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The Nutritive Value of South African Feeding Stuffs II.*—Digestible Nutrients and Metabolizable Energy of Lucerne Hay at Different Planes of Intake for Sheep.

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Introduction.

A considerable amount of work has been done during the last dozen years at this Institute with the object of securing data on the nutritive value of the most important feed of the country, namely, the natural pasture. In practically all these studies chemical analysis alone formed the basis for estimating the feeding value of the pasture, the exceptions being two publications on the digestibility of indigenous grasses [Myburgh (1937) and Louw (1938)]. Work on the digestibility of South African feeding stuffs has indeed, been grossly neglected in the past, as was emphasized by Ross and Bosman (1927), Ross, Bosman and van Wyk (1931), and Botha (1938).

On account of the great variation in the magnitude of the digestive wastage of a feed the determination of its digestible nutrients constitutes a considerable advance in its evaluation on the information gained in this respect from a chemical analysis alone. However, as pointed out recently by Mitchell (1942) in a report of the American Society of Animal Production's special Committee on the evaluation of feeds, " the ordinary metabolism and digestion experiment does not measure all of the wastage of the nutritive material in the alimentary tract, since some of this wastage is in the gaseous form, representing the activity of micro-organisms inhabiting certain segments of the tract. While these losses can be measured directly only in a respiration chamber, they may be estimated for cattle indirectly from data obtainable in a simple digestion trial, and for sheep and horses when suitable prediction equations are devised ". The determination of the calorific values of the feed, faeces, and urine by means of a bomb calorimeter will in that event enable the investigator to compute the metabolizable energy of the feed; indisputably, a more significant measurement of the value of a feed in satisfying the energy requirements of the animal than is the sum of total digestible nutrients.

* This article is to be considered the second in a series of which " Grass hay as a maintenance ration for sheep during winter " is to be regarded as the first.

Information on the energy value is urgently required, not only in respect of our common farm feeds, but also in connection with pasture herbage under different systems of grazing management. It is proposed to make some contribution towards rectifying the present lack of knowledge by a series of digestion and metabolism studies which will be carried out in a manner conforming with the recommendations of the Committee quoted above. Until such time as a suitable prediction equation for their gaseous digestive wastage becomes available Armsby's factor for the methane production of cattle will be used in work with sheep. The value of any system for the evaluation of feeds depends upon whether the particular measure of total nutritive energy can form the basis of feeding standards which are to serve as guides in computing rations for various animal functions: maintenance, growth, and milk production. It will, therefore, be futile to determine, for instance, the metabolizable energy of a feed unless, at the same time, the requirements of the animal for a specific body function in terms of that metabolizable energy is known. For this reason the proposed series of studies will deal not only with the metabolizable energy value of feeds but also with the metabolizable energy requirements for different animal functions, in so far as such studies can be carried out with the available facilities.

It is realised that while the measurement of the metabolizable energy represents a step beyond digestible nutrients as a measure of the nutritive value of a feed, it falls short of being the final measure in that a variable portion of it, depending upon the chemical composition of the feed and the plane of nutrition, is lost as heat not useful to the body. The hypothesis that the utilization of metabolizable energy is constant for all well-balanced rations has, of late, repeatedly been advanced, not without a considerable amount of experimental evidence to support it [Mitchell (1937), Maynard (1937)]. It is, however, felt that whilst the ideal should be to ensure well-balanced rations for all farm animals, this will not be possible in practice, where individual feeds are frequently dealt with. Some measure of their value is, therefore, essential.

Several investigators have presented evidence to show that a close correlation obtains between the content of feeds in certain constituents and the digestibility of the organic matter as a whole, or some part of it. Thus, Axelsson (1940) demonstrated a close negative correlation between the crude fibre content of feeds and the digestibility of the organic matter by cattle. As the result of a statistical analysis of the digestibility data summarized by Morrison (1936), Mitchell (1942) was unable to indicate that the apparent digestibility of the protein in feeds containing 5 per cent. or more of protein may be predicted with a high degree of accuracy by the equation: $D = 42 \cdot 64(P - 5)^{\cdot 215}$ in which D is the apparent digestibility of the protein and P is the protein content on the dry basis. Such indications emphasize the advisability of further investigations on the relationship between the chemical composition of feeds and their digestibility and contents of metabolizable energy. Because of the objections which have been raised against the old routine method of analysis [Crampton and Maynard (1938) and Louw (1941)] it is , however, felt that use should be made of methods which will deal with " nutrients, or classes of nutrients, better characterized and more accurately determinable chemically (for instance, lignin, cellulose, fatty acids, etc.) than those involved in the old routine method of analysis ".

The available information bearing on the subject seems to indicate that an increase in the plane of nutrition is associated with a depression of digestibility and metabolizability of nutrients in the case of mixed rations, whereas no such influence appears to operate with all-roughage rations. Further studies along these lines are, however, deemed advisable.

In the first study of the series the value, in terms of dry matter and metabolizable energy, of a grass hay cut at the flowering stage of growth for the maintenance of sheep during winter has been estimated. The present paper deals with the nutritive value of the most widely used farm crop, namely, lucerne hay. Factors associated with its production and utilization in this country have been dealt with by Turpin *et al.* (1936).

Experimental Details.

Five full-grown Merino wethers weighing from 90 to 100 pounds were used as experimental animals. The experiment consisted of three periods. The digestibility and metabolizable energy of lucerne hay were determined with each sheep at the following levels of intake, corresponding to the three periods of the experiment: I. 600 grams per day, II. 800 grams per day, and III. 1,000 grams per day. Each trial consisted of an 8- or 10-day preliminary period during which the sheep received the exact ration which they were to receive later during the collection period, and a period of 10 days in metabolism crates of the Forbes type during which the collections of faeces and urine were made.

Prior to each trial a sufficient bulk of feed for the entire period was prepared by cutting lucerne hay into approximately 3-inch lengths, spreading it out on a clean floor, and mixing it thoroughly. Three samples, each of about 300 grams, were taken from different parts of the heap of hay for dry matter determinations and chemical analysis. At the same time the daily rations for the whole feeding period were weighed out into paper bags.

The lucerne hay was taken from supplies purchased from time to time for the feeding of the animals at this Institute. Conditions with regard to supply and demand prevailing at the time the trials were conducted did not permit of setting aside, from the same consignment, a sufficient amount of lucerne hay for all three trials of the experiment. This circumstance was responsible for the fact that hays differing in chemical composition were used in the several trials (c.f. Table 1).

Collections of excreta were made daily in the morning. The faeces were spread out in enamel trays and left to dry in the sun and later in the metabolism room for 24 hours, after which they were found to contain not more than about 10 per cent. moisture. They were then taken to the laboratory where an aliquot equal to one-tenth of the total weight of faeces was weighed out and stored in a suitable container. The aliquots for the whole collection period were composited, weighed, a representative sample taken for a dry matter determination, the remainder ground to a fine state of division, and a sample of this taken for the chemical analysis.

In connection with the collection of faeces it will be noted that no preservative was used. It has been our experience that if sheep faeces, which were invariably found to be a mixture of moist and partly dry material at collection time (in the Forbes type of crate), were spread out

in a thin layer in the sun to dry, their moisture content was 10-12 per cent. by 3 p.m., a moisture content at which decomposition presumably ceases. On cloudy or rainy days the faeces were dried in an air-oven at 60° F.

The urine was collected in bottles containing hydrochloric acid as a preservative. The daily collections were aliquoted and the aliquots composited for the period.

The sheep were fed twice daily; in the morning, immediately after the collections were made and in the afternoon. A little salt, about 5 grams, was scattered over the feed offered in the morning.

In addition to the usual routine determinations for ash, crude protein, and ether extract, the cellulose and lignin contents of the feeds and faeces were determined by the methods of Norman and Jenkins (1933) and Norman and Jenkins (1934), respectively. The gross energy in all samples of feeds, faeces, and urine was determined by the bomb calorimeter. In making the energy determinations on urine 10 c.c. portions were evaporated to dryness at room temperature on Whatman No. 40 (15 cm.) filter circles and ignited with the circles.

Experimental Results.

(a) *Chemical Composition of Lucerne Hay.*

A considerable amount of data are obtained in an investigation of this nature, but for the sake of economy of space, a necessity under war conditions, some of it will be omitted or given only in summarized form. The average percentage composition and gross energy content of the dry matter of the lucerne hay in periods I, II and III respectively, are given in Table 1. The presentation of the results on the composition of the feeds on the basis of the dry matter is considered preferable, for purposes of comparison, to the customary method of expressing such results on the air-dry basis, because of the variations in moisture content of the feeds with variations in climatic conditions.

Table 1.

Average Percentage Composition and Gross Energy Content of the Dry Matter of Feeds Consumed.

Period.	Crude Protein.	Ether Extract.	Ash.	Cellulose.	Lignin.	Other Carbohydrates.	Gross Energy per Kg. (Therms)
I.....	14·9	2·47	9·39	32·0	15·6	25·64	4·349
II.....	18·4	2·55	9·26	27·3	12·4	30·09	4·398
III.....	15·0	2·77	8·22	30·1	16·4	27·51	4·517

"Other carbohydrates" in Table 1 signifies that fraction which has not been determined, and include simple sugars, pectic substances and hemicelluloses.

Inspection of the values given in Table 1 reveals certain differences in the composition of the hays consumed in the respective periods of the experiment. This is unfortunate for the reason that an important issue in the

experiment, namely, the influence of the level of intake on digestibility may be somewhat obscured by a difference in composition which is known to influence digestibility. However, as stated previously, it was not possible to use the same lucerne hay in all three periods.

The outstanding difference in the composition of the three hays is the higher protein and " other carbohydrates " contents and the lower lignin and cellulose contents of the hay fed in period II as compared with those of the hays fed in periods I and III, respectively.

(b) Digestibility of Lucerne Hay.

The digestion coefficients of the nutrients consumed in each period were calculated in the usual manner and these are tabulated for each sheep and averaged for each period in Table 2. As pointed out by Mitchell (loc. cit).

TABLE 2.

Summary of Digestion Coefficients.

Sheep No.	Dry Matter.	Crude Protein.	Cellulose.	Lignin.	Ether Extract.	Other Carbohydrates.
PERIOD I—LUCERNE HAY, 600 GRAMS.						
1	57·3	76·4	52·3	25·6	17·6	82·4
2	59·4	75·8	55·0	25·8	19·8	87·1
3	58·3	77·3	52·1	16·9	21·4	87·3
4	57·3	76·1	51·9	25·1	19·1	81·4
5	58·8	76·7	52·2	28·4	21·4	84·6
Average	*58·2*	*76·5*	*52·7*	*24·4*	*19·9*	*84·6*
PERIOD II—LUCERNE HAY, 800 GRAMS.						
1	64·9	80·4	54·9	24·6	32·2	87·2
2	66·2	80·7	55·6	27·2	27·2	89·2
3	67·8	81·7	56·4	24·6	36·1	93·6
4	67·7	80·3	57·6	18·9	35·6	94·3
5	66·6	81·0	57·8	27·7	40·0	86·5
Average	*66·6*	*80·8*	*56·5*	*24·6*	*34·2*	*90·2*
PERIOD III—LUCERNE HAY, 1000 GRAMS.						
1	59·7	77·8	52·0	38·1	30·8	81·4
2	59·1	76·5	51·2	37·4	31·1	82·6
3	59·4	77·5	49·1	38·3	31·1	84·5
4	59·2	76·7	50·0	33·2	34·5	85·1
5	59·8	76·8	52·0	30·9	31·7	87·0
Average	*59·4*	*77·1*	*50·9*	*35·6*	*31·8*	*84·1*

the apparent digestibility of ether extract is of little significance for rations containing large amounts of roughage. The reasons for this are that the determination itself includes a large proportion of substances having no relation to the fats and that for rations low in ether extract the metabolic

products of the faeces may account for the greater part of the ether-soluble material. Coefficients of digestibility for this constituent have, nevertheless, been included in the table to complete the data required for the calculation of the total digestible nutrients of the feeds.

As may be seen by reference to Table 2 the variations among individual coefficients are, in general, small, especially for those constituents present in the ration in considerable amount. In order to test the significance of the differences among the average coefficients of digestibility for the various constituents of the hays consumed in periods I to III the relevant data have been subjected to a statistical analysis. The analysis of variance, which has been employed, revealed that the following differences between means are required for significance at P = ·05 and P = ·01 respectively: 1·22 and 1·72 for dry matter, 0·78 and 1·09 for crude protein, 1·76 and 2·47 for cellulose, 3·97 and 5·57 for "other carbohydrates", 5·18 and 7·26 for lignin, and, finally, 4·21 and 5·90 for ether extract. If these tests are now applied to the averages given in Table 2 it will be found that the dry matter, crude protein, cellulose, and "other carbohydrates" were digested more efficiently in the lucerne hay consumed in period II than in the hay consumed in either period I or period III, the differences in favour of period II being highly significant. In general there is no significant difference in the digestibility of the lucerne hays consumed in periods I and III, respectively. With regard to these two hays attention should, however, be drawn to the following features in their digestibility: the difference between the average coefficients for dry matter only just fails the test for significance in favour of the hay consumed in period III; cellulose has, on the contrary, been digested significantly better in period I than in period III, while the differences in favour of the coefficients for both lignin and ether extract in period III were found to be highly significant.

Owing to the differences in chemical composition (see Table 1) which, as stated previously, may be expected to influence digestibility it is not possible to draw satisfactory conclusions with regard to the influence of the plane of intake on the digestibility of lucerne hay. The small differences in digestibility, associated at the same time with small differences in chemical composition, obtained for the lucerne hays fed in periods I and III, the lowest and highest planes of intake, respectively, suggest, however, that the plane of nutrition did not affect the digestibility of the feeds. According to Watson *et al* (1935) the results of earlier investigations seem to indicate that the plane of nutrition has no very marked effect upon the digestibility of dried roughages. Using steers averaging 985 lb. in weight as experimental animals Watson and his co-workers found that for the range of 4·5 to 9·0 Kilograms of a mxed hay per day the plane of nutriton did not significantly affect the coefficients of digestibility. They did, however, find that at a level of feeding amounting to only 2·5 Kilograms per animal per day the coefficients of digestibility were slightly lower than at the other levels, an effect which they suggested was due to the low state of nutrition to which the animals were thus subjected. A similar influence may have been operating in period I of the present investigation and been responsible for the slightly lower digestibility of the dry matter in this period as compared with that of the dry matter in period III when a lucerne hay of very similar composition to that used in period I was fed. That the sheep were on a sub-maintenance ration during period I is indicated by the fact that they lost weight (unpublished data) during this

period, an observation which is substantiated by the circumstance, to be dealt with further on in this paper, that they ingested less metabolizable energy than is required for maintenance.

The possibility that the low state of nutrition was responsible for the somewhat lower coefficients of digestibility obtained in period I cannot, however, prejudice the conclusion that the observed differences in digestibility between the lucerne hays fed in periods II and III, respectively, were largely due to differences in their chemical composition.

Before concluding the discussion on digestibility it may be of interest to refer to the relative digestibilities of certain constituents in a grass hay, as previously determined [Louw (1941)], and lucerne hay. The hemicelluloses of the lucerne hay are, as stated earlier, included in the " other carbohydrates " fraction. It has been found (unpublished data) that its water-soluble fraction has practically the same digestibility as the " other carbohydrates " as a whole. From this it may be inferred that the digestibility of the hemicelluloses in the lucerne hays tested was very much the same as that found for the " other carbohydrates " fraction. In an earlier study Louw (1941) found that the coefficients of digestibility for cellulose, the hemicelluloses, and lignin were 68·2, 50·1 and 16·1, respectively, for a grass hay cut at the flowering stage of growth and containing 8·8 per cent protein and 10·0 per cent. lignin. Judged by its chemical composition (c.f. Table 1) the lucerne hay used in period II of this investigation was cut at approximately the 10-50 per cent.-bloom stage. The digestion coefficients for its cellulose, hemicelluloses, and lignin were, on the other hand, found to be 56·5, about 90, and 24·6, respectively. Unlike those present in a grass hay the hemicelluloses in a lucerne hay are thus seen to be highly digestible whereas the position is reversed with regard to the cellulose in the two types of feeds, that in the grass hay being appreciably more digestible than the cellulose in the lucerne hay. In view of the suggestion put forward [c.f. Louw (1941)], namely, that a close association exists in the cell walls of grasses between the hemicelluloses and the comparatively indigestible lignin, it is an attractive supposition that in the case of the lucerne plant the lignin is associated with the cellulose rather than with the hemicelluloses with the result that the former is rendered less digestible than the latter.

From the average coefficients of digestibility for the three rations and their average chemical composition, the average content in total digestible nutrients was computed in the usual manner, the results being given in Table 3. " Carbohydrates " in this table is the sum of the cellulose, lignin and " other carbohydrates " of Table 1.

The total digestible nutrient content of the hay fed in period II is higher than that of the hay fed in both periods I and III, while the hay fed in period III is somewhat superior in this respect to the hay of period I. It may be calculated, using the relevant data in tables 1 and 2, that the higher total digestible nutrient content of the hay fed in period III as compared with that of the hay of period I is largely due to its higher content of digestible lignin, a constituent of unknown nutritive value.

(c) Metabolizable Energy of Lucerne Hay.

The metabolizable energy of the lucerne hay fed in periods I, II, and III, respectively, was calculated in the usual manner, namely, by subtracting from the gross energy of the feed consumed the gross energy of the solid,

liquid, and gaseous excreta. In the absence of a suitable equation for the prediction of the methane production of sheep Armsby's (1917) factor of 4·5 grams methane for each 100 grams of digestible carbohydrates, has been utilized, a gram of methane having a calorific value of 13·34 Calories. The energy contained in the urine has been corrected to nitrogen equilibrium, 7·45 Calories being subtracted from the urinary energy for each gram of urinary nitrogen derived from the catabolism of body proteins (equal to negative nitrogen balance) and 7·45 Calories being added to the urinary energy for each gram of nitrogen stored in the body (equal to the positive nitrogen balance).

TABLE 3.

Average Percentage Composition of the Dry Matter of the Three Lucerne Hays.

	Organic Matter.	Crude Protein.	Carbohydrates.	Crude Fat.	Total Digestible Nutrients.
PERIOD I.					
Total	90·61	14·90	73·24	2·47	—
Digestible	54·18	11·40	42·33	0·49	54·83
PERIOD II.					
Total	90·74	18·40	69·79	2·55	—
Digestible	61·34	14·87	45·64	0·87	62·47
PERIOD III.					
Total	91·78	15·00	74·01	2·77	—
Digestible	56·72	11·57	44·41	0·88	57·96

The data relating to the metabolizable energy of each lucerne hay fed during the three periods are tabulated in Table 4. The metabolizable energy is expressed in therms per Kilogram of dry matter and, as an average only, per Kilogram of total digestible nutrients.

The differences in digestibility of the three hays, discussed in the preceding sections, are reflected, as may be expected, in their metabolizable energy contents. The availability, as metabolizable energy, of the gross energy of the feeds is 50·8 per cent., 46·7 per cent., and 43·2 per cent. for the hay fed in periods II, III, and I, respectively. The lowest figure, that obtained in period I, is practically the same as that (43·1) found for lucerne hay by Armsby in experiments on steers or that (42·9) obtained by Mitchell *et al* (1926) for the same type of feed with sheep. That the availability of the gross energy of lucerne hay is, however, not a constant may be indicated by quoting further examples from the literature on the subject. Thus, in experiments with steers, Christensen (1938) obtained a value of 44·8 per cent., whilst Hamilton *et al* (1928), experimenting with sheep, recorded a

value of 54·3 per cent. The percentages obtained for the lucerne hays fed in periods II and III of the present investigation fall within this range of values.

The metabolizable energy content, expressed in therms per Kilogram dry matter varies more or less in a manner similar to that indicated for the percentage availability of the gross energy of the lucerne hays, the highest figure, 2·234 therms, having been obtained for the hay fed in period II, and the lowest, 1·879 therms, for the hay fed in period I. In the last column of Table 4 the metabolizable energy contents of the experimental feeds have been related to their total digestible nutrient content, in the calculation of which allowance is made for the superior energy content of fat. The differences in the metabolizable energy values of different feeds become much less when expressed in this manner, a fact which is revealed by a glance at the relevant data in Table 4.

TABLE 4.

The Metabolizable Energy of the Lucerne Hays.

Sheep No.	Dry Matter Consumed. (Kg.).	Energy of Feed Consumed. (Therms)	Energy of Faeces. (Therms)	Energy of Urine. (Therms)	Energy of Methane. (Therms)	Total Metabolizable Energy. (Therms)	Metabolizable Energy as per cent. of Gross Energy.	Metabolizable Energy (Therms).	
								Per Kg. Dry Matter.	Per Kg. Total Digestible Nutrients.
Period I.									
1	·531	2·309	1·026	·175	·133	·975	42·3	1·836	—
2	·531	2·309	·972	·177	·140	1·020	44·2	1·922	—
3	·531	2·309	1·003	·180	·133	·993	43·0	1·870	—
4	·531	2·309	1·011	·175	·132	·991	42·9	1·867	—
5	·531	2·309	·986	·179	·136	1·008	43·7	1·900	—
Mean	—	—	—	—	—	—	*43·2*	*1·879*	*3·427*
Period II.									
1	·706	3·103	1·157	·229	·188	1·529	49·3	2·166	—
2	·706	3·103	1·109	·239	·193	1·562	50·4	2·211	—
3	·706	3·103	1·062	·241	·198	1·602	51·6	2·270	—
4	·706	3·103	1·053	·244	·197	1·609	51·8	2·280	—
5	·706	3·103	1·088	·239	·192	1·584	51·0	2·243	—
Mean	—	—	—	—	—	—	*50·8*	*2·234*	*3·576*
Period III.									
1	·903	4·078	1·647	·272	·240	1·919	47·1	2·125	—
2	·895	4·044	1·651	·275	·238	1·880	46·5	2·100	—
3	·895	4·042	1·642	·277	·238	1·885	46·6	2·107	—
4	·900	4·067	1·663	·278	·237	1·889	46·5	2·098	—
5	·898	4·056	1·634	·274	·241	1·907	47·0	2·123	—
Mean	—	—	—	—	—	—	*46·7*	*2·111*	*3·642*

(*d*) *Lucerne Hay as a Maintenance Ration for Sheep.*

Mitchell *et al* (loc. cit) computed the average maintenance requirement of sheep from the results of an experiment in which the ration consisted of lucerne hay alone and which included a slaughter test. They found the daily requirements per 100 pounds live weight to be 1,733 Calories of metabolizable energy, computel by the surface ratio. The average metabolizable energy content of the lucerne hays consumed in periods II and III of the present study was found to be 2,172 Calories per Kilogram dry matter (see Table 4), or, based on the finding that the hays in question contained on an average 90 per cent. dry matter, 1,955 Calories per Kilogram air-dry material. Using this figure and that quoted above from the experiment of Mitchell and associates it has been calculated that sheep will require daily 1·953 lb. (887 grams) of the type of lucerne hay used in periods II and III for maintenance per 100 lb. liveweight. Louw (loc. cit.) found, on the other hand, that 2·106 lb. of grass hay (*Digitaria* species) cut at the flowering stage of growth and containing 1,622 Calories of metabolizable energy were required for the maintenance of sheep per 100 lb. live weight. It is to be noted that according to these results the same animal function, namely maintenance, requires more of the metabolizable energy of lucerne hay than of that in a grass hay. This finding signifies that the metabolizable energy of the particular grass hay employed is utilized better in the maintenance of sheep than is the metabolizable energy of lucerne hay.

In conclusion mention should be made of the fact that the sheep, averaging at the time just under 100 lb. in live weight, consumed during period I on an average only 998 Calories of metabolizable energy. This figure is considerably less than that stated above as the maintenance requirement for sheep per 100 lb. live weight, a circumstance which, as stated previously, may have influenced the digestibility of the lucerne hay consumed in period I of this study.

Summary.

In an experiment consisting of three periods the digestibility and metabolizable energy content of lucerne hay were determined with each of five mature Merino wethers at the following daily levels of intake, corresponding to the three periods of the experiment: I. 600 grams, II. 800 grams, and III. 1,000 grams.

Whilst the differences in the coefficients of digestibility and metabolizable energy content of the lucerne hay fed in periods I and III, respectively, were, in general, found to be insignificant, the hay fed in period II was digested significantly better and contained significantly more metabolizable energy than the hay fed in either of the other two periods. These variations in digestibility and metabolizable energy content are considered to have been caused chiefly by the observed differences in chemical composition—protein, cellulose, and lignin contents—of the lucerne hays consumed in the several periods.

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