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RELATIVE ENERGY VALUE OF ALFALFA, CLOVER, AND TIMOTHY HAY FOR THE MAINTENANCE OF SHEEP

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CONTENTS

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The method in most common use of measuring the value of different feeds as sources of nutritive energy for farm animals involves the employment of average values of the total digestible nutrients. It seems clear, however, that the determination of the digestible organic matter of a feed, even when allowance is made for the differences in metabolizable energy among the individual nutrients, can give no certain information as to the utilization of the digestible material in metabolism.

There are two important objections to the use of values for the total digestible nutrients of feeds as measures of their content of nutritive energy, i.e., food energy available for expenditure in maintenance or work, or for storage in the tissues or secretion in the milk. The first objection relates to the fact that the calculation of such values is based on the assumption that the difference between the amounts of nutrients consumed and the amounts of nutrients appearing in the feces represents those fractions which are available to the animal for maintenance and production. In the case of nonruminants this assumption may be roughly true, but in the case of ruminants, in which extensive fermentations are occurring in the fore part of the alimentary tract, considerable amounts of gaseous material unavailable to the animal are formed and considerable amounts of heat representing losses in nutritive energy are being produced. These losses of matter and energy cannot be determined from an analysis of the feces, and yet they represent losses of nutritive energy as real as the energy of the undigested organic constituents of the feces. This objection has been developed and illustrated by Fries.[2]

The second important objection to the use of the total digestible nutrients of feeds as measures of nutritive energy relates to the fact that large losses of energy occur in animals during the digestion and assimilation of feed, these losses being represented by increases in the heat production of the animal. Regardless of the causes for such losses of energy, they are inevitable and therefore must relate to definite physiological processes occurring in the animal body consequent

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[2]Fries, J. A. Digestibility of cattle feed. Amer. Soc. Anim. Prod. Proc., 1922, 33.

upon the digestion of feed, its absorption into the blood and its transposition to the tissues. This increment in heat production is not available for maintenance except under conditions in which the environmental temperature is lower than the critical temperature of the fasting animal.

The net energy values of Armsby are complete expressions of the actual values of feeds as sources of nutritive energy, since they are obtained by deducting from the gross energy of the feed not only the gross energy of the feces, but also the energy losses due to gastro-intestinal fermentations, to incomplete oxidations in the body, and to the stimulating effect of feed on heat production. They represent, therefore, the ultimate net return to the animal in nutritive energy resulting from the consumption of the feed.

Altho net energy values represent a complete scheme of evaluating feeds with reference only to their content of nutritive energy, the total digestible nutrients of different feeds may still represent their *relative* energy values provided that the losses of energy not considered in digestion experiments were roughly proportional to the content of total digestible nutrients; in other words, that the net energy value per pound of digestible nutrients was practically the same for different feeds. However, the calculations contained in Table 1,

TABLE 1.—ESTIMATED NET ENERGY PER POUND OF DIGESTIBLE NUTRIENTS FOR A FEW REPRESENTATIVE FARM FEEDS

Feed	Net energy per 100 pounds[1]	Digestible nutrients per 100 pounds[2]	Net energy per pound digestible nutrients
	therms	*lbs.*	*therms*
Timothy hay	43.02	48.5	.887
Alfalfa hay	34.23	51.6	.663
Clover hay	38.68	50.9	.760
Oat straw	34.81	45.6	.763
Corn silage	15.90	17.7	.898
Corn	85.50	85.7	.998
Oats	67.56	70.4	.960
Wheat	91.82	80.1	1.146
Wheat bran	53.00	60.9	.870
Cottonseed meal, prime	90.00	75.5	1.192
Linseed oil meal, old process	88.91	77.9	1.141

[1]From Armsby's "Nutrition of Farm Animals," 1917. [2]From Henry and Morrison's "Feeds and Feeding," 18th ed., 1923.

of a few commonly used roughages and concentrates, indicate that the net energy value per pound of digestible nutrients varies considerably for different feeds and in general is lower for roughages than for concentrates.

Attention is called particularly to the content of alfalfa, clover, and timothy hay in total digestible nutrients and in net energy. According to their content of digestible nutrients these three hays are very nearly equal as sources of nutritive energy. Taking alfalfa hay as 100 in its content of total digestible nutrients, clover hay has a value of 99 and timothy hay a value of 94. However, according to the net energy calculations of Armsby, based upon the same average analyses of the hays as were used in computing their content of total digestible nutrients, considerable differences in their content of nutritive energy exist among them. Taking the net energy content of alfalfa hay as 100, clover hay has a value of 113 and timothy hay a value of 126. The net energy values of these hays have been recomputed by Forbes and Kriss.[1] If the revised net energy value per kilogram of dry matter of alfalfa hay be taken as 100, the revised value for clover hay becomes 106 and that for timothy hay 133.

The relatively high net energy value of timothy hay is particularly noteworthy, since it apparently contradicts the current belief of the superiority of alfalfa over timothy hay. The contradiction is, however, only apparent, since the established superiority of alfalfa over timothy hay is founded upon a basis other than its content of nutritive energy. Its greater palatability for most classes of livestock also contributes to its economic superiority over timothy hay.

The individual experiments of Armsby and associates relative to the utilization of the energy of these three hays are summarized in Tables 2, 3, and 4. In these calculations the original figures of Arms-

TABLE 2.—SUMMARY OF DETERMINATIONS OF UTILIZATION OF ENERGY OF ALFALFA HAY BY STEERS, REPORTED BY ARMSBY AND ASSOCIATES

(Energy per kilogram of dry matter)

Exp. No.	Steer No.	Gross	Metabolizable		Net available		Literature reference
		cals.	*cals.*	*pct. of gross*	*cals.*	*pct. of metab.*	
208........	C	4 405	1 820	41.3	684	37.6	J. Agr. Res. **3**, 435. 1915.
208........	D	4 407	1 729	39.2	392	22.7	
208........	E	4 408	1 837	41.7	635	34.6	
209........	F	4 338	1 810	41.8	671	37.1	
212........	H	4 368	2 056	47.1	1 017	49.5	
212........	H	4 374	2 012	46.0	895	44.5	
216........	J	4 334	1 945	44.9	927	47.7	Ibid. **18**, 269. 1918.
Average....	..	4 376	1 887	43.1	746	39.1	

TABLE 3.—UTILIZATION OF ENERGY OF RED CLOVER HAY BY STEERS SUMMARY OF EXPERIMENTS BY ARMSBY AND ASSOCIATES

(Energy per kilogram of dry matter)

Exp. No.	Steer No.	Gross	Metabolizable		Net available		Literature reference
		cals.	*cals.*	*pct. of gross*	*cals.*	*pct. of metab.*	
179........	I	4 438	1 926	43.4	934	48.5	J. Agr. Res. **3**, 435. 1915.
186a.......	I	4 486	2 076	46.3	1 651	79.5	
186b......	I	...	2 127	....	1 771	83.3	
220........	K	4 367	1 954	44.7	1 011	51.7	Ibid. **7**, 379. 1916.
Average....	..	4 430	2 021	44.8	973[1]	50.1[1]	

[1]Not including the results in Experiment 186.

[1]Forbes, E. B., and Kriss, M. Revised net energy values of feeding stuffs for cattle. Jour. Agr. Res. 31, 1083. 1925.

TABLE 4.—UTILIZATION OF ENERGY OF TIMOTHY HAY BY STEERS, SUMMARY OF EXPERIMENTS BY ARMSBY AND ASSOCIATES
(Energy per kilogram of dry matter)

Exp. No.	Steer No.	Gross	Metabolizable		Net available		Literature reference
		cals.	*cals.*	*pct. of gross*	*cals.*	*pct. of metab.*	
190........	A	4 495	1 785	39.7	1 067	59.8	J. Agr. Res. **3**, 435. 1915.
200........	A	4 509	1 835	40.7	1 306	71.2	
207........	A	4 515	2 086	46.2	1 184	56.8	
190........	B	4 493	1 844	41.0	922	50.0	
200........	B	4 509	1 895	42.0	1 102	58.2	
207........	B	4 515	2 036	45.1	1 082	53.1	
174........	I	4 483	1 953	43.6	1 294	66.3	
Average..	..	4 503	1 919	42.6	1 137	61.5	

by for the heat production of the steers were used rather than the recalculations of Forbes and Kriss.

Per kilogram of dry matter, the three hays are closely similar in their content of gross and metabolizable energy. The slight differences between the average figures are probably not significant. However, distinct differences appear with reference to their net energy content per kilogram of dry matter, particularly if the results of Experiment 186 on red-clover hay are omitted. Armsby himself was inclined to disregard this experiment in the computations of his average results on the basis of certain unsatisfactory experimental conditions, while Forbes and Kriss (*loc. cit.*) have definitely discarded it in their recomputations of Armsby's work. The close agreement between the much lower results of Experiments 179 and 220 may be taken as provisional justification for disregarding the results of Experiment 186, tho evidently the situation with respect to the net energy value of red-clover hay is in a very unsatisfactory condition.

These experiments indicate clearly that the metabolizable energy of timothy hay is distinctly better utilized by steers in covering their maintenance requirement for energy than is the metabolizable energy of alfalfa hay. The two concordant results on red-clover hay would indicate that it occupies an intermediate position in this respect. The average percentage utilization of the metabolizable energy of timothy hay is 61.5, of red-clover hay 50.1, and of alfalfa hay 39.1.[1] Forbes and Kriss, in their recomputations and reinterpretations of Armsby's work, arrive at different averages, i.e., 60.8 for timothy, 49.6 for clover, and 47.1 for alfalfa, bearing the same relation to one another, however.

[1]These values apply only from an approximate maintenance level of feeding to one permitting moderate fattening. Forbes and associates have shown that at lower levels of feeding, the metabolizable energy of feeds is utilized to a greater extent (Forbes, E. B., Fries, J. A., Braman, W. W., and Kriss, M. The relative utilization of feed energy for maintenance, body increase and milk production in cattle. Jour. Agr. Res. 33, 483. 1926.)

The considerable difference in the results obtained between the two most common methods of measuring the content of farm feeds in nutritive energy relative to the values for these three common hays, is sufficient justification for a redetermination of the value of these feeds as sources of energy in maintenance, preferably by some method different from that heretofore used. Altho the net energy values possess a sounder scientific basis than the contents of total digestible nutrients, it is always well to check up such laboratory results by observations obtained from feeding experiments of longer duration. It was the purpose of the experiments to be reported below to make such determinations and observations.

FIRST EXPERIMENT: ALFALFA, CLOVER, AND TIMOTHY HAY

Outline of Experiment

Fifteen western ewes, three to four years of age and weighing approximately 100 pounds each, were divided into three equal lots, the first to receive alfalfa hay, the second clover hay, and the third timothy hay. Since it was questionable whether timothy hay, in the amounts required for maintenance of body weight, would contain enough protein to cover the protein requirement, each sheep in the three lots was given approximately .15 pound of linseed oil meal per 100 pounds initial live weight daily. A possible deficiency of timothy hay in minerals was removed by allowing the timothy-hay sheep access to a mineral mixture consisting of equal parts of special steamed bone meal, finely ground limestone, and salt. In each lot the consumption of hay was regulated so as just to maintain the body weight of the sheep. Under these conditions the relative amounts of the different hays required for maintenance per 100 pounds live weight represent their relative values as sources of nutritive energy. All sheep were individually fed and at all times had access to salt. Except during feeding, each lot of sheep was allowed the run of a pen approximately 1 by 5 rods in dimensions.

Samples of feed were taken daily at the barns at the same time that the daily rations were weighed out, and these daily samples were composited for the entire experiment and submitted to routine chemical analysis. The analyses of these feed samples will be found in Table 5.

At the end of its maintenance period digestion and metabolism studies were made on each of the sheep in the three lots for the purpose of determining the content of the maintenance rations in digestible nutrients and in metabolizable energy. The feed, feces, and

TABLE 5.—PERCENTAGE COMPOSITION OF FEEDS FED AT BARN

Feed sample	Dry substance	Crude protein (N x 6.25)	N-free extract	Crude fiber	Ether extract	Ash	Gross energy per gram
	perct.	*perct.*	*perct.*	*perct.*	*perct.*	*perct.*	*sm. cals.*
Clover hay	94.73	10.19	43.32	31.70	2.32	7.20	4 154
Alfalfa hay	93.56	16.38	43.52	22.85	2.82	7.99	4 195
Timothy hay	96.15	7.44	51.19	27.73	4.09	5.70	4 317
Linseed oil meal	92.80	36.19	36.51	7.65	6.53	5.92	4 402

urine were submitted to a direct determination of gross energy by means of the bomb calorimeter. These determinations afforded the opportunity of computing the amounts of digestible nutrients and of metabolizable energy required for maintenance for each experimental ration.

The Experimental Data

Body Weights. The experimental feeding started July 9, 1924, and within the following two weeks the body weights of the alfalfa and clover-hay sheep were adjusted to the amounts of hay calculated to be sufficient for maintenance. The timothy-hay sheep were much slower in reaching a constant level.

In this experiment it was considered, somewhat arbitrarily, that a good determination of the maintenance requirement would result in a period of 8 weeks during which the body weight remained approximately constant on constant feed. Most of the maintenance experiments on the alfalfa and clover-hay groups were, however, of 13 to 15 weeks' duration.

The weekly weights of individual sheep are given in Table 6. One sheep in the alfalfa-hay group died in the early part of September from unknown causes and the data on this animal may not be of any considerable significance. It will be seen, however, that all of the alfalfa and clover-hay sheep maintained their weight at an approximately constant level from July 23 to the time when experimental feeding stopped. While the variation in weight from week to week was at times considerable, there is no apparent tendency for the weights of these sheep either to increase or to decrease progressively.

The maintenance trials on the timothy-hay sheep were not so satisfactory, since a constant level in weight cannot be considered to have been established until September 10. The experiment with these sheep may also be questioned on two other grounds. First, at the end of the experiment the condition of the sheep was noticeably poorer than that of the sheep in the alfalfa- and clover-hay groups, indicating that in part of the feeding period at least they had been compelled to draw upon their body stores of fat to provide sufficient energy for maintenance. This withdrawal of body stores very probably occurred in the interval from the beginning of the experiment to September 10,

Table 6.—Body Weight Records During Maintenance Experiment

(All weights expressed in pounds)

Date	Alfalfa-hay sheep					Clover-hay sheep					Timothy-hay sheep				
	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
1924															
July 23	82	117	92	98	128	111	118	106	80	111	108	98	116	111	101
July 30	92	125	96	101	131	115	129	113	83	119	101	99	115	110	101
Aug. 6	86	122	95	100	133	113	125	109	82	118	100	103	114	112	99
Aug. 13	90	125	93	97	131	112	122	111	83	118	101	102	105	106	99
Average	87	122	94	99	131	113	123	110	82	116	102	100	112	110	100
Aug. 20	88	122	93	99	129	110	121	111	80	115	98	94	106	106	96
Aug. 27	84	123	98	100	129	116	123	112	82	117	98	100	105	106	99
Sept. 3	82	113[1]	100	98	125	116	123	111	81	114	94	101	107	103	100
Sept. 10	87	...	98	101	126	113	118	110	82	118	87	98	104	98	92
Average	85	...	97	99	127	114	121	111	81	116	94	98	105	103	97
Sept. 17	86	...	92	98	126	115	118	108	81	118	87	95	105	100	98
Sept. 24	..	...	98	100	132	...	122	109	80	115	91	95	102	95	95
Oct. 1	..	...	100	102	128	...	124	110	83	116	91	97	106	100	98
Oct. 8	..	...	95	100	129	...	128	108	79	112	92	95	105	100	96
Average	..	...	96	100	129	...	123	109	81	115	90	95	104	99	97
Oct. 15	..	...	96	101	126	...	124	110	82	115	90	96	103	102	98
Oct. 22	..	...	..	...	...	...	116	108	80	108	86	93	98	97	92
Oct. 29	..	...	..	...	...	...	119	106	80	115	87	94	100	98	95
Average	..	...	..	...	...	...	120	108	81	113	88	94	100	99	95
Maintenance weight	86.3	122.7[2]	95.8	99.6	128.7	113.4	121.6	109.7	81.2	115.3	88.9[3]	95.4[3]	102.9[3]	98.8[3]	95.5[3]

[1]Died September 5. [2]Average from July 16 (125 pounds) to August 27 inclusive. [3]Average for last seven weeks only.

during which all decreased slightly in weight. Second, thru a misunderstanding at the barns small amounts of feed refused from the amounts offered after October 1 were not weighed or saved for analysis. This refused feed, however, is known to be inconsiderable in amount and probably is of no great significance in interpreting the results of the experiment. The effect of this oversight would be to introduce an error in the opposite direction from that consequent upon a possible withdrawal of fat from the bodies of the sheep during the maintenance trial.

Digestibility and Energy Content of Rations. The digestion and metabolism periods were of 10 days' duration. Tests were run upon each of the 15 sheep in the experiment; the results obtained with 4 of the sheep had to be discarded, because in these cases the allowance of linseed oil meal was inadvertently increased above the allowance that they had been receiving. Before the mistake was discovered these sheep had been taken off experiment and otherwise disposed of, so a repetition of their trials was impossible. However, three good digestion and metabolism studies remain on the alfalfa ration, four on the clover-hay ration, and four on the timothy-hay ration. No orts were left in any of these trials and they were in every respect satisfactory. A summary of the coefficients of digestibility is contained in Table 7.

TABLE 7.—COEFFICIENTS OF DIGESTIBILITY OF RATIONS

Sheep No.	Dry substance	Crude protein	N-free extract	Crude fiber	Ether extract
		Alfalfa-hay ration			
	perct.	*perct.*	*perct.*	*perct.*	*perct.*
156	67	77	79	44	63
157	66	75	78	46	54
158	64	74	78	41	59
Average	65.7	75.3	78.3	43.7	58.7
		Clover-hay ration			
160	61	60	76	44	80
161	56	58	78	23	76
162	60	63	74	41	81
163	56	50	77	30	80
Average	58.3	57.8	76.3	34.5	79.3
		Timothy-hay ration			
165	61	61	69	53	68
166	60	61	71	42	58
167	58	61	68	46	54
168	63	57	75	47	60
Average	60.5	60.0	70.8	47.0	60.0

The individual coefficients for the different rations agreed fairly well among themselves with few exceptions. For Table 8 the digestibility of the hays alone has been computed, assuming an average digestibility for the linseed oil meal as given in Henry and Morrison's "Feeds and Feeding." Because of the small proportion of linseed oil

TABLE 8.—COMPUTED COEFFICIENTS OF DIGESTIBILITY FOR HAYS ALONE

Sheep No.	Dry substance	Crude protein	N-free extract	Crude fiber	Ether extract
Alfalfa-hay ration					
	perct.	*perct.*	*perct.*	*perct.*	*perct.*
156	66	75	79	44	57
157	65	73	78	45	48
158	62	71	77	40	50
Average	64.3	73.0	78.0	43.0	51.7
Clover-hay ration					
160	59	52	75	44	76
161	53	50	78	21	71
162	58	57	72	40	78
163	55	41	77	29	81
Average	56.3	50.0	75.5	33.5	76.5
Timothy-hay ration					
165	59	45	68	53	67
166	57	43	71	42	52
167	55	43	67	45	48
168	61	38	75	47	57
Average	58.0	42.3	70.3	46.8	56.0

meal in the rations, the coefficients in Table 8 are quite similar to those in Table 7 with the exception of the coefficients of digestibility of protein for timothy hay, these coefficients being markedly lower than the similar coefficients for the combined ration of timothy hay and linseed oil meal.

From the average coefficients of digestibility for the three different rations and their average chemical composition, the average content of the experimental rations in total and digestible nutrients was computed, the results being given in Table 9. The alfalfa-hay and timothy-hay rations were very similar in their content of total digestible nutrients, the clover-hay ration being somewhat lower in this respect. The content of total and digestible protein decreased from the alfalfa hay thru the clover-hay to the timothy-hay ration.

TABLE 9.—AVERAGE PERCENTAGE COMPOSITION OF THE THREE EXPERIMENTAL RATIONS

	Dry substance	Crude protein	N-free extract	Crude fiber	Fat	Ash	Total digestible nutrients
Alfalfa-hay, oil-meal ration							
Total	93.50	18.01	42.94	21.60	3.13	7.82	...
Digestible	61.43	13.56	33.62	9.44	1.84	...	60.76
Clover-hay, oil-meal ration							
Total	94.56	12.52	42.71	29.54	2.70	7.08	...
Digestible	55.13	7.24	32.59	10.19	2.14	...	54.84
Timothy-hay, oil-meal ration							
Total	94.47	10.21	49.01	25.34	5.70	5.65	...
Digestible	57.15	6.12	34.70	11.91	3.42	...	60.42

In the digestion trials the urine was collected and analyzed for nitrogen, permitting a determination of the nitrogen balances. From Table 10 it is evident that all the sheep were in positive nitrogen balance. In general the positive balance with the timothy-hay sheep was less than the balances for the sheep on the other rations. However, the

TABLE 10.—NITROGEN BALANCES OF SHEEP IN MAINTENANCE PERIODS

Sheep No.	Nitrogen of feed consumed	Nitrogen of feces	Nitrogen of urine	Total nitrogen excreted	Nitrogen balance
Alfalfa, oil-meal ration					
	grams	*grams*	*grams*	*grams*	*grams*
156	26.7	6.1	18.5	24.6	+2.1
157	26.7	6.6	18.0	24.6	+2.1
158	29.6	7.7	20.8	28.5	+2.1
Clover, oil-meal ration					
160	21.3	8.5	10.7	19.2	+2.1
161	20.8	8.6	10.0	18.6	+2.2
162	17.0	6.2	8.2	14.4	+2.6
163	20.0	9.9	10.0	19.9	+ .1
Timothy, oil-meal ration					
165	11.0	4.3	4.9	9.2	+1.8
166	12.0	4.6	4.0	8.6	+3.4
167	11.5	4.5	5.4	9.9	+1.6
168	10.7	4.6	4.8	9.4	+1.3

storage of nitrogen on the clover-hay ration was evidently as extensive as the storage of nitrogen on the alfalfa-hay ration containing almost twice as much digestible crude protein.

The computations of the metabolizable energy of the different rations will be found in Table 11. The gross energy content of feed, feces, and urine was determined directly by the bomb calorimeter. From the daily intake of digestible carbohydrates the methane production was estimated by means of Armsby's average factor and the energy content of the methane produced was then computed, taking 1 gram of methane equal to 13.34 calories; a small correction of the energy of the urine was made to allow for the storage of protein.[1] The total metabolizable energy of the combined rations was computed per kilogram of dry matter and per pound of digestible organic matter. The average metabolizable energy per kilogram of dry matter was 2.292 therms for the alfalfa-hay ration, 1.944 therms for the clover-hay ration and 2.177 therms for the timothy-hay ration; per pound of digestible organic matter the values were respectively, 1.729, 1.589, and 1.668 therms. On the basis either of total dry matter or digestible organic matter the alfalfa ration was found to contain the greatest amount of metabolizable energy, the timothy-hay ration ranking next and the clover-hay ration least. The average percentage of the gross

[1]Armsby, H. P., and Fries, J. A. U. S. Dept. Agr. Bur. Anim. Indus. Bul. 101, 31. 1908.

TABLE 11.—CALCULATION OF METABOLIZABLE ENERGY OF THE THREE EXPERIMENTAL RATIONS

Sheep No.	Dry substance consumed	Digestible organic matter	Energy of feed consumed	Energy of feces	Energy of urine	Energy of CH_4[1]	Energy correction for N balance	Total metabolizable energy	Metabolizable energy in percent of gross energy	Metabolizable energy: Per kg. dry substance consumed	Metabolizable energy: Per pound digestible organic matter
Alfalfa, oil-meal ration											
	kgs.	*lbs.*	*therms*	*therms*	*therms*	*therms*	*therms*	*therms*		*therms*	*therms*
156	.840	1.13	3.738	1.304	.222	.221	.016	1.975	52.8	2.351	1.747
157	.840	1.12	3.738	1.375	.225	.221	.016	1.901	50.8	2.263	1.697
158	.909	1.18	4.048	1.507	.249	.228	.008	2.056	50.8	2.262	1.742
Average	....	....	.....	.....	....	....	....	1.977	51.5	2.292	1.729
Clover, oil-meal ration											
160	.855	1.09	3.766	1.568	.175	.237	.016	1.770	47.0	2.070	1.623
161	.847	1.00	3.772	1.811	.172	.215	.016	1.558	41.3	1.839	1.558
162	.703	.87	3.090	1.293	.128	.187	.019	1.463	47.3	2.081	1.682
163	.836	1.00	3.717	1.830	.170	.223	.001	1.493	40.2	1.786	1.493
Average	....	....	.....	.....	....	....	....	1.571	43.9	1.944	1.589
Timothy, oil-meal ration											
165	.718	.95	3.249	1.328	.127	.223	.013	1.558	47.9	2.169	1.640
166	.733	.94	3.320	1.416	.094	.220	.025	1.565	47.1	2.135	1.665
167	.724	.92	3.279	1.332	.138	.215	.012	1.582	48.2	2.185	1.719
168	.713	.96	3.226	1.279	.127	.229	.010	1.581	49.0	2.217	1.646
Average	....	....	.....	.....	....	....	....	1.572	48.0	2.177	1.668

[1]The methane produced is estimated at 4.5 grams per 100 grams of digestible carbohydrates. One gram of methane contains 13.34 calories of gross energy.

TABLE 12.—MAINTENANCE REQUIREMENTS OF SHEEP PER 100 POUNDS LIVE WEIGHT

Sheep No.	Maintenance weight	Average daily ration			Metabolizable energy per day	Average daily ration per 100 pounds live weight			
		Hay	Oil meal	Total		Weight ratio		Surface ratio	
Alfalfa-hay ration									
	lbs.	*lbs.*	*lbs.*	*lbs.*	*cals.*	*lbs.*	*cals.*	*lbs.*	*cals.*
154	86.3	1.800	.143	1.943	1 889	2.251	2 189	2.143	2 083
155	122.7	1.800	.186	1.986	1 929	1.619	1 572	1.733	1 683
156	95.8	1.800	.143	1.943	1 937	2.028	2 022	1.999	1 993
157	99.6	1.800	.143	1.943	1 865	1.951	1 872	1.947	1 869
158	128.7	1.886	.202	2.088	2 002	1.622	1 556	1.764	1 692
Average	106.6	1.817	.163	1.980	1 924	1.894	1 842	1.917	1 864
Clover-hay ration									
159	113.4	1.800	.186	1.986	1 656	1.751	1 460	1.826	1 522
160	121.6	1.800	.186	1.986	1 763	1.633	1 362	1.743	1 547
161	109.7	1.800	.171	1.971	1 555	1.800	1 417	1.853	1 462
162	81.2	1.520	.129	1.649	1 472	2.031	1 813	1.894	1 691
163	115.3	1.800	.186	1.986	1 521	1.723	1 319	1.806	1 383
Average	108.2	1.744	.172	1.916	1 593	1.788	1 474	1.824	1 521
Timothy-hay ration									
164	88.9	1.000	.143	1.143	1 080	1.286	1 215	1.236	1 168
165	95.4	1.500	.143	1.643	1 549	1.722	1 624	1.695	1 598
166	102.9	1.500	.186	1.686	1 564	1.541	1 520	1.654	1 534
167	98.8	1.500	.171	1.671	1 587	1.691	1 606	1.684	1 600
168	95.5	1.500	.143	1.643	1 584	1.720	1 659	1.694	1 633
Average	96.3	1.400	.158	1.580	1 473	1.592	1 525	1.593	1 507

energy that proved to be metabolizable was 51.5 for the alfalfa-hay ration, 43.9 for the clover-hay ration, and 48.0 for the timothy-hay ration.

Feed and Metabolizable Energy Requirements for Maintenance. The final computations of the experiment are given in Table 12. The maintenance weight of the individual sheep in the alfalfa-hay and clover-hay groups is simply the average of all weekly weights in Table 6, except for Sheep 155. In this case the last weight, taken two days before the death of the animal, is not included in the average. For the timothy-hay sheep the maintenance weight is taken as the average of the last eight weights in Table 6. During this period the weights of the sheep were maintained at a practically constant level. The average daily feed records given in Table 12 refer to the periods covered by the average maintenance weights. The metabolizable energy consumed daily was obtained by the use of the individual results of the metabolism trials in the case of those sheep upon which satisfactory trials were obtained; in the case of Sheep 154, 155, 159, and 164 the average results for their respective groups were used in computing their average daily intake of metabolizable energy. In the last four columns of Table 12 the average daily intake of feed (in pounds) and of metabolizable energy (in calories) has been computed to 100 pounds body weight, using both the direct-weight ratio and the surface ratio, i.e., the ratio of the weights to the two-thirds power. A comparison of the results obtained by the weight ratio with those obtained by the surface ratio shows that the latter method of computation gives individual results within the three groups agreeing much better among themselves. They will therefore form the basis of the following discussion.

The average weight of feed required per day per 100 pounds body weight was 1.917 pounds for the alfalfa-hay group, 1.824 pounds for the clover-hay group, and 1.593 pounds for the timothy-hay group. In view of the individual variations within the different groups of sheep the average difference between the alfalfa-hay ration and the clover-hay ration cannot be considered highly significant. The average difference between the timothy-hay group and either of the other two groups would seem to be highly significant, since none of the individual results on the alfalfa-hay ration or the clover-hay ration was as low as the highest result with the timothy-hay ration. It seems fair to conclude, therefore, from these results that the timothy-hay ration was distinctly higher in net energy than either of the other rations. The results also suggest that the clover-hay ration was higher in net energy than the alfalfa-hay ration. Since the proportion of linseed oil meal in the three experimental rations was approximately the same, it also seems fair to conclude that the timothy hay used in this experiment had a higher net energy value than either the alfalfa hay or the clover hay, and that the clover hay probably was higher in net energy than the alfalfa hay.

Considering the metabolizable energy required per 100 pounds live weight in the three groups, the average value for the alfalfa hay ration (1,864 calories) was distinctly higher than that for either the clover-hay ration (1,521 calories) or the timothy-hay ration (1,507 calories). Comparing the individual values of the alfalfa-hay group with the individual values of the clover-hay group, only one result in the former group is lower than the highest result in the latter group. All of the individual results of the alfalfa-hay sheep were higher than the individual results of the timothy-hay sheep. On the other hand, the average metabolizable energy required per day per 100 pounds live weight by the clover-hay sheep was practically the same as that required by the timothy-hay sheep, the individual variations within these two groups rendering the small average difference entirely insignificant. It appears, therefore, that for maintenance the metabolizable energy of clover hay is approximately of equal value with that of timothy hay. If it may be assumed that the net energy required for maintenance per 100 pounds live weight was the same in all groups, it may be concluded that the percentage availability of metabolizable energy was approximately the same for clover hay as for timothy hay, but was distinctly lower for alfalfa hay.

Summary of the First Experiment

The purpose of the experiment reported above was to determine the relative energy value of alfalfa hay, clover hay, and timothy hay for the maintenance of sheep. Three groups of mature sheep (ewes) containing five animals in each were fed individually approximately .15 pound linseed oil meal daily per 100 pounds initial live weight and enough of the three hays under investigation to maintain body weight. A determination of the digestibility and the content of metabolizable energy of the three rations was made on three of the alfalfa-hay sheep and four each of the clover and timothy-hay sheep.

The alfalfa-hay ration and the timothy-hay ration contained approximately the same percentage content of total digestible nutrients, i.e., 60.76 and 60.42 respectively, while the clover-hay ration was slightly lower with a percentage of 54.84. Since the proportion of linseed oil meal was approximately the same in all three rations, the contents of total digestible nutrients in the three hays were probably in the same proportion as in the rations.

The average metabolizable energy per kilogram of dry matter was 2.292 therms for the alfalfa-hay ration, 1.944 therms for the clover-hay ration, and 2.177 therms for the timothy-hay ration. The alfalfa hay used in this experiment was apparently higher in metabolizable energy than the timothy hay, which in turn was apparently higher than clover hay.

The average amounts of feed required per day per 100 pounds live weight were 1.917 pounds for the alfalfa-hay ration, 1.824 pounds for the clover-hay ration, and 1.593 pounds for the timothy ration. A comparison of the individual results in the three groups indicates that distinctly smaller amounts of the timothy-hay ration were required for maintenance than of the alfalfa or clover-hay ration. The average difference between the alfalfa-hay and the clover-hay rations suggests a superiority of the latter, but in view of the individual variations within the two groups, no positive conclusion is justified.

The average amounts of metabolizable energy per day per 100 pounds live weight required for maintenance were 1,864 calories for the alfalfa-hay ration, 1,521 calories for the clover-hay ration and 1,507 calories for the timothy-hay ration. A study of the individual data indicates that there is no significant difference between the clover and timothy groups in this respect. However, distinctly more metabolizable energy was required in the alfalfa ration than in either of the other two.

In view of the similar proportions of linseed oil meal used in the three experimental rations it may be concluded that timothy hay has a distinctly higher net energy value than either alfalfa hay or clover hay. The results also suggest that clover hay has a slightly higher net energy value than alfalfa hay.

It may also be concluded on the assumption that the basal metabolism per unit of body surface was the same in all groups that the net availability of the metabolizable energy of the alfalfa hay was distinctly lower than that of the clover hay or of the timothy hay. No difference between the latter two hays in this respect was noted.

Critical Consideration

In the preceding experiment no attempt was made with the sheep getting the alfalfa or clover rations to maintain them at exactly their initial weights, and as a result certain adjustments in weight occurred to the amounts of feed fed. With the sheep on the timothy-hay ration, an initial loss in weight was general and in most cases considerable, but these losses occurred in spite of all that could be done to avert them. They were due simply to the refusal of the sheep to consume enough of the ration offered. While there is no good reason to suppose that the slight adjustments of body weight to feed that occurred in the alfalfa and clover lots exerted any influence upon the energy requirements of the sheep, the objection may be raised against the timothy results that the considerable losses in weight incurred by the sheep in the first few weeks of feeding may have depressed their basal metabolism and possibly their activity, so that their energy requirements per unit of weight or of surface were appreciably less than those of the alfalfa-hay and clover-hay sheep. In such a case the smaller quantities of metabolizable energy in timothy hay required for maintenance of weight would not necessarily indicate a greater percentage availability, but may have been the result entirely of a lowered requirement of net energy by these sheep.

That marked undernutrition may lower the basal metabolism has been shown conclusively by Benedict, Miles, Roth, and Smith[1] for men and less certainly by Benedict and Ritzman[2] for steers; a general review of the subject has been written by Lusk.[3] It appears that under the conditions of a greatly restricted supply of food, the body adjusts itself to a more economical level of expenditure as a measure of self-preservation. Such experiments do not prove that small restrictions of diet, occasioning small losses in body weight, will exert such an effect upon metabolism. They also throw no light upon the relation of the fat stores in the body to the response to a restricted diet, altho it appears reasonable to suppose that a fat animal would respond less quickly than a lean animal since its stored food could, for a time, supplement its short rations.

It seems dangerous, therefore to generalize too widely from the limited data available, and in particular to assume that basal metabolism is readily altered by the plane of nutrition. If this were true, basal metabolism determinations would not show the remarkable constancy that has been repeatedly noted in human experimentation when allowance is made for differences in size, sex, and age, and standards of basal metabolism would be of little significance, contrary to general experience. Gulick[4] has found in his own case that overnutrition, inducing a 20-percent increase in body weight, had no effect on his basal metabolic rate. Overnutrition leading to extreme obesity (as much as 160 percent overweight) has been very conclusively shown by Means[5] to be associated with normal basal metabolic rates per square meter of body surface, a finding that has been confirmed by Strouse, Wang, and Dye[6] and others. The latter investigators have been unable to show that underweight is consistently associated with lowered

[1]Benedict, F. G., Miles, W. R., Roth, P., and Smith, H. M. Human vitality and efficiency under prolonged restricted diet. Carnegie Inst. Wash. Pub. 280. 1919.

[2]Benedict, F. G., and Ritzman, E. G. Undernutrition in steers: its relation to metabolism, digestion, and subsequent realimentation. Carnegie Inst. Wash. Pub. 324. 1923.

[3]Lusk, G. The physiological effect of undernutrition. Physiol. Rev. 1, 523. 1921.

[4]Gulick, A. Weight regulation in the adult human body during overnutrition. Amer. Jour. Physiol. 60, 371. 1922.

[5]Means, J. H. The basal metabolism in obesity. Arch. Int. Med. 17, 704. 1916.

[6]Strouse, S., Wang, C. C., and Dye, M. Studies on the metabolism of obesity. II. Basal metabolism. Arch. Int. Med. 34, 275. 1924.

basal metabolic rates, and Blunt and Bauer[1] have found that among a group of nineteen college women who were underweight by comparison with life insurance standards and were eating hardly enough food to supply their estimated daily needs, the basal metabolic rate averaged almost normal. Also Morgulis, in his book on "Fasting and Undernutrition,"[2] cites an experiment performed in Benedict's laboratory on a dog, in which a restriction in diet, causing a sharp drop in body weight, was not associated with a drop in basal metabolism per kilogram body weight.

It seems fair to conclude that while undernutrition may ultimately lower the basal heat production of an animal, there are conditions that may defer or obscure this result for considerable periods of time. Until more is known of these conditions, the result of undernutrition in any particular case cannot be foretold with any degree of certainty. In the foregoing experiment on sheep described in this bulletin, the timothy-hay sheep were undernourished during the first few weeks of the experiment. If this undernutrition had lowered their energy requirements,[3] it would be expected that the amounts of metabolizable energy ultimately shown to be required for maintenance of weight would be inversely correlated with the losses in weight sustained. That this is not the case is shown by the following comparison:

Sheep No.	Average initial weight	Average final weight	Loss in weight	Metabolizable energy required per 100 pounds average live weight
	lbs.	*lbs.*	*lbs.*	*cals.*
164	105	87	18	1 168
166	116	99	17	1 534
167	111	98	13	1 600
168	101	94	7	1 633
165	99	94	5	1 598

[1] Blunt, K., and Bauer, V. The basal metabolism and food consumption of underweight college women. Jour. Home Econ. **14**, 171, 226. 1922.

[2] Morgulis, S. Fasting and undernutrition: a biological and sociological study of inanition, 226. E. P. Dutton & Co. 1923.

[3] It is of course recognized that these requirements relate to voluntary muscular activity as well as to basal metabolism. The above discussion has been necessarily confined to the effect of undernutrition on the basal metabolic rate since no quantitative information has been found concerning its relation to voluntary activity. However, the experiments reported by Trowbridge, Moulton, and Haigh (Mo. Res. Bul. 18), on the live-weight maintenance requirements of cattle, may be cited in this connection. In these long-continued maintenance trials no effect of the condition of the steers can be detected when all of the data are considered; in particular a restricted food intake induced a somewhat higher maintenance cost per unit of area in the average (Tables 23 and 24, and conclusion 9). The later calculations of Hogan, Salmon and Fox (Mo. Res. Bul. 51, 1922) on growing and fattening steers, leading to the conclusion that the main-

The sheep are arranged in the order of decreasing losses in weight, and it is evident that, disregarding the exceptionally low result for Sheep 164,[1] there is no progressive or considerable increase in energy requirements with decreasing losses in weight.

It is frankly admitted, however, that the results obtained with the timothy-hay sheep may not be strictly comparable with those obtained in the other lots for the reasons explained above, and while it seems very unlikely that the conclusion drawn from the comparison is vitiated, it was considered advisable to repeat the alfalfa hay-timothy hay comparison in a second experiment planned to meet so far as possible the objections that may be raised against the first.

SECOND EXPERIMENT: ALFALFA AND TIMOTHY HAY

Outline of Experiment

It was realized at the outset of this experiment that it would be difficult to induce sheep to consume enough of a ration consisting largely of timothy hay to maintain weight. It was, therefore, planned to start two groups of sheep, one to receive a timothy ration and one an alfalfa ration, and to limit the food consumption of the alfalfa-hay sheep, if necessary, so that they would exhibit the same losses in weight as the timothy-hay sheep. At the end of 15 weeks the rations were to be changed, each sheep receiving as much of the second ration as it had been consuming of the first.

Nineteen western wethers and one ewe, averaging 93 pounds per head, were obtained in February, 1926, for this experiment. Six were slaughtered on February 23 and analyzed to determine the initial composition. The remaining 14 were divided into two lots, one to be fed the alfalfa ration and one the timothy ration. The timothy-hay sheep were later reduced to six, since one proved to be a poor feeder.

As in the first experiment, the sheep were individually fed and received in addition to the roughage approximately .08 pound of linseed oil meal daily per 100 pounds initial body weight. All sheep had access to salt at all times, and when consuming timothy hay they also received a small amount (6 grams) of steamed bone meal daily. The individual feeding crates are illustrated in Fig. 1.

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tenance energy cost increases with the plane of nutrition, are of less certain significance since the energy storage in the gains had to be estimated and, in particular, since the assumption is made that the net energy value of feeds is the same at different levels of feeding. This assumption cannot be justified by experimental findings and for low and high levels it is incorrect in all probability.

[1]No digestion and metabolism experiment was run on this sheep. The average results of the other four sheep were used in the calculation of the metabolizable energy content of the maintenance ration in this case.

It was found that the timothy-hay sheep would not consume continuously more than 1 pound per head daily, and on March 1 the feeding experiment began with this group at this level. The alfalfa-hay sheep were started at 1.5 pounds of hay daily per head, but were later reduced to 1 pound also, since on the higher level they gained in weight. All sheep lost slowly in weight on 1 pound of roughage daily, but the losses in the two groups were very closely the same.

During May and June all sheep were subjected to a digestion and metabolism trial lasting ten days, during which there were no feed residues. On June 2 the sheep were sheared and on June 14 the rations were reversed.

After the change in ration all sheep continued to lose slowly in weight, and in July the first deaths occurred among those receiving

FIG. 1.—THE INDIVIDUAL FEEDING CRATES USED IN THE EXPERIMENT

alfalfa hay. In this group two sheep died on July 12 and 13 respectively, and one on August 19. On September 13 the remaining three sheep on the alfalfa ration were again put in the metabolism crates for a ten-day period, immediately after which two of them died with no apparent symptoms but those of malnutrition. The remaining sheep was slaughtered and analyzed on September 27.

Among the sheep receiving timothy hay in the second period of the experiment, no deaths occurred until September, when three died on the 16th, 19th, and 24th, respectively. The remaining four sheep were put into the metabolism crates for ten days and were then slaughtered, one on September 27 and three on October 4.

Results of the Second Experiment

Chemical Composition of the Check Sheep. The live weights, empty weights, and fill of the six check sheep, slaughtered at the beginning of the experiment, are given in Table 13. An average of 72 percent of the "fill" was contained in the first three stomachs. The average weight of wool shorn from the sheep before slaughter was 5.5 pounds. The average weight of blood collected was 4.06 pounds, and the weights of caul fat and gut fat averaged 2.03 and .98 pound respectively. The dressing percentage ranged from 44.4 to 50.3, averaging 47.8.

TABLE 13.—LIVE WEIGHT, EMPTY WEIGHT, AND FILL OF CHECK SHEEP

Sheep No.	Live weight	Empty weight	Fill	Fill
	lbs.	*lbs.*	*lbs.*	*perct.*
34	70.1	62.2	7.9	11.2
50	91.2	79.3	11.9	13.1
11	116.1	100.6	15.6	13.4
30	83.2	70.3	12.9	15.5
12	97.2	87.3	9.9	10.2
44	88.9	78.9	10.0	11.2
Average	91.1	79.8	11.4	12.4

The entire carcass of each sheep was divided for analysis into three samples: (1) the flesh sample contained the boneless meat on one half of the dressed carcass, including one kidney, the left half of the carcass not being analyzed; (2) the bone sample included the bones of one half the dressed carcass, separated by knife, and the bones of the head and of two of the feet; and (3) the offal sample, made up of the blood, the hide, the flesh on the head, the abdominal fat, and all of the viscera with the exception of the kidneys. The wool of all six sheep was composited for analysis.

The weights of these samples from each sheep and the averages for all will be found in Table 14, while the results of their chemical analysis are given in Table 15. Besides the ordinary routine determinations the calcium was determined in these samples by the method of McCrudden[1] and the gross energy by combustion in the Parr oxygen bomb calorimeter.

TABLE 14.—WEIGHTS OF SAMPLES ANALYZED (FRESH BASIS) CHECK SHEEP
(All weights in kilograms)

Sheep No.	34	50	11	30	12	44	Average
Flesh samples	11.20	15.87	21.50	13.09	18.02	16.22	15.98
Bone samples	3.92	4.41	5.03	4.15	4.76	4.37	4.44
Offal samples	8.52	12.79	13.66	9.83	12.02	10.41	11.21

From these sample analyses the composition of the entire carcasses of the sheep has been calculated on the basis of the empty

[1]McCrudden, F. H. Jour. Biol. Chem. 7, 83, 1910; 10, 187, 1911-12.

Table 15.—Percentage Composition and Energy Content of Samples From the Check Sheep

Sheep No.	Dry substance	Total nitrogen	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
			Edible-flesh samples				
							sm. cals.
34.......	38.24	3.02	18.88	16.61	.96	.022	2 536
50.......	45.77	2.57	16.06	27.09	.86	.027	3 330
11.......	57.50	2.28	14.25	40.05	.69	.019	4 502
30.......	40.84	2.79	17.44	23.08	.94	.025	3 032
12.......	52.77	2.58	16.13	30.27	.81	.017	3 668
44.......	50.32	2.47	15.44	34.88	.75	.025	015
Average	47.99	2.62	16.37	28.66	.84	.023	3 514
			Bone samples				
34.......	59.66	3.29	20.59	18.34	18.50	6.93	2 854
50.......	59.71	3.46	21.62	20.04	17.34	6.46	2 836
11.......	61.14	3.49	21.83	17.58	20.09	7.50	2 828
30.......	58.95	3.48	21.77	17.71	18.32	6.81	2 823
12.......	60.88	3.45	21.58	20.37	17.99	6.98	3 042
44.......	65.00	3.31	20.68	21.88	20.56	7.73	3 169
Average	60.89	3.41	21.35	19.32	18.80	7.07	2 925
			Offal samples				
34.......	30.85	2.70	16.86	12.57	1.05	.035	2 119
50.......	34.34	2.33	14.58	17.91	.87	.034	2 501
11.......	40.64	2.34	14.65	23.95	.94	.032	2 960
30.......	30.12	2.50	15.62	12.71	1.09	.038	2 149
12.......	37.49	2.68	16.75	18.86	.95	....	2 651
44.......	41.80	2.21	13.81	25.97	.73	.027	3 284
Average	35.87	2.46	15.38	18.66	.94	.033	2 611
			Wool sample				
	94.74	9.31	58.19	21.85	14.7	.250	5 756

Table 16.—Percentage Composition and Gross Energy Content of the Check Sheep

Sheep No.	Live or empty weight	Dry substance	Crude protein	Ether extract	Ash	Calcium	Gross energy per gram
			On basis of live weight				
	kgs.						*sm. cals.*
34.......	31.80	36.51	18.26	13.19	4.05	.89	2 263
50.......	41.39	40.22	16.47	19.37	3.33	.72	2 698
11.......	52.68	44.32	14.45	25.27	3.14	.74	3 147
30.......	37.76	34.72	16.34	14.70	3.59	.78	2 300
12.......	44.11	43.69	16.77	20.94	3.36	.77	2 874
44.......	40.32	43.93	15.61	24.46	3.63	.87	3 162
Average	41.34	40.57	16.32	19.66	3.52	.80	2 741
			On basis of empty weight				
34.......	28.23	41.12	20.57	14.86	4.56	1.00	2 549
50.......	35.97	46.28	18.94	22.29	3.83	.83	3 102
11.......	45.61	51.19	16.69	29.18	3.62	.86	3 635
30.......	31.91	41.09	19.34	17.39	4.25	.93	2 722
12.......	39.62	48.64	18.67	23.31	3.74	.86	3 200
44.......	35.80	49.48	17.58	27.54	4.08	.98	3 561
Average	36.19	46.30	18.63	22.43	4.01	.91	3 128

weight and of the live weight. The results of these calculations are given in Table 16.

TABLE 17.—PERCENTAGE COMPOSITION AND GROSS ENERGY OF FEEDS

Dates	Sheep No.	Dry substance	Crude protein	N-free extract	Crude fiber	Ether extract	Ash	Gross energy per gram
Alfalfa hay—Period I								
								sm. cals.
Mar. 1-Apr. 2	1, 4, 5, 7, 9, 33, 60	83.29	13.99	34.28	26.77	1.94	6.30	3 675
Apr. 2-May 1	(do.)	83.57	13.09	38.17	24.14	1.82	6.35	3 687
May 1-June 2	(do.)	87.25	13.00	35.72	30.21	1.81	6.51	3 924
June 2-June 14	(do.)	88.03	15.31	38.05	25.63	1.59	7.45	3 914
May 12-May 22[1]	1, 4, 5	93.17	14.53	39.00	30.77	1.96	6.91	4 171
May 23-June 2[1]	7, 9	90.63	15.49	37.83	27.53	2.19	7.59	4 004
June 4-June 14[1]	33, 60	90.96	15.74	37.43	28.77	1.65	7.36	4 052
Alfalfa hay—Period II								
June 14-July 18	2, 3, 6, 8, 10, 11	87.39	13.63	36.54	30.35	1.37	5.50	3 887
July 18-Aug. 15	(do.)	87.44	13.75	38.59	27.42	1.49	6.19	3 979
Aug. 15-Sept. 27	(do.)	85.81	14.38	35.98	28.39	1.47	5.59	3 911
Sept. 14-Sept. 24[1]	2, 6, 11	88.11	13.50	34.74	32.60	1.51	5.76	4 012
Timothy hay—Period I								
Mar. 1-Apr. 2	2, 3, 6, 8, 10, 11	91.37	4.75	48.73	29.99	2.52	5.37	3 938
Apr. 2-May 1	(do.)	87.82	4.82	50.13	25.84	1.88	5.15	3 815
May 1-June 2	(do.)	89.74	4.20	46.30	32.03	1.51	5.70	3 975
June 2-June 14	(do)	89.12	4.13	46.34	31.44	1.82	5.39	3 985
May 12-May 22[1]	2, 3	92.34	5.85	49.78	28.77	2.22	5.72	3 963
May 23-June 2[1]	6, 8, 10	93.27	4.74	50.48	30.64	2.00	5.41	4 004
June 4-June 14[1]	11	91.60	4.22	48.91	31.61	1.51	5.35	4 018

TABLE 17.—*Concluded*

Dates	Sheep No.	Dry substance	Crude protein	N-free extract	Crude fiber	Ether extract	Ash	Gross energy per gram
Timothy hay—Period II								
June 14-July 18.......	1, 4, 5, 7, 9, 33, 60	88.55	5.56	46.41	29.77	1.68	5.13	3 915
July 18-Aug. 15.......	(do.)	89.24	5.34	48.95	28.07	1.81	5.07	3 939
Aug. 15-Sept. 24......	(do.)	88.22	5.16	45.67	30.36	1.56	5.45	3 861
Sept. 24-Oct. 4[2].......	(do.)	88.53	3.56	47.01	31.87	1.39	4.70	3 897
Sept. 14- Sept. 27.....	33	88.78	4.17	46.26	31.54	1.67	5.14	3 950
Linseed oil meal—Period I								
Mar. 1- Apr. 2........	Both lots	92.19	37.38	37.06	8.67	3.81	5.27	4 444
Apr. 2-May 1.........	Both lots	90.00	36.50	37.03	7.34	4.18	4.95	4 285
May 1-June 2.........	Both lots	91.70	33.56	38.97	7.91	5.56	5.70	4 311
June 2-June 14........	Both lots	89.62	31.81	36.56	8.90	6.12	6.23	4 327
May 12-May 22[1]......	2, 3, 1, 4, 5	90.66	34.94	38.78	7.67	3.64	5.63	4 326
May 23-June 2[1].......	6, 7, 8, 9, 10	92.02	34.06	36.41	8.77	6.32	6.46	4 317
June 2-June 14[1].......	11, 33, 60	89.93	33.25	36.08	8.44	5.94	6.22	4 291
Linseed oil meal—Period II								
June 14-July 18.......	Both lots	89.05	36.44	33.23	8.71	5.51	5.16	4 264
July 18-Aug. 15.......	Both lots	89.54	33.38	36.24	9.50	4.41	6.01	4 285
Aug. 15-Sept. 24......	Both lots	88.69	32.94	35.24	8.20	6.18	6.13	4 172
Sept. 24-Oct. 4........	Both lots	87.86	32.06	35.81	8.60	4.94	6.45	4 157
Sept. 14-Sept. 24......	2, 6, 11, 33	88.65	33.94	35.17	8.23	5.64	5.67	4 190
Sept. 24-Oct. 4[1].......	1, 4, 5	87.86	32.06	35.81	8.60	4.94	6.45	4 157

[1]Metabolism periods. [2]This sample was also fed to Sheep 1, 4, 5, during their metabolism period from September 24 to October 4.

The sheep were evidently not uniform in composition. The heavier individuals were in good condition since they contained 20 to 25 percent of fat, but the lighter individuals were considerably less fat.

Feeding Period and Changes in Body Weight. During the feeding of the other two groups of sheep at the barns, samples of the feed were taken daily and composited for analysis at approximately monthly intervals in so far as possible. In addition to these samples were those taken during the metabolism periods. The percentage composition of all samples is summarized in Table 17.

The individual feeding of the sheep started on February 22, but the first week was considered as preliminary in character. The sheep of Lot 1, consuming the timothy-hay ration, were adjusted to a daily intake of 1 pound of hay per head and .08 pound of linseed oil meal per 100 pounds initial body weight by March 1, but the sheep of Lot 2 were given 1.5 pounds of hay until March 2, when the ration was cut to 1 pound of hay per head and .08 pound of linseed oil meal per 100 pounds initial body weight in view of their rapid gain in

TABLE 18.—WEEKLY BODY WEIGHTS OF THE SHEEP IN LOT 1
(All weights in pounds)

Sheep No.	2	3	6	8	10	11	Average
Period I—Timothy hay							
Feb. 22	78	85	103	83	96	98	90.5
Mar. 1	69	77	92.5	67.5	87	86	79.8
8	71	75.5	91.5	71	87	88	80.7
15	73.5	77.5	96	73	90	87	82.8
22	73	76.5	93	70	85	83	80.1
29	74	78	86	71	86	83	79.7
April 5	70	74	85	70	86	82	77.8
12	72	75	88	71	87	83	79.3
19	71	73	86	68	85	79	77.0
26	75	76	87	70	87	80	79.2
May 3	68	74	90	69	86	78	77.5
10	70	72	86	67	83	74	75.3
17	74	75	85	68	87	76	77.5
24	65	69	83	72	86	75	75.0
31	70	74	82	65	82	77	75.0
June 7	63	58.5	74	58.5	74	70.5	66.4
14	70	67.5	78	67.5	79	70.5	72.1
Average	69.6[1]	72.3[1]	85.3[1]	67.8[1]	83.8[1]	78.4[1]	....
Period II—Alfalfa hay							
June 14	63[2]	60[2]	69[2]	61[2]	71[2]	62[2]	64.3[2]
21	63	58	65	60	68	65	63.2
28	61	60	66	62	70	63	63.7
July 5	61	63	71	64	73	65	66.2
12	58	47	64	60	68	63	60.0
19	60	Died 7-12	69	60	Died 7-13	65	....
26	57		63	59		61	....
Aug. 2	57		63	59		61	....
9	57		64	57		62	....
16	58		66	54		62	....
23	56		62	Died 8-19		61	....
30	55		61			58	....
Sept. 6	53		65			58	....
13	52		60			56	....
14	52		58			57	....
23	51		58			55	....
Average	57.3	57.6	64.2	59.3	70.0	61.0	....

[1]The sheep were sheared on June 2, but the weights given on June 7 and 14 include the wool weights. In the averages, however, the sheared weights on these dates have been used. [2]Sheared weights.

weight. The experimental period with this lot was not considered as starting until March 22. The weekly weights of the sheep thruout the two periods of feeding will be found in Tables 18 and 19.

TABLE 19.—WEEKLY BODY WEIGHTS OF THE SHEEP IN LOT 2
(All weights in pounds)

Sheep No.	1	4	5	7	9	33	60	Average
				Period I—Alfalfa hay				
Feb. 22	84	83	87	99	86	82	102	89
Mar. 1	78	72.5	82	90	78	71	90	80.1
8	79	76.5	81.5	90.5	80.5	76	92	82.3
15	83	78	85	93	86.5	75	96	85.2
22	80	74	80	89	82	74	90.5	81.4
29	80	74	78	87	82	74	88	80.4
Apr. 5	79	72	77	88	80	73	87	79.4
12	79	73	78	86	81	76	88	80.1
19	78	70	77	84	78	73	85	77.9
26	79	73	77	85	80	75	86	79.2
May 3	75	70	77	82	76	75	84	77.0
10	72	69	75	80	75	68	80	74.1
17	76	72	77	81	74	71	82	76.1
24	70	67	75	84	74	70	82	74.6
31	78	74	75	78	72	74	83	76.3
June 7	74.5	62.5	66.5	72.5	67.5	68	75.3	69.5
14	75.5	67.5	71.5	76.5	72.5	68	75.3	72.4
Average	75.2[1]	69.0[1]	74.4[1]	81.4[1]	75.5[1]	70.8[1]	82.2[1]	....
				Period II—Timothy hay				
June 14	66[2]	57[2]	63[2]	69[2]	66[2]	59[2]	67[2]	63.9
21	64	58	60	69	65	62	70	64.0
28	61	60	64	71	64	61	70	64.4
July 5	66	62	65	77	70	63	70	67.6
12	64	55	61	72	61	58	69	62.9
19	65	61	66	65	67	60	69	64.7
26	59	55	61	65	60	58	65	60.4
Aug. 2	60	54	61	63	60	58	65	60.1
9	62	54	61	65	61	59	66	61.1
16	61	58	66	69	64	62	68	64.0
23	63	56	63	67	64	62	67	63.1
30	60	51	60	62	59	56	63	58.7
Sept. 6	59	53	62	63.5	59	56	62	59.2
13	59	51	60	60	56	55	60	57.3
20	60	51	60	Died	Died	....	....	....
24	57	52	59	9–16	9–24	53	Died	....
Oct. 3	58	50	59			....	9–19	....
Average	61.4	55.2	61.8	66.8	61.9	58.9	66.1	....

[1]These averages include the period starting with the weight of March 22. They also include the shorn weights of June 7 and June 14 instead of these weights plus the wool removed on June 2, as given in the table. [2]Sheared weights.

Amount and Composition of Wool Sheared at End of Period I. On June 2 all sheep were sheared, the individual weights of fleeces being as follows:

Lot 1—Timothy	*lbs.*	Lot 2—Alfalfa	*lbs.*
No. 2	7.0	No. 1	9.6
3	7.5	4	10.5
6	9.0	5	8.5
8	6.5	7	7.5
10	8.0	9	6.5
11	8.5	33	8.0
		60	8.3
Average	7.75	Average	8.40

The wool from the alfalfa sheep averaged slightly heavier per head, but the lot difference is certainly not significant. The wool from each lot of sheep was composited and analyzed as a separate sample, with the following results:

	Dry matter	Total nitrogen	Crude protein	Ether extract	Ash	Gross energy (sm. cals. per gm.)
Wool from timothy sheep	88.56	7.79	48.69	22.44	11.89	4 907[1]
Wool from alfalfa sheep	91.00	7.95	49.69	22.02	13.73	5 068

([1]Estimated from chemical composition, assuming the gross energy values of protein and fat to be 5.7 and 9.5 calories per gram respectively.)

Apparently there was no significant difference in the percentage composition as well as in the weight of the wool from the two lots of sheep.

Digestibility and Metabolizable Energy Content of Rations. The digestion and metabolism trials inserted at the end of the two experimental periods yielded information relative to the digestibility of and the content of metabolizable energy in the two rations. The coefficients of digestibility obtained from these data will be found in Table 20. The timothy-hay ration was evidently considerably less digestible than the alfalfa-hay ration with respect to dry matter, crude protein, and nitrogen-free extract. On the average the dry matter of the timothy-hay ration was only 82 percent as digestible as that of the

TABLE 20.—SUMMARY OF DIGESTION COEFFICIENTS

	Sheep No.	Dry substance	Crude protein	N-free extract	Crude fiber	Ether extract
Alfalfa, oil-meal ration						
Period I	1	60	73	67	51	37
	4	58	70	66	47	32
	5	57	69	66	45	35
	7	53	68	62	33	44
	9	54	73	62	35	43
	33	53	70	61	37	26
	60	54	70	63	36	35
Period II	2	56	72	61	49	55
	6	60	77	64	52	44
	11	58	72	65	53	55
Average	..	56.3	71.4	63.7	43.8	40.6
Timothy, oil-meal ration						
Period I	2	49	53	56	42	53
	3	46	45	53	42	62
	6	44	38	51	41	45
	8	47	32	56	45	51
	10	48	38	57	45	47
	11	37	27	46	33	32
Period II	1	50	40	57	52	49
	4	46	30	55	46	29
	5	48	37	57	53	33
	33	48	40	57	49	36
Average	..	46.3	38.0	54.5	44.8	43.7

Table 21.—Losses of Energy and Their Percentage Distribution, and Metabolizable Energy Content of Experimental Rations

Feed and Period	Sheep No.	Dry matter eaten per day and head		Energy per kilogram of dry matter					Metabolizable energy		Energy losses			Percentage metabolizable
		Roughage	Concentrate	Total	Losses: In feces	Losses: In urine[1]	Losses: In methane[2]	Metabolizable	Per kg. dig. organic matter	Per kg. total dig. nutrients	In feces	In urine	In methane	
							Alfalfa-hay ration							
		kg.	kg.	therms	therms	therms	therms	therms	therms	therms	perct.	perct.	perct.	perct.
Period I...	1	.423	.024	4.488	1.861	.242	.266	2.119	3.685	3.628	41.47	5.39	5.93	47.21
	4	.423	.024	4.488	1.864	.251	.255	2.118	3.865	3.803	41.53	5.59	5.68	47.19
	5	.423	.029	4.496	1.934	.257	.250	2.055	3.776	3.716	43.02	5.72	5.56	45.71
	7	.412	.029	4.435	2.079	.270	.213	1.873	3.806	3.688	46.88	6.08	4.80	42.23
	9	.412	.024	4.427	2.011	.268	.216	1.932	3.827	3.726	45.43	6.05	4.88	43.64
	33	.413	.023	4.477	2.083	.264	.220	1.910	3.821	3.769	46.53	5.90	4.91	42.66
	60	.413	.029	4.473	2.068	.240	.222	1.943	3.835	3.768	46.23	5.37	4.96	43.44
Period II...	2	.400	.023	4.563	2.017	.232	.248	2.066	3.800	3.703	44.20	5.08	5.44	45.28
	6	.400	.028	4.568	1.736	.264	.259	2.309	4.033	3.952	38.00	5.78	5.67	50.55
	11	.400	.028	4.568	1.914	.250	.266	2.138	3.704	3.617	41.90	5.47	5.82	46.80
Average..	..	.412	.026	4.498	1.957	.254	.242	2.047	3.815	3.737	43.52	5.64	5.35	45.47
							Timothy-hay ration							
Period I...	2	.419	.024	4.314	2.244	.165	.255	1.650	3.432	3.323	52.02	3.82	5.91	38.25
	3	.419	.024	4.314	2.341	.165	.246	1.562	3.392	3.249	54.27	3.82	5.70	36.21
	6	.423	.029	4.327	2.412	.135	.241	1.539	3.515	3.395	55.74	3.12	5.57	35.37
	8	.423	.024	4.318	2.246	.136	.266	1.670	3.502	3.391	52.02	3.15	6.16	38.68
	10	.423	.029	4.327	2.232	.144	.268	1.683	3.475	3.367	51.58	3.33	6.19	38.90
	11	.416	.029	4.407	2.834	.133	.219	1.221	3.321	3.262	64.31	3.02	4.97	27.71
Period II...	1	.402	.023	4.416	2.224	.120	.287	1.785	3.497	3.434	50.36	2.72	6.50	40.42
	4	.402	.023	4.416	2.419	.125	.268	1.604	3.410	3.376	54.78	2.83	6.07	36.32
	5	.402	.028	4.423	2.256	.137	.286	1.744	3.440	3.394	51.01	3.10	6.47	39.43
	33	.402	.023	4.419	2.329	.132	.280	1.678	3.379	3.332	52.70	2.99	6.34	37.97
Average..	..	.413	.026	4.368	2.354	.139	.262	1.614	3.436	3.353	53.88	3.19	5.99	36.93

[1]Corrected to nitrogen equilibrium. [2]Estimated at 4.5 grams (60.03 calories) per 100 grams of digestible carbohydrates.

alfalfa-hay ration, the crude protein only 53 percent as digestible, and the nitrogen-free extract only 86 percent as digestible.

The losses of energy and the metabolizable-energy content of the rations were calculated in the usual manner, with the results given in Table 21. The alfalfa ration contained, on an average, 2.047 therms of metabolizable energy per kilogram of dry matter, and 3.737 therms per kilogram of digestible nutrients. For the timothy-hay ration these values were 1.614 and 3.353 therms respectively. For the same weight of dry matter, the timothy-hay ration contained only 79 percent as much metabolizable energy as the alfalfa-hay ration. An average of 45.47 percent of the gross energy of the alfalfa-hay ration proved to be metabolizable, while only 36.93 percent of the gross energy of the timothy-hay ration was metabolizable.

Nitrogen Balances. The nitrogen balances of the sheep during the digestion periods are given in Table 22. A negative balance was indicated in a large majority of the periods; the alfalfa ration, containing over twice the nitrogen of the timothy ration, occasioned smaller losses of nitrogen.

Table 22.—Nitrogen Balances of the Sheep During Digestion Periods

(All weights in grams)

	Sheep No.	Nitrogen in feed	Nitrogen in feces	Nitrogen in urine	Nitrogen excreted	Nitrogen balance
Alfalfa, oil-meal ration						
Period I	1	12.02	3.30	8.18	11.48	.54
	4	12.02	3.65	8.43	12.08	− .06
	5	12.35	3.84	9.01	12.85	− .50
	7	12.99	4.18	10.40	14.58	−1.59
	9	12.67	3.46	9.45	12.91	− .24
	33	12.82	3.81	8.38	12.19	.63
	60	13.14	3.89	9.65	13.54	− .40
Period II	2	11.22	3.12	7.95	11.07	.15
	6	11.55	2.62	9.05	11.67	− .12
	11	11.55	3.18	8.27	11.45	.10
Average	..	12.23	3.51	8.88	12.38	− .15
Timothy, oil-meal ration						
Period I	2	5.71	2.67	3.78	6.45	− .74
	3	5.71	3.14	4.00	7.14	−1.43
	6	5.18	3.20	3.08	6.28	−1.10
	8	4.86	3.31	3.36	6.67	−1.81
	10	5.18	3.20	4.14	7.34	−2.16
	11	4.77	3.47	2.94	6.41	−1.64
Period II	1	3.92	2.35	2.45	4.80	− .88
	4	3.92	2.74	3.43	6.17	−2.25
	5	4.24	2.69	2.95	5.64	−1.40
	33	4.00	2.38	2.94	5.32	−1.32
Average	..	4.75	2.92	3.31	6.22	−1.47

Chemical Composition of Surviving Sheep. At the end of the experiment 5 sheep remained alive in a greatly emaciated condition, 4 from the timothy-hay ration, and only 1 from the alfalfa-hay ration. They were slaughtered and analyzed to determine their fat and energy content in particular, and to permit of some estimate of the loss of body energy sustained by the sheep during the two periods of experimental feeding. The "fill" of these sheep averaged 11.43 pounds, or 21.5 percent of their live weight, and the dressing percentage averaged 39.6 and ranged from 33.5 to 46.0. There were practically no abdominal fat deposits, nor was there enough visible fat on the carcass to separate with the knife.

The chemical samples were prepared in the same manner as for the check sheep in this experiment. Their weights are summarized in Table 23 and their percentage composition in Table 24. The extreme leanness of these sheep is shown particularly in the low fat content of the flesh and offal samples. For three of the sheep (Nos. 11, 33, and

TABLE 23.—WEIGHTS OF SAMPLES ANALYZED FROM THE SURVIVING SHEEP

(All weights in kilograms)

Sheep No.	11	33	1	4	5	Average
Flesh sample	6.915	6.906	7.356	4.906	6.220	6.461
Bone sample	3.849	4.107	3.669	3.538	4.667	3.966
Offal sample	6.827	6.380	6.617	5.191	7.530	6.509
Wool sample	.667	.740	.715	.606	.545	.655

TABLE 24.—PERCENTAGE COMPOSITION AND ENERGY CONTENT OF SAMPLES FROM THE SURVIVING SHEEP

Sheep No.	Dry substance	Total nitrogen	Crude protein	Ether extract	Ash	Gross energy per gm.
Edible-flesh samples						
						sm. cals.
11	24.94	3.01	18.81	5.12	1.09	1 537
33	25.30	2.93	18.31	4.09	1.05	1 423
1	23.93	3.18	19.88	3.08	1.09	1 404
4	20.59	3.09	19.31	.63	1.08	1 138
5	19.39	2.74	17.13	1.70	1.02	1 097
Average	22.83	2.99	18.69	2.92	1.07	1 320
Bone samples						
11	60.50	2.91	18.21	20.62	20.56	2 917
33	54.90	2.83	17.70	19.44	17.62	2 736
1	53.88	2.87	17.92	15.05	18.69	2 583
4	36.84	2.94	18.36	1.27	17.07	1 167
5	34.02	2.33	14.55	5.98	13.06	1 382
Average[1]	.....	.....	.....	.....	.....	.....
Offal samples						
11	24.31	2.87	17.94	4.86	1.40	1 494
33	24.11	2.73	17.06	5.75	1.20	1 501
1	24.04	2.82	17.63	4.83	1.58	1 465
4	21.75	2.94	18.38	2.61	1.29	1 263
5	20.25	2.58	16.13	3.19	1.36	1 214
Average	22.89	2.79	17.43	4.25	1.37	1 387
Wool samples						
11	87.34	7.19	44.94	18.97	14.04	4 707
33	89.66	7.96	49.75	19.86	14.64	5 077
1, 4, 5	87.53	8.00	50.00	18.11	15.43	4 907
Average[2]	87.92	7.83	48.94	18.63	14.99	4 901

[1]The individual bone samples were too variable in composition, particularly in regard to the content of ether extract, to give significant averages. [2]Weighted average.

1), the fat in the bones was not greatly if at all lower than that of the check sheep (see Table 15), but for the other two sheep, the skeleton also was largely depleted of fat. For these two sheep (Nos. 4 and 5) the fat content of the flesh and offal samples was lower than that for the other sheep. The results suggest that, in undernutrition, the skeletal fat is the last to be drawn upon. The wool contained more moisture, less protein, but only slightly less fat than the wool of the check sheep.

Growth of Wool by Sheep on a Submaintenance Ration. For the five sheep that were slaughtered and analyzed after 210 to 227 days of feeding, it is possible to make more or less satisfactory estimates of the amount of protein and energy used daily for the growth of wool. These estimates were made on the assumption that the wool was shorn to an equal length in the case of the check sheep and of the surviving sheep, and that the latter, at the beginning of the feeding period on February 22 had on their backs as much protein and energy in their wool in proportion to live weight as did the check sheep. These amounts of protein and energy were subtracted from the sums of the amounts shorn from each sheep on June 2 and just previous to slaughter to get the amounts added during the feeding period. Dividing the differences by the numbers of days of feeding and by the average weights of the sheep[1] gave the daily additions per 1,000 pounds body weight. The results of these calculations are given in Table 25.

TABLE 25.—ESTIMATES OF DAILY STORAGE OF PROTEIN AND ENERGY IN WOOL OF SURVIVING SHEEP

Sheep No.	Storage per day		Storage per day per 1000 pounds body weight	
	Crude protein	Gross energy	Crude protein	Gross energy
	grams	*cals.*	*grams*	*cals.*
11	2.95	31.7	39.9	428
33	4.14	44.1	59.4	633
1	5.24	54.6	70.8	738
4	5.95	58.7	86.6	854
5	3.57	37.6	48.5	511
Average	4.37	45.3	61.0	633

Altho these sheep were losing weight steadily at an average rate of .05 to .10 pound per day, and were in almost continuous negative nitrogen balance, they were storing daily in the wool an average of 4.37 grams of protein and 45.3 calories of gross energy. Per 1,000 pounds live (unshorn) weight, these values become 61.0 grams, or .135 pound, of protein and 633 calories of gross energy. In a previous

[1]In getting the average weights, the weekly weights after June 2 were each increased by the weight of wool removed at that date. The weights thus obtained represent the sheep unshorn from the beginning of the experiment to the date of slaughter.

investigation[1] of sheep of approximately the same initial weight receiving alfalfa hay alone in amounts sufficient to support considerable increase in weight, the wool stored daily per 1,000 pounds body weight contained on an average .149 pound of protein and 566 calories of gross energy. Armsby[2] has computed the average daily growth of wool to contain .135 pound of protein per 1,000 pounds live weight. It is a remarkable demonstration of the independence of wool growth and of food intake that the sheep in this experiment, losing energy and nitrogen continuously and in considerable amounts daily from their bodies, should store energy and nitrogen in their wool at an approximately normal rate. Joseph[3] has shown the same independence of wool growth and nutrition, tho in a less striking way.

Comparison of Composition of Tissues From Well-Fed and From Emaciated Sheep. It is of great interest to compare the composition on the fat-free, or "protoplasmic," basis of the surviving emaciated sheep with that of the well-fed check sheep. Such a comparison is afforded by the calculations contained in Table 26.

TABLE 26.—PERCENTAGE COMPOSITION, ON FAT-FREE BASIS, OF SAMPLES FROM CHECK SHEEP (WELL-FED) AND SURVIVING SHEEP (EMACIATED)

Sample	Moisture	Crude protein	Ash	Ratio of protein to moisture
Flesh sample				
Well-fed sheep.....	72.90	22.95	1.18	1:3.18
Emaciated sheep...	79.49	19.25	1.10	1:4.13
Bone sample				
Well-fed sheep.....	48.48	26.46	23.30	1:1.83
Emaciated sheep[1]..	53.34	22.00	23.26	1:2.42
Offal sample				
Well-fed sheep.....	78.84	18.91	1.16	1:4.17
Emaciated sheep...	80.53	18.20	1.43	1:4.42

[1]Includes only the samples of Sheep 11, 33, and 1. The fat-poor bones of Sheep 4 and 5 showed much wider ratios of protein to moisture, i.e., 1 to 3.44 and 1 to 4.53 respectively. The moisture in these bones on the fat-free basis was 63.97 and 70.18 percent respectively.

Evidently emaciation has increased the moisture content of all tissue samples above that of the well-nourished tissues. This is in agreement with the findings of Hoagland and Powick[4] in regard to emaciated cattle. These investigators found that the flesh of emaciated cattle generally showed a ratio of protein to moisture of 1 to 4 or more, while in well-fed cattle the ratio was much narrower. In

[1]Mitchell, H. H., Kammlade, W. G., and Hamilton, T. S. A technical study of the maintenance and fattening of sheep and their utilization of alfalfa hay. Ill. Agr. Exp. Sta. Bul. 283, 245. 1926.

[2]Armsby, H. P. The nutrition of farm animals, 327. Macmillan. 1917.

[3]Joseph, W. E. Effect of feeding and management of sheep on the tensile strength and elasticity of wool. Jour. Agr. Res. 33, 1073. 1926.

[4]Hoagland, R., and Powick, W. C. A chemical study of the flesh of emaciated cattle. Jour. Agr. Res. 31, 1001. 1925.

the emaciated sheep of this experiment the ratio of protein to moisture in the flesh samples averaged 1 to 4.13, while that of the well-fed sheep averaged 1 to 3.18. Among the other two samples the ratio shows the same tendency to widen as a result of undernutrition.

Loss of Body Constituents During Feeding Period. From the weights of samples and their chemical composition, the percentage composition of the entire carcasses of the surviving sheep was calculated, with the results given in Table 27. The great emaciation of these sheep, particularly Nos. 4 and 5, is clearly shown by these figures.

TABLE 27.—PERCENTAGE COMPOSITION AND GROSS ENERGY CONTENT OF SURVIVING SHEEP

Sheep No.	Live or empty weight	Dry substance	Crude protein	Ether extract	Ash	Gross energy per gm.
On basis of live weight						
						sm. cals.
11	23.80	26.41	14.80	6.73	4.42	1 476
3	22.06	28.13	15.63	7.23	4.45	1 560
1	25.66	23.19	14.20	4.78	3.82	1 286
4	22.38	17.77	12.77	1.44	3.66	861
5	25.95	18.47	12.44	2.79	3.31	966
On basis of empty weight						
11	19.63	32.02	17.95	8.16	5.36	1 790
33	18.78	33.04	18.36	8.50	5.23	1 832
1	19.88	29.93	18.32	6.17	4.93	1 659
4	16.22	24.53	17.61	1.98	5.05	1 194
5	19.43	24.66	16.62	3.72	4.42	1 290

Assuming that the surviving sheep possessed the same composition on March 1 as the check sheep, killed on February 23, it is possible to make approximate estimates of their changes in composition during the entire feeding period of 212 to 227 days. They lost an average of 20.4 percent of their initial body weight, 35.9 percent of their initial content of dry matter, 71.2 percent of their initial content of fat, 47.7 percent of their initial content of gross energy, but only 6.6 percent of their initial content of protein. In making these estimates the nutrients and energy contained in the wool sheared on June 2 have been added to those found at slaughter. The discrepancy between the percentage loss in body weight and in dry matter evidently is due to only a small loss in water which averaged only 9.2 percent.

The ash content of the sheep increased somewhat when the wool is considered, but the ash of wool, being so largely dirt, is of little significance, altho it is an important factor in such calculations. Thus, in the check sheep, the ash of the wool shorn at slaughter made up an average of 25.6 percent of the ash of the entire carcass. Disregarding the wool, therefore, it appears that slight losses occurred from the bodies of the sheep, averaging 9.2 percent.

The losses of constituents from the sheep carcasses expressed as percentages of the losses in live weight, averaged 24.8 for water, 4.6 for protein, and 72.3 for fat. These may be considered to represent the average percentage composition of the losses in weight. The average loss contained 3.05 therms of gross energy per pound. The daily loss in energy averaged 217 calories for these five sheep. This is a measure of the daily deficiency in energy of the ration fed.

Feed Consumption and Its Content of Metabolizable Energy. The average results of the feeding experiment relative to losses in weight and daily consumption of feed and metabolizable energy in the two periods are summarized in convenient form in Table 28. In Period I the average daily losses in weight are obtained by taking the initial weight as the average of the weights on March 1, 8, and 15, for the timothy-hay group, and as the average of the weights on March 22, 29, and April 2, for the alfalfa-hay group, and by taking the final weight in both groups as the average of the weights on June 14, 21, and 28 plus the weights of wool removed on June 2. The calculations of Period II relate only to those sheep that survived into September. For the calculation of average daily losses in weight during this period the initial weight is taken as the average of the weights of June 14 and 21, and the final weight as the average of the last two weights secured.

In Period I the average daily loss in weight was practically the same for the two groups of sheep, tho there were large variations in this respect within each group. The daily intake of roughage as well as of oil meal averaged slightly less for the timothy-hay group than for the alfalfa-hay group.

The metabolizable energy intake of each sheep was calculated from its daily intake of gross energy and the percentage metabolizability of the gross energy of its feed as determined in the metabolism experiment of the same period (see Table 21). The average intake of metabolizable energy per day was considerably greater for the sheep consuming alfalfa hay than for those consuming timothy hay, averaging 820 calories as compared with 657 calories.

The metabolizable energy intake of each sheep has been computed to a standard weight of 100 pounds by two methods. In the first method the intake of metabolizable energy is multiplied by the ratio of the standard weight, 100 pounds, to the average weight of the sheep for the period. In the second method it is multiplied by the ratio of these two weights, each raised to the two-thirds power. Inasmuch as the surface of the sheep varies approximately with the two-thirds power of its weight, the second method obtains the metabolizable energy intake for a 100-pound animal in accordance with the ratio of surfaces rather than of weights. In so far as maintenance energy requirements consist of *basal* metabolic expenditures, the requirements

TABLE 28.—CHANGES IN BODY WEIGHT AS RELATED TO FEED AND METABOLIZABLE ENERGY CONSUMED

Sheep No.	Average daily losses in body weight	Average daily feed consumed					Metabolizable energy consumed daily		
		Hay	Oil meal	Total	Per 100 pounds live weight		Per head	Per 100 pounds live weight	
					Weight ratio	Surface ratio		Weight ratio	Surface ratio
Period I									
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	cals.	cals.	cals.
Alfalfa lot									
1	.059	1.000	.057	1.057	1.41	1.28	867	1 153	1 048
4	.054	.988	.057	1.045	1.51	1.34	856	1 241	1 097
5	.089	.988	.071	1.059	1.42	1.29	842	1 132	1 026
7	.129	1.000	.071	1.071	1.32	1.23	787	967	903
9	.117	1.000	.057	1.057	1.39	1.28	801	1 061	966
33	.060	.988	.057	1.045	1.48	1.31	774	1 094	974
60	.133	1.000	.071	1.071	1.31	1.22	810	985	923
Average	.092	.....	....	.....	1.406	1.279	820	1 090	991
Timothy lot									
2	.014	.971	.057	1.028	1.48	1.31	705	1 013	897
3	.094	.991	.057	1.048	1.45	1.30	680	941	844
6	.168	.906	.071	.977	1.14	1.09	620	727	689
8	.029	.990	.057	1.047	1.54	1.35	726	1 070	940
10	.098	.952	.071	1.023	1.22	1.15	714	852	803
11	.145	.924	.071	.995	1.27	1.17	495	632	582
Average	.091	.....	....	.....	1.352	1.230	657	873	793
Period II									
Alfalfa lot									
2	.113	1.000	.057	1.057	1.84	1.53	856	1 494	1 241
6	.078	1.000	.071	1.071	1.67	1.44	969	1 509	1 302
11	.074	1.000	.071	1.071	1.75	1.49	897	1 471	1 247
Average	.088	.....	....	.....	1.75	1.49	907	1 491	1 263
Timothy lot									
1	.067	1.000	.057	1.057	1.72	1.46	759	1 237	944
4	.058	1.000	.057	1.057	1.91	1.57	682	1 236	1 013
5	.022	1.000	.071	1.071	1.73	1.48	752	1 216	1 036
7	.080	1.000	.071	1.071	1.61	1.40	704	1 054	922
9	.088	1.000	.057	1.057	1.71	1.46	694	1 121	955
33	.064	1.000	.057	1.057	1.80	1.50	713	1 211	1 015
60	.082	1.000	.071	1.071	1.62	1.41	704	1 065	928
Average	.066	.....	....	.....	1.729	1.469	715	1 163	973

of animals of different sizes are best equated and compared by surface ratios; but in so far as they consist of energy expenditures in voluntary muscular activity, differences in size are best removed by weight ratios. In the present case both factors are involved and it seems impossible to decide which method is the better.

By both methods of computation, the timothy-hay sheep consumed about 20 percent less metabolizable energy than the alfalfa-hay sheep and yet their loss in weight was no greater. The conclusion seems warranted, therefore, that the metabolizable energy of the timothy-hay ration was considerably better utilized, i.e., possessed a higher percentage availability, than the metabolizable energy of the alfalfa-hay ration.

There is a close correlation in each group between the average loss in weight and the average intake of metabolizable energy per 100 pounds live weight. This correlation is approximately linear in character and may be expressed by the equation of a straight line. For the two sets of data relating to the energy consumed per unit of weight and for the two groups of sheep, the equations that were fitted to the data best by the method of least squares are:

Alfalfa-hay sheep
Weight ratio: $y = .438 - .000317x$ (1)
Surface ratio: $y = .506 - .000419x$ (2)

Timothy-hay sheep
Weight ratio: $y = .379 - .000330x$ (3)
Surface ratio: $y = .409 - .000401x$ (4)

in which y is the average daily loss in body weight in pounds, while x is the average daily intake of metabolizable energy per 100 pounds body weight in calories. In Table 29 the sheep in each group are arranged in the order of decreasing intakes of metabolizable energy per 100 pounds of weight for comparison with the actual average losses in weight and those computed by the above equations.

By the use of equations (1) to (4) it is possible to compute the metabolizable energy requirements for maintenance of body weight by solving for x when $y = o$. For the alfalfa sheep these estimated requirements are 1,382 calories per 100 pounds body weight, using the ratio of weights, and 1,208 calories, using the ratio of surfaces. For the timothy-hay sheep these estimated values are 1,149 and 1,020 calories respectively. These values should not be confused with energy requirements for energy equilibrium, since immature sheep, such as these were, would probably be in negative energy balance even tho the weight were constant.

The data of Period II are less complete than those of Period I because of the death of three of the alfalfa sheep shortly after the period started. The daily losses averaged somewhat less in this period than in the preceding, but the amounts of food consumed per 100 pounds weight were much larger, so there is no need for assuming that

TABLE 29.—CORRELATION OF INTAKE OF METABOLIZABLE ENERGY AND AVERAGE LOSS IN WEIGHT IN PERIOD I

Sheep No.	Metabolizable energy consumed daily		Average losses in weight		
			Actual	Computed by	
	Weight ratio	Surface ratio		Equations 1 or 3	Equations 2 or 4
Alfalfa-hay ration					
	lbs.	*cals.*	*lbs.*	*lbs.*	*lbs.*
4	1 241	1 097	.054	.044	.047
1	1 153	1 048	.059	.072	.068
5	1 132	1 026	.089	.078	.077
33	1 094	974	.060	.090	.099
9	1 061	966	.117	.101	.102
60	985	923	.133	.125	.120
7	967	903	.129	.131	.128
Timothy-hay ration					
8	1 070	940	.029	.026	.032
2	1 013	897	.014	.045	.049
3	941	844	.094	.069	.071
10	852	803	.098	.098	.087
6	727	689	.168	.139	.133
11	632	582	.145	.171	.176

the sheep were adjusting themselves to a lower level of energy expenditure. In fact quite the reverse is indicated. Of the three alfalfa sheep two showed smaller losses in weight than in the preceding period on timothy hay, while of the seven timothy sheep four showed smaller losses than in the preceding period on alfalfa hay.

The average daily intake of feed again averaged slightly less for the timothy-hay sheep than for the alfalfa-hay sheep, while their intake of metabolizable energy was considerably less. Per 100 pounds body weight the metabolizable energy consumed was much smaller in amount for the timothy sheep than for the alfalfa sheep.

The data of Period II therefore confirm those of Period I in indicating a greater availability of the metabolizable energy of timothy hay than of alfalfa hay.

On June 15, at the end of Period I, the lightest and heaviest sheep in each group were photographed against a checkered background, with the results pictured in Figs. 2 and 3. The alfalfa sheep appear to be in somewhat poorer condition than the timothy sheep. In early August, near the end of the second period, group pictures were taken of four sheep from each lot (see Figs. 4 and 5). These pictures are of value mainly in showing the wool growth that has occurred since the shearing on June 2.

Since the losses in weight of the alfalfa-hay sheep were as great as those of the timothy-hay sheep, it seems fair to assume that, thruout this experiment, their energy requirements were approximately the same per unit of weight or surface. Since it required more metabolizable energy from alfalfa hay than from timothy hay to maintain such

FIG. 2.—SHEEP 7 ABOVE AND SHEEP 4 BELOW WERE IN LOT II WHICH RECEIVED ALFALFA HAY

The photographs were taken on June 15, at the end of Period I. No. 7 was the heaviest sheep and No. 4 was the lightest in the alfalfa hay lot at this time.

equal nutritive states in sheep, the metabolizable energy of timothy hay must therefore be considerably better utilized in the body.

Summary of the Second Experiment

A comparison of the value of timothy hay and alfalfa hay as sources of energy has been made in feeding experiments on sheep. Two groups of yearling western wethers, weighing from 80 to 100 pounds, were placed, one group of seven sheep on a ration of alfalfa hay and linseed oil meal and the other group of six sheep on a ration

FIG. 3.—SHEEP 10 ABOVE AND SHEEP 3 BELOW WERE IN LOT I WHICH RECEIVED THE TIMOTHY RATION

The photographs were taken on June 15, at the end of Period I. No. 10 was the heaviest sheep and No. 3 was the lightest in the timothy-hay lot at this time.

of timothy hay and linseed oil meal. When it was found in this experiment, as in the preceding one, that the timothy hay was not being consumed in amounts sufficient to maintain weight, the intake of alfalfa hay by the other group was likewise restricted so that the loss in weight on both rations was approximately the same. One pound of timothy hay per head daily was as much as would be cleaned up consistently, and one pound of alfalfa hay daily proved to be equally efficient in preventing loss in weight, so this amount was offered daily thruout the experiment to all sheep. In addition each sheep received .08

pound of linseed oil meal daily per 100 pounds initial live weight. Salt was available to all sheep and a small amount (6 grams per head) of steamed bone meal was given to the sheep on the timothy ration. All sheep were fed individually.

After 100 days of feeding the sheep were sheared. At about this time or earlier a digestion and metabolism experiment was run upon each sheep.

At the end of 112 days of feeding the rations were reversed, those sheep getting alfalfa hay being put upon timothy hay, and vice versa. This second period lasted 112 days, and during the last few weeks digestion and metabolism trials were made upon all surviving sheep.

Six sheep, purchased at the same time and of the same age, breeding, and condition as the experimental sheep, were slaughtered at the beginning of the experiment in order to obtain a definite idea of the initial nutritive condition of the sheep subsequently fed. On the live-weight basis they were found to contain, on an average, 40.57 percent of dry matter, 16.32 percent of protein, 19.66 percent of fat, 3.52 percent of ash, and .80 percent of calcium. Their "fill" averaged 12.4 percent of their live weight.

The wool sheared from the sheep on June 2 was approximately the same in amount and composition for the timothy and for the alfalfa sheep.

All sheep decreased in weight from the beginning to the end of the experiment. The losses on the alfalfa ration were of the same order of magnitude as those on the timothy ration, and in each period the average losses were very nearly the same. Evidently, so far as may be judged from the changes in weight of the sheep, one pound of the alfalfa hay used was equal in energy value to one pound of the timothy hay used.

The digestion trials, however, showed conclusively that the alfalfa ration was much more digestible than the timothy ration. On an average, the dry matter of the timothy ration was only 82 percent as digestible as that of the alfalfa ration, the crude protein was only 53 percent as digestible, and the nitrogen-free extract only 86 percent as digestible. The digestibility of crude fiber and ether extract was not greatly different for the two rations.

For the same weight of dry matter the timothy-hay ration contained only 79 percent as much metabolizable energy as the alfalfa-hay ration. An average of 45.5 percent of the gross energy of the alfalfa ration was metabolizable, while only 36.9 percent of the gross energy of the timothy ration was metabolizable.

The prevailing nitrogen balances on both rations were negative, this being true of all of the balances obtained on the timothy ration. The average nitrogen balance was –.15 gram per day on the alfalfa ration and –1.47 grams per day on the timothy ration.

FIG. 4.—FOUR OF THE SHEEP OF LOT I, PHOTOGRAPHED EARLY IN AUGUST WHILE ON THE ALFALFA RATION

The picture shows the active growth of wool since early in June, on the markedly submaintenance ration.

Five of the six sheep on the alfalfa ration in the second period died of undernutrition before the termination of the experiment, while only three of the seven sheep on the timothy ration succumbed. The

FIG. 5.—FOUR OF THE SHEEP OF LOT II, PHOTOGRAPHED EARLY IN AUGUST WHILE ON THE TIMOTHY-HAY RATION

This photograph shows also the active growth of wool on a submaintenance ration.

surviving five sheep were slaughtered and analyzed. They were found to be in an extremely emaciated condition, the fat stores being practically depleted. On the live-weight basis they contained an average of only 4.6 percent of fat.

Three of the five sheep still retained considerable fat in their bones, indicating that marrow fat is among the last of the fat stores to be depleted in undernutrition. The two sheep showing inconsiderable amounts of fat in the bones were the most emaciated of the group.

The withdrawal of fat from the tissues was accompanied by an increase in moisture on the fat-free basis, so that the ratio of protein to moisture, particularly in the muscles and in the bones, was greatly decreased by undernutrition.

The wool sheared from these sheep, however, did not differ greatly in composition from the wool of the check sheep, even in its content of fat. Computations of the rate of deposition of protein and energy in the wool during more than 200 days on a submaintenance ration, indicated that it was normal as compared with similar data collected from sheep on production rations. The physical characteristics of the wool unfortunately were not studied.

During this protracted period of normal wool growth on submaintenance rations, the bodies of the sheep lost 71.2 percent of their fat content, 47.7 percent of their gross energy content, but only 6.6 percent of their protein content.

The data in both periods proved that, for apparently equal degrees of undernutrition, 20 percent less metabolizable energy was required in the timothy ration than in the alfalfa ration.

Conclusions of the Second Experiment

The metabolizable energy of timothy hay is considerably better utilized in the maintenance of sheep than is the metabolizable energy of alfalfa hay. Since, in general, the metabolizable energy per unit of dry matter is nearly the same for the two hays, the net energy content of timothy hay will average considerably higher than that of alfalfa hay, in accordance with the results of Armsby's calorimetric experiments on steers.

Undernutrition withdraws fat from the muscular and glandular tissues before the marrow fat is affected. The withdrawal of fat from all tissues is accompanied by an increase in the ratio of protein to moisture. Neither the composition of the wool, however, nor its chemical growth is greatly affected by undernutrition.