is contained in its leaves. This estimate is in close agreement with the average of determinations made in connection with the six main tests herein reported. At the time of cutting, composite samples were taken and analyzed for leafiness and for protein content of the leaves and stems separately. (Table 2.) The leaves were found to constitute 47 per cent of the dry weight. These analyzed 27.5 per cent protein, while the stems contained 11.4 per cent. According to these figures, 68 per cent of the total protein was contained in the leaves. These results correspond with those previously reported by the writers (*4*), in which, as a 4-year average, the portion of the protein borne by the leaves ranged from 75 per cent in the prebloom stage to 70 per cent in the full-bloom stage.

Since more or less shattering of leaves occurs with the various haymaking operations, the question arises as to just what may be the relation between the leafiness and the protein percentage of alfalfa hay. In answer to this question, the coefficients of correlation between the proportion of leaves by weight and the protein percentage of the hay have been calculated for the various samples of these six main curing tests. The number of samples available for any one test ranged from 40 to 46. The respective coefficients of correlation for these six tests were 0.933 ± 0.021, 0.572 ± 0.106, 0.899 ± 0.029, 0.861 ± 0.038, 0.826 ± 0.048, and 0.922 ± 0.024. A combined correlation coefficient for the six tests was 0.864 ± 0.011 (*8a, p. 163*). The correlation for the entire 253 samples considered collectively was 0.721 ± 0.026. The distribution of the 253 samples with respect to leafiness and protein is shown in Table 13.

TABLE 13.—*Distribution of 253 samples of alfalfa hay with respect to leafiness and protein content, 1928*

Percentage of leaves	Number of samples having a percentage protein content of—																	Frequency
	13.2	13.7	14.2	14.7	15.2	15.7	16.2	16.7	17.2	17.7	18.2	18.7	19.2	19.7	20.2	20.7	21.2	
20		1																1
21																		
22	1																	1
23																		
24																		
25																		
26		1																1
27				1														1
28																		
29		1																1
30				1														1
31							1											1
32					1													1
33						3	3		1									7
34							2	1	1	1								5
35					1	1	1	3	1									7
36					2	3	5	5	1	1								17
37					1		8	5	2									16
38						1	7	5	4	2	3	2						24
39						1	2	8		2	1							14
40						3	4	7	2	1	1							18
41						1	3	6	4	2	6							22
42							4	4		2	5	5	1					21
43								10	4	1	2	1	2					20
44								6	1		2	6		5				20
45								1	5	2			1					9
46								3	1	2		3	1	1				11
47								1	3	5	1	1	2	1				14
48											1			2				3
49									1	2	1	1		2				7
50												1		2	1		1	5
51												1				1		2
52															1	1		2
53													1					1
Frequency	1	3		2	5	13	40	65	31	23	23	21	8	13	2	2	1	253

PROGRESSIVE LOSS OF WATER FROM ALFALFA IN RELATION TO CURING PRACTICE

The comparative rates of water loss from alfalfa curing in the swath and under various methods of raking and cocking were determined for the first three days of four of the foregoing tests. These methods included raking the hay with side-delivery and sulky rakes into small, medium, and large windrows immediately and four hours after cutting. An additional medium-sized windrow included in each case was turned after four hours of windrow curing. Comparative cock curing was also determined in the case of small and large cocks when cocked immediately and after four hours of swath curing. The rate of drying was established by determining the moisture content of composite samples of hay taken from each condition at 9 a.m., and 1 and 5 p.m. The results are reported in Table 14.

As a grand average, the hay in the swath cured more rapidly than the hay cured under any of the other conditions. Swath-cured hay reached a field-cured condition during the second afternoon, compared with the third afternoon for the hay curing under most of the other practices. The large windrows raked immediately after cutting and all of the cocked hay still remained uncured at the close of the third day. Curing was rather consistently retarded as the size of windrow or cock was increased. Turning the windrow after four hours of windrow curing slightly increased the curing rate. Hay curing in the swath or small windrows was more affected by external moisture, such as higher humidity and dews, than was the hay in the larger windrows and cocks. Comparative differences due to the various practices were less marked when partial swath curing preceded windrowing.

TABLE 14.—*Comparative rates of curing alfalfa hay in the swath and under various methods of raking and cocking, the hay being cut at 9 a. m.*

[Average of four tests]

Time and methods of raking and cocking	Moisture content of hay (per cent)								
	First day			Second day			Third day		
	9 a. m.	1 p. m.	5 p. m.	9 a. m.	1 p. m.	5 p. m.	9 a. m.	1 p. m.	5 p. m.
Cured in the swath	75.3	57.3	42.5	46.5	28.8	23.8	31.8	19.8	19.3
Raked immediately:									
Side-delivery rake—									
Small windrow	------	63.0	53.8	49.3	37.5	32.3	39.5	27.5	21.5
Medium windrow	------	66.8	59.0	53.8	42.0	34.5	43.8	27.8	21.8
Medium windrow [1]	------	63.0	53.3	50.0	30.3	33.5	35.5	32.7	20.8
Large windrow	------	66.5	56.5	56.8	47.0	38.3	41.8	37.3	27.3
Average	------	64.8	55.7	52.5	41.5	34.7	40.2	31.3	22.9
Sulky rake—									
Small windrow	------	62.8	49.8	42.0	32.3	27.0	35.3	24.3	22.0
Medium windrow	------	61.8	50.0	50.8	38.3	32.0	35.3	24.8	22.5
Medium windrow [1]	------	60.8	53.3	48.5	36.5	30.5	33.8	23.3	22.8
Large windrow	------	62.3	52.8	55.5	42.0	39.0	45.0	31.5	27.7
Average	------	61.9	51.5	49.2	37.3	32.1	37.4	26.0	23.8
Raked at 1 p. m.:									
Side-delivery rake—									
Small windrow	------	------	47.3	45.3	30.8	26.3	33.0	23.0	20.8
Medium windrow	------	------	45.8	43.3	34.0	32.5	35.0	23.8	22.3
Medium windrow [1]	------	------	47.0	42.0	33.3	26.3	32.3	23.0	21.5
Large windrow	------	------	49.8	44.8	37.8	35.0	34.1	26.0	22.5
Average	------	------	47.5	43.9	34.0	30.0	33.6	24.0	21.8
Sulky rake—									
Small windrow	------	------	48.0	43.8	32.8	27.8	33.5	22.5	17.8
Medium windrow	------	------	44.8	42.0	31.3	30.3	31.3	22.3	22.3
Medium windrow [1]	------	------	43.5	43.5	31.8	28.5	30.0	23.0	21.3
Large windrow	------	------	45.3	41.0	34.5	29.3	33.8	25.8	25.8
Average	------	------	45.4	42.6	32.6	29.0	32.2	23.4	21.8
Raked and cocked immediately:									
Small cock	------	66.8	61.8	61.3	59.8	54.0	51.8	47.5	41.0
Large cock	------	67.5	64.5	64.0	60.5	50.0	55.8	53.8	51.8
Raked and cocked at 1 p. m.:									
Small cock	------	------	47.5	45.8	40.3	37.0	38.0	34.3	32.8
Large cock	------	------	52.3	45.8	40.3	38.8	40.3	35.0	31.5
Grand average									
Cured in the swath	75.3	57.3	42.5	46.5	28.8	23.8	31.8	19.8	19.3
Raked immediately:									
Small windrow	------	62.9	51.8	45.7	34.0	29.7	37.4	25.9	21.8
Medium windrow	------	64.3	54.5	52.3	40.2	33.3	39.6	26.3	22.2
Medium windrow [1]	------	61.9	53.3	49.3	37.9	32.0	34.7	28.0	21.8
Large windrow	------	64.4	54.7	56.2	44.5	38.7	43.4	34.4	27.5
Average	------	63.4	53.6	50.9	39.4	33.4	38.8	28.7	23.3
Cock (average)	------	67.2	63.2	62.7	60.2	56.5	53.8	50.7	46.4
Raked at 1 p. m.:									
Small windrow	------	------	47.7	44.6	31.8	27.1	33.3	22.8	19.3
Medium windrow	------	------	45.3	42.7	32.7	31.4	33.2	23.1	22.3
Medium windrow [1]	------	------	45.3	42.8	32.6	27.4	31.2	23.0	21.4
Large windrow	------	------	47.6	42.9	38.2	32.2	34.0	25.9	24.2
Average	------	------	46.5	43.3	33.3	29.5	32.9	23.7	21.8
Cock (average)	------	------	49.9	45.8	40.3	37.9	39.2	34.7	32.2

[1] Hay turned after four hours of windrow curing.

Although it was not altogether consistent, there was a slight indication that the hay in the windrows raked by the sulky rake cured more rapidly than that raked by the side-delivery rake. This difference in curing rate may have been due to a somewhat greater surface exposure of the windrows made by the sulky rake.

HOW MOISTURE IS LOST FROM STEMS IN CURING

In view of conflicting opinion, it seemed desirable to study further the loss of moisture from cut alfalfa stems. Previous studies by Willard (*13*), Westover (*12*), and Kiesselbach and Anderson (*5, 6*) have shown that the leaves do not function materially in withdrawing moisture from the stems during the curing period. It has not been shown, however, to what extent moisture loss may take place through "bleeding" or direct evaporation from the cut ends of the stems.

During each of two tests three small samples of freshly cut alfalfa were prepared in duplicate for curing in the laboratory, as follows: (1) Normal stems as cut in the field, (2) normal stems with the cut end sealed with waterproof wax, (3) stems with leaves removed and all mutilated stem and branch ends sealed with wax.

The hay was taken to the laboratory, the various samples prepared, and first weights taken within 30 minutes after cutting. The samples were scattered thinly on paper (the detached leaves with the stems) in a well-ventilated room for drying. Weights were taken at hourly intervals during the first day and three times each during the second and third days. The comparative rates of accumulative moisture loss under the various treatments are shown in Table 15.

BLEEDING FROM STEM ENDS OF CUT ALFALFA

A study of the data reveals no material acceleration of moisture loss through bleeding in the case of normal alfalfa cut as for hay. The water losses for the entire period averaged but 0.3 per cent greater for the unsealed than for the sealed stems. This suggests that the loss of water from alfalfa during the curing process is primarily by direct evaporation through the epidermis of the stems and leaves and not by exit through the cut ends of the stems.

TABLE 15.—*Progressive rates of moisture loss from cut alfalfa plants, under laboratory conditions, when all points of mutilation on the stems are sealed, as compared with unsealed stems*

Period	Treatment of— Leaves	Treatment of— Stems	Initial water content	Accumulative percentage of the initial moisture content that is lost during drying: First day, 8 a. m.	9 a. m.	10 a. m.	11 a. m.	12 m.	1 p. m.	2 p. m.	3 p. m.	4 p. m.	5 p. m.	6 p. m.	Second day, 7 a. m.	1 p. m.	6 p. m.	Third day, 7 a. m.	1 p. m.	6 p. m.
			Per ct.																	
Sept. 6 to 8	Attached	Unsealed	76.4	0	7.5	12.0	16.5	19.3	23.8	28.0	32.1	35.5	39.1	41.2	64.6	73.2	80.5	86.3	87.8	89.8
	do	Sealed	75.3	0	7.6	11.6	16.2	19.0	23.0	27.5	31.4	35.2	38.6	40.9	63.3	72.9	80.1	86.1	87.5	90.3
	Detached	do	75.1	0	3.0	10.5	11.9	15.1	19.6	24.3	28.7	31.9	36.3	38.5	60.6	69.2	76.0	82.8	84.0	87.4
Sept. 13 to 15	Attached	Unsealed	75.9	0	7.4	13.2	17.4	22.1	26.9	32.1	37.6	42.9	47.0	51.1	76.7	82.5	85.8	88.9	90.0	92.3
	do	Sealed	75.4	0	7.2	12.5	17.1	22.0	26.8	32.0	37.6	43.0	47.3	51.0	77.0	82.3	85.9	88.7	89.9	92.1
	Detached	do	75.8	0	6.0	11.0	15.9	20.9	26.3	31.5	37.1	42.1	46.4	50.1	73.1	79.6	83.1	86.5	87.7	90.4
Average	Attached	Unsealed	76.2	0	7.5	12.6	17.0	20.7	25.4	30.1	34.9	39.2	43.1	46.2	70.7	77.9	83.2	87.6	88.9	91.1
	do	Sealed	75.4	0	7.4	12.1	16.7	20.5	24.9	29.8	34.5	39.1	43.0	46.0	70.2	77.6	83.0	87.4	88.7	91.2
	Detached	do	75.5	0	4.5	10.8	13.9	18.0	23.0	27.9	32.9	37.0	41.4	44.3	66.9	74.4	79.6	84.7	85.9	88.9

TRANSPIRATION FROM LEAVES AS A FACTOR IN DRYING STEMS

A direct comparison may be made of the rate of water loss from the alfalfa having its leaves intact with that from alfalfa having the leaves removed and all cut ends of the branches sealed. Since bleeding was prevented, any pumping action of the leaves in drying out the stems should be reflected in a differential rate of water loss from the two kinds of samples. As an average for the 16 successive readings, the rate of water loss was retarded 3 per cent by removing the leaves. This slight difference is not regarded as significant, since it may have been due in part to an unavoidable waxing of the stem epidermis in close proximity to the cut surface at the time of applying the wax.

All of these data suggest that both bleeding from the stem ends and the transpiratory function of the leaves are negligible factors under field-curing conditions.

DISCUSSION AND CONCLUSIONS

In view of the fact that nearly three-fourths of the protein of alfalfa is found in the leaves, any practical plan for curing the hay will be directed toward leaf conservation. The loss from leaf shattering is twofold. It results in an actual reduction in the yield and also in the quality of the hay. In these tests the leaves constituted 47 per cent of the entire crop, and analysis showed their protein content to be 141 per cent higher than that of the stems. The self-evident relation of leafiness to protein content and feeding value is borne out by the high average correlation coefficient of 0.864 ± 0.011 between the two factors—leafiness and protein content. Another important consideration is the avoidance of unnecessary damage due to rain. This is best accomplished through the use of methods that hasten the evaporation of moisture from the alfalfa and thereby shorten the interval between cutting and storage. So long as the forage remains in the swath, windrow, or cock, it is subject to spoilage due to rain. This often leads to serious discoloration and mustiness, as well as added loss of leaves. The trade regards the presence of mold or must so unfavorably that hay so affected is immediately designated as Sample grade.

Conclusions may be drawn from the average of six duplicate curing tests regarding the degree to which various practices succeed in meeting these specified requirements. It appears that there may be considerable latitude in procedure and yet that adherence to certain cardinal principles leads to best results.

The question often arises as to what is the best time of day to cut alfalfa with respect to likelihood of favorable curing. No marked difference was experienced in the time required or in the quality of hay, whether the cutting was done in the morning, at midday, or in the late afternoon, provided comparable swath curing preceded raking. Naturally, cutting should be delayed until the dew has dried from the plants. Whatever the time of cutting, the raking should be done before the leaves dry sufficiently to cause much shattering. No specified time limit can be set for the duration of this initial curing in the swath because of variability in both weather and condition of the hay. Ordinarily a period of about four to eight hours in the swath prior to windrowing will materially facilitate rapid drying in case the hay is cut in the forenoon or early afternoon. Favorable results may be expected by cutting in late afternoon and delaying the raking until after the dew has dried off the following forenoon. Very little discoloration will result from a heavy dew or light rain while the cut alfalfa is still in a fairly fresh or unwilted condition. In these tests, raking the hay immediately following the mower has lengthened the curing period and lowered the color regardless of the type of rake or the size of windrow.

If for any reason alfalfa hay has been permitted to overcure in the swath so that handling in this dry condition may result in serious loss of leaves, such leaf shattering may be materially lowered by raking early in the morning while the hay is tough from dew. The leafiness of overcured hay was 6 per cent greater when raking was done in the morning while the hay was damp than when raking was delayed until midday.

As might be expected, increase in size of windrow resulted in reduced curing rate. It may be assumed that the larger the mass the slower the evaporation. This is especially pronounced in the case of immediate raking. In averaging six tests, small, medium, and large windrows containing 2, 4, and 8 mower swaths, respectively, the hay required 64, 80, and 92 hours to reach a fairly comparable cured condition when raked immediately after cutting. When four hours' swath curing preceded raking, the hay in corresponding windrow sizes required 50, 60, and 71 hours, respectively.

The direction of raking with either type of rake, whether parallel or crosswise to the mower swath, had no material effect upon either the rate of curing or the quality of the hay. The same may be said with respect to the direction of the windrow.

From the data at hand it appears to make no difference in the quality or curing rate of the hay whether it is windrowed with a side-delivery or a sulky rake, provided comparable conditions are maintained. Of course, if the customary small windrow made by the side-delivery rake is contrasted with the usual large windrow of the sulky rake, it is to be expected that the former will cure more rapidly. When comparable windrows of equal size were compared, the sulky rake was fully as effective with respect to drying rate. In the case of immediate raking, small windrows made by a side-delivery rake required 64 hours and large windrows made by a sulky rake 90 hours to reach a cured condition. Reversing the comparison, small windrows made by a sulky rake cured in 63 hours and large windrows made by a side-delivery rake in 94 hours. A continuation of the normal functioning of transpiration by the leaves in withdrawing moisture from the cut stems within the windrows appears equally unimportant with windrows made by either type of rake. Evidently choice of rake type may be based upon questions pertaining to their comparative efficiency of operation.

Under normal conditions the time required for curing may be somewhat shortened by turning the windrows. Such treatment after 4 hours of windrow curing shortened the curing period 16 hours when the hay was raked immediately after cutting and 4 hours when it was raked 4 hours after cutting. No change in commercial grade resulted from such turning, although the color was somewhat improved in the case of hay raked immediately after cutting.

Under some circumstances, as in the case of rain or very slow drying weather, it may prove desirable to turn the windrows. The side-delivery rake is superior for this purpose.

Ordinarily under such conditions as prevail in Nebraska, cocking alfalfa hay as a part of the curing procedure is inadvisable. Such practice, regardless of the size of cocks, retards moisture loss and exposes the hay in the field to greater chances of damage from rain. In these experiments the time required was increased nearly threefold as compared with combined swath and windrow curing. Cocking did not appreciably improve the color, leafiness, protein, or other properties of the hay. On the other hand, because of rain and slow drying, it frequently resulted in musty or moldy forage which of necessity was placed in Sample grade.

Under continued favorable drying conditions, a maximum of color and leafiness is retained by the hay placed in relatively large windrows or cocks as soon as it has reached a wilted condition. Loss of color through bleaching is then largely in proportion to the amount of surface exposure.

Turning or scattering partially cured windrows or cocks that have become wet from rain has shortened the period of curing 28 hours as an average for 33 trials. Such turning had practically no effect upon the color, leafiness, or protein content. However, more cases of Sample grade, due to mustiness, developed where the hay was not turned.

Hay dried in 2¾ hours with heated air by means of a forced draft did not differ materially in quality from hay requiring 127 hours for curing indoors, and it was but slightly higher in color, leaves, and protein than hay cured in the field by a favorable combination of swath and windrow curing. In a poultry-feeding comparison by the poultry department of the Nebraska station, in which artificially dried and field-cured alfalfa samples from these experiments were included in a basic ration which was lacking in vitamin A, no significant differences resulted.

Regardless of the curing practice, all hay of good quality produced in these experiments was characterized by a sweet fragrant odor. In no case, however, was a distinct aroma observed.

Considerable interest has attached to the question of how the moisture is removed from the stems of cut alfalfa during the curing process. Investigations of this problem have indicated that neither bleeding from the cut end nor transpiration by a continuation of normal leaf functioning are appreciable factors. The internal moisture appears to make its exit by direct evaporation through the stem epidermis, which is well supplied with stomatal apertures.

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