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The Nutritive Value of South African Feeding Stuffs. III.—Digestible Nutrients and Metabolizable Energy Content of a Mixture (1:1) of Lucerne Hay and Yellow Maize at Different Planes of Intake for Sheep.

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Previous publications from this laboratory dealt with the amino acid deficiencies and supplementary relations of the proteins of the two most important cultivated feeding stuffs of this country, maize and lucerne hay [Marais and Smuts, 1939; Marais and Smuts, 1940 (1), 1940 (II)]. A marked supplementary effect among the proteins was observed, a result pointing to the desirability of feeding mixtures of these feeds to farm animals.

Lucerne hay is considered lacking not only in certain amino acids but also in available energy for certain productive purposes. For instance, it is held that a high producing cow is incapable of consuming sufficient of this roughage for meeting its energy requirements; some form of concentrate like maize must be fed in addition. Furthermore, it is generally recognised that the digestible nutrients of an all-roughage ration are not as efficiently utilized for growth or milk production as when it is supplemented with a concentrate. A study of the digestibility, an essential preliminary to a complete nutritive evaluation of any ration, of mixtures of lucerne hay and maize is, therefore, of more than usual interest.

In the second paper of this series it was reported (Louw, 1944) that the plane of intake had no influence on the digestibility of lucerne hay for sheep. This particular aspect of the general problem relating to the factors affecting the digestibility and nutritive value of feeds is continued with the present study on a simple production ration of equal parts by weight of crushed yellow maize and lucerne hay.

Experimental Procedure.

The program embraced a series of three consecutive experiments in which the digestibility and metabolizable energy content of a ration of equal parts by weight of lucerne hay and crushed maize were determined at three different levels of intake. These trials were carried out during August, September and October,

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1943, with five full-grown Merino wethers. Since they happened to have been fed on lucerne hay *ad lib.* for some months prior to the commencement of the trials the sheep were in excellent condition, averaging over 100 lb. in live weight.

In the first trial each animal received an amount of the ration estimated to be sufficient for the maintenance of body weight. This was followed by a period in which the feed of all the sheep was increased by 50 per cent. In a final experiment the maintenance allowance of the first trial was doubled.

The general procedure followed in this work was essentially the same as that previously described (Louw, loc. cit.), and need for that reason not be repeated here. Preliminary periods lasted 13, 11 and 9 days in the case of trials I, II and III, respectively. Faeces and urine were in each case collected for 10 days. The method of Norman and Jenkins (1934) for lignin was retained but their procedure for cellulose was replaced by that of Crampton and Maynard (1938).

The feeds used were taken from supplies purchased on the open market for general feeding purposes on the station.

Some of the data were analysed statistically by Fisher's analysis of variance method.

Results.

Table 1 describes the chemical composition and gross energy content of the dry matter of the feeds consumed. It will be noted that, judged by protein content, the lucerne hay was of an exceptionally good quality, and that no great differences occurred in the composition of the feeds used in the several periods.

TABLE 1.

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

Period.	Feed.	Crude. Protein.	Ether Extract.	Ash.	Cellulose.	Lignin.	* Other Carbohydrates.	Gross Energy per Kg. (Therms)
I........	Lucerne Hay.......	20·2	2·5	9·8	26·1	8·4	33·0	4·372
	Maize.............	11·3	5·5	1·2	2·0	—	80·0	4·540
II........	Lucerne Hay.......	21·4	2·6	9·8	26·4	8·3	31·5	4·434
	Maize.............	11·8	5·4	1·2	2·0	—	79·6	4·546
III.......	Lucerne Hay.......	21·1	2·4	9·8	26·2	8·3	32·2	4·435
	Maize.............	10·5	5·3	1·2	2·0	—	81·0	4·528

* Signifies the fraction not determined and includes sugars, starch, hemicellulose, etc.

The general collection data, composition of the faeces and urine and the nitrogen balances are given by tables A and B in an appendix. Digestion coefficients calculated in the customary manner are summarised in table 2.

TABLE 2.

Summary of Digestion Coefficients.

Sheep No.	Dry Matter.	Crude Protein.	Cellulose.	Lignin.	Ether. Extract.	Other Carbo-drates.
PERIOD I.—MAINTENANCE.						
1............	82·7	84·3	70·8	10·8	70·4	94·6
2............	81·9	83·0	71·2	6·3	72·8	94·0
3............	82·4	82·5	73·2	12·9	70·9	94·0
4............	82·8	83·0	70·4	6·4	73·3	94·7
5............	82·0	83·0	70·0	7·5	70·5	94·5
MEAN.....	82·4	83·2	71·1	8·8	71·6	94·4
PERIOD II.—1½ × MAINTENANCE.						
1............	79·3	78·7	69·8	5·6	68·9	91·8
2............	80·0	80·1	68·0	5·3	68·7	93·5
3............	80·0	80·4	68·6	3·6	68·7	93·3
4............	79·9	80·2	67·5	4·3	68·0	93·5
5............	80·1	79·0	68·2	4·1	69·8	93·5
MEAN.....	79·9	79·7	68·4	4·6	68·8	93·1
PERIOD III.—2 × MAINTENANCE.						
1............	81·2	78·6	71·8	19·7	71·2	92·3
2............	79·1	77·1	69·2	15·3	73·5	89·9
3............	78·0	76·4	67·6	11·2	67·6	89·3
4............	81·5	81·2	68·4	9·4	65·4	93·5
5............	80·4	76·9	70·2	11·6	66·8	92·5
MEAN.....	80·0	78·0	69·4	13·4	68·9	91·5

Digestibility.

The ration of lucerne hay and crushed maize proved a highly digestible mixture for sheep: 82·4 per cent. of the dry matter was on an average digested at the lowest level of intake. Compared with mean digestion co-efficients ranging from 71·1 per cent. for cellulose to 94·4 per cent. for "other carbohydrates" lignin stood out by itself amongst the individual fractions of the dry matter with an average digestibility of only 8·8 per cent. This figure is much lower than that of about 24·5 per cent. reported for the digestibility of the lignin in a ration composed of grass hay alone, and a similar figure for that of one consisting only of lucerne hay, reported in previous publications (Louw, 1941, 1944). It may be estimated, from a knowledge of the general composition of maize and lucerne hay, that at least 80 per cent. of the "other carbohydrates" portion of the ration was composed of starch and sugar. The fact that this fraction was almost completely digested was, threfore, not unexpected. At all events in a ration of maize and lucerne hay "lignin" and "other carbohydrates" represent chemical fractions showing greatest difference in biological utilization, the former proving the least and the latter the most digestible constituent of the ration.

The differences between the mean digestion coefficients of any two periods for the dry matter and some individual fractions of the rations, and their statistical significance, are summarised in table 3.

TABLE 3.

Difference between mean Digestion Coefficients and their Significance.*

Periods Compared.	Dry Matter.	Crude Protein.	Cellulose.	Other Carbohydrates.
I and II	2·5‡	3·5‡	2·7†	1·3*
I and III	2·4‡	5·2§	1·7*	2·9‡
II and III	—0·1*	1·7*	—1·0*	1·6†

*=No Significance. †=Significant at P=·05. ‡=Significant at P=·01. §=Significant at P=·001.

From the data in table 3 it would appear that a small, though significant, decrease occurred in the digestibility of the dry matter offered in periods II and III when compared with that fed in period I. This decrease which was similar in magnitude at the medium and at the high level of nutrition affected the constituents of the dry matter differently. Thus, whilst in the case of protein there was a substantial and progressive drop in apparent digestibility as the plane of nutrition increased, amounting to 5·2 absolute per cent. at the high level, "other carbohydrates" appeared to be less influenced by increased levels of nutrition, the digestibility of this fraction decreasing only from 94·4 per cent. in period I to 91·5 per cent. in period III. It is to be noted, too, that whilst with protein the greatest decrease in digestibility took place at the medium level of intake (period II) the lowering effect seemed in the case of "other carbohydrates" most marked at the high plane of intake (period III). This latter phenomenon may be due not so much to decreased digestibility of the feed than to the possibility that the absorption mechanism of the digestive tract could not cope with the increased supply of digested nutrients.

Cellulose behaved very much like the dry matter: a significant drop in digestibility from 71·1 to 68·4 per cent. coincided with a 50 per cent. increase in the maintenance level but no material change in the efficiency of digestion was in evidence with a further increase in the plane of nutrition. Similar remarks apply to the ether extract fraction of the ration.

The finding, referred to above, that the digestibility of crude protein was depressed more than any other constituent of the production ration, apparently by increased feed consumption, is in agreement with the results of an experiment by Watson *et al* (1936) on the influence of plane of nutrition on the digestibility of a hay barley ration. These workers designed their experiment in a manner allowing of the elimination of a possible seasonal (period) effect on digestibility and found that only the nitrogen of the ration was affected by the plane of nutrition, a depression in digestibility amounting to approximately 6 absolute per cent. being recorded at the highest level of intake. However, the question remains whether the differences in digestibility noted in the present experiment were due to the plane of nutrition or to the period effect referred to above. In other words, are the observed differences to be ascribed to plane of nutrition *per se* or must they be taken as normal variations in the efficiency with which an animal will digest the same feed at different times of the year? A definite answer to this question must await the results of an investigation, now under way at this Institute and designed to throw light on the existence and magnitude of the so-called period effect.

The total and digestible nutrient content of the rations consumed have been calculated in the usual manner from data in Tables 1, 2 and A (Appendix) and presented in table 4.

TABLE 4.

Average Percentage Composition of the Dry Matter of the three Rations.

	Organic Matter.	Crude. Protein.	Carbohydrates.	Crude Fat.	Total Digestable Nutrients.
PERIOD I.—MAINTENANCE.					
Total............	94·50	15·75	74·75	4·00	—
Digestible........	79·57	13·10	63·24	2·86	82·77
PERIOD II.—$1\frac{1}{2} \times$ MAINTENANCE.					
Total............	94·50	16·60	73·90	4·00	—
Digestible........	77·49	13·23	61·49	2·75	80·91
PERIOD III.—$2 \times$ MAINTENANCE.					
Total............	94·50	15·80	74·85	3·85	—
Digestible........	77·02	12·33	62·00	2·65	80·29

" Carbohydrates " in this table is the sum of the cellulose, lignin and " other carbohydrates " of table 1. Attention should be drawn to the finding that whilst the total digestible nutrient contents at the $1\frac{1}{2}\times$ maintenance and the $2\times$ maintenance levels were practically the same that recorded for the maintenance level was found higher by approximately 2 absolute per cent.

Metabolizable energy.

By subtracting from the gross energy of the feed consumed the gross energy of the solid, liquid and gaseous excreta the metabolizable energy content of the rations fed in the three periods of the experiment have been calculated and presented in table 5. The gaseous energy loss was estimated at the rate of 4·5 grams of methane per 100 grams of digestible carbohydrates, the calorific value of this gas being taken at 13·34 Calories per gram. The urinary energy has been corrected to nitrogen equilibrium, 7·45 Calories being subtracted from or added to this energy fraction for each gram of urinary nitrogen lost from (negative N-balance) or stored in (positive N-balance) the body.

TABLE 5.

The Metabolizable energy of the Lucerne Hay-maize Rations.

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.
MAINTENANCE.									
1	0·561	2·497	0·455	0·152	0·213	1·677	67·2	2·990	—
2	0·543	2·418	0·457	0·148	0·205	1·608	66·5	2·961	—
3	0·516	2·299	0·442	0·166	0·192	1·499	65·3	2·906	—
4	0·579	2·576	0·462	0·201	0·222	1·691	65·7	2·923	—
5	0·587	2·616	0·498	0·177	0·223	1·718	65·7	2·925	—
MEAN	—	—	—	—	—	—	66·2	2·941	3·554
$1\frac{1}{2}\times$ MAINTENANCE.									
1	0·855	3·838	0·829	0·223	0·313	2·473	64·4	2·892	—
2	0·819	3·678	0·753	0·236	0·303	2·386	64·8	2·912	—
3	0·784	3·519	0·734	0·214	0·289	2·282	64·8	2·912	—
4	0·873	3·918	0·813	0·254	0·322	2·529	64·5	2·898	—
5	0·891	3·998	0·828	0·249	0·330	2·591	64·8	2·912	—
MEAN	—	—	—	—	—	—	64·7	2·905	3·591
$2\times$ MAINTENANCE.									
1	1·135	5·087	1·010	0·292	0·429	3·356	66·0	2·957	—
2	1·100	4·928	1·064	0·274	0·403	3·187	64·7	2·898	—
3	1·037	4·646	1·076	0·265	0·376	2·929	63·1	2·825	—
4	1·171	5·247	1·022	0·277	0·440	3·508	66·9	2·995	—
5	1·190	5·331	1·109	0·294	0·447	3·481	65·3	2·926	—
MEAN	—	—	—	—	—	—	65·2	2·920	3·588

As may be expected the digestibility of the rations previously discussed were reflected in their metabolizable energy content. This becomes evident from a study of table 5. Of the gross energy of the maintenance ration of maize and lucerne hay 66·2 per cent. was found metabolizable. This means that a kilogram of dry matter contained 2941 Calories of metabolizable energy, a figure which is considerably higher than the 2,748 Calories reported by Forbes *et al* (1928) as the metabolizable energy content, determined in the respiration calorimeter with two steers, of a Kilogram of the dry matter of a similar ration. The higher value obtained in the present investigation is probably largely due to the better quality of lucerne hay used. At the higher levels of nutrition somewhat lower percentages of the gross energy consumed, 64·7 for the medium and 65·2 for the high level, were found metabolizable.

Nitrogen balances.

It could normally be expected that the sheep, being mature animals, would be in nitrogen equilibrium during all the periods of the experiment. Reference to table A in the appendix shows that this expectation was not realised. Substantial negative nitrogen balances were recorded in period I, followed by equally substantial positive balances in period II, whilst still larger amounts of nitrogen were apparently stored in period III. Though improbable, there is the possibility of a deficiency in the energy requirement for maintenance in period I, a circumstance which would cause some tissue breakdown accompanied by increased excretion of nitrogen in the urine. An alternative explanation is, however, suggested by the fact that a limited amount of amino acids and proteins can be stored in the bodies of full-grown animals. Presumably, the magnitude, within limits, of this storage is determined by the level of protein intake. During a period following a sharp decrease in protein intake, as occurred at the commencement of the experiment when the sheep were transferred from an *ad lib.* ration of lucerne hay to the maintenance allowance of period I, a loss of accumulated tissue protein will, therefore, take place until the level of reserve protein corresponding with the new level of protein intake is attained. Apparently then, the preliminary period of 13 days on the maintenance ration was not sufficiently long to permit complete readjustment to the lower deposit protein level before the collection period was started. The result was a negative nitrogen balance. The plus nitrogen balances of periods II and III, on the other hand, could be explained on the basis that when an animal's protein intake is increased positive nitrogen balances will prevail until equilibrium is eventually established at the new higher level, and that this process of adaptation was still in operation for at least part of the collection periods of the second and third trials.

SUMMARY.

Mature Merino sheep were used as experimental subjects in a study of the digestibility of a ration of equal parts by weight of lucerne hay and crushed maize at three levels of nutrition, viz. maintenance, $1\frac{1}{2}\times$ maintenance and $2\times$ maintenance. The data yielded the following conclusions:

(1) The digestibility of the dry matter was significantly decreased by 2·4 absolute per cent. when the maintenance ration was increased by 50 per cent. Doubling the maintenance allowance had no further influence in this respect.

(2) The apparent digestibility of the protein decreased progressively as the plane of nutrition was increased, the decrease over the whole range being 5·2 absolute per cent. This difference was statistically highly significant.

(3) The cellulose fraction behaved somewhat like the dry matter whilst "other carbohydrates" (sugars, starch, and hemicelluloses) showed, with increase in plane of nutrition, a progressive decrease in digestibility amounting to 2·9 absolute per cent. at the highest level of intake. This decrease was highly significant statistically.

(4) The digestibility of the lignin fluctuated from 4·6 per cent. at the $1\frac{1}{2}\times$ maintenance level to 13·4 per cent. at the $2\times$ maintenance level.

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APPENDIX.

TABLE A.

Average Daily Collection Data and Nitrogen Balances.

Sheep.	Live Weight (lb.)		Ration (gm.).		Dry Matter Intake (gm.)			Dry Matter Excreted (Gm.)	* Urine Excreted (Litres).	Nitrogen Intake. (Gm.)	N. Excreted (gm.).			N. Balance.
	Initial.	Final.	Lucerne Hay.	Crushed Maize.	Lucerne Hay.	Crushed Maize.	Total				Faeces.	Urine.	Total.	
Period I.—Maintenance.														
1.	109	108	315	315	288·2	272·5	560·7	97·3	3·30	14·16	2·22	13·20	15·42	—1·26
2.	106	104	305	305	279·1	263·8	542·9	98·5	3·29	13·72	2·35	12·40	14·75	—1·03
3.	96	96	290	290	265·4	250·9	516·2	90·8	3·08	13·04	2·28	11·90	14·18	—1·14
4.	111	110	325	325	297·4	281·1	578·5	99·5	3·30	14·61	2·49	14·55	17·04	—2·43
5.	116	116	330	330	302·0	285·5	587·4	106·2	3·33	14·84	2·52	12·95	15·47	—0·63
Period II.—1½ × Maintenance.														
1.	116	118	480	480	434·0	421·0	8·550	178·1	3·36	22·81	4·86	16·19	21·05	+1·76
2.	113	112	460	460	415·8	403·4	819·2	163·4	3·36	21·85	4·35	16·43	20·78	+1·07
3.	102	102	440	440	397·8	385·9	783·7	156·8	3·18	20·90	4·09	15·32	19·41	+1·49
4.	120	118	490	490	443·0	429·7	872·7	175·2	3·18	23·29	4·61	18·41	23·02	+0·27
5.	122	127	500	500	452·0	438·5	890·5	177·2	3·24	23·76	5·00	17·69	22·69	+1·07
Period III.—2 × Maintenance.														
1.	120	126	630	630	581·0	554·4	1,135·4	213·9	3·45	28·91	6·18	18·69	24·87	+4·04
2.	120	121	610	610	562·9	536·8	1,099·7	230·2	3·64	27·99	6·42	18·82	25·24	+2·75
3.	105	110	580	580	526·6	510·4	1,037·0	228·4	3·42	26·33	6·24	16·31	22·55	+3·78
4.	126	133	650	650	599·2	572·0	1,171·2	216·6	3·52	29·80	5·61	19·82	25·43	+4·37
5.	132	137	660	660	609·2	580·8	1,190·0	233·9	3·66	30·29	6·99	18·74	25·73	+4·56

* Including Washings.

Table B.

Percentage Composition of the Urine and of the Dry Matter of the Faeces.

Sheep No.	Crude Protein.	Ether Extract.	Ash.	Cellulose.	Lignin.	Other Carbohydrates.	Energy (Cal.).	Urine (per 100 c.c.) Nitrogen (gm.).	Urine (per 100 c.c.) Energy (Cal.).
Period I.									
1	14·2	6·7	15·4	24·2	22·2	17·3	467·8	0·40	4·59
2	14·9	5·9	15·3	23·3	22·3	18·3	463·5	0·38	4·51
3	15·7	6·5	15·5	21·9	21·4	19·0	486·4	0·39	5·38
4	15·7	6·1	16·3	24·7	23·5	13·7	464·5	0·44	6·09
5	14·9	6·4	15·9	23·8	22·1	16·9	468·9	0·39	5·33
Period II.									
1	17·1	5·9	15·3	20·9	19·1	21·7	465·5	0·48	6·26
2	16·6	6·2	16·3	23·1	20·0	17·8	460·8	0·49	6·80
3	16·3	6·2	16·0	22·6	20·3	18·6	468·2	0·48	6·37
4	16·5	6·3	16·0	23·3	20·1	17·8	463·9	0·58	7·93
5	17·6	6·0	15·4	22·9	20·3	17·8	467·2	0·55	7·43
Period III.									
1	18·1	5·8	13·4	21·5	18·1	23·1	472·5	0·54	7·58
2	17·4	4·8	12·2	21·2	17·2	27·2	462·4	0·52	6·99
3	17·0	5·6	12·0	21·0	17·0	27·4	471·4	0·48	6·91
4	16·2	5·5	13·1	24·6	20·8	19·8	471·9	0·56	6·93
5	18·7	6·7	13·0	21·7	19·1	21·1	473·9	0·51	7·10