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ARTIFICIAL DRYING OF FORAGE CROPS¹

By E. D. GORDON and W. M. HURST, *associate agricultural engineers, Division of Mechanical Equipment, Bureau of Agricultural Engineering*

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NEED FOR FORAGE DRIERS

The production and curing of forage crops is an important part of the program of farm operations in most parts of the United States. Not only is forage a basic ingredient of livestock rations but it also has an important place in crop rotation and in the conservation of soil fertility. Since it is desirable to bring quality production in line with profitable operation, attention is being given to the curing of forage artificially. The reason for this comparatively new undertaking lies in the results of feeding experiments which show that forage of high grade (U. S. grade) is usually superior in feeding value to low-grade forage.

Feeding experiments have demonstrated (p. 21) that with artificial drying forage of superior quality can be obtained from a crop that otherwise, under unfavorable weather conditions, would be of inferior quality. Methods and equipment employed in harvesting, curing, and subsequent processing operations govern to a large degree the value of the product for feed. This is especially true in the more humid areas. Overdrying, leaf shattering, and discoloration by rain and dew, reduce the returns to the grower regardless of whether the hay is used on the farm or is sold. Occasionally unfavorable conditions result in practically a total loss of the crop.

The use of green, leafy alfalfa hay and of alfalfa meal as a source of vitamin A has also stimulated interest in artificial drying. When the crop is cut at the proper stage and dried artificially without injury, hay or hay products equivalent to U. S. No. 1 Extra Green, Extra Leafy alfalfa may be obtained. The carotene content, source of vitamin A activity, usually is higher in hay artificially dried than in sun-cured hay of the same grade. Artificial drying also tends to preserve the protein and mineral elements of hay by eliminating the

¹ The investigation on which this report is based was conducted under cooperation between the Bureaus of Agricultural Engineering, Animal Industry, Dairy Industry, Plant Industry, and Agricultural Economics.

possibilities of leaf shattering in handling and of leaching due to weathering in the field.

TYPES OF DRIERS

The artificial drying of forage crops has been practiced to a limited extent in some localities in the United States for many years. Available information does not indicate the exact date of the first hay drier in this country. However, about 1909 an experimental drier was constructed and used in Missouri for alfalfa. Also, a machine was constructed for drying native grasses in Louisiana as early as 1910. Since that date many attempts have been made by commercial, State,

FIGURE 1.—Apron-conveyor type of forage drier.

and Federal agencies to develop satisfactory forage driers, but few were developed beyond the experimental stage.

The design of many of the early machines indicated a radical departure from established practices in the utilization of heat for evaporating moisture from damp or wet materials. In other cases slight changes in design and alterations were made of equipment typical of that used for drying materials other than hay. The most common types were those generally known as apron-conveyor and revolving-drum driers. An apron-conveyor drier of the type com-

FIGURE 2.—Revolving-drum type of forage drier, single-drum design.

monly used for hay is diagrammatically illustrated in figure 1, and drum driers in figures 2 and 3.

The principles involved in these machines are not new, but the direct exposure of material to be dried to the furnace gases is a practice that has been closely associated with the development of hay driers of various types in the United States. Previously steam was commonly used, the material to be dried being brought into direct contact with or exposed to air heated by steam radiators. Higher efficiency in the utilization of heat and elimination of the expense and trouble commonly associated with steam boilers are factors frequently cited in favor of direct application of furnace gases.

In the apron-conveyor type (fig. 1) the green forage is loaded on an endless screen-wire apron and conveyed through the drying chamber

where hot air or furnace gases are circulated through the layer of forage on the apron by means of one or more fans. Driers of this type may have a single endless conveyor, or several conveyors one above the other. As the drying air becomes saturated with moisture it is drawn or allowed to escape from the machine into the atmosphere. The forage may be fed into the drier whole, crushed, or chopped. Drying the forage whole is more satisfactory in single-apron machines, especially if the plants are small and light as is usually the case with alfalfa, some clovers, and grasses. The crushing operation is intended to be sufficient only for cracking open the heavier stemmy plants including weeds. The crushing-roll pressure should not be sufficient for complete maceration. In connection with experimental work the crushing was done by passing undried soybean plants between a pair of rollers, one of which was steel and the other rubber coated. The drying was noticeably more uniform through the "mattress" of hay as compared with the un-

FIGURE 3.—Revolving-drum type of forage drier, triple-drum design.

crushed hay plants. The chopped material offers more resistance to the movement of air than do the whole plants, crushed or uncrushed, and many of the finely chopped particles fall through the screen apron.

Drum driers of the single-drum type (fig. 2) used for drying granular substances such as salt have the feed end slightly elevated. As the drum revolves the material is picked up by baffles or flights fastened to the inside of the shell and then allowed to fall. Each time some of the material is picked up it falls somewhat closer to the discharge end due to the sloping position of the drum. In drying hay the drum is placed in a horizontal position and a current of heated air or furnace gases relied upon both for drying and for moving the forage through the machine. With drum driers it is necessary to chop the forage before it is fed into the machine. In some driers of this type the dry material is drawn into a chamber at the discharge end, from which it is conveyed mechanically to a storage structure. In most cases, however, the dry hay passes through the exhaust fan and is blown to a dust collector from which it may be sacked or conveyed to a haymow.

In the single-drum drier (fig. 2) the chopped hay passes directly from the wet end (feed end) to the discharge end (dry end). In the triple-drum drier (fig. 3) the material moves through the center shell, back through the second, and out through the third, thus traveling approximately three times the length of the drier before it passes to the exhaust fan.

The apron-conveyor drier is a relatively low-temperature drier in which the material remains for a considerable period of time. The temperature of the drying air or furnace gases entering the machine

is usually held at from 250° to 350° F., and the period of exposure may vary from 15 to 45 minutes, depending in part upon the initial moisture content of the forage. The temperature of the hay remains much lower than that of the surrounding gases due to the cooling effect of evaporation. The temperature of the forage also tends to coincide with the wet-bulb temperature of the drying air, which, in a hay drier, is much below the dry-bulb temperature.

Apron-conveyor driers are usually much larger machines than drum driers, due in part to the long period of exposure. Single apron-conveyor driers for hay are frequently 150 to 200 feet in length with the equivalent of 10 by 10 feet in section.

Drying the plants without chopping or chopping them in long pieces also tends to increase the time during which the material must remain in the machine. The leafy portions and fine stems dry quickly, whereas considerable time is required for drying the long, coarse stems. The overdrying of some parts of the plant and heat losses from the long tunnel may result in a low thermal efficiency for some machines of the apron-conveyor type.

The drum drier when used for hay may be classed as a high temperature machine, necessitating a short period of exposure to prevent charring or burning of the hay. The temperature of the furnace gases entering the machine is usually held at from 1,000° to 1,500° F., by means of adjustments on the secondary air inlet to the furnace or its quantity of fuel supplied to the burner. The material remains in a drier of the drum type for approximately 1 to 3 minutes, or even less, depending somewhat upon the initial moisture content of the forage. However, as is the case with the apron-conveyor type, the temperature of the hay is much below that of the drying gases.

The chopping of the hay into short pieces enables it to dry quickly and thereby makes possible the use of high temperatures in drum driers. As the air is used for moving the material through the drier, the light particles move more rapidly than the stemmy material, which is helpful in preventing overdrying.

The use of high temperatures and a short period of exposure in drum driers makes possible a rather small, compact unit in comparison with the apron-conveyor type. Single-drum driers are usually 40 to 60 feet in length and from 7 to 9 feet in diameter. Double- or triple-drum driers may be somewhat shorter than single drum units, as the use of multiple drums increases the length of the drying zone with reference to over-all length.

In drum driers there seems to be a definite relation between the temperature of the exhaust gases and the moisture content of the hay as it is discharged from the machine. An exhaust-gas temperature of about 200° to 250° F. is usually maintained by controlling the rate of feed of undried hay. If the moisture content of the forage entering the drier is high (65 to 75 percent) the exhaust temperature should be kept at the high point of the range. With moisture contents around 50 percent the exhaust temperature can be held at the lower end of the range. The high exhaust temperature represents a considerable loss of heat which tends to reduce the thermal efficiency of drum driers.

TESTS OF DRIERS

Investigational work by the United States Department of Agriculture was begun in 1930 in a study of the mechanics of artificial drying

of forage crops, the elements of cost, and the feeding value of artificially dried forage. A small apron-conveyor drier of the type commonly used in drying cotton linters was set up on the Iberia Livestock Experiment Station at Jeanerette, La., for experimental use in drying crops for feeding trials (fig. 4). This machine was approximately 46 feet long, 11 feet wide, and 9 feet high. The drying chamber was approximately 8 by 36 feet, and the machine would usually evaporate from 500 to 1,000 pounds of water per hour under the

FIGURE 4.—Apron-conveyor drier used in forage-drying experiments at Iberia Livestock Experiment Station. Drying air enters fan 1 from furnace manifold and is discharged above apron, is drawn through apron by fan 2 and released above it in second compartment, and then is drawn again through apron by fan 3 and released outside the drier. Circulation through fans 4, 5, and 6 is similar.

conditions in which it was operated. This drier was used for several seasons, but its capacity was insufficient for drying the forage needed for feeding trials. It was unsatisfactory also for drying coarse-stemmed crops such as soybeans.

In all the experimental driers discussed herein, electric power was used for operating the machinery and fuel oil was used for heat, because of the ease of measuring the quantities used and of controlling operations.

After the conveyor-type drier had been used for a few years, a revolving-drum drier was installed. This machine consisted of a single shell 6 feet in diameter and 24 feet in length, mounted horizontally. Flights or flanges were attached to the inside of the shell, for picking up and dropping the chopped forage as the drum revolved.

A furnace was connected to one end of the drum and an exhaust fan to the other. The dried forage passed from the drum through the fan and was blown into a dust collector or cyclone. This machine was inefficient because of the short drying zone or length of travel and period of exposure of the material in the drier.

For increasing the efficiency of this machine a cylinder 2 feet in diameter and 20 feet long was installed inside and concentric with the large drum (fig. 5). This cylinder was connected to the furnace and to the feeder for the undried material at the furnace end of the drier. At the opposite end the 2-foot cylinder was open and ended 3 feet from the end of the outer cylinder. An exhaust fan was connected to the outer shell at the furnace end in such a manner as to move the furnace gases together with the chopped hay first through the inner cylinder and back through the outer cylinder. The dried forage, after passing through the fan, was blown into a dust collector.

FIGURE 5.—Revolving-drum drier used in forage-drying experiments at Iberia Livestock Experiment Station.

This reverse current or two-pass system lengthened the evaporating zone and greatly increased the efficiency of the machine.

From 1931 to 1936, inclusive, the apron-conveyor and double-drum driers, were used in drying about 300 tons of hay, including alfalfa, pasture grass, clovers, and soybean hay. Approximately 250 tons were used in feeding tests with dairy animals, and the remaining portion with beef cattle. In operating these experimental driers records were kept of the tonnage handled, the power, labor, and fuel requirements, and the moisture content of the forage before and after drying. As time permitted, trips were made to farms operating forage driers in Louisiana, where similar data were obtained.

Observations of the various factors entering into the dehydration of forage takes into account a large number of factors, many of which are rather difficult to measure with any degree of precision. A drying machine handling such a bulky product as forage must of itself be large and any attempt to measure air velocities, temperatures, or make hydrometric measurements of the drying gases are only an approximation. It is furthermore impossible to make check runs on the average lot of forage because of the wide range of moisture contents which it has before entering the drier. The presence of weeds and mixtures of other kinds of forage enter into the actual test work and provide data which are somewhat difficult to interpret.

The performance of the apron-conveyor and rotary driers located at Iberia Livestock Experiment Station were observed especially as to the power, labor, and fuel requirements for various kinds of crops, for

crops of different maturity, and for different methods of processing. Other factors incidental to these observations were time length of the drying run, drier-inlet and exit-gas temperatures, moisture content of forage entering and leaving the drier, the weight of the material entering the drier, and if possible the weight of the material leaving the drier. When it was not practicable to obtain the weight of the material both entering and leaving the drier the unknown weight was computed from the known weight and the moisture content of the forage (wet basis) before and after drying. Under normal operating conditions it is assumed that the difference between the weight of the forage as it enters and leaves the drier represents the water evaporated and that the quantity of dry matter is constant.

From observations and tests of the two driers at the Iberia Station, which have been summarized in tables 1 and 2, the following is noted:

1. In drying alfalfa (whole) on the apron-conveyor drier the average percentage loss in weight is about the same for the seasons 1932 and 1934. Not much forage was dried during the 1933 season. The power consumed per unit weight of material dried, and per unit weight of water evaporated was reduced in 1934 from that shown during the 1932 season. The same holds true for the heat requirements of the drier per unit weight of material dried and per unit weight of water evaporated, although the hourly output and evaporation weight do not show an increase. This more efficient utilization of power and heat in the apron-conveyor drier was due to the scheme of blowing the air counter current to the apron travel for the first half of the apron length. The intake and exhaust system on the apron-conveyor drier was arranged so that the drying gases after first being forced through a section of the apron might be drawn into a fan and then forced through another section of the apron either toward the feed end or discharge end of the drier. If the air moved toward the feed end the counter-current system was obtained. If toward the discharge end (fig. 4), the air moved concurrently with the hay. The air velocity through the mat of forage ranged from 80 to 150 feet per minute in all of these observations.

TABLE 1.—Drying alfalfa, soybean, and cowpea hay with experimental apron-conveyor drier

WHOLE ALFALFA, 1932 SEASON

Test No.	Duration of test	Temperature of drying air		Weight of forage		Moisture content of forage 1		Water evaporated	Loss in weight of forage 2	Power used	Fuel used	Heat input, B. t. u.	Power used 2		Heat input, B. t. u. 2		Drier output per hour 2	Water evaporated per hour 2
		Inlet	Exit	Entering	Discharge	Entering	Discharge						Per ton of hay	Per 1,000 pounds of water evaporated	Per ton of dried hay	Per 1,000 pounds of water evaporated		
	Hours	° F.	° F.	Pounds	Pounds	Percent	Percent	Pounds	Percent	Kilowatt-hours	Gallons	Mil-tons	Kilowatt-hours	Per ton of water evaporated	Mil-tons	Mil-tons	Pounds	Pounds
1	5.9	---	---	5,745	2,520	63.5	16.7	3,225	56.1	115	105.1	15.40	91.3	35.7	12.22	4.78	427	547
2	5.38	---	---	5,730	2,535	58.1	8.9	3,195	55.8	91	89	13.05	71.8	28.5	10.29	4.08	471	594
3	0.41	---	---	795	235	72.7	7.9	560	70.4	11	10	1.47	93.2	19.6	12.46	2.63	573	1,366
4	3.41	---	---	5,795	2,085	71.2	19.9	3,710	64.0	63	65	9.53	60.4	17.0	9.13	2.57	611	1,088
5	4.61	---	---	6,855	2,080	68.2	18.6	4,175	60.9	92	98	14.37	68.7	22.0	10.73	3.44	581	906
6	8.26	320	195	11,495	5,080	61.1	11.9	6,415	55.8	164	156	22.87	64.6	25.6	10.68	3.56	615	777
7	9.58	311	183	13,530	5,085	61.0	7.4	7,845	58.0	203	207	30.35	71.4	25.9	10.68	3.87	593	819
8	2.83	311	170	3,805	1,845	56.4	10.1	1,960	51.5	60	52	7.62	65.0	30.6	8.26	3.89	632	693
9	7.02	353	181	10,310	4,240	60.3	3.4	6,070	58.9	125	151	22.14	59.0	20.6	10.44	3.65	604	865
10	3.17	400	183	4,265	1,645	62.7	3.3	2,620	61.4	57	62	9.09	69.3	21.8	11.03	3.47	519	826
11	2.50	369	176	3,330	1,480	59.0	7.9	1,850	55.6	42	53	7.77	56.8	22.7	10.50	3.47	592	740
12	2.60	369	176	4,295	1,810	60.7	6.7	2,485	57.9	48	56	8.21	53.0	19.3	9.06	3.30	696	956
13	12.75	361	188	18,120	9,160	52.3	5.7	8,960	49.4	238	220	32.25	52.0	26.6	7.04	3.60	718	703
14	7.25	340	136	12,400	7,910	44.2	12.5	4,490	36.2	138	103	13.10	40.0	35.2	3.82	3.39	1,091	619
15	2.6	330	146	5,710	2,325	42.1	7.6	1,385	37.3	45	29	4.25	38.7	32.5	3.65	3.07	1,076	641
16	4.50	---	---	7,185	5,240	31.8	6.5	1,945	27.1	94	62	9.09	35.9	48.3	3.47	4.67	1,104	432
17	1.41	---	---	2,495	1,675	42.7	14.7	820	32.9	26	20	2.93	31.0	31.7	3.50	3.37	1,188	582
18	2.83	248	148	5,665	2,890	52.4	6.6	2,775	49.0	59	52	7.62	40.8	21.3	5.28	2.75	1,021	981
Total or average	86.57	334	171	125,525	61,040	55.8	9.3	64,485	51.4	1,691	1,590.1	233.11	55.4	26.2	7.64	3.61	705	745

WHOLE ALFALFA, 1933 SEASON

19	0.42	278	186	442	235	51.0	8.0	207	46.8	9	7.2	1.06	76.6	43.5	9.02	5.12	560	493
20	.33	288	192	398	241	54.0	24.0	157	39.4	6	4.8	.70	49.8	38.2	5.81	4.46	730	476
Total or average																		
	.75	566	378	840	476	52.4	16.1	364	43.3	15	12.0	1.76	63.0	41.2	7.39	4.84	635	485

WHOLE ALFALFA, 1934 SEASON

21.....	22.0	29,545	15,730	53.2	12.1	13,815	46.8	407	242.0	35.47	51.8	29.5	4.52	2.57	715	628
22.....	4.75	4,100	1,565	68.8	18.2	2,535	61.8	86	57.0	8.36	109.8	33.9	10.70	3.30	329	534
23.....	2.25	3,795	2,090	53.6	15.7	1,705	45.0	40	33.0	4.84	98.3	23.5	4.62	2.83	929	758
24.....	11.58	19,905	8,320	66.9	20.8	11,585	58.2	235	187.0	27.41	56.5	20.3	6.59	2.37	718	1,000
25.....	13.2	15,450	6,000	65.6	11.5	9,450	61.2	230	170.0	24.82	76.7	24.3	8.30	2.64	455	716
26.....	7.55	11,260	5,040	59.2	18.9	6,220	53.2	107	116.3	17.05	42.5	17.2	6.77	2.74	668	824
27.....	3.6	5,350	2,755	55.9	15.3	2,595	48.5	40	60.7	8.90	29.0	15.4	6.46	3.43	765	721
28.....	3.3	5,370	3,580	43.1	11.3	1,990	35.7	41	33.0	4.84	22.9	20.6	2.70	2.43	1,085	603
29.....	3.85	5,300	2,835	52.7	10.6	2,525	47.1	45	41.5	6.08	31.7	17.8	4.29	2.41	736	656
30.....	3.82	7,890	4,380	51.9	13.5	3,510	44.5	98	98.0	14.37	44.8	27.9	6.57	4.10	1,147	919
Total or average.....	75.99	108,225	52,295	58.2	13.6	55,930	51.7	1,329	1,038.5	152.24	50.8	23.8	5.82	2.72	689	737

CHOPPED SOYBEAN, 1932 SEASON

31.....	10.41	315- 375	240- 255	11,800	6,810	54.2	20.7	4,990	42.3	141	203.4	29.82	41.4	28.2	8.76	5.98	654	479
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WHOLE COWPEA, 1932 SEASON

32.....	20.8	21,735	10,055	57.9	9.0	11,680	53.7	257	343	50.3	51.1	22.0	10.0	4.31	483	562
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¹ Averages in these columns are weighted.

² Averages in these columns are based on total for crop season.

TABLE 2.—*Drying chopped alfalfa, soybean, and cowpea hay with experimental rotary drier*
ALFALFA (SOME JOHNSON GRASS), 1934 SEASON

Test No.	Duration of test	Temperature of drying air		Weight of forage		Moisture content of forage ¹		Loss in weight of forage ²	Power used	Fuel used	Heat input, B. t. u.	Power used ³		Heat input, B. t. u. ²		Drier output per hour ²	Water evaporated per hour ²
		Inlet	Exit	Entering	Discharge	Entering	Discharge					Per ton of hay	Per 1,000 pounds of water evaporated	Per ton of dried hay	Per 1,000 pounds of water evaporated		
	Hours	° F.	° F.	Pounds	Percent	Pounds	Percent	Pounds	Kilowatt hours	Gallons	Mil-lions	Kilowatt hours	Mil-lions	Mil-lions	Mil-lions	Pounds	Pounds
33	8.15	---	---	8,800	71.3	2,825	10.6	5,975	98	98	14.37	69.4	10.4	10.8	2.41	347	733
34	1.75	---	---	1,450	76.1	392.5	11.7	1,057.5	8	14.5	2.13	40.8	7.6	10.87	2.01	523	1,410
35	21.00	---	---	36,100	69.9	12,450	12.7	23,650	289	351.4	51.52	46.4	12.2	8.25	2.18	593	1,126
Total or average	29.90	---	---	46,350	70.4	15,667.5	12.3	30,682.5	395	463.9	68.02	50.4	12.9	8.68	2.22	524	1,026

ALFALFA (HEAVY JOHNSON GRASS MIX) 1935 SEASON																	
36	1.10	---	---	2,525	855	72.7	19.3	1,670	17	19	2.79	39.7	10.2	6.52	1.67	777	1,518
37	1.00	---	---	1,815	660	68.5	13.6	1,155	15	20	2.93	45.5	13.0	8.88	2.54	660	1,155
Total or average	2.1	---	---	4,340	1,515	70.9	16.8	2,825	32	39	5.72	42.2	11.33	7.55	2.02	721	1,345

SOYBEAN, 1934 SEASON																	
38	18.77	---	---	18,745	8,130	64.0	17.0	10,615	208	172.7	25.32	51.2	19.6	6.23	2.39	433	566
39	2.50	---	---	3,280	1,035	77.2	27.8	2,245	26	44.0	6.45	50.2	11.6	12.45	2.87	414	898
40	1.60	---	---	2,750	880	67.6	9.3	1,870	16	46.5	6.82	36.4	8.6	15.50	3.65	550	1,169
41	32.45	---	---	47,535	20,240	63.3	13.8	27,295	411	515.0	75.50	40.6	15.1	7.46	2.77	624	856
42	6.64	---	---	11,090	5,405	58.0	13.8	5,685	97	117.0	17.15	33.9	17.1	6.34	3.02	814	856
Total or average	61.96	---	---	83,400	35,690	63.4	14.8	47,710	758	895.2	131.24	42.5	15.9	7.35	2.75	576	770

SOYBEAN, 1935 SEASON

43 (80-day)-----	18.35	800	196	28,810	12,730	60.9	11.5	16,080	55.8	310	304.8	44.68	48.7	19.3	7.02	2.78	694	876
44 (80-day)-----	4.25	765	190	5,970	2,865	62.3	21.4	3,105	52.0	68	70.0	10.26	47.5	21.9	7.16	3.30	674	731
45 (80-day)-----	3.75	800	220	6,800	3,200	56.9	10.1	3,540	52.1	57	66.8	9.79	35.0	16.1	6.01	2.77	869	944
46 (120-day)-----	1.20	740	215	2,005	1,025	54.6	11.1	980	48.9	19	20.7	3.03	37.0	19.4	5.91	3.09	854	817
47 (120-day)-----	1.10	735	195	1,915	1,030	66.1	11.2	1,185	61.9	16	20.8	3.05	43.8	13.5	8.36	2.57	664	1,077
48 (120-day)-----	1.15	730	200	2,100	1,170	51.9	13.6	930	44.3	14	14.8	2.17	23.5	15.1	3.65	2.53	1,017	869
Total or average----	29.80	787	199	47,600	21,780	60.1	12.7	25,820	54.4	484	497.9	72.98	44.4	18.8	6.70	2.83	731	866

COWPEA, 1934 SEASON

49-----	10.85			18,220	6,615	68.3	12.7	11,605	63.7	165	212	31.08	49.9	14.2	9.4	2.68	610	1,070
50-----	1.75			2,680	1,695	47.5	16.9	985	36.8	16	21	3.08	18.9	16.2	3.63	3.13	969	563
51-----	4.91			8,125	3,545	61.2	11.1	4,580	56.4	92	105	15.40	51.9	20.1	8.69	3.36	722	933
52-----	5.25			7,800	2,630	74.9	26.2	5,150	66.0	67	87	12.75	50.6	13.0	9.62	2.48	505	981
53-----	9.63			14,545	5,190	72.1	21.8	9,355	64.3	117	137	20.10	45.1	12.5	7.75	2.15	575	1,036
Total or average----	31.79			51,370	19,695	68.2	17.0	31,675	61.7	457	562	82.41	46.4	14.4	8.37	2.60	620	996

¹ Averages in these columns are weighted.² Averages in these columns are based on totals for the crop season.

2. When the apron-conveyor drier was used to dry chopped soybean hay, the drying proved to be very uneven and poor, the average discharge moisture content being approximately 20 percent. At this moisture content it is doubtful if artificially dried forage will keep in good condition, free from mold and spoilage.

3. Cowpea hay in the apron-conveyor drier presented much the same problem as to nonuniformity of drying as did soybean hay.

4. The data for the 1935 season for the rotary drier were taken when the material was further reduced by passing it through a hammer mill after it had been cut in a silage cutter. The power requirements per 1,000 pounds of water evaporated were greater for drying soybean hay in 1935 than in 1934. The heat required per unit of material dried was about the same, but the hourly evaporation was increased from 770 to 866 pounds or an increase of 13 percent. In drying alfalfa there also appears to be an increase in thermal efficiency as well as capacity of the drier due to the shredding of the undried forage with a hammer mill.

5. Data taken on the effect of maturity on power and fuel requirements showed that the 120-day growth Ootootan soybean hay required slightly less power and fuel for dehydration than 80-day growth hay of the same variety. This difference was not due to initial moisture content of the green material.

6. The thermal capacity for evaporating moisture is affected materially when the forage is reduced to fine particles. The inner parts of the forage plant come in more direct contact with the drying gases when chopped and shredded than when left whole as they are in the apron-conveyor drier.

Data were also taken on several commercial driers operating on neighboring plantations. The performance of these driers are summarized in table 3 under the heading of "Single-drum" and "Triple-drum." So far as the data show the large commercial driers were somewhat more efficient in the utilization of heat than the small experimental units.

USE OF DRIERS

CAPACITY

Alfalfa when cut for hay may contain more than 70 percent moisture. When such material is hauled to the drier and dried immediately, as much as 3,860 pounds of water must be evaporated to produce 2,000 pounds of hay containing 12 percent moisture (fig. 6). If the hay is left in the swath for several hours its moisture content may be reduced to about 55 percent. Under such conditions it will be necessary for the machine to evaporate approximately 1,930 pounds of water to produce a ton of hay at 12 percent moisture. In the latter case the capacity of the drier in tons of hay per hour may be twice as great as with 70-percent moisture content forage.

The capacity of a dryer will also depend somewhat upon the kind of forage and the degree of processing before it is fed to the machine. With drum dryers the fineness and uniformity of chopping greatly influence the performance of the machine. Alfalfa, some varieties of clover, and meadow grasses usually dry much easier than soybean hay or other coarse-stem plants. The capacity of a hay drier is frequently referred to in terms of tons of dried material delivered per hour. While this method gives an indication as to what tonnage may be expected

FIGURE 6.—Quantities of water evaporated, and loss in weight, in drying hay from and to different moisture contents.

under some conditions, it may be misleading unless reference is also made to the initial moisture content and kind of forage dried.

Forage driers may be obtained with rated capacities ranging from approximately 1,000 to 6,000 pounds of water per hour. However, a machine capable of evaporating 3,000 pounds of water per hour approaches the lower limit of capacity for practical purposes under the conditions hay driers are usually operated in the United States.

FURNACE AND FUELS

A properly designed furnace of ample size is important for a forage drier, as air much in excess of that required for complete combustion is drawn through the furnace. The capacity of the furnace should be large enough, and the size of the openings great enough so as not unduly to increase resistance to the flow of the drying gases. With a drum drier the air requirements at the discharge fan are taken roughly as the equivalent of 1.2 cubic feet of dry air per minute per pound of water evaporated per hour. Since the temperature of the drying gases at the discharge end is in the neighborhood of 250° F. and that at the drier inlet is about 1,500°, the inlet volume is about three times greater than the volume at discharge. Therefore, a dryer with an evaporative capacity of about 3,000 pounds of water per hour should allow the passage of about 10,800 cubic feet of air per minute at the inlet. The entrance velocity should not greatly exceed 1,500 feet per minute.

With a thermal efficiency of 60 percent the evaporation of 3,000 pounds of water will require in the neighborhood of 5,500,000 B. t. u. This quantity of heat would be supplied by 40 to 45 gallons of fuel oil or 5,500 cubic feet of natural gas fuel.

In practice final dilution of furnace gases takes place at the secondary air inlet. This inlet is so arranged that the atmospheric air is warmed by passing over heated portions of the exterior of the combustion chamber (note drawing of Dutch-oven type of furnace, fig. 7). The furnace gases may be still further diluted by providing an opening just ahead of the drier inlet although this is not essential.

FIGURE 7.—Dutch-oven furnace.

Furnace design may be either of the cylindrical or rectangular cross section (figs. 7 and 8). The rectangular cross-section furnace is usually termed the Dutch-oven type and can be built more economically than the cylindrical type of furnace because only the standard shaped firebrick are required in the combustion chamber. The outer wall can be built of ordinary second-hand construction brick. These two general types of furnaces are adaptable for burning either oil or gas fuels.

The problem of utilizing solid fuels in drying forage is one requiring special consideration, so that the drying gases are rendered smokeless and do not contain incandescent particles of flying ash. Oil- or gas-burning equipment possesses advantages that place the coal- or coke-burning furnace at a disadvantage for hay driers unless a mechanical stoker is available.

In order not to localize the combustion of the fuel in too small a space it has been found that, with the fuel oil used at Jeanerette, from 1.75 to 2 pounds of oil may be fired per hour per cubic foot of combustion space. This quantity of oil has a heat value of about 33,000 B. t. u.

In drying hay it required the combustion of a fuel capable of generating approximately 5,500,000 B. t. u. of heat energy to evaporate 3,000 pounds of water per hour. On the above basis it would require a combustion chamber with a volume of from 165 to 175 cubic feet. For practical purposes the dimensions might be as follows: Width 4 feet, height to top of arch 5 feet, and length to bridge wall 10 feet.

The combustion of gaseous fuels is relatively simple, requiring only a suitable mixing carburetor. For oil fuels it is essential that there be smokeless combustion which can be accomplished only by thorough atomization of fuel. Under ordinary conditions, satisfactory results are more certain if oil having a specific gravity greater than 0.93 is not used. This specific gravity corresponds to 20.6° (American Petroleum Institute). Fuels heavier than this usually require preheating equipment in order to insure proper combustion.

FIGURE 8.—Cylindrical furnace, with sliding rings for controlling air flow.

POWER REQUIREMENTS

In a forage drying plant, power is needed for the following purposes:

(1) Processing the undried forage. This includes chopping, chopping and shredding, or crushing depending upon the type of drier and the operator's preference.

(2) Transporting the dried forage to a storage structure or processing plant either by a drag conveyor or a pneumatic system or a combination of both.

(3) Conveying the drying gases to the drier from the furnace, and removing them after they have performed their work in vaporizing the moisture from the forage.

(4) Miscellaneous uses such as operating fuel pump and blower for the burner, rotating the drum or actuating the apron conveyor of the drier, operating the unloading hoist, baling or grinding the dried material, etc.

The choice of the power unit depends somewhat on its availability and the cost per unit of energy. From the standpoint of convenience, electric power has the advantage. Where electric energy is available, in most instances the rates are low enough so that it can be used profitably.

Apron-conveyor driers are not adapted to handling finely chopped forage, especially the single-apron machines, because the apron screen allows a considerable portion of the material to drop through and

unless it is placed in a comparatively thin layer the chopped hay forms a mattress practically impervious to the passage of the drying gases. However, crushing of the forage by running it through a crushing device patterned after a clothes wringer and cracking the stems, especially the nodes, is found to be of appreciable assistance in drying the forage.

The ordinary silage cutter can be adapted for chopping the forage by slowing down the feed table so that the forage is cut into lengths less than three-eighths of an inch long. A combination silage cutter and hammer mill has been found suitable for processing the undried material. No screens are used in the hammer mill and it is set to receive the chopped forage directly from the silage cutter. The impact of the hammers on the chopped green forage has been found sufficient to crack open the stemmy sections and further aid the evaporation of water in the drier.

Examination of table 3 shows that the power requirements for the experimental apron-conveyor drier ranged from 22 to 28 kilowatt-hours per 1,000 pounds of water evaporated. The power requirements are distributed approximately as follows:

	Percent
Moving apron and auxiliary conveyors.....	11
Moving drying gases.....	83
Oil-burner operation.....	6

For an experimental rotary drier the power requirements ranged from 11 to 19 kilowatt-hours per 1,000 pounds, distributed roughly as follows:

	Percent
Chopping forage.....	25 to 35
Moving drying gases.....	45 to 60
Oil-burner operation.....	4 to 8
Rotating drum and conveying forage.....	10 to 15

With these figures in mind it will be found that a drum drier capable of evaporating 3,000 pounds of water per hour will need motive power equivalent to 35 or 40 horsepower to run it. This would be divided as follows:

	Horsepower
Chopper.....	15
Fan and drum.....	20
Burner.....	1½
Conveying equipment.....	3

A danger in motor installation is to overmotorize. Induction-type electric motors running underloaded heat up badly as well as deliver power at low efficiencies, thus increasing the power consumption. Where electric power is not available, power distribution to the various places about the drier may be accomplished by means of a long countershaft. The motive power in this case may be in the form of a tractor or a stationary gas, oil, or Diesel engine.

OPERATION OF DRIERS AND COST OF DRYING

By care in the planning of a forage-drier installation, economies can be effected in all of the important items that go to make up the cost of operation. The cycle of operations comprises unloading the trucks or wagons, feeding the wet forage into a chopper or directly into the drier, and disposing of the dried material at the point where it is discharged from the drier system. Ordinarily the material is

blown or conveyed into a bin or haymow. The problem of bagging the chopped forage is aggravated by the fact that comparatively small quantities of it can be packed in a bag. Chopped forage can be baled by using especially rugged balers. Baling of artificially dried forage is, however, not recommended for either chopped or whole hay with present available equipment. The leafy and fine stem portions of the whole hay shatter badly if baled as it emerges from the drier. Chopped hay from a drier, due to its short length, is more difficult to bale than chopped field-cured hay.

The unloading of trucks and wagons can be accomplished in several ways by means of a power hoist or horse-drawn unloading fork. The green forage can be placed convenient for those who feed the chopper or drier. Oftentimes trucks or wagons are provided with dump bodies. By means of the hay-carrier fork and track system, bunches of hay can be picked up after they are dumped and placed conveniently near the cutter. However, there are a great variety of schemes by which the material can be brought close to the point where it is required. In anchoring the chopper, for instance, it can be so placed that the feeding conveyor is practically at the ground level, thereby saving a great amount of lifting of wet forage. The use of machines in process of development by commercial firms for harvesting, chopping, and loading into a wagon or truck in the field will doubtless reduce labor requirements at the drier.

The following points should be kept in mind regarding drier operation:

1. For a drum drier the forage should be reduced to a uniform size, the size of the particles not being greater than about three-eighths of an inch in any one dimension.

2. The inlet temperature should be kept as high as possible, preferably around 1,400° to 1,500° F. Temperatures in excess of these can be used although corrosion of the brick and steel work may occur more readily at temperatures in excess of 1,500°.

3. The temperature of the exhaust gases should range between 200° and 250° F. for a drum drier, depending upon the initial moisture content of the forage.

4. The furnace, drum, fan, and dust collector should be close-coupled to eliminate piping resistance.

5. Conveying chopped forage pneumatically may be accomplished at the expenditure of slightly greater amounts of power than by drag conveyors. Pneumatic conveying of the dried product allows for greater flexibility than do drag methods. However, from the standpoint of fire prevention, any smoldering sparks of forage will be more readily detected in the open conveyor than in other systems of conveying. For horizontal runs of pneumatic systems the air velocity should be in the neighborhood of 4,000 feet per minute.

6. The matter of fire prevention is important at the forage-drying plant. Unforeseen stoppages and break-downs may result in fire outbreak. Convenient garden-hose connections with short pieces of hose will repay themselves many times over in extinguishing fires in their incipency. Forage driers should not be placed in barns or buildings where quantities of inflammable farm products are stored. An inexpensive fire-resistant shelter for the drying plant can be made from second-hand steel pipe and corrugated sheet-metal roofing.

7. It is very important that the forage be thoroughly dried down to its safekeeping moisture content, which for practical purposes should approximate 12 percent. Too often the inexperienced operator attempts to increase the output of the drier beyond its capacity or without due regard to the heat input. The result is a partially dried product that may mold or may heat sufficiently to cause spontaneous combustion. Whole field-cured hay usually can be stored with a moisture content of from 15 to 25 percent, depending upon locality, without danger of heating. Experience indicates that artificially dried hay, especially when chopped, should have a lower moisture content. Such material, when conveyed directly to a mow from the drier, has a higher temperature than that of the atmosphere and there is likely to be some variation in the moisture content of the particles.

The cost of operating a drier (power, labor, and fuel) depends in part upon the thermal efficiency of the drier; the initial moisture content of the forage; the unit costs of power, labor, and fuel; and the kind of forage to be dried. However, results of tests made by the Department of Agriculture in Louisiana on several commercial and experimental driers shown in table 3 will give an indication of what may be expected in this connection. The labor was computed at 20 cents per man hour, fuel oil at 3.5 cents per gallon, and electric current at 4.7 cents per kilowatt-hour.

Barr ² shows from 20 to 29 kilowatt-hours, 16 to 26 gallons of oil, and from 0.97 to 4 man-hours per 1,000 pounds of water evaporated in various types of driers. With the same unit costs for power, labor, and fuel as shown in table 3 the cost per 1,000 pounds of water evaporated ranged from \$1.69 to \$3.07.

Clyde ³ gives as the cost of drying per ton of dry hay (2,400 pounds water evaporated at an over-all thermal efficiency of 65 percent for the drier) the following items exclusive of overhead charges:

Fuel, 29½ gallons oil at 7 cents-----	\$2. 07
Labor, 3 men, 1.35 hours at 40 cents, 30 cents, and 30 cents-----	1. 35
Power, 20.4 kilowatt-hours at 3 cents-----	. 61
Repairs, estimated-----	. 17
	<hr/> 4. 20

In using the same unit costs for power, labor, and fuel as previously indicated the cost would approximate \$1.23 per 1,000 pounds of water evaporated.

At the Lewisburg, Tenn., station of the Bureau of Dairy Industry, approximately 170 tons of hay were dried artificially with a commercial rotary-drum drier during the 1935 season, as shown in table 4. The total cost of drying the hay, including the harvesting in the field and mowing in the barn, but not including interest or depreciation on the equipment, was \$11.77 per ton of dry hay. Repairs (labor and parts) accounted for \$3.20 of the above cost, the major portion of which was spent on the upkeep and repairs on field-harvesting machinery. Much of this expense appears to be due to the fact that this equipment was manufactured for handling dry hay and was not strong enough to handle the heavier green material.

² BARR, H. T. ARTIFICIAL CURING OF FORAGE CROPS. La. Agr. Expt. Sta. Bull. 261, 14 pp., illus. 1935.

³ CLYDE, A. W. NEW DEVELOPMENTS IN HAY DRIERS. Agr. Engin. 14: 127-129, illus. 1933.

TABLE 3.—Power, labor, and fuel requirements at the drier in artificially drying some forage crops

Type of drier	Hay	Loss in weight	Output of hay per hour	Water evapo- rated per hour	Requirement per ton of dry hay obtained				Requirement per 1,000 pounds of water evaporated					
					Fuel		Power	Man labor	Cost ¹	Fuel		Power	Man labor	Cost ¹
					Oil	B. t. u.				Gallons	Millions			
		Percent	Pounds	Pounds	Gallons	Millions	Kilowatt- hours	Hours	Dollars	Gallons	Millions	Kilowatt- hours	Hours	Dollars
Apron conveyor ²	Whole alfalfa.....	51.6	689	736	39.7	5.82	50.8	8.71	5.52	18.6	2.73	23.8	4.08	2.59
Do.....	Chopped Biloxi soybean.....	42.3	654	480	59.7	8.75	41.4	9.17	5.87	40.7	5.97	28.2	6.25	4.00
Do.....	Whole native grasses.....	43.0	901	653	48.1	7.05	35.0	6.66	4.66	31.8	4.66	23.2	4.59	3.12
Do.....	Whole cowpea.....	53.8	483	561	68.2	10.00	51.1	12.4	7.27	29.4	4.31	22.0	5.35	3.13
Do.....	Whole Lespedeza.....	56.3	567	701	69.8	10.23	57.4	10.6	7.26	27.1	3.97	22.2	5.35	3.13
Do.....	Whole white clover.....	54.3	709	819	47.1	6.90	58.4	8.23	5.98	19.9	2.92	24.6	3.68	2.59
Double drum ²	Chopped alfalfa.....	58.4	678	902	58.3	8.55	46.2	8.85	6.04	20.8	3.05	16.5	3.33	2.17
Do.....	Chopped alfalfa and Johnson grass.....	65.0	721	1,345	51.4	7.54	42.2	8.32	5.45	13.8	2.02	11.3	2.23	1.46
Do.....	Chopped Biloxi soybean.....	59.1	574	828	56.6	8.30	42.8	10.45	6.00	19.6	2.87	14.8	3.62	2.11
Do.....	Chopped Ootootan soybean.....	54.3	730	867	45.7	6.70	44.4	8.22	5.33	19.3	2.83	16.2	3.46	2.25
Do.....	Chopped cowpea.....	57.0	668	916	52.9	7.76	42.9	8.98	5.67	20.0	2.93	18.3	3.28	2.12
Single drum.....	Chopped Biloxi soybean.....	64.4	1,242	2,991	76.1	11.16	27.0	7.3	5.40	21.0	3.08	7.45	2.02	1.49
Do.....	Chopped Ootootan soybean.....	69.4	950	2,180	74.5	10.92	34.8	10.6	6.37	16.4	2.40	7.7	2.24	1.38
Triple drum.....	Chopped soybean.....	52.8	2,000	2,185	4.37	4.37	40.7	8.0	4.56	3.1.96	1.96	18.5	3.68	2.08
Do.....	Chopped corn and soybean; soybean; velvetbean and corn; hegari; sorghum.	61.7	1,890	3,060	3.5.5	5.5	63.5	10.5	6.40	1.71	1.71	19.7	3.26	1.99

¹ Prices paid were: For fuel, 3½ cents per gallon (23.9 cents per million B. t. u.); for power, 4.7 cents per kilowatt-hour; for labor, 20 cents per man-hour.² A small experimental machine.³ Thousands of cubic feet of natural gas.

In addition to the cost of operating a drier, the cost of harvesting and hauling the material to the machine must be considered, and the overhead charges. With suitable equipment, the cost of harvesting and loading should approximate that for field-cured hay except for the larger tonnage in hauling wet forage instead of dry hay. Overhead charges per 1,000 pounds of water evaporated depend in large measure upon the initial cost of the drier and the tonnage of hay handled each year.

TABLE 4.—Hay crops dried at the Lewisburg, Tenn., station during the 1935 season

Hay	Moisture content		Rate of drying	Quantity dried	Fuel oil per ton of hay
	Before drying	After drying			
	Percent	Percent	Pounds per hour	Tons	Gallons
Alfalfa.....	62.9	11.6	1,674	65	32.7
Lespedeza ¹	37.1	5.5	2,352	21	13.3
Sorghum.....	67.5	4.6	1,201	13	46.0
Soybean.....	60.7	10.4	1,632	71	31.6

¹ Korean, common, and *L. sericea*.

The initial cost of a drum drier installed approximates \$2,000 per 1,000 pounds-per-hour evaporating capacity. On this basis and assuming 6 percent interest on the average investment (one-half the initial cost), 10 percent annual depreciation, and 5 percent for taxes, insurance, and repairs, the overhead cost would approximate \$360 per 1,000 pounds-per-hour evaporating capacity, or \$1,080 per year for a drier capable of evaporating 3,000 pounds of water per hour.

The overhead cost of a drier is, for all practical purposes, a fixed annual cost, but when computed on a per-ton basis decreases as the total volume of hay dried per season increases. With a \$6,000 investment in a drier and only 100 tons of hay dried annually, the overhead cost would approximate \$10.80 per ton. If the drier handled 1,000 tons per year the overhead would approximate \$1.08 per ton. From this it can be seen that the cost of drying may be excessive unless a large quantity of hay is dried annually.

FEEDING VALUE OF ARTIFICIALLY DRIED HAY ⁴

The progress of the feeding tests in which the dehydrated forage was fed to beef cattle and dairy animals at the Iberia Livestock Experiment Station, has shown that, as compared with the sun-cured product, it will produce slightly greater gains in weight; that the cost of producing the dehydrated product is somewhat greater, thus making the cost of animal gain a trifle higher; that the market grade of the dehydrated product is generally higher; that results of chemical analyses of comparable grade of hay show but slight variations in favor of the artificially dried product.⁵ However, the carotene content of the artificially dried hay was considerably higher than that of

⁴ This section was prepared in collaboration with R. R. Graves, Chief, Division of Dairy Cattle Breeding, Feeding, and Management, Bureau of Dairy Industry.

⁵ If the average field-cured hay at the Jeanerette station were used in making the comparative chemical analyses, the results would undoubtedly be considerably in favor of the artificially dried product for the reason that much of the field-cured hay is badly damaged by unfavorable weather conditions during curing. If this loss in quality were taken into consideration, the cost of the good field-cured hay would be greatly increased.

the sun-cured based on a limited number of tests from the Jeanerette station as shown in table 5.

TABLE 5.—*Grade and carotene content of samples of the same lot of forage sun-cured and artificially dried*

Crop	Sun-cured		Artificially dried	
	United States grade	Carotene	United States grade	Carotene
		<i>Parts per million</i>		<i>Parts per million</i>
Alfalfa.....	U. S. No. 2, Heavy Grass Mixed.....	36	U. S. No. 2, Heavy Grass Mixed.....	104
Soybean.....	U. S. No. 1, Extra Green.....	52	U. S. No. 1, Extra Green.....	75
Do.....	U. S. No. 1.....	17	U. S. No. 2 ¹	27
Do.....	do.....	43	U. S. No. 1, Extra Green.....	64

¹ Slightly scorched while drying.

In sampling the forage at Jeanerette on which grade and carotene determinations were made, a portion of an undried lot of forage was spread on a screen bottom tray and set in the sun to dry. This material was put under shelter at night and also when rains occurred. The remaining portion of the forage was put through the drier and a sample obtained as it came from the machine. This procedure, while providing comparable samples, resulted in obtaining higher-quality sun-cured hay than would have been possible under prevailing weather conditions at Jeanerette, La.

The protein content of the dehydrated product from the Jeanerette station ran about 1 percent higher than for the sun-cured forage, although this did not hold true in every instance. It should be borne in mind that no feeding value is added in the dehydration of forage. Obviously the manner in which the hay is harvested and artificially dehydrated makes for more complete conservation of the feeding value of the forage in that the leaf loss is minimized. Since one advantage of artificial drying is to prevent weathering and reduce leaf loss, especially with alfalfa, dehydrated forage is likely to be rich in protein and calcium as these elements are formed principally in the leaves.

With grade Aberdeen Angus beef cattle there was a slight advantage in favor of the artificially dried forage under prevailing test conditions at Jeanerette as to gain per hundredweight of feed consumed. This advantage amounted to about 2.5 to 6 percent.

In feeding trials with dairy cattle at Jeanerette six Jersey bull calves were castrated and placed on a ration consisting entirely of artificially dried roughage, at 6 months of age. They gained an average of only 148 pounds each from 6 to 12 months of age, which was only 60 percent of normal. Between 12 and 18 months of age, however, they made normal gains but, of course, were below normal weight at 18 months of age because of the small gains made between 6 and 12 months.

In an experiment now in progress five Jersey heifers were started on artificially dried roughage with no grain at 12 months of age. They have maintained slightly more than normal gains between 12 and 18 months of age. These and other experiments indicate that if Jersey heifers are at normal weights at 1 year of age they can maintain normal gains from that time on when fed machine-dried roughage of high quality.

In feeding dairy animals when the entire ration consists of dehydrated forage, the production of milk and butterfat is about 60 to 70 percent of the production made on a full-grain ration. In an experiment conducted by the Bureau of Dairy Industry at the Lewisburg, Tenn., station, 16 registered Jersey cows made 17 lactation-period records on rations restricted to machine-dried hay (largely legume) and pasture. Their average production, calculated to a mature-equivalent basis, for an average lactation period of 361 days was 6,333 pounds of milk and 329 pounds of butterfat. The average loss in body weight was 33 pounds to the end of the lactation, but this does not take into consideration gains that normally would be made during the dry period prior to the next calving. The same cows made comparable records under register-of-merit testing conditions when they were fed machine-dried legume hay, pasture, and liberal amounts of a grain mixture. Under these conditions the same cows produced an average of 9,656 pounds of milk and 527 pounds of butterfat with an average gain of 70 pounds in body weight to the end of their lactation period. On the roughage-alone ration the cows produced 66 percent as much milk and 62 percent as much butterfat as they produced under the register-of-merit conditions. During the time the cows received hay without pasture they consumed an average of 28.6 pounds of hay per cow a day, or at the rate of 3.44 pounds of hay per 100 pounds of body weight.

However, in feeding forage to animals, the question of palatability is an important factor and artificially dried hay is very palatable to animals. Some forage plants such as the clovers and alfalfa appear to be more readily consumed by the animals than the coarser, heavy-stemmed legume forages such as soybeans and cowpeas. Artificially dried hay will be uniformly good if the hay is cut at the proper stage of maturity, while much of the nutritive value of field-cured hay may be lost in any given year due to unfavorable weather conditions for field curing. Machine drying is an insurance against losses in quality of hay that results from unfavorable weather conditions for field curing.

Two experiments, conducted at the Western Washington Experiment Station by the Bureau of Dairy Industry and the Washington Experiment Station, have a bearing on the nutritive value of artificially dried pasture grasses. These experiments were conducted with a small experimental rotary-drum drier. In view of the fact that the drying material is not expected to attain a higher temperature than that of the gases at the outlet from the drier, the outlet temperatures in these experiments were taken as the temperature of drying. However, as the material dried in passing from the feed end to the discharge end of the machine it was subjected to temperatures in excess of that indicated as the exhaust temperature.

Artificially dried roughage that has a minimum of exposure to sunlight after cutting is thought likely to be deficient in vitamin D. The first experiment⁶ was conducted to determine the comparative calcifying powers of similar samples of green, artificially dried, and sun-cured pasture herbage. It was found that pasture herbage when fed in a green, artificially dried, or sun-cured form, constituting 3 percent of the dry matter in the ration, caused a significantly greater degree of calcification in rats than did the basal diet. Increasing the amount

⁶ HODGSON, R. E., and KNOTT, J. C. THE CALCIFYING PROPERTIES OF GREEN, ARTIFICIALLY DRIED AND SUN-CURED PASTURE HERBAGE. *Jour. Agr. Research* 48: 439-446. 1934.

of the grass fed did not result in a greater degree of calcium deposition. Either the green or the artificially dried grass was as efficient in producing calcification as was similar grass that was cured by exposure to 15 hours of sunlight. The results of this experiment are not in accord with the results of an experiment conducted by Bechdel⁷ at the Pennsylvania station who found that there was an appreciable difference in the antirachitic potency of artificially dried alfalfa hay and sun-cured alfalfa hay when fed to 6-month-old dairy calves. A severe rachitic condition developed during a 6-month feeding period when 1 pound of artificially dried hay was added to the basal diet, and a mild rachitic condition developed when 1 pound of sun-cured hay was added. As much as 2.5 pounds of artificially dried hay did not prevent the development of a mild rachitic condition, while the same amount of sun-cured hay prevented the appearance of rickets. Perhaps the calcifying power of the artificially dried pasture herbage was due to the fact that the grasses were immature and growing rapidly at the time of cutting.

In the second experiment⁸ digestion trials were conducted with sheep on mixed pasture grasses that were artificially dried at exhaust gas temperatures of 250°, 300°, 350°, and 400° F. to determine the effects of these temperatures on the digestibility and availability of the nutrients in the pasture herbage. The results were that the percentage of apparent digestibility of the feed constituents of the rations of sun-cured grass and of the grass dried artificially at exhaust-gas temperatures of 250°, 300°, and 350° showed no significant differences, indicating that artificial drying under these conditions had no depressing effect on the availability of the nutrients. The percentage of apparent digestibility of the nutrients in the sun-cured and in the artificially dried grasses at 250°, 300°, and 350° averaged for dry matter, 76; for crude protein, 76; for crude fiber, 83; for ether extract, 73; for nitrogen-free extract, 83; and for ash, 44.

The results of the feeding trials of the material dried at 400° F. showed that this temperature for the exhaust gas from the drier had a depressing effect on the apparent digestibility of the crude protein, dry matter, and nitrogen-free extract. There was also evidence of the burning of some portions of the more leafy material when dried at the outlet temperature of 400° F. The apparent digestibility of most constituents was somewhat lower for the green grass than for the material dried at 250°, 300°, 350°. As the exhaust temperature of drying was increased by 50° intervals there was a definite lowering of the percentage of natural color in the herbage. That dried at 400° had only 76.3 percent as much color as that dried at 250°.

⁷ BECHDEL, S. L., and others. RICKETS IN CALVES. Pa. Agr. Expt. Sta. Bull. 291, 41 pp., illus. 1933.

⁸ HODGSON, R. E., KNOTT, J. C., GRAVES, R. R., and MURER, H. K. EFFECT OF TEMPERATURE OF ARTIFICIAL DRYING ON DIGESTIBILITY AND AVAILABILITY OF NUTRIENTS IN PASTURE HERBAGE. Jour. Agr. Research 50: 147-164; illus. 1935.

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This circular is a contribution from

<i>Bureau of Agricultural Engineering</i>	S. H. McCRORY, <i>Chief</i> .
<i>Division of Mechanical Equipment</i>	R. B. GRAY, <i>Chief</i> .