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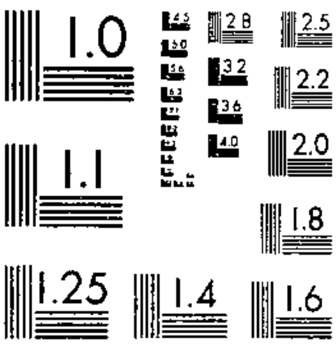

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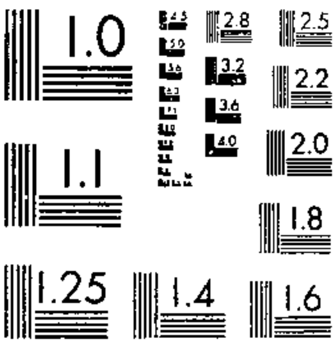

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NATIONAL BUREAU OF STANDARDS-1963-A

TECHNICAL BULLETIN No. 239 JUNE, 1931

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

A METHOD OF DETERMINING THE VOLUME AND TONNAGE OF HAYSTACKS

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In cooperation with the Agricultural Experiment Stations of California, Colorado, Idaho, Minnesota, Montana, Nebraska, Nevada, Oregon, South Dakota, and Utah

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STACK HAY SALES IMPORTANT BUT METHODS INACCURATE

Large quantities of hay have been bought and sold in the stack on a tonnage basis for many years. The parties interested in such transactions commonly agree on the quantity of hay in each stack by measuring it and then computing the volume and tonnage according to various rules that have been devised.

This method of marketing hay is followed extensively in the Pacific and Intermountain States and in the surplus-hay-producing areas of the Great Plains States. The cattlemen and sheepmen of these areas, who do not have a sufficient quantity of forage to feed their stock during the winter, often buy their supplies by measurement. Some stockmen do not have any meadow land, but follow a regular

[1] The author wishes especially to acknowledge the assistance received in the bureau from E. C. Parker and H. R. Tolley in outlining the work and reviewing the bulletin; and from W. J. Spillman, H. R. Tolley, and M. J. B. Ezekiel in the mathematical studies presented.

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practice of driving their flocks and herds into the high mountain valleys or range lands for pasture in the spring and summer, and of driving the stock down again in the fall and wintering them on alfalfa stubble and on hay bought from the valley farmers.

Hay dealers purchase hay by this method in some areas, although this is not a general practice, because the dealer realizes that there is considerable variation in individual stacks and that the tonnage bought by measurement may not hold out by weight. Dealers learn also that some farmers put up their hay in a manner that will cause it to weigh out less than the average tonnage provided by the rule in use in that section. Farmers often discover, too, that if they build large, weather-resisting stacks, the hay may weigh out a greater tonnage than that provided by the rule commonly used.

REASONS WHY HAY IS SOLD BY MEASURE

One of the principal reasons why hay is sold by measure is that in many communities no scales are available to weigh the hay. Another reason is that the method of feeding the hay is sometimes such as to make weighing impracticable even though farm scales are available. Often the sheepmen or cattlemen make arrangements with the hay producers to pasture the meadows during the fall and winter and to feed the hay direct from the stack when snow covers the pasture, or when the pasture becomes so short that hay feeding is necessary. In such feeding operations the hay is either scattered direct from the stack with a short haul and consequent economy of labor, or feed racks are arranged about the stack so that the hay is not loaded on a wagon or sled. On the large farms and ranches, to load all hay and haul it to and from a wagon scale would often add an expense in the feeding operations that would be as great as any gains possible from buying weighed hay instead of measured hay.

In some sections in which the dealers purchase hay by measure the farmers are satisfied with the returns they receive. Where this custom is followed the dealer is often the operator of an alfalfa mill, who buys his season's hay supply from the farmers in the fall of the year, and who hauls the hay from the stack to the mill as it is needed. In the sections in which this method of selling hay is practiced, the farmer realizes that even though the estimate of tonnage determined by measurement is not so accurate as that determined by weight, it is preferable to use this estimate rather than await payment for several months until the hay can be weighed at the mill. Moreover, he runs no risk from damage that may occur to hay in the stack.

POPULAR MEASUREMENT RULES NOT BASED ON RESEARCH

The most popular measurement rules, such as the Frye-Bruhn, Quartermaster, and Outlaw rules, that have been in use for many years, are not based on the results of extensive research. Those who have used these rules have never known much about their accuracy for computing the volume of haystacks. These rules were born of necessity and were the outgrowth of a situation that required some method of determining the volume of haystacks to meet the practical conditions of hay marketing in the important hay and livestock States.

UNITED STATES DEPARTMENT OF AGRICULTURE
Washington, D. C.

CORRECTION

Technical Bulletin 239 of the U. S. Department of Agriculture "A Method of Determining the Volume and Tonnage of Haystacks".

In the preparation of the manuscript for Technical Bulletin No. 239 "A Method of Determining the Volume and Tonnage of Haystacks" an error in the mathematical formulas was introduced and was not noted until the publication was printed. The following corrections should be inserted in this publication:

Page 18: The formulas should read

$$(0.52 \times \underline{O} - 0.44 \times \underline{W})\ \underline{W}$$
$$(0.52 \times \underline{O} - 0.46 \times \underline{W})\ \underline{W}$$
$$(0.56 \times \underline{O} - 0.55 \times \underline{W})\ \underline{W}$$

Page 20: In table 3 the formulas in the box headings should read as above.

Page 28: In the fifth paragraph the coefficients of $\underline{L}$ should be as stated above.

Page 35: In the fifth paragraph the coefficients of $\underline{L}$ should be as stated above.

Page 24: In the middle of the third paragraph, the formula should read
$$\underline{V} = (0.04 \times \underline{O} - 0.012 \times \underline{C})\ C^2$$

Page 35: The formula in the next-to-last paragraph should read as next above.

REVIEW OF PREVIOUS RESEARCH

Agricultural literature does not contain many references to rules for determining the volume of haystacks or the number of cubic feet required for a ton that were developed from research. The most important references are given herewith:

Spillman,[2] in 1905, referred to the rules now known as Outlaw and Frye-Bruhn rules and said that these rules are not accurate but give results 15 to 30 per cent less than the actual volume. He gave a rule in which height is one of the measurements required; but since this is very difficult to measure, the rule was never used extensively. He stated that it was a common custom to consider 512 cubic feet as a ton for hay that had been stacked only a few days and 350 to 380 cubic feet for hay that had stood two months or more.

The United States Department of Agriculture, during the years 1910 to 1912, carried on some investigations for the purpose of determining the number of cubic feet in ricks or stacks of hay and to determine the number of cubic feet required for a ton. The results of this study were published in 1913.[3]

In 1916 this material was revised, data relative to errors in measurement and rate of settling of hay in the stack were added, and a second publication was issued.[4] These department publications gave the formula $FOWL$ = Volume. In this formula O = over, W = width, L = length, and F some factor varying from 0.25 to 0.37, depending upon the height and fullness of the stack. For low, wide stacks the factor used was small (0.25); for tall stacks with full sides the factor was large (0.37). The cross-section drawings of nine stacks of different shapes were shown so that the factor to be used could be selected according to the shape of the stack measured.

These department publications also gave a method for determining the volume of round stacks. The method suggested divided the stack into several geometrical figures and then gave the formulas for determining the volume for each of these figures. In the formula the circumference was given instead of the diameter and a factor varying from 0.027 for cone-shaped stacks to 0.053 for dome-shaped stacks was given. When the stack had a distinct base with straight or sloping side walls, that portion was considered as a cylinder or frustum and a special formula was given therefor.

In connection with this study, 92 stacks were measured, and the hay was subsequently weighed for the purpose of determining the average number of cubic feet per ton. These data were obtained in the States of Virginia and New York and showed that timothy hay stacked less than 30 days required an average of 590 cubic feet for a ton. Hay stacked more than 30 but less than 60 days required 581 cubic feet per ton, and hay that was stacked more than 74 but less than 155 days required 515 cubic feet per ton. These figures were obtained on timothy and mixtures of timothy and clover and were not intended to be applicable to alfalfa or prairie hays.

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[2] SPILLMAN, W. J. FARM GRASSES OF THE UNITED STATES; A PRACTICAL TREATISE ON THE GRASS CROP, SEEDING AND MANAGEMENT OF MEADOWS AND PASTURES, DESCRIPTIONS OF THE BEST VARIETIES, THE SEED AND ITS IMPURITIES, GRASSES FOR SPECIAL CONDITIONS, ETC. 248 p., illus. New York and London. 1905.

[3] MCCLURE, H. B., SPILLMAN, W. J., and FROLEY, J. W. MEASURING HAY IN RICKS OR STACKS. U. S. Dept. Agr., Bur. Plant Indus. Circ. 131: 19–24, illus. 1913.

[4] ——— and SPILLMAN, W. J. MEASURING HAY IN RICKS OR STACKS, U. S. Dept. Agr., Off. Sec. Circ. 67: 10 p., illus. 1916.

Macpherson[5] reported a method of calculating the volume of oblong and round hay stacks:

For calculating the contents of oblong or square haystacks (Fig. 1) take the length and breadth of the stack in feet and inches halfway between the upper part of the stack bed and the eaves, A to B and B to C, an allowance (from 3 inches in trimmed stacks to 8 inches in others) being made in each measurement for the

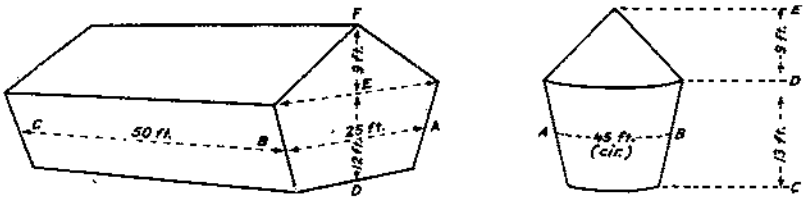

FIGURE 1.—Measurements taken in computing volume of haystacks. These are the measurements used by Macpherson for determining the volume of oblong and round stacks.

loose outsides; then take the height from the upper part of the stack bed to the eaves, D to E.

For stacks with gable ends take one-third of the perpendicular height of roof E to F.

For stacks with hipped ends take one-fifth of perpendicular height of roof.

EXAMPLES

Breadth of stack (A to B)		25 ft.
Length of stack (B to C)		50 ft.
Height from upper part of stack bed to eave (D to E)	12 ft.	
One-third of height from eaves to ridge (E to F) (9 ft.)	3 ft.	
Total average height of stack		15 ft.

Contents of stack = length × breadth × total average height:—

$$\begin{array}{r} 25 \\ 50 \\ \hline 1250 \\ 15 \\ \hline 6250 \\ 1250 \\ \hline 27)\underline{18750}\ \text{cub. ft.} \\ 694.4\ \text{cub. yd.} = \text{contents of stack.} \end{array}$$

Having a stack fairly well settled, and weight per cubic foot 8.25 lb., this would give, according to table, 10 cubic yards to the ton. Therefore weight of hay in stack is 694.4÷10=69.44 tons.

To determine the number of cubic feet contained in a round stack with a conical top [fig. 1] the average girth must be measured at AB. The mean or average height is ascertained by taking the perpendicular height from the base of the stack to the eaves CD and adding to it one-third of the perpendicular height from the eaves to top DE.

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[5] MACPHERSON, A. MEASUREMENT OF STACKS TO FIND WEIGHT OF CONTENTS. New Zeal. Jour. Agr. 20: 115-117, illus. 1920.

Multiply the average girth, 45 ft., by itself:—

```
       45
       45
      ---
      225
     180
     ----
     2025
Multiply the result by   .0795
     ------
    10125
   18225
  14175
  -------
  160.9875 sq. ft.
```

Multiply then by height C to D = 13 ft. plus one-third height of D to E = 3 ft. = 16 ft.:

```
   160.9875
         16
  ---------
   9659250
  1609875
  ---------
  2575.8000
```

If hay in stack is fairly well settled and weight per cubic foot 8.25 lb., this would give, according to table, 10 cubic yards to the ton, by which figure divide, as follows:—

```
27)2576 cub. ft.
10)95.4 cub. yd.
    9.5 tons.
```

The weight of hay per cubic yard in the stack depends on the nature of the hay, its age, the size of the stack, and the part of the stack taken. It varies from 112 lb. to 300 lb. per cubic yard. For different conditions of hay and stacks the number of cubic yards to a ton will approximately vary as follows:

Condition of Stack	Oblong or Square Stacks, Cubic Yards	Round Stacks, Cubic Yards
Not well settled	12 [324 cu. ft.]	13 [351 cu. ft.]
Fairly settled	10 [270 cu. ft.]	11 [297 cu. ft.]
Very compact	8 [216 cu. ft.]	9 [243 cu. ft.]

Second-cut clover hay will require 13 [351 cu. ft.] or 14 [378 cu. ft.] cubic yards to a ton.

The weight may be ascertained very accurately by actually measuring the cubic contents of a truss, and from this calculating the weight of a cubic foot.

McCarrol [6] says that the best method to determine the volume of hay stacks is by use of the prismoidal formula and gives illustrations of various-shaped stacks, the measurements that are necessary to determine the volume of these different-shaped stacks, and the constant multiplier that must be used for the different shapes.

He states that the number of tons of hay in a stack will vary with a number of factors: (1) size of stack; (2) age of stack; (3) condition of stack; (4) sort of hay; and (5) quality of hay.

[6] McCarrol, W. Quantity estimations on the farm. Agr. Gaz. N. S. Wales 39: 696-699, illus. 1928.

The following table gives the number of cubic feet of hay of various kinds to the ton for various periods after completion of stacking, the figures being the results of actual experiments:—

Cubic Feet of Hay to the Ton

Period after stacking	Oaten		Wheaten		Lucerne
	Sheaf	Loose	Sheaf	Loose	
Immediately on completion of stack.	350	400	400	500	Varies greatly from 400 to 300 cu. ft. to the ton.
One week after	325	375	375	450	
One month after	300	350	350	400	
Twelve months after	300	325	350	400	

At Bathurst Experiment Farm, wheaten hay averaged 297 cubic feet to the ton, and loose straw 892 cubic feet to the ton. Any figure taken can only be approximate. The figures in the above table will serve as a guide and indicate that little or no settling takes place after the first month.

Rabate,[7] a French authority on methods of stacking hay and grain, gives rules for determining the volume of hay stacks. He gives rules for determining the volume of cone-shaped stacks, truncated cone-shaped stacks, and prismatic stacks. These are the usual mathematical formulas used for determining volume of such figures, except that the diameters are expressed in terms of the circumference because circumference of the stack is easily measured. Rabate also gives the following information relative to the weight of a cubic meter:

The weight of the cubic meter is rather difficult to determine. It varies, not only with the kind of commodity stacked, but also with the duration of the settlement and the height of the stacks. It is greater in the lower layers or on the parts of the stack where the wagons have been unloaded. To determine the exact weight of the cubic meter in a hay or straw stack in distribution, measure the volume of a section of the stack, remove the section and weigh it. Ringelmann calculates the weight of a cubic meter of hay, in the case of sheaves pressed into stacks, as from 70 to 80 kilograms [457 to 400 cubic feet per ton]. Lefour and Wagner make it 90 to 100 kilograms [356 to 320 cubic feet per ton] in the case of hay in large stacks, firmly pressed down.

COOPERATIVE INVESTIGATIONS ON STACK MEASUREMENTS, 1927, 1928, AND 1929

OBJECTIVES

Farmers and stockmen for many years have called the attention of the United States Department of Agriculture to the importance of haystack sales by measurement, and to the fact that no accurate rule, which could be easily applied, for determining the volume of stacks has ever been developed. The many letters on this subject which the department receives indicate that it is a problem of wide spread importance in the important hay-producing States. In 1927, and at the instigation of one of the western alfalfa-producing States, a project was organized in the Bureau of Agricultural Economics to investigate

[7] RABATE, E. LES MEULES. Vie Agr. et Rurale Année 5 (13): 229–234, illus. 1915.

the problem and to determine, if possible, whether more accurate rules could be formulated than those heretofore developed.

A second purpose of these investigations was to check the rules in use at the present time for determining volume of hay stacks. As these rules are not based on the results of research their accuracy is doubted. If the investigational work should show such rules to be inaccurate the necessity for new rules would be apparent; or if one or more of these should be found accurate, their use could then be recommended.

The third purpose of these investigations was to determine the number of cubic feet required for a ton for different kinds of hay. Little work on this subject had ever been done. The work of the Department of Agriculture in 1910 to 1912 provided the only data available, and that gave information only for timothy and timothy and clover mixed hays on relatively small stacks. No data on the number of cubic feet of alfalfa or prairie hays required for a ton were available except figures used by the farmers; these were not the result of careful measurements and weights. It is in the sections in which these two hays are grown most generally that selling by measure is a common practice.

SCOPE OF WORK

The investigations were organized in cooperation with a number of the important hay States in which the sale of surplus hay by measure is a frequent practice. In many of these States the surplus hay can not be shipped out of the State either because of alfalfa-weevil quarantines or because high freight rates prevent marketing in the eastern part of the United States.

Data were obtained on stacks of alfalfa, timothy, timothy mixed, wild or prairie grass, and grain hays. The timothy mixed consisted of mixtures of timothy and clover, timothy and alfalfa, and timothy and wild or prairie grasses. In all cases timothy made up 50 per cent or more of the mixture. The wild or prairie hay consisted mainly of upland grasses, although a few stacks were mixtures of upland and cultivated grasses such as timothy and redtop. Because of the similar texture of these various grasses no attempt was made to segregate such mixtures into separate groups when the wild grasses made up over 50 per cent of the hay.

Most of the stacks were measured during the fall of 1927 and 1928, but in Colorado measurements and weights were obtained on a number of stacks each year from 1923 to 1928, and in Oregon data were obtained on stacks from 1919 to 1928.

A total of 1,932 rectangular stacks or ricks were measured. Many of these were measured from two to five times at approximately 30-day intervals to determine shrinkage while the hay remained in the stack. Six hundred and ninety-five round stacks were measured. All the stacks measured in Nebraska were round and a few round stacks were measured in Minnesota and Nevada. Few of the round stacks were measured more than once. A few of the field records had to be eliminated because of obvious errors, but 1,585 cross-section drawings of the ends of rectangluar stacks and 695 drawings of the round stacks were found to be free of errors and were used. Figure 2 shows the geographic areas in which the measurements were obtained and the number of stacks measured in each area.

Weights were obtained on 1,758 stacks of hay, of which 1,150 were rectangular and 608 were round. Many of these stacks were measured from two to five times so that 2,659 cases were used in the determination of the number of cubic feet per ton.

DATA COLLECTED

The data collected consisted not only of the various dimensions of the stack and the weight of hay at the time it was sold or fed, but also information about the kind of hay, cutting, method of stacking, maturity of hay when cut, texture, amount of rainfall from time of

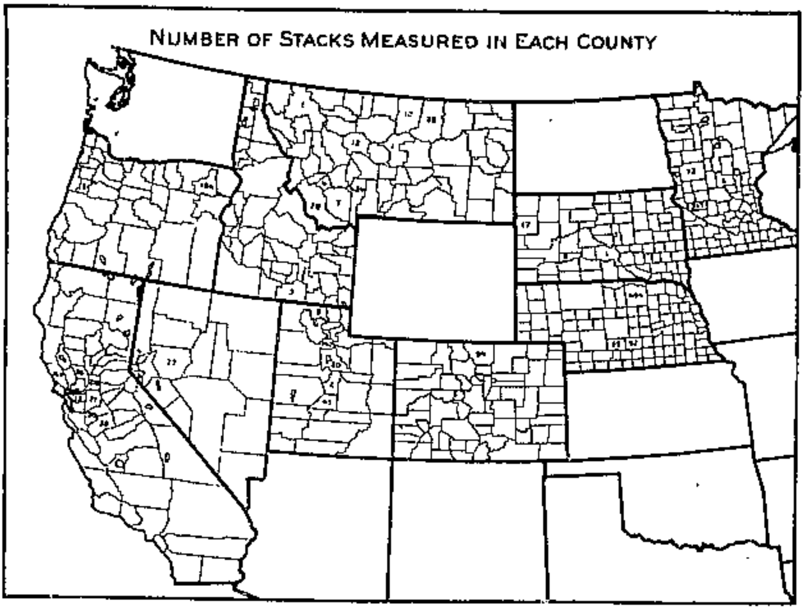

FIGURE 2.—Of the 2,627 stacks measured, 523 were located in California, 94 in Colorado, 3 in Idaho, 365 in Minnesota, 524 in Montana, 671 in Nebraska, 36 in Nevada, 159 in Oregon, 32 in South Dakota, and 220 in Utah

stacking to date of measurement, and any other obtainable facts that might be of value in tabulating the data.

DATA SHEETS

A uniform data sheet (fig. 3) was prepared by the department for the use of the field agents. On the reverse side of each sheet (fig. 4), a cross-section diagram was printed.

The cooperators were instructed to fill out a data sheet for each stack measured. The several dimensions for rectangular stacks were defined as follows:

Width.—The width of the stack is the distance between the lines at which the two sides meet the base. This dimension should be measured at the ground. It is a good plan to measure both ends of the stack and take an average of the two measurements. Width measurements should not follow the bows or contours of stack ends but along a straight line between two points, each point being where the side line of the stack meets the ground. In case the stack varies in width from point to point it is necessary to make allowance for such variations in determining the width, the allowance being a matter of judgment.

Length.—If the ends of the stack are straight up and down, measurement of the length of the stack is a simple matter. If the ends are somewhat sloping, as they frequently are, especially near the top of the stack, it is necessary to choose a point such that if the hay below it were cut off and used to fill in above, this hay would make the ends straight up and down. In most cases this point should be about one-third of the distance from the bottom to the top of the stack.

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DATA FOR STACK MEASUREMENT PROJECT 1928

Stack No. 2 (SE Stack)

State Utah District Salt Lake City

Farmer's name and address Thomas Doe, Doeville, R. F. D. #2.

Kind of hay Alfalfa Cutting First Date stacked June 15

Method used in building stack: Hand pitched Sleds

Kind of stacker Mormon derrick Fork or Slings

Stack exposed in wind or sheltered Exposed

Maturity of hay when cut 3/4 bloom

Texture: Coarse Medium Yes Fine

Measurements

	Approx. 30 days	Approx. 60 days	Approx. 90 days	Approx. 120 days	Approx. 150 days	Last time before weighing
Date Measured		Aug. 17	Sept. 20	Oct. 19	Nov. 20	
Height		19'	19'	19'	19'	
Width		25'	25'	25'	25'	
Length		34.5'	34.5'	34.5'	34.5'	
Over		54'	53'	53'	52'	
Over			53'			
Over						
Over						
Over						
Height to bulge						
Volume						

Date weighed Dec. 20 Weight or estimate of waste hay No waste

Weight of good hay 64,730 lbs. Total weight 64,730 lbs. = 32.3650 T.

Degree of moisture: Tough Medium dry Yes Dry

Approximate amount of rainfall from time of stacking to date of each measurement
Precipitation from June 15 to November 20, 1928 - 4.14 inches.
Precipitation from June 15 to December 20, 1928 - 5.04 inches.

Other remarks: Well cured and stacked. 45% leaves. 75% color.

(See reverse side for diagram of stack cross section.)

FIGURE 3.—Copy of data sheet

Height.—About the best way to measure the height (fig. 5) of a stack is to stand a rod straight up as close to the end of the stack as convenient. Then stand at a distance of 15 to 20 feet from the stack and observe the point on the rod horizontally even with the top of the stack. Observing the height of the stack from the side rather than directly back of the measuring rod will give the most accurate measurements. A rod with the feet and half feet marked so as to be easily seen should be provided for this work.

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Over.—The over of a stack is the distance from the ground on one side over the stack to the ground on the other side. If the stack is wider some distance above than at its base, care should be used to measure the over from the ground at the base of the stack rather than at a point directly under the widest part of the stack. In the case of long stacks where there is a possibility of variation in the over at various points in the stack, a number of over measurements should be made and recorded in the spaces provided on the data sheet.

Height to bulge.—The height to bulge is the distance from the ground to the widest portion of the stack. This measurement should be a perpendicular distance from the point of the bulge to the ground. If the height of the bulge varies several measurements should be made.

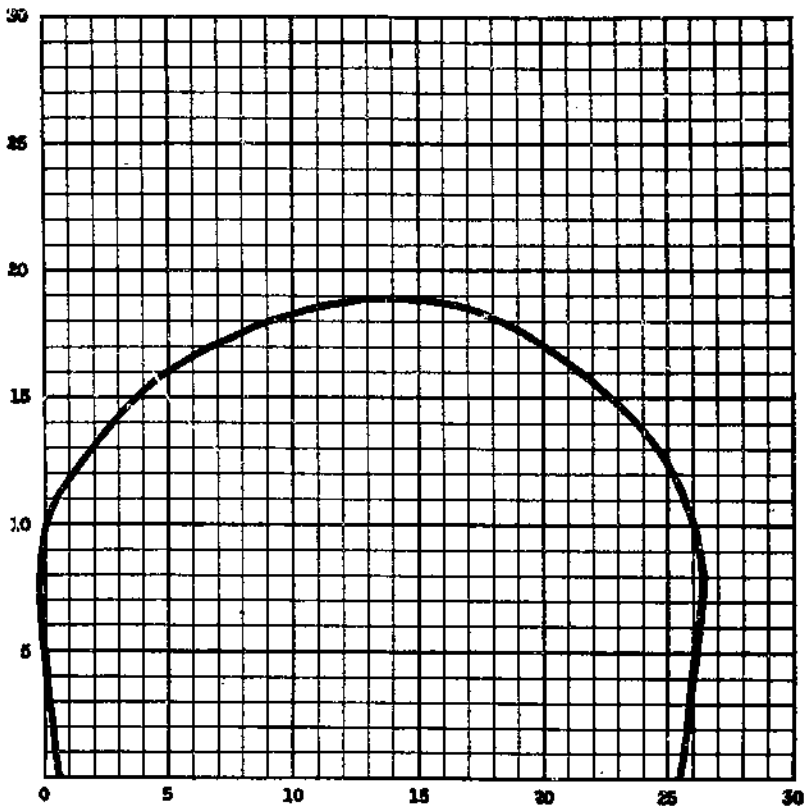

FIGURE 4.—Reverse side of data sheet

For round stacks the total height, height to the bulge, the circumference at the base, and the circumference at the bulge were the measurements taken. These measurements were defined as follows:

Height.—The height of the stack may be obtained by using the same methods as are used in determining the height of square or oblong stacks.

Height to bulge.—Height to bulge may be determined by using the same methods as for square or oblong stacks.

Circumference at base.—Circumference at base is the distance around the stack at the ground level. This measurement can be made with a long tape, care being taken to see that the tape is drawn in close to the stack at all points.

Circumference at bulge.—Circumference at bulge is the circumference at the widest part of the stack; care should be taken in all cases to prevent the tape from sagging, as this will result in an inaccurate measurement.

Over.—The over of a round stack is the distance from the ground on one side over the peak of the stack to the ground on the other side. Two overs at right angles to each other should be taken.

A cross-section drawing of each stack measured was made on the reverse side of the data sheet. This drawing was made to scale and was used as a check on the measurements taken, and for the purpose of determining the actual cross-section area of rectangular stacks and the actual volume of the round stacks. In other words, these cross-section drawings were the bases upon which was determined the accuracy of the various rules for computing the volume of both rectangular and round stacks.

METHOD OF COLLECTING DATA

Several methods were followed in collecting the field data. The project was organized on the basis that the States should collect the field data under the general direction of the United States Department of Agriculture and that the department should tabulate and summarize the data. In most of the States the data were collected by a State employee. These employees made the necessary contacts with the farmers, measured the hay, and obtained the weights or made arrangements for obtaining them. In several States the data were collected by reliable farmers or hay dealers under the general direction of State or Federal men. These cooperators were paid on the basis of the number of completed records turned in.

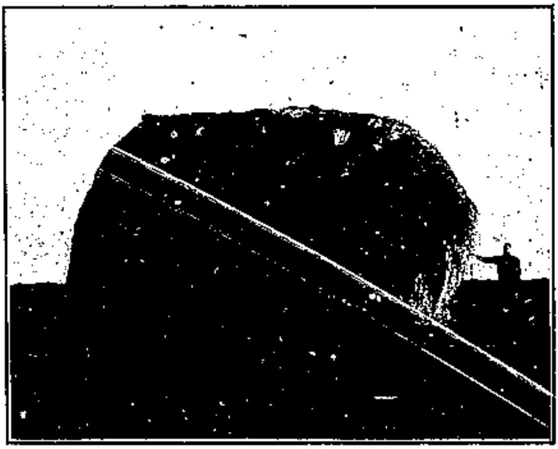

FIGURE 5.—Measuring the height of stacks. A rod marked in feet and half feet is stood up at one end of the stack. From a distance of 15 to 20 feet from the stack, the point on the rod horizontally even with the top of the stack is read. This gives the height of the stack

DIFFICULTIES ENCOUNTERED IN OBTAINING WEIGHTS OF INDIVIDUAL STACKS

Considerable difficulty was encountered in obtaining the weights of hay in the stacks. In 1928 there was a very large hay crop. Much hay that was harvested and stacked with the idea of shipping it to market later in the season was never sold; or it was sold locally, and the weights were not obtained. Throughout the entire period of the investigations many stacks were measured on farms the owners of which intended to bale the hay, weigh it, and ship it to market, but the hay was subsequently sold in the stack by measurement, thus making it impossible to obtain weight data.

PROBLEMS PRESENTED FOR STUDY

Three distinct problems were presented for consideration when this study was begun: (1) Volume studies for rectangular stacks or ricks,

(2) volume studies for round stacks, and (3) studies covering the number of cubic feet of various kinds of hay required for a ton.

VOLUME OF RECTANGULAR STACKS

STUDIES ON AREA OF CROSS SECTIONS

Some method of determining the actual volume of the various hay stacks measured had to be devised in order to decide whether the rules for determining volume at the present time are accurate. It was decided that the most practicable method for checking the old rules was to use the area of the cross-section drawing of each stack as the basis for comparison. The drawing of the cross section of the stack might not be absolutely accurate, but it would give the general contour of the stack.

This outline drawing obtained in the field was checked by the field agent at the time the drawing was made by measuring the over of the outline drawing with a road or map tracer. If the result obtained by this instrument did not agree with the over obtained by the tape, the drawing was corrected or the field measurements were checked. The field men found the road tracer of considerable aid in the field work since it tended to check both the outline drawings and the field measurements.

All outline drawings made by the field agents were measured again by the author with the road tracer, and in those cases in which the over obtained by the road tracer did not agree with the actual over given on the data sheet, a correction in the cross-section area was made. The formula for making this correction was $A=\frac{O^2}{O_1^2}A_1$. (A equals correct area of cross section; A_1 equals the area of the outline drawing; O equals the actual over given on the data sheet; and O_1 equals the over of the outline drawing.) This formula was assumed to be sufficiently correct for this work since the outline drawing and the measurments of over and width might also contain an experimental error that could not be checked.

Another method for correcting the area of the cross section was followed by H. E. Murdock, of the Montana Agricultural Experiment Station. He redrew the outline drawing of each stack until the over of the outline drawing was equal to the actual over given on the data sheet. When he made this new drawing he increased the height of the drawing but retained the same general outline as that made in the original drawing. This method gave results similar to those obtained by the formula given above.

The actual area of the outline drawing of each individual stack was measured by a planimeter. The planimeter was so calibrated that 1 square inch was recorded on the planimeter scale as 0.1. Since 1 square inch on the data sheet was equal to 25 square feet on the actual stack, 1 square foot of the actual area of the stack represented 0.004 on the planimeter scale. Since the scale could be read in thousandths, and since each cross section was measured twice and required to check within 0.004, the actual area of the cross section was measured to within 1 square foot of its area. This measured area was then corrected according to the formula given in the preceding paragraph, and the corrected area was used as the basis of all future calculations.

STUDIES OF CROSS-SECTION AREAS BY OLD RULES

The two rules most commonly used at present for determining volume of haystacks are the Frye-Bruhn rule, or rule of two, and the Quartermaster rule. Several others are used occasionally; The Outlaw rule, the FOWL rule, and the mathematical or triangle rule. A description and a discussion of each of these rules are given in the paragraphs next succeeding. Table 1 shows the accuracy of the various methods for determining the cross-section area of a stack by some of the rules mentioned. The percentage range of accuracy by each of the methods is very wide. The accuracy of these rules was obtained by using the actual cross-section area of the stack as 100, and the results obtained by the various rules were expressed as percentages of this base. In all these rules W is a symbol for width, O for over, H for height, L for length, and F for a variable factor, depending on the size and shape of the stack.

TABLE 1.—*Comparative accuracy of rules now in use: Number of stacks and percentage of total falling into certain percentage ranges for each of four rules as obtained by computing the area of the cross section by each rule and comparing such area with the actual cross-section area*

Percentage range (actual=100)	Stacks measured and accuracy of measurements determined by the—							
	Frye-Bruhn rule $\frac{(O-W)W}{2}$		Quartermaster rule $\left(\frac{O+W}{4}\right)^2$		Outlaw rule $\frac{OW}{4}$		Triangle rule $\frac{1}{2}WH+SB$ [1]	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
60 to 64.9					4	0.25		
65 to 69.9					37	2.33		
70 to 74.9	4	0.25			134	8.45		
75 to 79.9	49	3.09	1	0.06	285	17.98	1	0.06
80 to 84.9	525	33.12	2	.13	435	27.44	11	.69
85 to 89.9	837	52.81	153	9.65	353	22.27	126	7.96
90 to 94.9	165	10.41	597	37.67	184	11.61	390	24.64
95 to 99.9	3	.19	513	32.37	99	6.25	865	54.64
100 to 104.9	2	.13	211	13.31	28	1.77	153	9.67
105 to 109.9			69	4.35	13	.82	30	1.89
110 to 114.9			20	1.26	8	.51	5	.32
115 to 119.9			11	.70	3	.19		
120 to 124.9			6	.38	2	.13	2	.13
125 to 129.9			1	.06				
130 to 134.9			1	.06				
Total	1,585	100.00	1,585	100.00	1,585	100.00	1,583	100.00

[1] See text for derivation of SB.

THE FRYE-BRUHN RULE

The Frye-Bruhn rule, or rule of two, $\frac{(O-W)W}{2}L$, is mentioned several times in some of the older literature on the subject of measuring hay in the stack. Spillman[8] says that this is a common rule for determining the volume of a haystack. This rule is in common use throughout all of the Western States where hay in rectangular stacks is sold by measure. The theory upon which this rule was developed was that the cross section of the stack could be reduced to a rectangle by subtracting the width from the over and then dividing the result by two to obtain the average height of the stack. The area of the

[8] Spillman, W. J. Op. cit.

cross section is then obtained by multiplying the width by this average height. This rule is on the statute books of at least two States (Montana and South Dakota) as the method for determining the volume of rectangular stacks, unless some other method of determining volume has been agreed upon previously.

The check made of the Frye-Bruhn rule shows that 96 per cent of the cases ranged between 80 and 95 per cent (Table 1) of the actual area, but that in a few cases this rule gave less than 75 per cent of the actual area, and in only two cases did it give an area equal to or greater than the actual area of the cross section. On an average this rule gave only 86.06 per cent (Table 2) of the actual area, therefore it gave a result that was about 14 per cent less than the actual area.

TABLE 2.—*Average percentage and average deviation for the Frye-Bruhn, Quartermaster, Outlaw, and Triangle rules as compared with the actual area*

State	Frye-Bruhn		Quartermaster		Outlaw		Triangle	
	Average percentage	Average deviation	Average percentage	Average deviation	Average percentage	Average deviation	Average percentage	Average deviation
California	88.13	±11.87	99.23	±5.58	87.39	±14.04	92.24	±8.02
Idaho	86.82	±13.18	92.41	±7.59	79.23	±20.77	96.23	±3.77
Minnesota	85.77	±14.23	97.04	±4.32	85.46	±14.62	97.08	±2.77
Montana	84.66	±15.34	95.48	±5.47	84.30	±15.78	97.39	±4.00
Nevada	87.58	±12.42	91.62	±8.41	76.04	±23.66	95.64	±4.40
Oregon	84.11	±16.45	97.41	±4.99	87.10	±13.31	96.57	±4.95
South Dakota	83.11	±16.89	96.59	±5.52	85.76	±15.01	94.98	±5.02
Utah	86.99	±13.01	92.08	±8.10	76.99	±23.01	95.69	±4.42
All States	86.06		96.19		84.17		95.98	

THE QUARTERMASTER RULE

The Quartermaster rule, $\left(\frac{O+W}{4}\right)^2 L$, known in some localities as the Government rule, was probably developed by the Quartermaster Department of the United States Army and was used by that department for determining the volume of haystacks or ricks in the purchase of forage for Army posts on the frontier many years ago before the department was able to purchase forage supplies by weight. This rule is based on the theory that the area of the cross section of the stack is equal to the area of the cross section of a square with sides equal to one-fourth of the perimeter of the stack (over plus width divided by 4).

The check made of the Quartermaster rule shows that 83 per cent of the cases ranged between 90 and 105 per cent (Table 1) of the actual area. The fact that for some types of stacks this rule gave less than 85 per cent of the actual area and for others gave over 125 per cent of the actual area, indicates that this rule gives very inaccurate results in some cases. On an average the Quartermaster rule gave 96.19 per cent (Table 2) of the actual area of the cross section of the stack.

THE OUTLAW RULE

The Outlaw rule, $\frac{OW}{4}L$, (also called the New Mexico rule) has been used for many years. At one time it was on the statutes of the

State of New Mexico as the legal method to be used for determining the volume of rectangular haystacks. This rule is based on the theory that the area of the cross section of the stack is equal to one-half the area of the cross section of a triangle which has a base equal to the width of the stack and an altitude equal to half the over of the stack.

The check made on the Outlaw rule shows that 79 per cent of the cases ranged between 75 and 95 per cent (Table 1) of the actual area. The average percentage of accuracy for this rule was 84.17 per cent. (Table 2.) This rule is the most inaccurate of all the rules in use at present and should never be used for determining the volume of a haystack.

THE FOWL RULE

The "Fowl" rule, FOWL, was developed by the United States Department of Agriculture and is a modification of the Outlaw rule. Instead of using a constant factor of 0.25, as is done in the case of the Outlaw rule, a variable factor ranging from 0.25 to 0.37 was used. The factor used depended upon the size and fullness of the stack. As an aid in determining which factor to use, cross sections of nine stacks of different shapes were illustrated, and the factor for each shape was given.

The accuracy of the FOWL rule could not be determined. An attempt was made to divide the stacks into the nine types illustrated in Circular 67,[9] but many stacks were found that did not conform to any of these nine types; others that closely resembled some of the types were of such shape that it was impossible to decide which factor should be used. For this reason the accuracy on a percentage basis was not calculated. The value of the factor F was calculated for each stack and found to vary from 0.19 to 0.38. The fact that it was very difficult to classify the outline drawings according to the nine shapes given in Circular 67 indicated that it would be unwise to recommend this method for use in determining the volume of hay stacks.

RULES REQUIRING HEIGHT MEASUREMENT

Several other rules based on mathematical formulas have been suggested from time to time, but they have always been so complicated that they were impracticable for use. Such formulas require the use of a height measurement which is extremely difficult to make. One of these formulas, the Triangle rule $(\frac{1}{2}\,WH+SB)L$, was studied to find what results were given by rules in which height was necessary. By this rule the cross section area of the stack is divided into three triangles, and the areas of these are determined. The area of one triangle is obtained by the formula, $\frac{1}{2}\,WH$. The other two triangles are equal and the area is obtained by the formula SB. In this formula $S=\sqrt{(\frac{1}{2}\,W)^2+H^2}$ and $B=\sqrt{(\frac{1}{4}\,O)^2-(\frac{1}{2}\,S)^2}$.

The check made of the Triangle rule shows that 79 per cent of the cases ranged between 90 and 100 per cent (Table 1) of the actual area. The average percentage of accuracy was 95.96 per cent (Table 2). This rule is the most accurate of any of the four rules studied but can not be recommended for popular use because it is very complicated to calculate and because a height measurement is necessary, which is difficult to obtain with accuracy.

[9] McClure, H. B., and Spillman, W. J. Op. cit.

FORMULATION OF NEW RULES FOR DETERMINING CROSS-SECTION AREA

Consideration was given to a method for accurately determining the area of the cross section of haystacks that would use only the two most easily obtained measurements, namely, width and over. An attempt was made, therefore, to find an accurate expression of correlation between the area of the cross section and these two measurements. In the belief that there should be some definite correlation between these three known factors, several different correlations were formulated and studied. A correlation between the area and the over divided by the width was tried. This study showed a fairly definite average correlation, but several extremes of variation appeared, which indicated that there was no dependable degree of correlation. A second study was made in which the area divided by the width, was plotted against the over divided by the width. This correlation was based upon the same theory as the Outlaw rule, and it was thought that probably factors could be determined which would give a higher degree of accuracy than that obtained by the constant factor 0.25. This plan gave a fairly definite average correlation, but, as in the first case, wide extremes of variation appeared.

A third study was made in which the area divided by the square of the width was plotted against the over divided by the width, thus making both linear values. This correlation was based upon the same theory as the Frye-Bruhn rule, and it was believed that values could be determined to take the place of the divisor 2 used in this rule that would give more accurate results than the old rule. This method gave a very definite correlation with no wide variations, and a preliminary regression line was calculated on the data from each State.

The equations for these regression lines for each State were then computed, using the formula:

$$y = na + bx$$
$$xy = ax + bx^2$$

The values of a and b in the equation for the various States were as follows:

California	$a = -0.524,$	$b = +0.546.$
Idaho	$a = -0.566,$	$b = +0.5714.$
Minnesota	$a = -0.4371,$	$b = +0.51028.$
Montana	$a = -0.4469,$	$b = +0.5192.$
Nevada	$a = -0.4895,$	$b = +0.538.$
Oregon	$a = -0.4618,$	$b = +0.5333.$
South Dakota	$a = -0.4549,$	$b = +0.5246.$
Utah	$a = -0.4818,$	$b = +0.5340.$

The values of a and b given above are similar for the States of Montana, Minnesota, and South Dakota, where the low, round-topped stacks (fig. 6) are the general type. The values of a and b are similar for the States of Nevada, Oregon, and Utah where the high, round-topped stacks (fig. 7) are the usual type built. The values of a and b for Idaho are only tentative because only three stacks were used in determining the equation of the regression line.

The values of a and b for the California stacks seemed to be distinctly different from those of other States. Most of the California stacks were square and flat-topped. When the formula obtained from the data from a given State was applied to determine the cross-section area of the stacks measured in that State, some percentage

FIGURE 6.—Low, round-topped stack of alfalfa hay

variations of from 10 to 15 per cent were found. This indicated that the formula for that State did not give the correct value of the cross-

FIGURE 7.—High, round-topped stack of the type built in the valleys of Utah, Nevada, and Idaho

section area for certain stacks in the State. Upon examining the cross-section drawings of these stacks it was observed that those that had a large percentage of error were of different shape from those that made up the bulk of the cases in that State.

In some cases there was a considerable difference between the values for a and b, as, for instance, in California and Montana, whereas for Montana and Minnesota there was no difference. Upon examining the cross-section drawings for a number of these stacks, it was decided to separate the stacks into three groups (fig. 8), as follows: (1) Low, round-topped stacks of the type built commonly in Montana and Minnesota, or throughout the area where the overshot stacker is the usual type of stacker used, and which usually contain less than 10 tons of hay and often not over 5 tons; (2) high, round-topped stacks, with high side walls and well-rounded tops to shed water, of the type built in Utah, Nevada, Idaho, and Oregon, which usually contain 15 tons or more, and may in some cases contain 100 tons; and (3) square, flat-topped stacks, of the type built in certain parts of California that are not built primarily to shed water and are limited, therefore, to areas of very low rainfall.

Scatter diagrams (fig 9) were then made in which each dot represented the relation between the ratio of over to width and the ratio

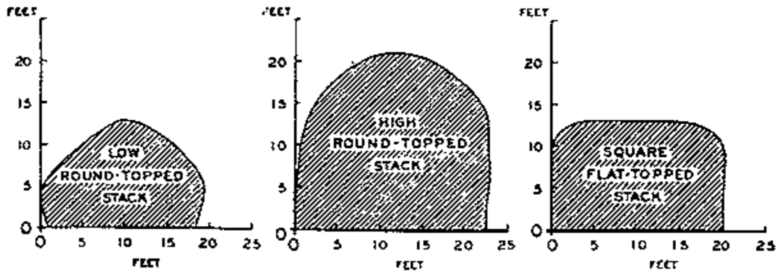

FIGURE 8.—Outline drawings of hay stacks of different shapes

of area of cross section to the square of the width for each individual stack. It is evident from these diagrams that a very high degree of correlation exists between these two factors when the stacks are separated into three groups according to their general shape. These diagrams also show the regression lines. New values for a and b were then calculated using the same equation as given above and the following formulas for determining the cross-section areas were developed for the three different shapes of stacks:

Low, round-topped stacks of the Minnesota and Montana type,

$$(0.52 \times O) - (0.44 \times W)W$$

High, round-topped stacks of the Utah and Nevada type,

$$(0.52 \times O) - (0.46 \times W)W$$

Square, flat-topped stacks of the California type,

$$(.056 \times O) - (0.55 \times W)W$$

The accuracy of these formulas is given in Table 3. This table shows that by these formulas a cross-section area may be computed

RELATION BETWEEN THE RATIO OF "OVER" TO "WIDTH" AND THE RATIO "AREA OF THE CROSS-SECTION" TO THE "SQUARE OF THE WIDTH" FOR THREE TYPES OF STACKS

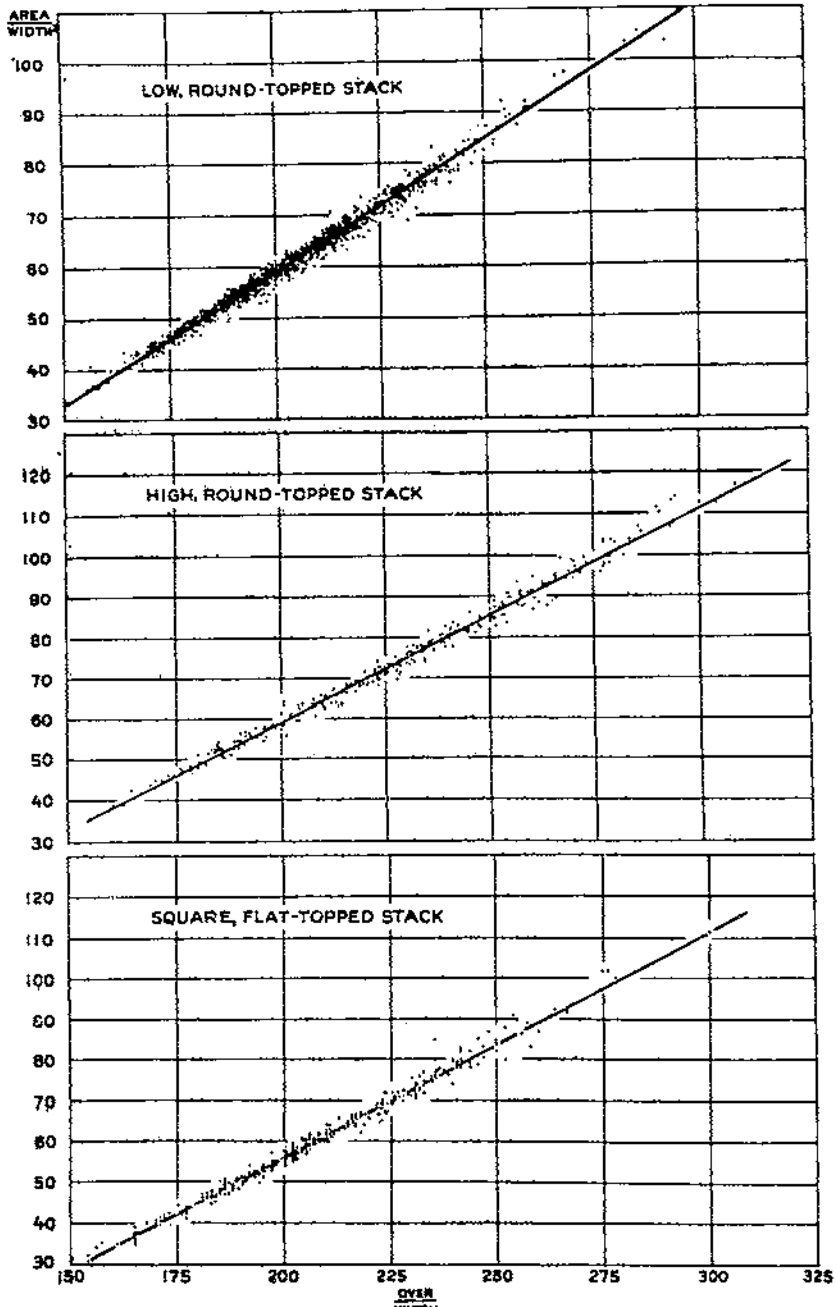

FIGURE 9.—This chart indicates a very high degree of correlation between these two ratios. Trend lines were fitted and mathematical formulas for determining the volume of each of the three types of stacks were developed

that is within 5 per cent of the actual cross-section area in practically all cases. In all three types of stacks the formulas gave results that were within 2 per cent of the actual cross-section area 63 to 67 times out of each hundred. This is a much higher accuracy than is given by any of the rules in use at present for determining the volume, as shown by Table 1. The average percentage and average deviation for these formulas are given also in Table 4. This table shows that all three formulas give an average percentage of a little over 100 per cent, and that the average deviation is less than 2 per cent for all three formulas.

TABLE 3.—*Accuracy of the factor method: Number of stacks and percentage of total falling into certain percentage ranges for each of the three types of stacks. The cross-section area of each stack was computed by the proper formula and compared with the actual cross-section area*

Percentage range (actual = 100)	Stacks measured and accuracy of measurements determined for—					
	Low, round-topped stacks $(0.52 \times O) - (0.44 \times W) W$		High, round-topped stacks $(0.52 \times O) - (0.46 \times W) W$		Square, flat-topped stacks $(0.56 \times O) - (0.55 \times W) W$	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
92 to 92.9					2	0.60
93 to 93.9					1	.30
94 to 94.9	3	0.31			4	1.21
95 to 95.9	5	.52	9	3.08	10	3.02
96 to 96.9	44	4.57	17	5.82	18	5.44
97 to 97.9	100	10.40	27	9.25	27	8.16
98 to 98.9	173	17.98	46	15.75	40	12.08
99 to 99.9	202	21.00	54	18.49	54	16.31
100 to 100.9	144	14.97	45	15.41	75	22.66
101 to 101.9	124	12.89	40	13.70	43	12.99
102 to 102.9	84	8.73	22	7.53	29	8.76
103 to 103.9	40	4.16	12	4.11	19	5.74
104 to 104.9	23	2.39	14	4.80	3	.91
105 to 105.9	15	1.56	6	2.06	3	.91
106 to 106.9	5	.52			3	.91
Total	962	100.00	292	100.00	331	100.00

TABLE 4.—*Average percentage and average deviation for the formulas for rectangular stacks as compared with the actual area*

Type of stack	Average percentage	Average deviation
	Per cent	*Per cent*
Low, round-topped stacks	100.03	±1.06
High, round-topped stacks	100.04	±1.10
Square, flat-topped stacks	100.02	±1.52

These tables and charts show that the factor formulas constitute much more accurate methods of determining the volume of rectangular stacks than do any of the rules in use at present and are as easy to use.

VOLUME OF ROUND STACKS

STUDIES ON THE DETERMINATION OF VOLUME

To determine the accuracy of the various methods for measuring the volume of round stacks (figs. 10 and 11), some method of calculating the actual volume of the round stacks had to be worked out. Outline drawings of each round stack measured were made on the reverse side of the data sheet. These drawings were checked by using the road tracer to measure the over of the outline drawing and thereby to ascertain whether the over of the drawing checked with the actual over of the stack measured in the field.

These measurements were checked again by the author when the data sheets were received for tabulation, and a correction factor was determined for each stack if the over of the outline drawing was not the same as the over obtained in the field. This correction factor was obtained by dividing the cube of the actual over by the cube of the over of the outline drawing.

The volume of a stack having a central-vertical-section figure similar to the drawing on the reverse side of the data sheet for that stack was then multiplied by this correction factor, and the result was used as the actual volume of the round stack. The correction formula may be represented as follows: $V=\frac{O^3}{O_1{}^3}V_1$. In this formula V equals actual volume of the stack; V_1 equals the volume of a figure having a central vertical section similar to the outline drawing; O equals the over as measured in the field; and O_1 the over of the outline drawing.

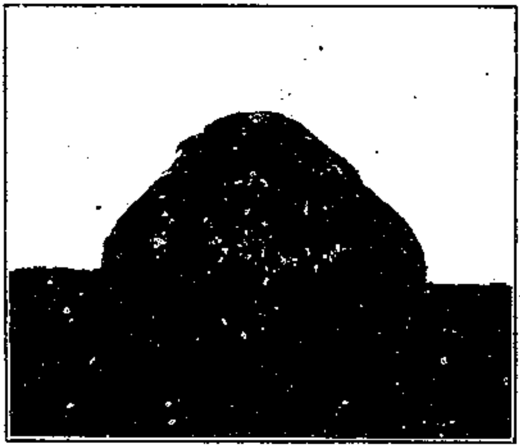

FIGURE 10.—Small round stack of the type built in Nebraska and Minnesota

Determination of the volume of round stacks presented some difficult problems, and the method that was used in this study may not give exact results, but it is the best that could be devised from the data that were obtained in the field. The field agents made outline drawings of each stack measured. These outline drawings showed the general contour and shape of the stack and were assumed to represent a vertical section taken through the center of the stack. The diameters of these outline drawings were measured at 1-foot intervals, and the volume of each of these frustums was determined. The sum of the volumes of the frustums gave the volume of a figure with a vertical section similar to the outline drawing. If the stack was peaked, the top part was considered as a cone instead of a frustum. The actual volume of the stack was then obtained by using the correction factor discussed above for that particular stack. This corrected volume was used as the basis for all future calculations.

STUDIES OF THE ACCURACY OF OLD VOLUME RULES FOR ROUND STACKS

The rules that have been used most commonly for determining the volume of round stacks are the Quartermaster round-stack rule and the so-called Prismoidal rule. These two rules are described and discussed in the two paragraphs next succeeding. In the formulas presented C is used as a symbol for circumference, O for over, H for height of frustum, and H_1 for height of part above frustum.

QUARTERMASTER ROUND-STACK RULE

The Quartermaster round-stack rule, $\left(\frac{C}{4}\right)^2 \times \left(\frac{O-\frac{C}{4}}{2}\right)$, is the most common rule in use at present for determining the volume of round stacks. This rule, also known as the Government rule, has been used in Nebraska for many years. The rule is based on the theory that the volume of a round stack is equal to the volume of a square stack one side of which is equal to one-fourth of the circumference of

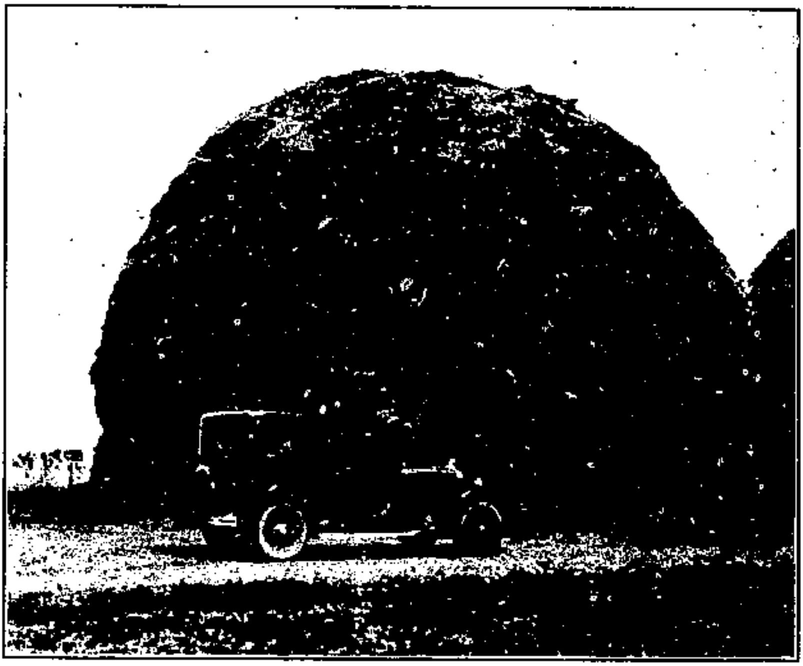

FIGURE 11.—Large round stack of the Nevada type

the round stack, and whose average height is equal to one-half of the difference between the over and one-fourth of the circumference of the round stack.

The volume of each individual stack measured in the field was calculated by this rule. The accuracy of the rule was then ascertained by using as a base the actual volume obtained by dividing the stack into a series of frustums and calculating an accuracy percentage for each stack. Table 5 shows that 88 per cent of the cases fell between the 85 and 105 per cent range of accuracy, and Table 6 shows that this rule on the average gives 95.25 per cent of the actual volume. This table also gives the average deviation for this rule.

TABLE 5.—*Comparative accuracy of rules for determining volume of round stacks: Number of stacks and percentage of total falling into certain percentage ranges for each of three rules as obtained by determining the volume by each rule and comparing such volume with the actual volume*

Percentage range	Stacks measured and accuracy of measurements determined by the—					
	Quartermaster rule		Prismoidal rule		Chart method	
	Number	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
40 to 44.9			1	0.16		
45 to 49.9			3	.48		
50 to 54.9			2	.32		
55 to 59.9			12	1.91		
60 to 64.9			13	2.07		
65 to 69.9			19	7.02		
70 to 74.9			43	6.85		
75 to 79.9	7	1.06	74	11.78		
80 to 84.9	19	2.87	72	11.46		
85 to 89.9	115	17.37	69	10.99	10	1.51
90 to 94.9	206	31.12	67	10.67	134	20.24
95 to 99.9	152	22.96	69	10.99	219	33.08
100 to 104.9	111	16.77	60	9.55	165	24.93
105 to 109.9	41	6.19	26	4.14	93	14.05
110 to 114.9	8	1.21	32	5.10	31	4.68
115 to 119.9	3	.45	24	3.82	10	1.51
120 to 124.9			13	2.07		
125 to 129.9			8	1.27		
130 to 134.9			4	.64		
135 to 139.9			4	.63		
140 to 144.9			5	.80		
145 to 149.9			3	.48		
150 to 154.9			3	.48		
155 to 159.9			1	.16		
160 to 164.9						
165 to 169.9						
170 to 174.9						
175 to 179.9			1	.16		
Total	662	100.00	628	100.00	662	100.00

TABLE 6.—*Average percentage and average deviation for the Quartermaster and Prismoidal rules and the Chart method for round stacks as compared with the actual volume*

Rule	Average percentage	Average deviation
	Per cent	*Per cent*
Quartermaster	95.25	±6.73
Prismoidal	91.55	±10.50
Chart method	100.03	±4.75

PRISMOIDAL RULE

The rule given in Circular 67 [10] which is referred to throughout this publication as the Prismoidal rule was used also to determine the volume of each individual stack. The stacks were segregated into the several types necessary to determine the volume according to the diagram of shapes given in Circular 67, that is, cone shaped, half-sphere shaped, a shape intermediate between the cone and half-sphere shape, and each of these three shapes superimposed on a cylinder or a frustum in those cases in which the stack had a lower part with straight side walls, or the side walls had a distinct bulge. Some difficulty was encountered in segregating the stacks into these types because there were all gradations from the cone to the half sphere.

[10] MCCLURE, H. B., and SPILLMAN, W. J. Op. cit.

The accuracy of this rule was calculated in the same way as for the Quartermaster rule. Table 5 shows that this rule gives a very wide range of accuracy, varying from less than 50 per cent to as high as 175 per cent of the actual volume, and only 35 per cent of the cases fell within 10 per cent of the actual volume. Table 6 shows that on the average this rule gives 91.55 per cent of the actual volume. This table also gives the average deviation for this rule.

FORMULATION OF NEW RULE FOR DETERMINING VOLUME OF ROUND STACKS

Much thought was given to the development of a rule or formula that would give satisfactory results for determining the volume of round stacks. It was recognized that farmers can obtain only two measurements with any degree of accuracy, namely, circumference at the base of the stack and over, and that a formula should be based, therefore, on these two measurements. In these investigations the over was taken twice, usually at right angles to each other, and the average was used as the actual over. The height of each stack was measured for this study but as considerable difficulty was encountered, it was concluded that height was not a practical measurement for use in determining volume.

A number of correlations were studied. The principal ones were: (1) Correlation between the volume divided by circumference and over multiplied by circumference, (2) correlation between the volume divided by circumference squared and the over, and (3) correlation between the volume divided by circumference cubed and over divided by circumference. The last correlation gave results that were practically as good as any method that was tried. The formula developed from this correlation is: $V=(0.04\times O)-(0.012\times C)C^2$. Various attempts were made to separate the stacks into groups that would give correlations more accurate than the average one, but none gave better results. This rule is based on the same theory as the Quartermaster rule, but the factors have been corrected so that the average percentage will be 100 per cent rather than 96 per cent. A logarithmic method was tried using the equation $\log V=\log a+b \log C+c \log O$, in which V is volume, a, b, and c are undetermined constants, C the circumference, and O the over. The above equation is merely the logarithmic form of the equation $V=AC^bO^c$. This method did not give results that could be used.

It was finally decided to try a graphic method for determining the volume. In this method the stacks were divided into groups according to given circumferences; that is, all stacks with 60 feet circumference were put together, those with 61 feet circumference, etc. The volume was then plotted against the overs for a given circumference, and preliminary trend lines were drawn. Readings for volume by circumference were then made on these trend lines and recorded for given overs. The volume was then plotted against the circumference for the individual over readings, and the final trend lines were drawn. From the last chart Table 7 was made. On this table the vertical axis was marked with the circumference and the horizontal axis with the over, the volume for a given circumference and over was read on the trend chart and recorded on the table where these two axes crossed. This table was made to cover stacks with circumferences ranging from 45 to 98 feet, and overs ranging from 25 to 50 feet.

The accuracy of this method was then calculated in the same way as for the Quartermaster rule; although it gives some variation, the results were more accurate than any of the other methods. Ninety-two per cent of the cases fell within 10 per cent of the actual volume, as shown by Table 5. Table 6 shows that on the average this method gives 100.03 per cent of the actual volume. This table also gives the average deviation.

TABLE 7.—*Volume of round stacks*[1] *of specified dimensions*

Circumference in feet	Indicated volume in cubic feet[2] when the over in feet is—																								
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
45	825	960	1,090																							
46	840	975	1,105	1,235																						
47	855	990	1,120	1,250	1,385	1,505																				
48	870	1,005	1,135	1,265	1,400	1,525	1,650	1,785																		
49	885	1,020	1,150	1,285	1,420	1,540	1,670	1,805	1,935																	
50	900	1,035	1,165	1,300	1,435	1,560	1,690	1,825	1,955	2,090	2,215															
51	915	1,050	1,180	1,315	1,450	1,580	1,710	1,845	1,980	2,110	2,240	2,370	2,495													
52	930	1,065	1,200	1,330	1,465	1,600	1,730	1,865	2,000	2,130	2,265	2,400	2,530	2,665	2,795											
53	945	1,080	1,215	1,345	1,485	1,615	1,750	1,880	2,020	2,155	2,290	2,430	2,560	2,700	2,835	2,975										
54	960	1,095	1,230	1,360	1,500	1,630	1,770	1,900	2,040	2,180	2,320	2,460	2,595	2,735	2,875	3,015	3,160									
55	975	1,110	1,245	1,380	1,515	1,650	1,790	1,920	2,065	2,205	2,345	2,490	2,630	2,770	2,915	3,060	3,210	3,360	3,505							
56	990	1,125	1,260	1,395	1,530	1,665	1,810	1,940	2,085	2,230	2,375	2,520	2,660	2,805	2,955	3,105	3,255	3,415	3,565	3,720						
57	1,005	1,140	1,275	1,410	1,550	1,685	1,830	1,960	2,105	2,250	2,400	2,545	2,695	2,845	2,995	3,150	3,305	3,465	3,625	3,785	3,940					
58	1,020	1,155	1,290	1,435	1,565	1,705	1,850	1,980	2,125	2,275	2,425	2,575	2,725	2,880	3,035	3,195	3,350	3,515	3,680	3,850	4,010	4,175				
59	1,035	1,170	1,310	1,450	1,580	1,720	1,865	2,000	2,150	2,300	2,455	2,605	2,755	2,915	3,075	3,235	3,400	3,570	3,740	3,915	4,080	4,245	4,415			
60	1,050	1,185	1,325	1,465	1,600	1,740	1,885	2,020	2,170	2,325	2,480	2,635	2,790	2,950	3,115	3,280	3,445	3,625	3,795	3,975	4,150	4,320	4,490	4,670		
61	1,065	1,200	1,340	1,485	1,615	1,760	1,905	2,040	2,195	2,345	2,510	2,665	2,825	2,985	3,155	3,325	3,495	3,675	3,855	4,040	4,215	4,390	4,570	4,750	4,925	
62	1,080	1,215	1,355	1,500	1,635	1,775	1,925	2,060	2,215	2,365	2,535	2,695	2,855	3,020	3,195	3,365	3,540	3,730	3,915	4,105	4,285	4,465	4,650	4,830	5,015	5,200
63	1,095	1,230	1,370	1,515	1,655	1,795	1,945	2,080	2,235	2,390	2,560	2,725	2,890	3,055	3,235	3,410	3,585	3,780	3,970	4,165	4,355	4,540	4,730	4,910	5,105	5,295
64	1,110	1,245	1,385	1,530	1,670	1,810	1,960	2,100	2,260	2,415	2,585	2,755	2,920	3,090	3,275	3,455	3,635	3,835	4,030	4,230	4,425	4,615	4,805	4,995	5,195	5,390
65	1,125	1,260	1,400	1,545	1,685	1,830	1,980	2,120	2,280	2,440	2,615	2,780	2,950	3,125	3,315	3,495	3,680	3,885	4,085	4,290	4,490	4,690	4,885	5,075	5,285	5,485
66	1,140	1,275	1,420	1,560	1,705	1,850	2,000	2,140	2,300	2,465	2,640	2,810	2,985	3,160	3,355	3,540	3,730	3,935	4,145	4,355	4,560	4,760	4,960	5,160	5,370	5,580
67	1,155	1,290	1,435	1,575	1,720	1,865	2,020	2,160	2,325	2,485	2,665	2,840	3,015	3,195	3,395	3,585	3,780	3,990	4,205	4,420	4,630	4,830	5,040	5,245	5,460	5,670
68	1,170	1,305	1,450	1,595	1,740	1,885	2,040	2,180	2,345	2,510	2,690	2,870	3,050	3,230	3,430	3,630	3,825	4,045	4,265	4,485	4,695	4,900	5,120	5,330	5,550	5,765
69	1,185	1,320	1,465	1,610	1,755	1,905	2,055	2,200	2,365	2,530	2,715	2,900	3,030	3,265	3,470	3,670	3,875	4,095	4,320	4,545	4,760	4,970	5,195	5,415	5,640	5,860
70	1,200	1,335	1,480	1,625	1,770	1,925	2,075	2,220	2,385	2,555	2,745	2,930	3,115	3,300	3,510	3,715	3,920	4,150	4,375	4,610	4,825	5,045	5,275	5,495	5,730	5,955
71	1,215	1,350	1,495	1,640	1,790	1,940	2,095	2,240	2,405	2,580	2,770	2,960	3,145	3,335	3,550	3,760	3,970	4,205	4,435	4,670	4,895	5,120	5,355	5,580	5,820	6,050
72	1,230	1,365	1,515	1,660	1,805	1,960	2,115	2,260	2,430	2,605	2,795	2,990	3,175	3,375	3,590	3,805	4,015	4,255	4,495	4,735	4,965	5,195	5,435	5,665	5,910	6,145
73	1,245	1,380	1,530	1,675	1,820	1,975	2,135	2,280	2,450	2,625	2,825	3,015	3,210	3,410	3,630	3,845	4,065	4,310	4,550	4,795	5,030	5,270	5,515	5,750	6,000	6,240
74	1,260	1,395	1,545	1,690	1,840	1,995	2,150	2,300	2,470	2,650	2,850	3,045	3,245	3,445	3,665	3,890	4,110	4,360	4,610	4,855	5,095	5,340	5,595	5,835	6,090	6,335
75		1,410	1,560	1,705	1,855	2,010	2,170	2,320	2,495	2,675	2,875	3,075	3,275	3,480	3,705	3,935	4,160	4,415	4,670	4,915	5,165	5,415	5,675	5,915	6,180	6,430
76		1,425	1,575	1,725	1,870	2,030	2,190	2,340	2,515	2,695	2,905	3,105	3,310	3,515	3,745	3,975	4,205	4,465	4,725	4,980	5,235	5,490	5,750	6,000	6,270	6,525
77			1,590	1,740	1,890	2,050	2,210	2,360	2,540	2,720	2,930	3,135	3,340	3,550	3,785	4,020	4,250	4,520	4,785	5,045	5,305	5,560	5,830	6,085	6,355	6,620
78			1,605	1,755	1,905	2,070	2,230	2,380	2,560	2,745	2,955	3,165	3,375	3,585	3,825	4,065	4,300	4,570	4,840	5,105	5,370	5,635	5,910	6,170	6,445	6,715
79				1,775	1,925	2,090	2,250	2,400	2,580	2,765	2,980	3,195	3,405	3,620	3,865	4,105	4,345	4,625	4,895	5,170	5,440	5,710	5,990	6,255	6,535	6,810
80				1,790	1,945	2,105	2,270	2,420	2,605	2,790	3,010	3,225	3,440	3,655	3,905	4,150	4,395	4,675	4,955	5,235	5,510	5,785	6,070	6,340	6,625	6,905
81				1,805	1,960	2,125	2,285	2,440	2,625	2,815	3,035	3,255	3,470	3,690	3,945	4,195	4,440	4,730	5,010	5,295	5,575	5,855	6,145	6,425	6,715	7,000
82				1,820	1,975	2,145	2,305	2,460	2,645	2,835	3,060	3,280	3,500	3,725	3,985	4,240	4,490	4,785	5,0 0	5,360	5,645	5,930	6,225	6,510	6,800	7,090
83					1,995	2,160	2,325	2,480	2,665	2,860	3,090	3,310	3,535	3,760	4,025	4,280	4,535	4,830	5,130	5,425	5,715	6,005	6,305	6,595	6,890	7,185
84						2,180	2,345	2,500	2,690	2,880	3,115	3,340	3,570	3,795	4,065	4,320	4,580	4,885	5,190	5,485	5,785	6,080	6,385	6,675	6,980	7,280
85								2,520	2,710	2,905	3,140	3,370	3,600	3,830	4,105	4,365	4,630	4,935	5,245	5,550	5,850	6,155	6,465	6,760	7,070	7,375
86									2,735	2,930	3,170	3,400	3,635	3,865	4,145	4,410	4,675	4,990	5,300	5,615	5,920	6,230	6,545	6,845	7,160	7,470

87											3,195	3,430	3,665	3,900	4,185	4,455	4,725	5,040	5,360	5,680	5,990	6,300	6,620	6,930	7,250	7,565
88												3,460	3,700	3,940	4,220	4,500	4,770	5,090	5,420	5,745	6,060	6,375	6,700	7,015	7,340	7,660
89												3,490	3,730	3,975	4,260	4,540	4,815	5,145	5,475	5,805	6,125	6,450	6,780	7,100	7,430	7,755
90													3,765	4,010	4,300	4,585	4,860	5,200	5,535	5,865	6,195	6,525	6,860	7,185	7,520	7,845
91														4,045	4,340	4,630	4,910	5,250	5,595	5,930	6,265	6,600	6,940	7,270	7,605	7,940
92														4,080	4,380	4,670	4,955	5,305	5,650	5,995	6,335	6,675	7,020	7,355	7,695	8,035
93															4,420	4,715	5,005	5,360	5,710	6,055	6,400	6,750	7,095	7,440	7,785	8,130
94															4,460	4,760	5,050	5,410	5,765	6,120	6,470	6,825	7,175	7,525	7,875	8,225
95																4,805	5,100	5,465	5,825	6,180	6,540	6,895	7,255	7,610	7,965	8,320
96																	5,150	5,515	5,885	6,245	6,610	6,970	7,335	7,695	8,055	8,415
97																	5,195	5,570	5,945	6,310	6,680	7,045	7,415	7,780	8,145	8,510
98																		5,625	6,000	6,370	6,750	7,120	7,495	7,865	8,235	8,605

[1] The volume of stacks that have circumferences or overs greater or less than those given in the table can be determined by using the formula, $V=(0.04\times O)-(0.012\times C)\ C^2$.
[2] Volumes given to the nearest 5.

DETERMINATION OF CUBIC FEET REQUIRED FOR A TON

STACKS OF VARIOUS KINDS SEGREGATED

The stacks for which weights were obtained were divided into a number of groups for the purpose of tabulating the number of cubic feet per ton. First they were segregated as to the kind of hay, such as alfalfa, timothy, and prairie. In those cases in which the hay was a mixture of several kinds it was grouped according to the kind of hay that predominated in the mixture. The stacks were divided into the following groups: Alfalfa, prairie, timothy and timothy mixtures, grass hay, and tame oat hay.

The timothy mixtures were mixtures of timothy and clover and timothy and wild grasses. The last-named mixtures were common in certain areas of Nebraska, Montana, and Minnesota where cultivated grasses, such as timothy and redtop, are sown in the native meadows to increase the yield and quality of the hay harvested. These cultivated grasses thrive only in those parts of the native meadows where there is plenty of moisture.

The grass hay was of two kinds: That produced in California which consisted mainly of wild oats, cheat, and bur clover; and that produced in South Dakota which was chiefly awnless bromegrass.

The stacks were divided also into groups according to the number of days from the time of stacking to the time of measuring. Many of the stacks were measured more than once, and therefore were placed in several groups according to the length of time in the stack. At first the stacks were divided into 5-day intervals, but these were later grouped into the following groups: 30 days and less, 35 to 60 days, 65 to 90 days, 95 to 120 days, etc.

METHOD OF DETERMINING VOLUME PER TON

For the purpose of determining the number of cubic feet per ton the volume of each stack was calculated by the formula applicable. For the low, round-topped stacks the rule $(0.52 \times O) - (0.44 \times W)WL$ was used; for the high, round-topped stacks the rule $(0.52 \times O) - (0.46 \times W)WL$ was used; for the square, flat-topped stacks the rule $(0.56 \times O) - (0.55 \times W)WL$ was used; and for the round stacks the volume was obtained from Table 7, which gives the volume for the various circumferences and overs.

The volume, as determined by these methods, was used in preference to the actual volume of rectangular stacks, as obtained by measuring the area of the cross section and multiplying it by the length of the stack, or of the round stacks, as obtained by calculating the volume of the 1-foot frustums, because there were many stacks for which cross-section drawings were not available upon which to base the actual volume, and thus the volume had to be figured from measurements only. The stacks that were measured at the Eastern Oregon Branch Experiment Station prior to 1927, and those measured at the Colorado Agricultural College had to be computed in this manner. Had the actual volume been used, a large group of valuable data could not have been used, or if used, would not be entirely comparable with the other data. Moreover, it seemed preferable to use the formulas for determining volume because the number of cubic feet per ton would then be based on the same method by which the volume would be determined in a practical application of the results of this study.

CUBIC FEET PER TON

The volume of each stack was then divided by the number of tons by weight to determine the cubic feet required for a ton of hay. These computations gave a wide range of results, indicating that there was a large variation in the density of the hay in the stacks. Table 8 shows the average number of cubic feet required for a ton of the various kinds of hay and the maximum and minimum number of cubic feet found in each group.

TABLE 8.—*Number of cubic feet per ton of principal kinds of hay in stack standing various periods*

Period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
ALFALFA				
30 and less	294	483	1,102	224
35 to 60	419	483	1,185	234
65 to 90	276	489	1,026	107
95 to 120	237	472	948	224
125 to 150	159	471	879	258
155 to 180	91	470	853	247
185 to 210	18	431	677	292
215 to 240	6	481	693	420
245 to 270	2	651	683	580
275 to 300	2	565	632	508
395 to 420	9	410	497	169
425 to 450	4	513	631	418
455 to 480	1	450	450	450
485 to 510	1	538	385	538
TIMOTHY AND TIMOTHY MIXED				
30 and less	39	757	1,195	433
35 to 60	75	644	994	319
65 to 90	67	624	929	410
95 to 120	20	633	912	474
125 to 150	12	600	797	547
155 to 180	3	716	805	650
WILD HAY				
30 and less	92	830	1,554	392
35 to 60	195	574	1,265	264
65 to 90	101	633	1,153	326
95 to 120	130	468	1,109	277
125 to 150	110	426	592	299
155 to 180	59	399	515	302
185 to 210	31	440	519	346
215 to 240	19	398	478	318
395 to 420	9	617	798	534

Table 9 shows by States the average number of cubic feet required for a ton of the various kinds of hay, as well as the maximum and minimum number of cubic feet. These figures indicate that differences in type of stack, method of stacking, and size of stack do not cause significant differences in the number of cubic feet required for a ton.

TABLE 9.—*Number of cubic feet per ton for different kinds of hay in stack standing various periods, by States*

ALFALFA HAY

State and period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
California:				
30 and less	174	443	507	224
35 to 60	118	424	596	259
65 to 90	22	392	555	209
95 to 120	1	224		
Colorado:				
30 and less	16	455	919	262
35 to 60	18	452	752	259
65 to 90	32	453	654	327
95 to 120	24	424	614	322
155 to 180	2	400	449	358
425 to 450	1	418		
Idaho:				
30 and less	3	660	731	573
65 to 90	2	651	673	620
125 to 150	1	547		
Minnesota:				
30 and less	10	835	1102	542
35 to 60	36	502	920	286
65 to 90	46	501	901	267
95 to 120	25	497	948	277
125 to 150	1	486		
Montana:				
30 and less	37	511	761	260
35 to 60	65	537	853	258
65 to 90	40	513	758	402
95 to 120	59	507	853	361
125 to 150	40	540	879	374
155 to 180	35	522	853	369
185 to 210	8	485	544	387
245 to 270	2	651	683	580
275 to 300	2	565	632	508
395 to 420	6	451	497	401
Nebraska:				
30 and less	6	328	392	288
35 to 60	19	374	557	254
65 to 90	24	450	1026	201
95 to 120	49	436	762	242
125 to 150	58	419	690	279
155 to 180	12	433	532	284
185 to 210	4	456	677	380
215 to 240	3	520	693	426
Nevada:				
30 and less	4	625	733	580
35 to 60	9	564	677	398
65 to 90	11	582	708	232
95 to 120	1	671		
125 to 150	2	556	649	411
Oregon:				
30 and less	11	527	774	397
35 to 60	78	512	1185	234
65 to 90	22	495	714	251
95 to 120	23	454	777	309
125 to 150	14	414	778	298
155 to 180	21	400	816	292
185 to 210	4	349	538	292
395 to 420	2	210	254	169
425 to 450	2	587	631	546
485 to 510	1	538		
South Dakota:				
30 and less	32	450	732	307
35 to 60	18	343	691	237
65 to 90	24	341	676	167
95 to 120	17	342	742	258
125 to 150	14	360	671	258
155 to 180	1	346		
Utah:				
30 and less	21	564	842	276
35 to 60	58	529	894	289
65 to 90	53	520	875	382
95 to 120	38	468	855	356
125 to 150	29	506	749	365
155 to 180	20	450	686	246
185 to 210	2	536	539	535
215 to 240	3	455	518	420
395 to 420	1	483		
425 to 450	1	464		
455 to 480	1	450		

TABLE 9.—*Number of cubic feet per ton for different kinds of hay in stack standing various periods, by States*—Continued

CLOVER HAY

State and period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
Minnesota:				
65 to 90	1	365		
Oregon:				
30 and less	2	769	800	732
65 to 90	2	718	758	672

GRASS HAY

State and period elapsed prior to measurement, days	Measurements taken	Average	Maximum	Minimum
California:				
35 to 60	128	658	926	429
65 to 90	11	533	587	488
South Dakota:				
30 and less	2	312	362	274
35 to 60	2	328	329	328
65 to 90	2	325	326	324
95 to 120	2	311	312	309
155 to 180	1	311		

PEAS AND BARLEY HAY

State and period elapsed prior to measurement, days	Measurements taken	Average	Maximum	Minimum
Oregon:				
35 to 60	1	602		
65 to 90	1	1,099		
95 to 120	1	578		
125 to 150	1	578		
155 to 180	2	722	943	582

SWEET CLOVER HAY

State and period elapsed prior to measurement, days	Measurements taken	Average	Maximum	Minimum
Minnesota:				
65 to 90	3	419	692	331

TAME OAT HAY

State and period elapsed prior to measurement, days	Measurements taken	Average	Maximum	Minimum
California:				
35 to 60	10	528	613	393

TIMOTHY

State and period elapsed prior to measurement, days	Measurements taken	Average	Maximum	Minimum
Minnesota:				
30 and less	9	983	1,195	772
35 to 60	12	832	994	695
65 to 90	9	799	929	672
95 to 120	1	883		

TIMOTHY MIXED

State and period elapsed prior to measurement, days	Measurements taken	Average	Maximum	Minimum
Minnesota:				
30 and less	6	833	972	640
35 to 60	12	628	837	319
65 to 90	7	636	750	474
95 to 120	7	650	912	474
Montana:				
30 and less	23	596	836	433
35 to 60	51	601	831	415
65 to 90	51	577	914	410
95 to 120	18	620	813	501
125 to 150	12	600	707	547
155 to 180	3	718	805	680

TABLE 9.—*Number of cubic feet per ton for different kinds of hay in stack standing various periods, by States*—Continued

WILD HAY

State and period elapsed prior to measurement, days	Measurements taken	Volume per ton at time of measurement		
		Average	Maximum	Minimum
	Number	*Cubic feet*	*Cubic feet*	*Cubic feet*
Minnesota:				
30 and less	58	965	1,554	392
35 to 60	56	840	1,265	588
65 to 90	50	781	1,153	566
95 to 120	20	738	1,100	541
385 to 420	9	617	798	534
Montana:				
30 and less	2	559	628	508
35 to 60	10	476	520	431
65 to 90	2	498	602	436
95 to 120	17	458	584	392
185 to 210	9	469	510	428
Nebraska:				
30 and less	32	487	490	417
35 to 60	120	428	610	264
65 to 90	40	428	522	326
95 to 120	93	411	510	277
125 to 150	110	426	592	299
155 to 180	59	399	515	302
185 to 210	22	423	519	347
215 to 240	19	398	478	318

The variation in the figures on the cubic feet per ton for the various kinds of hay shows the reason for the difference of opinion that has existed as to the number of cubic feet required for a ton. The hay dealers and stockmen have realized that there was considerable variation in density, even if they have had no accurate data to prove this idea. These average figures show that the 512 cubic feet per ton for alfalfa at the end of 30 days' settling, in use in many sections now, is fairly accurate. Table 8 shows also that stacks do not settle much after 30 days, and that the old figure of 422 cubic feet after 90 days' settling is too low. These figures show further that more cubic feet per ton are required for prairie hay than for alfalfa hay instead of less, as was generally supposed, and that the figures of 422 cubic feet per ton after 30 days' settling, and 343 cubic feet per ton after 90 days' settling, are entirely too low for prairie hay.

VARIATIONS IN DENSITY

A number of studies were carried on to find the reason for these variations in density, but the data obtained were not sufficiently comprehensive to provide a satisfactory explanation. Data obtained in Montana[11] on stacks in various parts of the State showed that there was considerable variation in the density of the hay. Samples (approximately 5 cubic feet in each instance) were taken from various parts of these stacks and weighed. (Fig. 12.) These samples were obtained by forcing the prongs of the hay sampler shown in Figure 13 into the hay and then cutting around the sample with a hay knife. When the sample had been cut loose on all sides, it was lifted out onto a canvas and weighed. (Fig. 14.) By this method a sample of hay was obtained that gave the approximate density of the

[11] These data were collected by H. E. Murdock, of the Montana Agricultural Experiment Station. The sampling device was devised by Mr. Murdock.

hay at that point in the stack. By taking several samples in various parts of the stack, the approximate average density was ascertained. Samples taken from the same general location in different stacks varied as much as 10 pounds, which was about a 50 per cent variation. This sampling method indicates that the variations in density, shown in Tables 8 and 9, are not due to errors in the weights given for the individual stacks, but to some undetermined cause.

Several theories as to the reason for these variations in the density of stacked hay have been presented, but no data to prove or disprove these theories have been collected. The theory that the moisture at time of stacking is an important factor in the density of the hay has much to recommend it. Hay with 20 to 25 per cent moisture at time of stacking is more pliable and is heavier per cubic foot than hay with

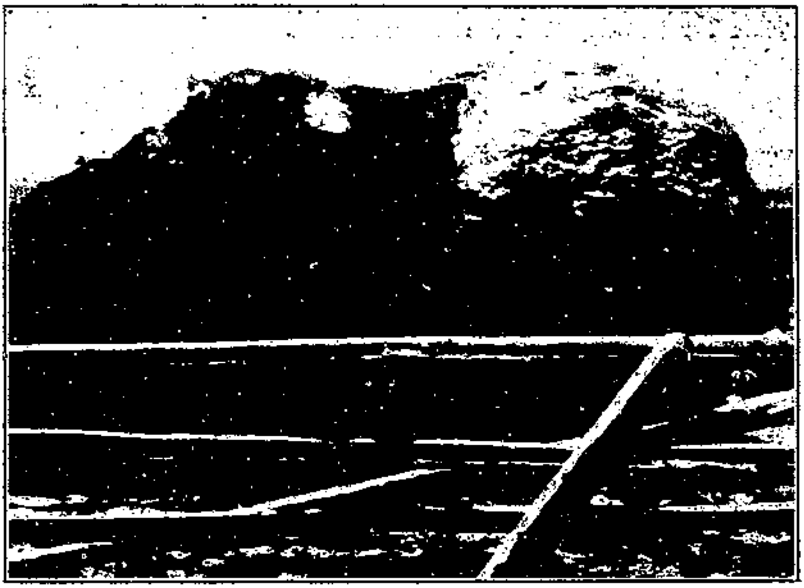

FIGURE 12.—Stack of hay that has been sampled for density. Samples were taken at various depths to determine the variation in density of the hay at different points and to determine the average density of the stack

only 12 per cent moisture, and therefore would settle more and become more compact. Observations made by the writer in the various hay-producing areas tend to support this theory. It is much easier to force the hand or a rod into a stack of hay made from overcured hay, especially alfalfa, than it is to force the hand or rod into a stack of hay that was stacked before the hay became overdry. The Montana data support this theory, because in several instances the hay was reported to have been stack sweated when the sample taken from the stack was much heavier than the average for the group of stacks sampled. Moreover, in several instances in which the sample taken was exceptionally light, it was noted that the hay was very dry and fluffy at the time of sampling.

Another factor that may influence density is the coarseness or fineness of the hay, or the quantity of hard, woody stems that do not collapse when weight is added. Hay that is overripe or that contains large quantities of harsh and woody weeds probably does not settle so much as hay that has pliable stems or that is free of foreign material. Other factors may affect the density of hay in the stack, but the ones mentioned are probably the most important.

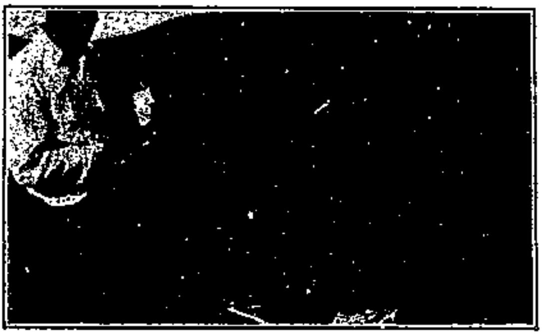

FIGURE 13.—Sampling device for determining the density of hay in the stack. The hay is cut away from around the frame to the depth of the prongs, then the hay knife is inserted under the central prongs and the sample lifted out and weighed

NEED FOR ADDITIONAL RESEARCH

A determination of the reasons for the variation in the number of cubic feet of hay required for a ton under different conditions is a problem that should receive additional study. Because of the conditions under which much hay is fed in many sections, it will continue to be sold by measure even if the interested parties realize that there is a large variation in the number of cubic feet required for a ton, and that this variation can not be measured in a practical way under existing rules.

Additional research should be carried on, therefore, in a few well-chosen localities where the various factors that influence the density of the hay can be measured and observations made which will explain the variations in density. Special attention should be given to the following factors: Percentage of moisture in the hay at the time of storing; texture and maturity of the hay; leafiness of the hay in the case of alfalfa and clover; and rate of settling during the first 30 days.

A series of stacks were measured in California in 1928 to determine rate of settling, but because no common first measurement was given these data could not be tabulated.

FIGURE 14.—Weighing the density sample of hay

Methods should be investigated for determining the density of stacks, either by taking samples from a definite place in the stack and then determining the average density of the stack from the sample, or by developing an instrument by means of which the density can be measured by the degree of resistance encountered upon thrusting the instrument into the stack.

It is only by such research that the reasons for the variation in density and shrinkage of hay in the stack can be found, that the number of cubic feet required for a ton under various conditions can be determined, and that satisfactory methods of selling hay by measure can be recommended.

SUMMARY

Much hay is sold annually by measure, especially in the Western States. Accurate rules for determining the volume of rectangular and round stacks and accurate information relative to the number of cubic feet necessary for a ton should be available.

The rules for determining volume of rectangular stacks in use at present are not very accurate. On an average the Frye-Bruhn rule gives only 86 per cent of the actual volume, the Quartermaster rule 96 per cent of the actual volume, and the Outlaw rule 84 per cent of the actual volume. All three of these rules have a wide range of error, in some cases giving only 70 per cent of the actual volume, and in others 130 per cent.

The formulas recommended in this bulletin are as easy to apply as any of the above-mentioned rules and give results that are much more accurate than any of the old rules.

The formulas recommended for determining the volume of rectangular stacks are as follows:

For low, round-topped stacks $(0.52 \times O) - (0.44 \times W) WL$

For high, round-topped stacks $(0.52 \times O) - (0.46 \times W) WL$

For square, flat-topped stacks $(0.56 \times O) - (0.55 \times W) WL$

The rules for determining volume of round stacks in use at present are not very accurate. On the average the Quartermaster rule gives only 95 per cent, and the Prismoidal rule only 92 per cent, of the actual volume.

The volume of a round stack of a given circumference and over can be determined readily from Table 7. The volume obtained from this table is more accurate than that obtained from either of the above-mentioned rules. Should the circumference or over be greater or less than those given in the table the volume of the stack can be determined by using the following formula $V = (0.04 \times O) - (0.012 \times C) C^2$. This formula will give results that are as accurate as those obtained from Table 7.

If the hay can not be weighed, or the density determined, the cubic feet per ton which may be used with fairly satisfactory results with hay 30 to 90 days in the stack are 485 for alfalfa, 640 for timothy and timothy mixed, and 600 for wild hay, and for hay more than 90 days in the stack, 470 for alfalfa, 625 for timothy and timothy mixed, and 450 for wild hay. These figures, when used with the rules for determining volume given above, will give more accurate results than can be obtained from the figures for cubic feet per ton now in use when employed with present volume rules.

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