UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 873

Contribution from the Bureau of Markets
GEORGE LIVINGSTON, Chief

Washington, D. C. September 15, 1920

THE SHRINKAGE OF MARKET HAY

By

H. B. McCLURE
Specialist in Hay Marketing

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INTRODUCTION.

There is a widespread misunderstanding regarding the so-called loss caused by shrinkage of hay. The Department of Agriculture is constantly receiving requests for definite statements as to the extent of this loss under various conditions, and for methods of curing and storing hay which will tend to prevent loss by shrinkage. Most of these inquiries come from those who want data on shrinkage or loss after the hay has been put into the barn or stack. A few, however, wish to know how much shrinkage takes place from the time hay is cut until it is sufficiently cured to be removed from the windrow or cock. Those interested in shrinkage are hay growers, country shippers, city receivers, commission men, brokers, and consumers in nonproducing territories.

Any request from the producer for data on this subject immediately and naturally suggests this question: "Why should the hay grower, in general, worry about *loss* due to shrinkage?"

The answer is that the farmer believes that a substantial loss usually occurs when hay is stored in the barn or stack, when, as a matter of fact, ordinarily there is no loss of feedng value, and properly no loss in market value. (For a definition of market hay as discussed in this bulletin see p. 30.)

Those who have been accustomed to regard all kinds of field-cured hay as marketable hay at the time it is stored and the loss of water as a real loss will be interested in the following report on some experiments conducted at the Kansas Agricultural Experiment Station in 1904:

Occasional reports have appeared in the agricultural press of the Middle States advocating the baling of clover hay while in a wilted or partially cured condition, claiming that the method was an economical practice, and that it made a better grade of hay than could be made in the ordinary way. These reports have led to considerable discussion among western farmers and in the farm papers as to whether alfalfa could be profitably handled in the same way. In order to determine at what stage of curing alfalfa may safely be baled, and whether this method of handling the crop is a practical one, the Farm Department conducted the following experiment last season:

The baling was done July 16 with a 14 by 18 * * * [two-horse] hay press * * * . This press has a capacity of 1 ton or more of prairie hay per hour. The alfalfa used was the second cutting of medium growth, from an old field, and was about one-fourth in bloom when cut. Fifteen bales were made from green alfalfa, which was raked and hauled to the baler immediately after being mowed. Six bales were made from alfalfa that was wilted, having been mowed in the morning and baled in the afternoon of the same day. Fourteen bales were made from alfalfa that was cut July 14 and put in cocks July 15. This alfalfa was in the "sweat" when baled, and did not differ much in moisture content from the wilted alfalfa. Nineteen bales were made from well-cured hay in proper condition to stack.

TABLE XVI.—*Giving data on baled alfalfa.*

Stage of curing when baled.	Average weight of bales at baling.	Average dry weight of bales Oct. 12.	Loss of weight.
	Pounds.	*Pounds.*	*Per cent.*
Green	164	57	65.2
Wilted	167	92	44.9
In sweat	171	96	43.9
Well cured	81	76	6.2

Baling green alfalfa was hard work for the men and teams, and was also a strain on the press. The cured hay handled much easier and baled faster. It will be observed from Table XVI that the average weight per bale of the cured alfalfa, when baled, was 81 pounds, while that of green alfalfa was 164 pounds, and the wilted 167 pounds. The wilted alfalfa was pressed tighter than the green alfalfa. The men who did the baling were inexperienced in the work and were able to make about twenty 3-foot bales in an hour from the green alfalfa. About one and one-fourth hours were required for making the same number of bales of the wilted alfalfa. The capacity of the baler was not tested in the dry alfalfa, but 10 tons per day of 10 hours would represent about the average capacity of the press.

The bales of alfalfa were stored in an open shed and placed on edge in single vertical tiers, a space of 6 to 10 inches being left between the tiers to allow a free circulation of air. The uncured alfalfa was examined at frequent intervals, and notes made on its condition of curing. It had developed considerable heat within 24 hours after baling, and the fermentation lasted about 25 days. The outsides of the bales which were exposed to the air were not at any time very warm, but the interior was very much heated. On October 12 the alfalfa bales were weighed and examined. All of the hay was found to be well dried. The bales from the green alfalfa were very light, and the wires were so loose that the bales could scarcely be handled. There was no good hay in any of these bales, and not much that would be eaten by stock. Much of the hay was covered by a white mold, and some of it seemed to be partially rotten. The hay which was baled when wilted and that baled from the cock was about of the same grade, and but little better in quality than the hay which was baled when green. The heavier and more closely pressed bales contained the best hay, but none of it was salable hay, and the best of it was inferior for feeding. The hay which was baled after being cured was seemingly as good a grade of hay as when baled, and just as good as if it had been stacked. It had a good color and the leaves were well retained. It would grade No. 1.

It may be concluded from this experiment that it is not advisable to bale alfalfa except when it is well cured and dry enough to stack * * * . (Kansas. State Agricultural Experiment Station. Bul. 123. March, 1904. Pp. 230–232.)

In this experiment an attempt was made to bale and market alfalfa in different stages of curing. The interest centers around the baling of hay when wilted and also in the sweat. It was found that such hay spoiled in the bale and was not even fit for feeding. The loss by shrinkage in the bale amounted to about 45 per cent, which was about the same as the loss in experiment 1, page 4. Thus it will be seen that it is an error to class such material as hay and to regard loss of water as causing a loss to the producer. The experiment also bears out the view that hay can not be classed as hay unqualified, until it has passed through the "sweat" which is the final stage of the curing process. It will be of interest to note that the hay which was well cured and in condition to be baled lost only 6.2 per cent of water when stored so that the air could circulate freely between the bales.

Commercial dealers in hay, on the other hand, sometimes sustain actual money losses on account of shrinkage, as, for example, when partially cured hay, containing more than the normal percentage of water, is delayed too long in transit, or when it is held for a considerable length of time in storage. If such hay is kept moving rapidly through the successive steps of marketing any loss that may be entailed by shrinkage will be so distributed that it will not seriously affect anyone, except, perhaps, the consumer. Even the latter does not lose if he buys by the bale rather than by weight.

Cases in which serious loss is entailed by shrinkage are the exception. Heavy shipments of "new" hay do not usually appear on the market until after the process of shrinkage is practically over; indeed, hay is not customarily classed as marketable until it is thoroughly cured; that is, until it has almost ceased to shrink. Thus it appears that no one has any real reason to feel seriously concerned over the question of shrinkage, least of all the producer.

As a matter of fact, however, a great many persons believe this question to be a vital one. All farmers know, of course, that if 100 tons of hay, for example, is put into the barn early in July, there may be a considerably smaller tonnage there three or six months later. (See experiment 6, p. 5.) In some instances there may be only 80 tons or even less when it is baled or weighed out several months later. Many hay growers have been led to believe that, in a case like this, a positive loss has been sustained of about one-fifth of the tonnage harvested. If it were true that an actual loss of nutrients takes place, there would be good reason for the hay grower to become alarmed and seek information that will enable him to prevent it. That the department is often asked to furnish data regarding methods of curing and storing hay which will tend to prevent shrinkage is evidence that many farmers believe that the question of shrinkage is a serious one.

Some farmers make a practice of weighing newly made hay just before it is put into the barn and wish to know the amount of shrinkage that will take place, under average conditions, in order to be able to estimate the amount of hay there will be after the shrinkage has ceased. This knowledge is desirable when estimating the quantity of hay that is needed on the farm or the quantity that can be sold at some later date. Buyers and shippers of hay often buy hay baled from the cock or windrow and then hold it for some time before selling it. A general knowledge of the question of shrinkage would be of value to them.

It is the purpose of this bulletin (1) to give data on the average water content of several kinds of hay at harvest time, (2) on the loss of water and dry matter during the curing process, (3) on the loss during the time the hay is stored, and (4) to point out when shrinkage in hay is an actual loss and whom this loss affects, and when the apparent loss is not a real loss, but is simply a natural result of the normal curing process that all good hay must undergo.

RÉSUMÉ OF DATA ON SHRINKAGE.

During the past 30 years many experiment stations have conducted experiments to ascertain the loss occurring in hay when stored for varying lengths of time in the barn or stack. The following selected data, arranged in order of decreasing percentages of loss reported, show what has been accomplished in trying to ascertain the rate of shrinkage in hay:

(1) The largest loss due to shrinkage is reported by the Pennsylvania station.[1] Two plots of clover, not adjoining, were cut at each of three periods of growth, (1) the clover heads in bloom, (2) partly dead, and (3) nearly all dead; the dates of cutting were June 22, July 3, and July 19. The hay was weighed when put into the barn, and then reweighed five or six months later, in order to determine the weight of the "dry" hay. The hay cut in bloom lost 42.2 per cent, that cut when partly dead lost 44.2 per cent, and that cut when heads were all dead lost 25.7 per cent.

(2) At the Missouri station[2] a stack of second-growth clover, weighing when put up in July 6,514 pounds, shrank in weight by the following March to 4,548 pounds, a loss of 30 per cent.

[1] Pennsylvania State College, Report for 1886, pp. 271-276.

[2] For report of experiment see Michigan, State Board of Agriculture and Experiment Station, 1901, p. 287.

(3) At the Pennsylvania station (see footnote[1], p. 4) the average shrinkage of early-cut timothy hay (in bloom and stored in the barn) was 25.7 per cent and of the late-cut timothy (nearly ripe) 18.8 per cent; varying in the former case from 14.9 per cent to 36.5 per cent and in the latter case from 15 per cent to 23.4 per cent. The average loss for all cases during two years was 22.2 per cent.

(4) At the Arizona station[3] in 1906 the third crop of alfalfa from the entire farm was cut and the stack completed about July 20. This stack contained 23 tons and 1,796 pounds. The stack was sold December 14 and at that time contained 17 tons of first-class hay and 2,825 pounds of poor hay, or a total of 18 tons and 825 pounds—a shrinkage of 5 tons and 971 pounds, or 23 per cent.

(5) At the Michigan station (see footnote[2], p. 4) on August 31 and September 1, 1896, 6,110 pounds of hay were put into the barn, made from clover sown in the spring of 1896. The growth had been succulent, but the hay was well cured. On February 6 following, during a period of damp weather, it was taken out and weighed and found to have lost 22.6 per cent. A portion of it was musty when reweighed.

(6) This station also reports[2] a similar loss with timothy hay. In the summer of 1887, 130.5 tons of timothy, in good condition, were put into the barn. The following January 100.5 tons were baled. The chaff, dirt, and short hay from under the press amounted to 1.5 tons. This indicates a shrinkage of 28.5 tons, or 21.7 per cent.

(7) Wale[4] found that the shrinkage of meadow hay in the stack several months amounted to 17.33 per cent. Clover hay stacked for several months lost from 15 to 17 per cent.

(8) A stack of alfalfa hay, containing 19,372 pounds, was made at the Colorado station[5] June 15, 1899. The following February it contained 15,904 pounds, a loss of 3,468 pounds, or 17.9 per cent.

(9) At the Utah station[6] a ton of timothy hay was weighed and placed in the barn July 20. On April 20, nine months later, it weighed 1,686 pounds. The loss amounted to 15.7 per cent.

(10) At the Kansas station[7] a bag of millet hay was buried in the mow from July 21 until the following March. The loss during the eight months amounted to 14.25 per cent.

(11) At the Michigan station[8] on July 6, 1898, 5,763 pounds of Mammoth clover hay that had been fairly well cured the day before,

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[2] For report of experiment see Michigan, State Board of Agriculture and Experiment Station, 1901, p. 287.
[3] Arizona Agricultural Experiment Station, Eighteenth Annual Report, 1907, p. 224.
[4] Journal South-Eastern Agricultural College, Wye, No. 18, 1909, pp. 52–53.
[5] Colorado Agricultural Experiment Station, Bul. 57, 1900, p. 7.
[6] Utah Agricultural Experiment Station, Fourth Annual Report, 1893, p. 36.
[7] Kansas Experiment Station, First Annual Report, 1888, pp. 117–121.
[8] Michigan State Board of Agriculture and Experiment Station. Annual report, 1901, p. 286–287.

kept in the heap overnight in the field, and hauled to the barn at 9 a. m., was stored in one of the large bays in the station barn. The hay had been very dry when raked. On February 18, 1899, the hay weighed 5,117 pounds, showing a shrinkage of 646 pounds, equivalent to 11.2 per cent in 7 months.

(12) Investigations made at the Kansas station [9] led to the conclusion that, as stacked, well-cured alfalfa will contain from 16 to 24 per cent of moisture, fully air-dried hay from the stack or mow should contain 10 to 12 per cent of moisture, and the average shrinkage of well-cured alfalfa hay put into the stack or mow, by loss of moisture, should not be greater than 10 per cent.

(13) At the Missouri station [10] 5,678 pounds of timothy was stacked as drawn from the field. When weighed the following spring, it had shrunk to 4,972 pounds, a loss of about 12.7 per cent.

(14) At the Kansas station (see footnote 7, p. 5) orchard grass hay lost 9.01 per cent and bluegrass hay lost 10.05 per cent in the mow in 6 months.

(15) At the same station (see footnote 7, p. 5) a bag containing prairie hay buried in the mow for 6 months lost 7.33 per cent.

(16) At the Michigan station (see footnote 8, p. 5) on June 27, 1896, 5 tons of very dry timothy was drawn from the field and, after weighing, was placed in the barn in a mow, separated from the rest of the hay in the barn. It was, later, temporarily covered with grain in the straw. Six months later, on January 26, it was removed and found to have lost 684 pounds, or nearly 7 per cent.

(17) At the Kansas station (see footnote 7, p. 5) a mixture of orchard grass, clover, and a little timothy, buried in a bag in the mow for 6 months, lost 5.71 per cent.

(18) At the Michigan station (see footnote 8, p. 5) in July, 1897, 1,100 pounds of clover hay, containing a little timothy, was put in the barn directly from the windrow, being unusually dry for hauling from the field. It was reweighed November 12 following, when it showed a loss of but 398 pounds, or 3.6 per cent.

(19) At the Utah station (see footnote 6, p. 5) a ton of clover hay put in the barn July 15, 1892, and removed April 20 following, lost 75 pounds, or 3.75 per cent.

(20) At the Kansas station (see footnote 7 p. 5) three tests with prairie hay buried in the mow for 6 months showed that the loss amounted to about 3.50 per cent.

(21) At the same station (see footnote 7, p. 5) one bag of prairie hay, buried in the mow for 6 months, lost only 0.58 per cent. In another case the loss amounted to but 0.29 per cent.

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[9] Kansas Agricultural Experiment Station. Bul. 155, 1908, p. 258–259.

[10] Michigan State Board Agriculture and Experiment Station. Annual report, 1901, p. 286–287.

GAIN IN WEIGHT IN HAY IN THE STACK AND BARN.

In some of the experiments carried on to determine the rate of shrinkage occurring under average conditions, it was found that instead of a loss there was a decided gain in weight in hay in the barn and stack during several months. The results of some of these experiments are as follows:

(22) At the Kansas station (see footnote 7, p. 5) a bag of prairie hay buried in a mow of hay for 4 months gained 0.4 per cent.

(23) A bag of clover hay, at the same time, gained 3.17 per cent in 4.5 months.

(24) Gains have also occurred when large amounts of hay were used in experiments. At the Utah station (see footnote 6, p. 5) 4,565 pounds of timothy hay was stacked on July 20, 1892. On April 21, 9 months later, the hay was weighed and found to have gained 70 pounds, or 1.5 per cent.

(25) Again, at the same station (see footnote 6, p. 5), 4,090 pounds of clover was stacked on July 15, 1892, and the following April the hay weighed 4,528 pounds, showing a gain of 438 pounds or 10.7 per cent.

DATA NOT CONCLUSIVE.

In evaluating the results of these experiments two outstanding facts must be taken into consideration. The first is the wide and seemingly unexplainable variation in the percentages of loss due to shrinkage. The extreme loss, experiment 1, amounts to 44.2 per cent. The losses found in the other experiments gradually decrease until a minimum loss of only 0.29 per cent is found in experiment 21. Experiments 22 to 25 show actual gains in weight, varying from 0.4 to 10.7 per cent. In other words, the extremes show a range of gain and loss amounting to 55 per cent from the time the hay was taken from the field until it was well cured in the stack or barn.

The second fact to be considered is the lack of data concerning the manner in which the experiments were carried out. There are practically no data on the methods used in curing the hay or the treatment the hay received up to the time it was removed from the field. In order to interpret or understand the results secured in a shrinkage experiment it is necessary to note carefully every factor that may have a bearing on shrinkage. These are the factors that every good haymaker observes and makes allowances for, more or less, when making hay, such as condition of the weather, presence or absence of dew, temperature, clouds, wind, humidity, all factors which bear on the rapidity of curing; the yield, whether light or heavy; the use of the tedder to accelerate curing; length of time the hay is in the swath, windrow, bunch, or cock; time of day the hay is put into the barn or stack; and water content of the hay when stored.

When data on these vital factors are included along with the results of a shrinkage experiment, the loss or gain in weight, whether it be large or small, at once becomes easy to interpret and will be found to be in accord with the natural laws that govern the curing of hay.

Many shrinkage experiments have been made without determining the water content, either at the time the hay was taken from the field or at the end of the experiment. (See experiments 2, 4, 5, and 6.) The hay was merely weighed when put into the barn or stack and again at a specified later time and the amount of loss by shrinkage was determined by the difference between the two weights. It is the publishing of the results of such experiments, especially when a comparatively large loss occurred, that has led many hay growers to believe that an actual instead of an apparent loss takes place when hay is in storage for some time.

This belief has been further strengthened, in some instances, by statements to the effect that besides the loss of water there has been a loss of dry matter, because of fermentation (the amount of which, however, is unknown) without giving adequate evidence to show that any such loss has occurred or even that conditions were favorable for fermentation.[11] The loss of dry matter will be discussed later.

FACTORS AFFECTING DETERMINATION OF SHRINKAGE.

FIRST FACTOR—WATER CONTENT WHEN CUT.

There is a great difference in the amount of water contained in grasses and legumes when cut, while curing or being made into hay, and after becoming well-cured hay. A knowledge of the normal water content of hay in these various stages will throw light on what may be expected to happen during the final stages of curing. Table I, compiled from Henry's Feeds and Feeding, shows the average water content of different kinds of hay, as determined by a long series of tests.

TABLE I.—*Water content of "unwilted" hay.*

	Average.	Minimum.	Maximum.	Difference between extremes.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Timothy, at different stages	61.6	47.0	78.7	31.7
Redtop, in bloom	65.3	51.5	76.2	24.7
Red clover, at different stages	70.8	47.1	91.8	34.7
Alsike clover, in bloom	74.8	72.3	77.3	5.0
Alfalfa, at different stages	71.8	49.3	82.0	32.7
Cowpeas	83.6	72.8	93.1	20.3
Soy beans	75.1	63.6	81.5	17.9
Johnson grass	61.0	51.1	70.8	19.7
Barley	76.8			
Oat	73.9			
Rye	78.7			
Wheat	72.6			

[11] Utah Agricultural Experiment Station, Third Annual Report, 1892, p. 47-48. U. S. Department of Agriculture, Bulletin 353, 1916, p. 6, 17.

Forage plants contain comparatively large amounts of water at harvest time. The average water content of timothy, redtop, Johnson grass, and other grass hays is from 60 to 70 per cent. The water content of alfalfa, clovers, cowpeas, etc., is somewhat higher, ranging from 70 to a little more than 80 per cent. The maximum water content of hay plants occurs, not at harvest time, but when they are young and are growing vigorously. As the plant approaches maturity its water content is gradually lessened,[12] because the growing has almost stopped and the plant requires only sufficient food to mature its seed. The minimum water content is found at this stage.

There is a rather wide difference between the maximum and minimum water content of grasses and legumes at the time they are cut for hay, depending largely on the length of the harvest season, which sometimes exceeds three weeks. Hay cut at the earliest possible date will have a much larger water content than that cut at the end of the haying season. The variation in the quantity of water in timothy cut at these two extremes amounts to almost 32 per cent. (See Table I.) A slightly greater difference is found in some of the legumes, clover and alfalfa, for example.

This great variation in the quantity of water in hay when cut is alone ample cause for a considerable difference in the amount of shrinkage that occurs in the barn or stack. This is the first important factor that influences shrinkage of hay. In actual practice it frequently happens that hay cut at the end of the haying season is more throughly cured than that cut at the beginning of the season, because the late-cut hay will lose a greater percentage of its total water content in a given length of time, other things being equal, than will early-cut hay "full of sap." Therefore it is obvious that there may be a considerable difference in the water content of two lots of hay when they are removed from the field and, consequently, a difference in the amount lost by shrinkage. The water content of field-cured hay varies considerably, as is shown in Table II.

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[12] See Utah Agricultural Experiment Station Bul. 48, 1897. Alfalfa or lucern for water content of alfalfa from May 4, when plant was 6½ inches high, until August 24, when leaves were dry.

U. S. Department of Agriculture. Bul. 353, 1916.

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TABLE II.—*Water content of field-cured and well-cured barn and stack-cured hay.*[1]

	Field-cured hay.	Well-cured barn or stack hay.		
	Maximum.	Minimum.	Average.	Difference between minimum and maximum water "content."
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Timothy (all analyses)	28.9	6.1	11.6	22.8
Timothy, early to full bloom	28.9	7.0	12.8	21.9
Timothy, late bloom to early seed	21.6	7.0	14.1	14.6
Redtop (all analyses)	[2] 28.0	6.8	9.8	22.2
Redtop, in bloom		6.8	8.0	
Alsike clover		5.3	12.3	
Alfalfa (all analyses)	30.0	4.6	8.6	25.4
Red clover (all analyses)	31.3	6.0	13.0	25.3
Cowpea		7.6	9.7	
Soy bean	20.0	6.1	8.6	13.9
Johnson grass			10.1	
Barley	15.0	6.4	10.0	8.6
Oat	26.5	9.5	12.0	17.0
Rye			8.1	
Wheat			8.1	
Prairie	17.1	6.5	10.0	10.6

[1] Taken from U. S. Department of Agriculture Farmers' Bulletin 22, 1901, Henry's Feeds and Feeding, 16th edition, and various experiment station reports.

[2] Estimated.

SECOND FACTOR—MAXIMUM WATER CONTENT WHEN STORED.

Available experimental data and the experience of practical hay makers establish the fact that there is a wide variation in the amount of water in hay when put into the barn and stack. This is the second important factor bearing upon the percentage of shrinkage in hay. The highest recorded percentages of water in hay when put into the barn and stack (see Table II) show that the average maximum for timothy, alfalfa, and red clover is about 30 per cent, timothy 28.9 per cent, alfalfa 30 per cent, and red clover 31.3 per cent. It is not known under what conditions hay with a 30 per cent water content will cure out properly, or whether the safe maximum is higher or lower than this amount, since here again there is a lack of definite data that would be of utmost value to the haymaker. No systematic experiments have been made to determine the maximum water content that field-cured hay may have without subsequent injury by heating.

It is safe to assume that the three lots of clover used in experiment 1 (p. 4) contained considerably more than 30 per cent of water. Their losses by shrinkage were 42.2, 44.2, and 25.7 per cent. If these lots when cured contained the average amount of water found in good barn-cured hay (13 per cent), it follows that they contained 49.7, 51.4 and 35.3 per cent of water, respectively, when put into the barn. It is not known whether the hay in these experiments cured out properly or was spoiled because of the high water content, but in one case (experiment 5, p. 5) clover hay, which lost only 22.6 per cent by shrinkage, was partly musty at the end of the experiment. Considering that the normal water content of cured hay amounts to 13 per cent, the percentage of water in this particular lot at the time it was put in the barn was 32.66 per cent.

The Kansas station [13] has found that alfalfa containing as much as 24 per cent of water will cure out properly in the stack. In the semiarid West it may be safe to stack hay containing more than 24 per cent of water, while in the South and parts of the East, where the humidity is greater and unfavorable weather often prevails, it may not be safe to put up hay with such a large water content.

THIRD FACTOR—NORMAL WATER CONTENT WHEN CURED.

The normal water content of cured hay is the third important factor to be taken into account. Shrinkage in hay practically ceases when the water content reaches a certain point which varies with climate (See "Average," Table II), and not until then is the curing process finished in barn or stack hay, which may then be rightly classed as well-cured, marketable hay. As the water content of hay baled from the windrow or cock is sometimes above normal, it is subject to shrinkage in the bale. The average normal water content of hay is the amount of water usually contained in hay after it has passed through the "sweat" or "heat" in the stack or barn and is ascertained by averaging all available water-content analyses. In the case of timothy (see Table II), 221 water analyses have been averaged, giving an average of 11.6 per cent. In the cases of other hays fewer analyses are available, which probably accounts, in part at least, for the variation in the figures presented as representing the average water content of the different grass and legume hays.

FOURTH FACTOR—MINIMUM WATER CONTENT.

Sometimes hay becomes very dry. In fact, in the West "dry" hay is discriminated against on account of the loss by shattering and because it is thought to lack palatability. The water content in "dry" hay is shown in Table II, under "minimum." When the percentage of water in hay is so low that the air will no longer absorb any of it, the hay is said to contain a minimum amount of water. The minimum water content which is the fourth factor depends upon the humidity of the air, length of time the hay is exposed to such air, and the amount or bulk of hay in the stack or barn.

To lower the natural minimum it is necessary to subject the hay to artificial drying, as is done in the laboratory when making a determination of dry matter. The figures given in the table do not imply

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[13] Kansas Agricultural Experiment Station, Bull. 155, 1908. pp. 258–259.

that hay usually becomes that dry or that the hay grower should expect such a low water content under average conditions. A low minimum water content is reached naturally only during very unusual conditions, such as a long exposure in a very dry and hot climate like that found in the Southwest. Neither should it be expected that the water content, having once reached the minimum, will remain constant, unless the temperature and humidity of the air remain constant, a condition which does not prevail in the larger part of the hay-growing section of the United States for any great length of time.

From the data presented it is shown that the minimum water content of timothy is 6.1 and of alfalfa 4.6 per cent. The minimum for the other kinds of hay is slightly higher—the average for all being 6.52 per cent. If the average or normal water content figures are averaged for all of the hays for which the minimum has been figured, it is found that hay, in general, contains about 10.32 per cent of water when well cured. The difference between the two averages is 3.6 per cent.

FIFTH FACTOR—ATMOSPHERIC HUMIDITY.

The water content of cured hay in the stack, barn, or bale is subject to fluctuations, caused by changes in atmospheric humidity which is the fifth factor to be considered. If hay contains a larger percentage of water than does the air there will be a loss by evaporation. If the hay is drier than the air it will absorb water. A change in humidity affects a small quantity of hay to a relatively greater extent in a given time than it does a large bulk.[14]

Oat hay was baled on June 1, 1913. The average loss during July and August, when the weather was unusually dry and hot, amounted to 1.4 per cent. Small samples, weighing 44.5 ounces, taken from the bales and inclosed in cotton bags and suspended under shelter, where the air could circulate freely, lost an average of 4.3 per cent during the same period. Again, on June 1, 1913, four large bales of oat hay, averaging 243.8 pounds, were made. The loss by August 1 amounted to 9.8 pounds, or 4.02 per cent. During the first 25 days of September there was an aditional loss of 3.4 pounds, or 1.4 per cent. From September 25 to December 1 there was a gain of 1.4 per cent, which brought the weight back to 234.1 pounds, the weight on August 1.

Experiments with small bales of oat hay made the following year (1914–15) showed a much larger proportional fluctuation. The bales weighed, on an average, 178 pounds, or one-third less than the large bales used the year before. The small bales, baled on June 1, 1914, had lost 8.1 per cent by August 31. From that date until February 25, 1915, they gained a total of 5.9 per cent, making the net loss from June 1 to February 25 but 2.2 per cent. The loss was attributable to the dry weather during July and August, and the gain to the wet weather during the winter months.

It should not be inferred, from the results of experiments to date, that hay in small bales will always lose more by shrinkage, or that their normal water content will be subject to a greater degree of fluctuation than that of hay in large bales. Information is lacking on the one

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[14] U. S. Department of Agriculture, Bull. 353, 1916. p. 32.

practical point of interest to the hay maker and shipper—that is, the manner in which the bales were stored during the experiment. If they were stored separately, cross piled, placed on the top or outside of a pile, or in a small pile by themselves, then the small bales would naturally be influenced by weather conditions to a greater extent proportionally than would large bales. If baled hay is stored flatwise—that is, the bales resting on their sides and no air space allowed between, then there should be practically no difference in the amount of gain and loss due to changes in the weather, etc., between hay in large bales and hay in small bales, provided the degree of compression were the same.

Reactions from changes in the weather do not affect the entire mass of hay quickly unless the bulk is small. In large mows and stacks the hay in the interior is more or less protected by the top and side layers of hay; consequently it loses water slowly without being affected by exterior changes in humidity. The center of the stack often dries out much more slowly than the top and bottom. The Colorado station[15] found a difference of 10.3 per cent in the amount of water lost by different parts of stacked alfalfa hay. A large stack of well-cured alfalfa was put up June 15, being divided into four layers by slats. On February 12, eight months later, the loss of the different layers was found to be as follows: Bottom layer 17.6 per cent, third layer 17 per cent, top layer 23.8 per cent, and the second layer only 13.5 per cent. Experiments by Wale [16] also show a greater loss by shrinkage in the top layers of stacked hay than in the lower layers.

These experiments explain why hay that is baled after having passed through the sweat sometimes loses weight by shrinkage. The loss of water occurs in the hay taken from the middle of the stack, where it has been insulated by the hay on the outside.

It is not definitely known to what extent the degree of atmospheric humidity influences the water content in well-cured hay in the barn or stack. The data indicate that, under average conditions, the water content will vary with the weather from 2 to 4 per cent below normal, to about the same amount above normal. There is need for a number of carefully conducted experiments to determine the extent of gain or loss of cured hay in storage.

The loss by shrinkage of well-cured hay during dry weather is, in time, offset by the gain in weight during wet weather, although, in individual cases, shrinkage may cause a loss to the producer or shipper. In various hay-growing sections the high price of hay during the summer months (see p. 26) more than makes up for any loss caused by low water content.

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[15] Colorado Agricultural Experiment Station, Bull. 57, 1900. p. 6–10.
[16] Journal Southeastern Agricultural College, Wye, No. 18. 1909. p. 52–53.

SIXTH FACTOR—EFFECT OF TIME ON SHRINKAGE.

The sixth factor in the shrinkage of hay is that of time. The time factor is not nearly as important as it would seem to those who have not given the matter careful consideration. A study of the 25 experiments given on pages 4 to 7 will show that, in general, there is no correlation between percentage of loss and lapse of time, as affecting hay in the barn or stack. In other words, the amount of loss that may occur during three months has absolutely no mathematical relation to the amount occurring during six months, nine months, etc. The average loss by shrinkage in the 25 experiments amounted to about 16 per cent. The average length of the experiments was about six months, the shortest experiment lasting four months and the longest about nine months. The average loss of weight in these experiments has no significant relation to average time. (See rule for measuring shrinkage, p. 21.) The relation of time to amount of shrinkage of barn and stack hay is significant only during a comparatively short period, that is, while the hay is going through that part of the curing process commonly known as "sweating" (heating and fermentation), which lasts from three to six weeks, or perhaps a little longer. While this process or change is taking place in the stack or mow, the greatest reduction in water content also takes place, and very soon after sweating ceases the hay will be found to contain its normal percentage of water. The amount of shrinkage that takes place after the first month or two is comparatively small, and humidity or condition of the weather becomes a much more important factor than does that of time. The factor of time is important, however, while hay is curing in the field, in that it affects shrinkage later on.

SHRINKAGE OF NEWLY MOWN HAY.

It has been pointed out (see Table I) that newly-mown hay contains a large amount of water, and that about three-fourths (see Table II) of the water must be "cured out" in the field before hay is ready to be put into the barn or stack, if it is desired to make first-class hay. The prime question regarding shrinkage is not how much hay will shrink from the time it is cut until it can be stored, but how much the haymaker should allow hay to cure in the field. During ideal hay-making weather hay loses water rapidly and in a comparatively short time, if not handled properly, will lose as much as 90 per cent or even more of its water content, becoming so dry that there will be no further loss by shrinkage in the stack or barn. When this happens there is liable also to be a decided loss of color, and with legume hay there may be a large loss of leaves by shattering when the hay is handled.

Experiments [17] made in California showed that, in one instance, alfalfa cut at 10.22 a. m. lost 39.1 per cent of the water in an hour and a half, and that by 4 p. m., about 6½ hours later, it had lost 63.7 per cent of its total water content. Timothy, in Ohio, lost 30.4 per cent of water from noon until 5 p. m., when the temperature at noon was but 76° F., indicating that the conditions were not very favorable for curing.

The Iowa station [18] found that different plats of alfalfa cut and hauled on the same day may vary as much as 20 per cent in shrinkage, the hay handled early in the day possibly containing twice as much moisture as that hauled in the afternoon.

A comparatively small difference in the length of time hay remains in the field, in the swath, and in the windrow after it has cured sufficiently to be stored may make a decided difference in the amount lost by shrinkage in the barn or stack.

At the Utah station [19] two lots of clover hay put up the same day showed a difference of 14.45 per cent after being stored nine months. The hay stored in the barn lost 3.75 per cent and that stacked gained 10.7 per cent.

The knowledge which enables the farmer to tell when hay has lost just enough water to make it safe to put it into barn or stack is valuable and indeed essential, while a knowledge of the exact percentage of shrinkage that takes place during field curing is neither necessary nor helpful to the average haymaker.

LOSS OF DRY MATTER.

A part of the so-called loss in hay, through shrinkage, is sometimes due to an actual loss of dry matter. The accepted usage of the term "lost" to denote both loss in water content and a reduction in the amount of dry matter in hay after being in storage for some time is somewhat misleading. It is quite proper and self-explanatory to say that hay has lost a part of its water content, for this is exactly what has happened—the water has actually been taken out of and away from the hay. But when it is said that there has been a loss of dry matter during the shrinkage of hay, the impression may be given that the dry matter is also carried out of and away from the hay. As a matter of fact, dry matter is "lost" in a more roundabout way than is water, which evaporates whenever the percentage of water in the air is lower than that in the hay. Furthermore, once gone, dry matter can not return, as water may.

Water is a comparatively simple compound and readily changes in form as the temperature of the air varies. The dry matter of hay,

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17 U. S. Department of Agriculture Bull. 353, 1916. p. 28–30.
18 Iowa Agricultural Experiment Station Bull. 137, 1913. p. 57–58.
19 Utah Agricultural Experiment Station, Fourth Annual Report, 1893. p. 35–37.

however, is composed of a number of rather complex substances, such as protein, carbohydrates, fats, and fiber, which are not appreciably affected by the changes of ordinary air temperatures, or by time, as limited by the length of time hay is usually in storage.

If the term "destroyed" were used in place of "lost" it might better convey the idea that a loss of dry matter does not take place as easily as does that of water, or at least that the conditions under which it occurs are different. The indiscriminate use of the term "lost" and a lack of knowledge of conditions under which dry matter may be destroyed seem to have led some to assume, in certain instances at least, that dry matter has been destroyed when conditions do not warrant such an assumption.

The primary cause of loss of dry matter in hay is improper or insufficient curing of the hay before it is put into the barn or stack. Hay that contains too much water, either because it has not been sufficiently cured in the field or because it has been wet by rain, is liable to lose a part or even most of its dry matter later on. The loss of dry matter is not due merely to direct loss of water, as is sometimes supposed, but largely to conditions arising from the mistakes or misfortunes of the haymaker. Hay is stored when insufficiently cured, either because the haymaker uses poor judgment or because he is unable, on account of unfavorable weather, lack of haymaking machinery or help, to cure his hay properly. In such cases as the water content is above the maximum, destruction of dry matter is possible.

When wet or undercured hay is put into the barn or stack it soon begins to sweat and ferment, just as does properly cured hay. The degree of heat engendered in the fermentation of well-cured hay does not injure the dry matter. In the undercured or wet hay the temperature continues to rise until more or less of the hay is discolored, charred, or even burned to ashes. Such high temperatures are engendered primarily by the excess water in the hay, which creates conditions favorable for bacterial growth and chemical action, involving various changes in which heat is produced. In some instances continued cloudy, rainy, or foggy weather, by preventing the evaporation of water from the hay, may render conditions favorable for the destruction of dry matter, a situation which could not arise during dry, sunny weather.

Keable and Wale [20] found that "newly ricked hay (clover), undergoing a natural fermentation, soon reaches its maximum temperature, i. e., toward the end of the first or the beginning of the second week after the hay was put into the rick." It was also found that a second fermentation occurred, beginning about three weeks after

[20] Journal Southeastern Agricultural College. Wye. No. 18, 1909, p. 52–55.

the hay was ricked. It was also found that there was a direct relation between temperature and water content of the hay, the highest temperature occurring in the stack that contained the largest percentage of water.

The material for rick No. 1—first-cut clover hay— was in ordinary good condition for stacking, and when cut into in December was found to have undergone a rather low fermentation, being only slightly browned and in good condition.

The material of rick No. 2—second-cut clover hay— was greener when stacked, and as was to be expected, the maximum thermometer readings were somewhat higher than in the case of rick No. 1. The hay produced also showed a deeper brown color, owing to the higher temperature of fermentation.

The highest temperature occurring in the two stacks while undergoing fermentation was between 140° and 150° F. The investigator's conclusions are as follows:

It seems unlikely that any harm to the dry matter will result where the hay has not exceeded a temperature of 150°F. How much higher the temperature may safely rise it is at present impossible to say; so much depends on the size of the rick and the degree of consolidation that has taken place. The less the consolidation the more air there is present, and the higher the temperature is likely to rise. At the same time imperfect consolidation is generally to be found in ricks of small size, but on account of the small bulk more heat is lost by radiation. and hence there is less liability to fire.

According to Hoffman,[21] the organic matter in hay is destroyed at a temperature of 226° F. or over.

When spontaneous combustion occurs in clover, heat is generated in the hay, oxygen being taken up from the air and the organic matter transformed into carbon dioxid and water. The water moistens the hay, and the moistened material ferments because of the presence of bacteria. The fermentation also produces carbon dioxid and water, as well as small amounts of hydrocarbons, hydrogen, organic acids, enzymes, etc. Heat is also produced from the fermentation. The fermentation is more rapid if the clover is moistened at the beginning. However, the water produced by the oxidation of the material is sufficient to start it. The fermentation of the hay causes the temperature of 133° F. At this temperature a more violent oxidation takes place and the temperature rises to about 194° F. Other processes then take place which char the material and cause a slow rise in temperature to 226° F. When this temperature is reached, the hay rapidly heats and the charring proceeds rapidly. All these processes destroy at least half of the material. Theoretically the temperature may reach 374° F.

According to the tests made, clover hay may become ignited at 302° F. to 392° F. Therefore the temperature may rise sufficiently high to cause spontaneous combustion. Oxygen from the air is essential to combustion.

These experiments confirm the belief that there can be no appreciable loss by destruction of the dry matter in hay in storage when it has been properly cured in the field, provided the hay is protected from injury by rain. In other words, the natural sweating or curing and the resultant shrinkage of hay in the stack or barn do not involve

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[21] Hoffman, F. H., Zeitschr. Spirit-ind., 1897, Nos. 35, 39, 41, 42, 45, 47, 50, abs. in Biedermanns-Centralblatt fur Agriculturchenue, v. 27, No. 6, 1898. p. 295, 296.

a destruction of dry matter, because such hay does not contain enough water to engender a temperature sufficiently high to injure the dry matter.

It should not be inferred, however, that such loss from well-cured hay in the stack will be no greater than in the same kind of hay in the barn. It is a matter of common knowledge that there is often quite a serious loss when hay is stacked for several months. An unavoidable loss, caused by the action of the sun and rain, is sustained when hay is stacked and left uncovered. The sun bleaches the outside of the stack and rain often causes the hay to discolor or even to rot. The amount of loss in such cases depends largely upon the skill exercised in building the stack, and while the greater part of the loss is caused by discoloration, which lowers the grade and, consequently, the market value, there is also an actual loss of dry matter because of mold and rotting.

Lipscomb [22] in 1907 showed that there was a decided loss through discoloration by rain, when hay had been stacked for several months. Two stacks of timothy hay were put up in July. At the end of four months 20 per cent of the hay in one stack was found to be unsalable and fit only for bedding or feed as roughage. There was a loss of about 40 per cent in the other stack at the end of eight months. As a matter of fact, there was, strictly speaking, no great loss of dry matter, but such hay is considered as worthless or lost since it is not marketable.

METHODS OF MAKING HAY TO PREVENT UNNECESSARY SHRINKAGE.

There is no method known whereby hay can be so cured that it will retain, indefinitely, a larger percentage of water than is normally contained in such hay after it has gone through the sweat and is thoroughly cured. The water in hay is not chemically locked up as is the dry matter, and, for this reason, the haymaker is unable to control, except within very narrow limits, the water content of hay after it has once become entirely cured. A knowledge of these facts should not cause the haymaker anxiety, for, as will be shown later, the loss of water or shrinkage does not ordinarily entail a real money loss to him.

It is very important that a close watch be kept on the water content, or rather on the rapidity with which water is being taken from hay while in the various stages of curing in the field, not with a view of checking the shrinkage to take place later in the barn or stack, but because loss by shattering depends upon the dryness of the hay when handled. The more dry hay becomes in the windrow or swath the more it will lose by shattering, and this is a real loss of the most nutritious part of the plant, especially of legumes. Hence, it is highly

[22] U. S. Department of Agriculture, Farmers' Bulletin No. 362. 1909, p. 26.

important that the haymaker watch the curing of hay very closely, to note, first, just how long it may lie in the swath without shattering too much when raked into the windrow, and, second, just how soon the water content falls so low that the hay can be stored without danger of spoiling in the sweat. Incidentally another benefit accrues from handling hay at just the proper moment. The hay that has not been allowed to become too dry when stored has the best color. This is an important factor in market hay, for color "sells" hay.

STAGE AT WHICH HAY IS CUT.

The stage of maturity at which hay is cut does not affect the amount of water contained in hay after it has gone through the sweat. The Pennsylvania station [23] conducted experiments for two years to determine the best time for cutting timothy to secure the greatest amount per acre of total nutrients. There was a difference of about 16 days between the early cutting and the late cutting. The average shrinkage of early cut hay (in bloom) was 25.7 per cent and of the late cut (nearly ripe) 18.8 per cent. The amount of shrinkage was determined by weighing the hay, and had the exepriment been concluded with merely the weighing, as many others have been, the results would have indicated that it is best to cut timothy late, since there is less shrinkage, about 7 per cent in this instance, than there is in early cut hay. However, after the hay had been weighed, a water analysis was made in each case, which showed that the early cut hay contained an average of 8.94 per cent water and the late-cut hay 8.83 per cent, indicating that the time of cutting has practically no influence on the water content of thoroughly cured hay. Late-cut timothy in reality is inferior to early cut, since the former contains a smaller percentage of total nutrients and is inferior in color to the latter, and hence does not command as good a price on the market.

At the Maine station [24] two lots of timothy were cut, one in full bloom and the other 18 days later. The early cut hay lost 16.6 per cent of water in 9 months and the later-cut hay lost 18.1. At the end of the experiment the early cut hay contained 10.4 per cent of water and the late-cut hay 9.7, a difference of only 0.7 per cent.

The results of these experiments indicate that while the percentage of shrinkage of early cut and late-cut hay may vary greatly, the water content of the hay when cured does not vary appreciably with the stage of maturity at which it is cut.

[23] Pennsylvania State College. Report for 1882-86, pp. 271-276.

[24] Maine Agricultural Experiment Station, Annual Report, 1890, p. 55-67.

CURING PRACTICES.

The best way to prevent a large shrinkage in stored hay is to get rid of the greater part of the surplus water while the hay is curing in the field. If this is done, the commodity when put into the barn or stack will be good field-cured hay, instead of partially cured forage which must of necessity be subject to a large shrinkage, frequently accompanied by discoloration and destruction of dry matter by heating and other processes.

Detailed methods of curing hay[25] will not be given here, but the careful use of the tedder, or of the left-hand side-delivery rake, or both, will, in average haying weather, cause the hay to cure quickly and evenly throughout and thus prevent excessive shrinkage later on.

Heavy yields of mixed timothy, clover, and alfalfa should be tedded soon after cutting and sometimes again before being raked. If hay is left undisturbed in the swath until it is hauled the top hay appears dry and leads the haymaker to believe that it is ready to haul in. Such partially cured hay will lose considerably by shrinkage in storage. The use of the tedder will cause the hay to cure out evenly. If part of the curing is done in the windrow, the left-hand side delivery should be used, as it throws the hay into loose windrows in such a position that the air has access to it and cures it rapidly. It is safe to rake hay in a greener state when the side-delivery rake is used than with the straight or sulky rake. This is the chief advantage of the side delivery. It is not to be recommended for raking legume hay that cures altogether in the swath, because of the loss of leaves by shattering.

METHOD OF STORING.

If he thinks it worth while, the haymaker may control, to a limited extent, the loss of water from part of his hay at least, by the way in which he stores it. It has already been noted (see p. 13) that when hay is put into large mows or stacks the hay in the interior shrinks more slowly than does that of the top and sides. Water is lost more rapidly from hay in small stacks or mows than from large ones. It would not pay, however, to build large hay barns or stacks merely in an attempt to delay the escape of a comparatively small percentage of water for a short period. The economy of making large stacks depends on such factors as amount of labor required and the method of disposing of the hay, rather than on that of trying to conserve water above the normal percentage found in well-cured hay.[26] The practical haymaker does not give the matter of shrinkage any thought in deciding what size to make his stacks, as the labor involved in making a large stack counteracts the saving in shrinkage.

[25] See Farmers' Bulletin 943 for information on haymaking.

[26] See Farmers' Bulletin No. 1009 for a general discussion of size of stack to make under different conditions.

LIMITATIONS OF RULES FOR MEASURING SHRINKAGE.

If a definite rule for measuring shrinkage could be laid down, it could be used to advantage in all of the hay-growing sections. That there is a need for such a rule is shown by the number of inquiries received by the Department of Agriculture. Such a rule could be used to determine the yield of experimental plots, but its greatest use would be to the hay grower who hauls his hay on wagons to the barn and has easy access to wagon scales, for it would enable him to compute, to the ton, just how much hay he would have for sale after deducting the amount needed on the farm. Again, if he grows hay for the winter feeding of stock, he could easily determine, by using a rule for shrinkage, how much live stock he could keep during the winter. Merely weighing the hay as it comes from the field, on its way to the barn, does not give a significant figure to the average hay grower, since he does not know whether the shrinkage will be 10, 20, or 30 per cent; indeed is not sure that there may not be a gain a few months later.

The Rhode Island station used a rule allowing a 20 per cent reduction in the weight of field cured hay to represent barn-cured hay. This rule was based on the usually accepted idea of practical farmers in that State. In 1902 the actual weights of field-cured and barn-cured hay were taken to check the accuracy of the 20 per cent rule. With one plot there was an error of about 6 per cent, in another about 5 per cent, and in another about 0.5 per cent in total shrinkage. In each instance it was found that a 20 per cent allowance for shrinkage was too great.[27]

The Kansas station says, in regard to the average amount of shrinkage:

> Men experienced in handling hay usually figure on about 20 per cent loss in the weight of the hay after it is put into the mow. The statement is also made that each bale (size and weight not given) will shrink from 2 to 5 per cent in weight.
>
> It appears that the amount of moisture retained in cured hay when stacked varies with different kinds of hay and with different conditions of curing. Ordinarily the loss in the weight of hay stacked when well cured and protected from loss other than that which may occur by natural shrinkage should not be greater than 10 to 15 per cent.[28]

According to this investigator, hay in the mow loses considerably more by shrinkage than hay in the stack, provided the stack is protected from loss other than that which may occur by natural shrinkage; that is, loss from bleaching and rotting due to exposure to the weather. To prevent such loss it would be necessary to protect the top and sides of the stack, which is exactly what the barn does, and the amount of shrinkage would of necessity be the same in the barn

[27] Rhode Island Agricultural Experiment Station Bull. 82, 1902, p. 130–131.

[28] Kansas Agricultural Experiment Station Bull. 175, 1911, p. 331.

and protected stack if the same kind of hay (cured to the same degree) were placed in each. There are no experimental data showing that hay in the barn loses more by shrinkage than hay in the stack. In fact, the average loss of the hay stored in the barn, in the data cited on pages 4 to 7, amounted to 14.7 per cent, while the average loss in the stacked hay was 18.6 per cent.

An earlier statement from the same investigator regarding the average amount of shrinkage does not agree with the one just reviewed. In speaking of the shrinkage of alfalfa he says: "The average shrinkage of well-cured alfalfa hay put into the stack or mow by loss of moisture should not be greater than 10 per cent."[29] Again: "Men experienced in the handling of hay usually figure on about 20 per cent loss in weight after the hay is put into the stack or until it is sold or baled."

In these instances the implication is that there will be the same amount of shrinkage in the mow as in the stack, and in either case it "should not be greater than 10 per cent." This estimate is about half of the amount of shrinkage figured by men experienced in handling hay in Kansas.

From these and other data presented it will be seen that any general rule for measuring shrinkage would have to allow for such wide variations that it would cease to be a rule, while a rule based on the average amount of shrinkage would be of no value to the individual hay grower.

The shrinkage of hay is influenced by such variable factors as the weather, stage of maturity when harvested, and different methods of curing, and the resulting product varies from half-cured forage to dry-sunburnt hay. What the individual haymaker wants to know is approximately how much hay shrinks when cured by a given method under given weather conditions. For example, the man who lives in a dry, irrigated section and cures his hay in the swath and windrow wants to know the average shrinkage of hay cured under such conditions. Again, those who put their hay into the cock and leave it standing until it is really well cured, want to know how much hay cured in this manner will shrink. The average shrinkage of hay from all hay-growing sections means nothing to the individual. The results of experiments already made show such a wide variation that they are of but little value, if any, to the haymaker in any specified hay-growing section. (See p. 7.)

This being true, how then can the haymaker, who so desires, estimate the shrinkage of his hay? There are two ways of determining shrinkage. First, when the hay is cured in a more or less haphazard manner—that is, when no definite system is used—or when unfavorable weather interferes with the curing, average samples of

[29] Kansas Agricultural Experiment Station Bull. 155, 1908, p. 258.

the hay may be taken and a water determination made, as is done in determining the grade of shelled corn. By subtracting the average normal water content of the kind of hay in question from the average found by analysis a fairly accurate estimate may be made. This elaborate process must be repeated every year, and for every field of hay cured under new conditions. The taking of average samples will be found to be no easy matter, and it is doubtful if it will pay, in many instances, to have a water determination made. By the application of the second method it will be possible to establish a definite rule for the shrinkage of hay on a particular farm under given conditions in regions where weather conditions are fairly constant. The conditions under which it will be possible to work out such a rule are: The acreage of hay cut must be comparatively large, so that haymaking is one of the principal farm enterprises; a fully equipped crew, well organized, must be used; and the weather must not be subject to sudden changes.

In the prairie and alfalfa section of the Middle West and West haymaking is often conducted on a rather large scale, day after day, during most of the summer. In a well-organized crew the rakes are kept a certain length of time behind the mowers. The hay always remains about the same length of time in the swath and windrow and it is nearly always cured to about a standard degree when taken from the field to barn, stack, or press. In other words, the haymaking is done in a businesslike and systematic manner, and guesswork is entirely eliminated, so that well-cured hay one day means exactly the same thing as well-cured hay on any other day. Under such conditions it is possible to work out a definite and permanent rule for shrinkage. This can be done by weighing the hay before and after storing or by having water determinations made in a laboratory. The average shrinkage as determined for one year will hold true for following years as long as the system used and the conditions remain the same.

The weather in the East and South is sometimes very changeable, which makes it impossible always to cure hay as desired in the field, so that no shrinkage rule could be worked out that would apply uniformly to hay cured in these regions.

MONEY LOSS CAUSED BY SHRINKAGE.

The grower, feeder, and shipper naturally wish to know whether or not shrinkage causes a direct money loss, and, if so, under what conditions, and whom such loss affects. From a practical or economic standpoint it may be said that shrinkage becomes of importance only when it affects the feeding value or tonnage of hay. In considering such loss shrinkage will here be considered as loss of water only, since it is the loss of water in most instances, and not dry matter, that has a bearing on the practical side of the question.

Considered purely from a farm-management standpoint, shrinkage in storage always means a certain initial loss to the producer, inasmuch as the handling, hauling, and storing of hay containing an excess of water increases the cost of production by requiring extra labor and time to handle the excess weight. Sometimes this extra cost is more than offset by improvement in the quality of the hay, because it is stored as soon as it is safe to haul, and thus cures out properly in the barn or stack. The extra expense of handling heavy, improperly cured hay that will afterwards spoil by heating, however, is an absolute loss that can not be recovered when the hay is sold or fed.

THE PRODUCER DOES NOT LOSE.

The shrinkage of hay does not cause a direct money loss to the producer who feeds his hay, for the water lost has no actual feeding value, and there is just as great a total of nutrients in a barn of hay after a normal shrinkage has taken place as there was when the hay was put into the barn. In calculating rations, however, it will be necessary to feed a smaller amount of thoroughly cured hay to furnish the required amount of nutrition than when feeding "green" hay (see definition, p. 31) containing an excess of water. For this reason the producer who grows hay for feeding on the farm need not be concerned about the so-called loss from shrinkage.

When hay is grown for the market, shrinkage sometimes involves a money loss under the present system of marketing, though not to the grower. Hay is not graded according to the percentage of water contained, as is corn. Hay containing more than the normal amount of water is often shipped to market. This kind of hay does not always bring top prices, however, for if it is "hot" it may be graded down, until the price not only makes allowance for the excess weight of water contained, but also for the damage (discoloration, etc.) resulting from excessive heating during shrinkage. When hay which has passed through the sweat, but still contains a higher water content than normal is shipped to market, the producer is paid for the extra water therein at the rate paid for the hay itself. This selling of water at the price of market hay is allowable at present, but when a deliberate attempt is made to make and market hay with a water content above normal it very nearly approaches, in theory, at least what may be called "sharp practice."

The hay grower, however, should not be blamed entirely for attempting to avoid what he may think is likely to be an actual loss by shrinkage. In 1882 Jordan [30] advocated that the hay grower

[30] Jordan, W. H. Experiments and investigations conducted at the Pennsylvania State College, 1881-82. p. 7-14. [Unnumbered publication.]

protect himself against loss of water by shrinkage. He assumed that if hay was worth, say, $10 per ton when cured in the field, the producer should not receive less than this price during the remainder of the year. According to his theory the farmer should advance the price of hay sufficiently from time to time to cover the loss of water. In other words, he advocated that if hay is worth $10 per ton when made, and loses 24 per cent by winter, the producer should sell it for about $12.50 per ton.

There are serious practical objections to this theory. In the first place, it is assumed that the price of hay remains stationary during the entire year, which does not happen in practice, since the price varies according to demand, size of current crop, local conditions, etc. Again, the producer does not ordinarily determine the price of hay. This is done in the city markets, and the price of hay sold locally is based, in general, on the quotations of the nearest city market.

As a matter of fact, only a very small percentage of the annual hay crop is sold on the market while it contains an abnormally large amount of water, for during the time it is going through the "sweat," in the barn or stack, which usually continues from 3 to 6 weeks, hay is not marketable and is not in condition even to be baled. Hence there is no logical reason for assuming that the water lost during this period of the curing process causes a loss to the producer, since the hay is not a marketable product until shrinkage is over.

Neither is there any valid reason for assuming that the price of hay at haymaking time, when both old and new hay are scarce, should set the price of hay for the remainder of the year. The price of new hay during July and August is much higher in several of the leading markets than during the winter months when shrinkage has ceased. The high price of new hay is due, in part, to the comparatively small amount baled, and to the fact that during July and August farmers are too busy with such crops as hay, corn, and small grain to haul hay to market. In other words, new hay often sells for more than it is really worth, if we consider the high percentage of water it sometimes contains and the price of thoroughly cured hay during the winter months. The 20-year average monthly price ("high") of timothy in four leading markets is shown graphically in figure 1.

The amount of newly made hay sold loose from the field during the hay-making period is comparatively small, and the local price has no effect on the price of thoroughly cured market hay later on. If the price of new hay happens to be lower when hauled from the field than the price of thoroughly cured hay later, it is not necessarily because its large water content is taken into consideration, but more likely because the cost of baling is eliminated, as is also the cost of hauling and storing away or stacking, if the buyer does the hauling.

There is also another very serious and practical objection to the recommendation that the producer protect himself against loss of water by price fixing. Let us assume, for the moment, that the producer is able to fix prices on hay so that he will receive the same rate, based on the price of hay at harvest time, for a ton of dry matter during the entire year. Here the impracticability of this

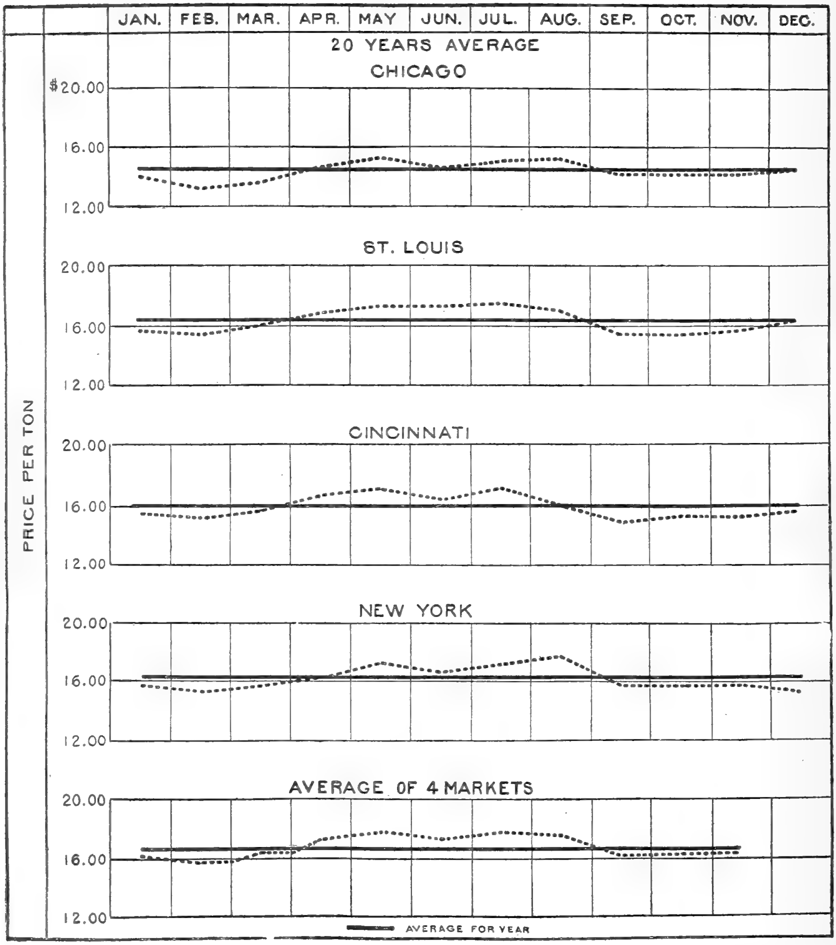

FIG. 1.—Average "high" price per ton of timothy hay, by months, for 20 years, 1896–1915, for four leading hay markets. (Data compiled from Yearbooks of the U. S. Department of Agriculture.)

scheme becomes evident. How can the producer determine the water content of his hay so that he can fix the price before it is sold? He can not very well reach all parts of the mow or stack to get the sufficient number of average samples to ascertain the actual water content by a chemical analysis. Samples can easily be taken while the hay is being baled, but the greater percentage of hay is sold or the price per ton is agreed on before it is baled. For these and other reasons it seems evident that if the hay grower takes advantage of what he considers a good offer for his hay he may safely forget about any so-called loss because of shrinkage.

This view was also held by Failyer [31] 30 years ago. Writing in 1888, which was about the time that many of the earlier experiments were being made to determine the rate of shrinkage in hay, he said, in discussing the results of a number of shrinkage experiments, made with several kinds of hay: "The conclusion to be drawn from these results is that if the hay is not obviously green and illy cured, no great shrinkage need be feared."

Failyer did not favor advancing the price of hay as it cured out in the stack or barn to make up for the loss of water. Instead of using the price of hay at harvest time as a basis for computing the value of throughly cured hay in winter, he advocated the reverse. He figured the value of newly made hay from that of hay after shrinkage had taken place. In discussing an experiment in which there was shown a loss of 10 per cent of water, and which he regards as an exceptional case, he says:

> Even in these excepted cases the shrinkage is much less than many suppose. * * * This [referring to a 10 per cent loss] means that a ton of the hay as hauled in [field cured] would weigh only 1,800 pounds in the winter, and that if a ton of this hay weighed in midwinter is worth four dollars, the ton weighed at the time the sample was buried [when put into the barn] would have been worth three dollars and sixty cents. This would be worth considering; but in most cases the loss is much less than this.

LOSS TO SHIPPER AND COMMISSION MERCHANT.

Shrinkage sometimes causes a loss of money to those who make a business of dealing in market hay. Such loss may be entailed when hay is held in storage, in the bale, waiting for a favorable market. The amount of shrinkage in hay that has passed through the sweat is not large, yet if large quantities of hay are held in storage the total shrinkage will "run into dollars" very quickly.

Loss of this kind is most likely to be sustained in storing hay that has been baled from the windrow or cock and bought immediately. When those who handle this class of hay dispose of it quickly they suffer no serious loss of money through shrinkage. In other words, as long as the hay is kept moving from shipper to commission man, and from him to retailer or consumer, no one person who handles the hay will lose very much on account of shrinkage, except possibly the consumer. If the hay is held in storage the loss may sometimes be made up by disposing of it on a good market. Those who make a business of speculating in hay count on the price advancing sufficiently to cover the loss from shrinkage and allow them a profit besides.

[31] Kansas Agricultural Experiment Station. First Annual Report, 1888, pp. 117-121.

The dealer may lose money on account of shrinkage when he buys a certain undoubted amount of excess water in the hay at the price of market hay. Therefore he is wholly justified in assuming that when this loss is caused by shrinkage it is a positive money loss. In order to make up for such loss he advances the selling price when it is within his power to do so.

WHAT IS HAY?

The misunderstandings regarding shrinkage, especially those bearing upon economic phases, would never be so widespread as they are to-day if there were a clear and definite understanding as to just what is hay, and if there were standard terms used to designate the kind or condition of hay at any stage of curing.

It may seem, at first thought, that it is a comparatively easy matter to describe or define hay so that all of those engaged in the production or utilization of this crop may have a common, definite understanding concerning it, a product with which almost everyone is more or less familiar. It is only when one undertakes to define the term that he begins to appreciate the difficulties that make practically impossible the framing of a single definition that will embrace all of the different kinds of hay and that will be acceptable to all classes of people engaged in the hay industry.

These difficulties have nothing to do with the question of grades or quality of hay as they are known on the market, because the question of grade concerns only a definite and well-understood kind of hay. The unqualified term "hay," however, may mean any one of a great number of things, from grass that has been just cut to hay that contains less than the normal water content. In view of this fact it becomes apparent that to be able to define precisely it will be necessary to have not merely one, but several definitions, each of which should describe accurately a particular kind of hay.

INDISCRIMINATE USE OF TERMS.

No one class of men concerned with the hay industry may be said to be responsible for the present conflicting ideas as to just what constitutes hay. Hay, in the farm management or labor sense, may be something quite different from hay as viewed from the standpoint of the city commission man or the consumer. For example, it is quite common, indeed almost universal, for the farmer to speak of "mowing hay," "tedding hay," or "cocking hay," when as a matter of fact the material thus spoken of is not in reality hay at all. Strictly speaking, we mow grass, and use the tedder on fresh or partly cured forage that is being made into hay.

The many terms commonly used to describe hay that is ready to be put into the stack, barn, or bale are given in Table III.

TABLE III.—*Terms variously used by growers to describe the condition of hay when put into the barn, stack, or bale.*

[Actual condition of the hay.]

Undercured: Stems full of sap but leaves dead and dry. Spontaneous combustion and heavy shrinkage indicated.	Fairly well cured: Evenly cured, but water content too high. High degree of fermentation indicated, considerable shrinkage, destruction of dry matter, and possibly discoloration.	Well cured: Entire plant cured out evenly and sufficiently. Will have a normal shrinkage and make "choice" hay.	Overcured: Stems brittle. Leaves dead, dry, and sunburnt. Will be little or no shrinkage; possibly a gain in water in storage. Will make medium to poor quality of hay.
Green	Green		
Slightly green	Slightly green		
Tough	Tough	Tough	
Damp	Damp	Damp	
	Fairly dry	Fairly dry	
	Fairly well cured	Fairly well cured	
		Well cured	
	Dry	Dry	Dry.
	Cured	Cured	Cured.
	In good condition	In good condition	In good condition.
	Successfully cured	Successfully cured	Successfully cured.
Fit	Fit	Fit	Fit.
	Ready to haul	Ready to haul	Ready to haul.
		In good shape	In good shape.
		Ready to bale	Ready to bale.
Swath-cured	Swath-cured	Swath-cured	Swath-cured.
Windrow-cured	Windrow-cured	Windrow-cured	Windrow-cured.
Cured in cock	Cured in cock	Cured in cock	Cured in cock.
Cured in bunch	Cured in bunch	Cured in bunch	Cured in bunch.
Field-cured	Field-cured	Field-cured	Field-cured.

Many of these terms are used interchangeably, and often it will be found that a term which means one thing in one locality will mean something else in another. Thus "tough" hay may be either hay that is undercured or hay that has been thoroughly cured out but has become dampened by dew or rain. The terms "successfully cured," "ready to haul," "swath-cured," "bunch-cured" or "windrow-cured," are all more or less confusing and are interpreted differently by individual haymakers. To one, "dry" hay in the field is hay that is ready to haul to the barn or stack but will be subject to a normal amount of shrinkage. To another, "dry" hay is hay that has been overcured, while those who bale from the field think of "dry" hay as hay ready for baling without serious heating or loss of moisture in the bale.

It is only natural that hay producers should occasonally describe conditions of field-cured hay in local terms that are misleading to farmers in other parts of the country. There is less excuse, however, for the spreading of the same confusion by official scientific publications.

A review of the literature on shrinkage experiments shows that sometimes investigators themselves do not understand clearly what constitutes hay, or at least they have not used terms that accurately describe the material with which they were experimenting.

In experiment 5, page 5, "well-cured" hay lost 22.6 per cent by shrinkage, while in experiment 11, page 5, hay that was only "fairly well cured" lost only one-half as much, or 11.2 per cent.

In experiment 18, page 6, hay that was "unusually dry" lost 3.6 per cent by shrinkage, while the hay in experiment 11 which was "very dry" lost 11.2 per cent by shrinkage, or more than three times as much water as the hay that was "unusually dry." These two terms should be practically synonymous, yet the results with two lots of hay varied greatly.

It has been shown that the general term "hay" is universally used to describe material that varies in degree of curing from that of "hay" that is nothing more than green forage to "hay" that is so dry that it contains but 3 per cent of water. Since it is not to be expected that such general and long-established usage will be changed, it becomes necessary, for convenience, so to qualify the general term as to make terms that specifically and accurately apply to the several different stages through which hay passes before it becomes what in the strict sense would be classed as hay, that is to say, the kind that is recognized as hay on the market.

In compiling the following suggested definitions of different kinds of hay, as determined by stage of curing, the experience and terminology of shippers, receivers, and farmers in the several hay-growing sections of the country have been drawn upon. No attempt has been made, of course, to define the various grades and mixtures of market hay.

The definitions here suggested deal only with the several stages in the process of curing.

DEFINITIONS OF HAY.

Market hay.—Hay that is thoroughly cured and can be baled immediately and marketed if it is so desired is market hay. (The term "market hay" has been used in this sense in this bulletin.) The trade rules for the better grades of hay require, in part, that the hay shall be *properly cured, sound,* and of a good or otherwise specified color. In order to meet these requirements hay must go through the sweating or final stage of the curing process. Properly cured, sound hay which has gone through the sweat can contain only the normal percentage of water, except during long periods of extremely wet or dry weather. Even then the water content will not vary more than a few per cent either way from normal. The question of shrinkage or loss of water in market hay need not concern the hay producer, since there is just as great a chance of a gain above the normal content as there is of loss in many sections of the United States.

New hay.—New hay is a term used on the city market to distinguish the current crop from last year's crop. It is most frequently applied to hay that has been baled from the field and shipped to market. It is not used after the "old" hay crop has been disposed of.

Old hay.—Old hay is a market term used, after hay has been harvested, to describe last year's crop.

Hot hay.—Hot hay is a term frequently applied to hay, especially alfalfa hay that reaches the market while undergoing sweating. Hot hay is in the final stage of curing. The heating may sometimes be caused by tight packing in a car with a metal roof which becomes hot and starts the heating. If new hay is a long time in transit it often heats, whereas if it reaches the market quickly and is unloaded and properly piled in a warehouse, heating may sometimes be avoided.

Dry hay.—Dry hay is a market term used, especially in the West, when hay has become so dry that it shatters easily when handled. This kind of hay is thought by some feeders to lack palatability. The term "dry" is used locally to denote the condition of hay when ready to be put into the barn or stack, and also to describe hay after shrinkage has ceased.

Green hay.—A term proposed for use on the farm to describe all hay that has been field-cured but is not sufficiently cured to be baled and marketed is green hay. Such a term would correspond, in a way, to the term "green" as applied to unseasoned lumber to distinguish it from air-dried or kiln-dried lumber, and would have no special reference to the color of the hay. If this or some other more appropriate term were customarily used in speaking of hay in the barn or stack while it is in the sweat or heating period, during which time the larger part of the water lost by shrinkage occurs, it would tend to correct the hay growers' impression that shrinkage causes an actual money loss. After "green" hay has passed through the sweat it becomes "new" (market) hay.

Barn or stack cured hay.—The farm terms barn-cured or stack-cured hay are sometimes used in speaking of hay that has passed through the final (sweating) stage of curing and is ready to be baled and shipped. Very little, if any, shrinkage is likely to occur in hay that has been thoroughly cured in the barn or stack.

Field-cured hay.—Field-cured hay is a very indefinite term embracing all of the terms given in the list on page 29. It is used to denote the degree of curing in the field. When partially-cured hay is put into the stack, barn, or bale it is said to be "field-cured."

The degree of curing of this kind of hay is not always the same, since it depends on how the hay is to be utilized. If hay is to be put into the barn or stack, then field-cured hay, in sections where the weather is subject to sudden changes, should be cured just enough so that it will go through the sweat without developing temperatures that will injure the hay. This is done to avoid, as far as possible, any danger of loss by sun and rain which may occur if the hay is left exposed too long in the field. A shrinkage of 10 or 15 per cent in field-cured hay is to be expected as a part of the natural curing process.

If the hay is to be baled in the field, from the windrow or cock, it must be cured out more than when it is to be put into the barn or stack. The curing should be carried as far as possible without making the hay so brittle that it will break or shatter easily when being baled. The loss of water by shrinkage will be considerably less in hay properly field-cured for baling than in hay properly field-cured to be put in barn or stack.

First-cutting hay, etc.—The terms "first-cutting hay," "second-cutting hay," etc., are used to distinguish different crops of hay, such as alfalfa and clover that are cut more than once a year. It has become necessary to use these terms in the market, especially for alfalfa, because a consumer may, for various reasons which are not always very clear or well-based, prefer a certain cutting for feeding a certain class of stock.

SUMMARY.

(1) The question of shrinkage is one that has always been of interest to those engaged in the production and utilization of hay. The producer wants to know how much hay shrinks because be believes that it results in a direct money loss when he grows hay for the market. The shipper and dealer want to know how much hay shrinks, so that they can make allowance for this factor and thereby avoid disputes and losses.

(2) The percentage of shrinkage in hay is influenced by the following factors: (1) water content when cut, (2) maximum water content when stored, (3) normal water content when cured, (4) minimum water content, (5) atmospheric humidity, and (6) effect of time.

(3) Many experiments have been conducted, during the last 30 years, to determine the rate of shrinkage in hay in the barn and stack. The loss in weight was found to range from 0.29 per cent to 42.2 per cent and the gain in weight ranged from 0.4 per cent to 10.7 per cent, making a total variation of about 53 per cent.

(4) All efforts by investigators to determine the average rate of shrinkage, in order to formulate a definite rule to be used at harvest time to calculate the percentage of "dry" or marketable hay, have failed. The reason an unvarying shrinkage rule can never be used for a large producing territory is because of the effect of such factors as variation in the time of cutting, methods of curing, and the weather, which will always cause a wide difference in the percentage of shrinkage in hay on individual farms within a given territory.

(5) The experiments show that there is no correlation between the lapse of time and the percentage of loss by shrinkage. In other words, the amount of loss that may occur during 3 months has no mathematical relation to the amount occuring during 6 months, 9 months, or other period.

(6) The widespread publication of experimental data showing comparatively large losses by shrinkage, during several months, has been misleading, especially to producers, because the investigators failed to point out *that the greater part of the loss occurs before the hay is in proper condition to be baled or marketed* and that the loss, which is practically of water only, is simply a part of the natural curing process, and, therefore, should have no commercial value.

(7) If hay is marketed in the proper condition, shrinkage does not affect the profits of the producer until after the final curing stage, known as fermenting or sweat stage, has been finished in the stack or barn and the water content has become normal. The shrinkage that actually affects the producer's profits is due to a relatively small loss in weight caused by continued dry weather which lowers the normal water content of marketable hay. This loss is liable to be offset by the increase in water above normal, which takes place during the damp weather when hay absorbs water from the air.

(8) Shrinkage causes an actual loss to the shipper or dealer when he buys and stores hay containing more than the normal water content for well-cured barn or stack-cured hay (*a*) when the hay has been baled from the windrow or cock and is bought before it has gone entirely through the "sweat," or (*b*) when a large mow or stack is baled and sold immediately after having gone through the "sweat." In the first instance practically every bale will shrink more or less, while in the second instance only the hay from the interior of the pile will lose in weight.

(9) There is practically no loss of dry or nutrient matter during the shrinkage of hay while in the barn or stack, provided the hay has been properly cured before it is hauled from the field. Undercured hay, containing an excessive amount of water, is liable to become so hot in the barn or stack that it will become discolored, charred, or, in extreme cases, entirely burned up by spontaneous combustion.

(10) Under certain conditions the producer can determine how much shrinkage to expect in hay produced on his farm. These conditions necessitate (*a*) an adequate, full sized, experienced haymaking crew; (*b*) the use of a definite, efficient, and practically unchangeable method of operation and curing; and (*c*) comparative freedom from interference by unfavorable weather. Under these conditions the average shrinkage can be determined by weighing a given quantity or by a water analysis. The percentage of shrinkage found will be applicable until the conditions are changed.

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