Factors Affecting the Utilization of Food by Dairy Cows

7. The Effect of Limited Water Intake on the Digestibility and Rate of Passage of Hay

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Data collected in earlier experiments (Balch, 1950; Balch & Johnson, 1950) had suggested that increasing proportions of water in the contents of the reticulo-rumen increased the rate of breakdown of foods. On many farms cows do not have constant access to water and may sometimes be allowed less than their optimum requirements. Woodward & McNulty (1931) found that cows watered only once daily drank 11·8% less than when they could drink at will and 13·3% less than when watered twice daily.

The main experiment reported in this paper was conducted to find out whether a restricted intake of water affected the digestibility of hay. A similar experiment was conducted by Larsen, Hungerford & Bailey (1917), who found an increased digestibility of foods by cows receiving limited amounts of water.

Any effect that a limited water intake may have on the digestibility of food is likely to be due to changes in either the rate of breakdown of food in the reticulo-rumen or the length of time the food remains there. Accordingly, in the main experiment described below, the rate of passage of hay through the cows was measured during digestibility trials, and, at a later date, the effect of a limited water intake on conditions in the reticulo-rumen was determined in a cow with a rumen fistula.

METHODS

Arrangement of digestibility trial

The main experiment was conducted on six dry Dairy Shorthorn cows from the herd of this Institute. Throughout the experiment each cow received daily 8·2 kg good-quality hay consisting mainly of lucerne with small amounts of grasses. The cows had access to mineral licks. The animals were treated identically except that in treatment 1 they received water *ad lib.*, whereas in treatment 2 their water intake was restricted.

The experiment was divided into three parts each of 24 days. Each part consisted of a preliminary period of 14 days and a period for the collection of faeces lasting 10 days. The cows were paired according to the digestibility of dry matter in the first part of the experiment, when all cows received water *ad lib.*, the pairs being: cows A

and F, C and B, E and D. The order in which cows from each pair received the treatments, determined at random, was:

Part of experiment	Treatment 1 (water *ad lib.*)	Treatment 2 (restricted water)
1	All cows	—
2	Cows A, C and E	Cows B, D and F
3	Cows B, D and F	Cows A, C and E

When receiving treatment 1 the cows had constant access to water from a cowshed drinking bowl. Each bowl was supplied with water from a small tank filled daily, the amount drunk by the cows being shown by graduated glass indicator-tubes on the side of the tanks. When receiving treatment 2 the cows were allowed only 60% of their mean daily water intake during part 1. This amount was placed in the tanks at 12.00 noon each day and the cows drank it immediately.

Faeces and urine were collected quantitatively with the equipment described by Balch, Bartlett & Johnson (1951), the faeces in bags and the urine in tanks below floor level. The bags were changed every 6 h throughout the collection periods, except on the 1st day (see below). The bags were immediately weighed, and the bulk of their contents was shaken out into metal bins with lids. At the end of each day the accumulation in the bins was thoroughly mixed and sampled, sub-samples for drying being taken in proportion to the weight of faeces voided.

The hay was sampled daily and the samples were dried at 90° and retained for analysis. Analyses were carried out on milled, air-dry samples by the standard methods of feeding-stuffs analysis (Balch, 1950). Energy determinations were made by combustion in a Berthelot-Mahler bomb calorimeter. Urine was collected for the last 8 days of the collection periods and sampled daily in proportion to the weight produced. These daily samples were stored in large jars, kept at 0°, and after thorough mixing subsamples were taken at the end of the period for nitrogen determination. Apparent digestibility coefficients and nitrogen balances were calculated.

Values for the starch equivalent of the hay were calculated according to the method of Kellner (1907) by summing the products of the digestible crude protein $\times 0{\cdot}94$, the digestible ether extract $\times 1{\cdot}91$ and the digestible crude fibre plus the digestible nitrogen-free extract $\times 1{\cdot}0$ and subtracting $0{\cdot}58 \times$ the percentage of crude fibre in the hay. The correction suggested by Wood (1927), consisting of an increase of 20%, was then made.

The rate of passage of hay was determined once in each period. A mixture of 250 g each of red and green stained hay was given at one meal on the 1st day of the collection period, and the numbers of stained particles in samples of faeces subsequently voided were determined, as described by Balch (1950).

Arrangement of experiment with fistulated cow

An experiment lasting 7 weeks was conducted with Winsome 22, a fistulated cow, which had previously been fed for several months on hay similar to that used in the digestibility trial. During the experiment the cow received a daily ration of 7·3 kg of this hay.

The experiment was divided into three parts, the first and third of which were control periods of 2 weeks and 1 week, respectively. Part 2 was an experimental period of 4 weeks during which the first 3 and last 2 days were devoted to gradual changes to and from an intake of 70% of the amount of water drunk in part 1. As the weather was becoming warmer during the experiment it was considered that a reduction to 70% would be comparable with the reduction during the main experiment.

On 5 days in each week except the 3rd, the contents of the reticulum and of the dorsal and ventral sacs of the rumen were sampled at noon, for the determination of dry matter. At the same time on two of these days the entire contents of the reticulo-rumen were removed into stainless steel pails, weighed, sampled for dry matter and returned, all within 30 min. The dry-matter content of all samples was determined by drying at 90°.

The daily maximum and minimum temperatures in the cowshed were recorded throughout the experiment, as also were the amounts of hay left uneaten. The dry-matter content of faeces was determined on small numbers of samples taken at irregular intervals.

During weeks 2, 5 and 7 the rate of breakdown of the cellulose of cotton threads suspended in various parts of the rumen was determined. Coils were made of 3 m of cotton thread and groups of three coils were suspended in the dorsal or ventral sacs of the rumen for 24 h. Replicate determinations were carried out on 5 days in each week. The method of tying the coils and of washing, drying and weighing them was as previously described (Balch & Johnson, 1950), except that in this instance the group of coils in the ventral sac was anchored to a brass weight but not attached to the cannula closing the fistula.

RESULTS

Behaviour of the cows in the digestibility trial

Daily measurements of heart rate and of rectal temperature showed that the health of the cows was not affected by the restriction of water. When changed to treatment 2 the cows soon became accustomed to the daily routine and, apart from some lowing as watering time approached, showed no signs of distress. With the exception of cow F, the heaviest cow of the group, all the cows refused to eat part of their hay when receiving restricted amounts of water. Details of the weights of the cows are given in Table 1. All the cows lost weight when receiving restricted amounts of water, the mean loss being 38 kg with a range, between cows, of 21–58 kg. The three cows that received treatment 1 after treatment 2 regained their original weight during the experimental period.

Values for the intake and excretion of food and water are given in Table 2. Complete water balances could not be calculated, as losses due to transpiration were not measured, but a partial water balance, based on intake of water in hay and by drinking and losses in faeces and urine, has been calculated for each cow in each part of the experiment. There was a marked fall in the amounts of water consumed by cows A, C and E, and the water balances of these cows fell by over 50% in part 2, as com-

pared with part 1 of the experiment, although they received unrestricted water in both periods; this effect may be related to the change in cowshed temperature, for which mean maximum values fell from 72° F in part 1 to 65° F in part 2. Cow F, which had the smallest water balance in part 1, was in negative balance in part 2 when she received restricted water and in part 3 when she drank very large amounts of water, suggesting that the water relationships of this cow were somewhat abnormal.

The effect of a restricted water intake on the digestibility of hay

Values for the composition of the hay fed in the three parts of the digestibility trial are given in Table 3. Apart from a slight fall in the content of crude protein during the last two parts, the composition was very constant.

Table 1. *Weights of the cows before and after periods of restricted and unrestricted water intake* (*kg*)

	Stage of experiment			
Cow	Beginning	End of part 1	End of part 2	End of part 3
A	587	607	606	569*
C	628	631	630	595*
E	623	645	650	592*
Mean	613	628	629	585*
B	690	690	653*	692
D	536	542	505*	532
F	705	715	694*	712
Mean	644	649	617*	645

* Period in which water intake was restricted.

Digestibility coefficients obtained in the three parts of the experiment are given in Table 4. There were no consistent changes in the values for crude protein, ether-extractable substances or nitrogen-free extract between periods of unrestricted and restricted water intake. However, during periods of restricted water intake there was a small rise in the digestibility of the total dry matter due to an increase in the digestibility of crude fibre. The mean digestibility of crude fibre by cows A, C and E was 4·7 percentage units higher in part 2 than in part 1, although the cows received unrestricted amounts of water in both parts. The mean digestibility of crude fibre by cows receiving unrestricted water was 59·0% (cows A, C and E) and 58·0% (cows B, D and F) in parts 2 and 3 respectively, while values for the groups receiving restricted water at the same time were 60·9% (cows B, D and F) and 60·8% (cows A, C and E), a mean increase of 2·4 percentage units.

The digestibility of the total energy of the hay was slightly higher during periods of restricted water intake.

The effect of a restricted water intake on the nutritive value of hay

Information about the nutritive value of the hay is summarized in Table 5. As a result of the slightly raised digestibility of the crude fibre, the starch equivalent of the hay, calculated from the digestible nutrients, rose during periods of restricted

Table 2. *Intake of food and water and excretion of faeces and urine by six cows receiving unrestricted or restricted amounts of water*

Part of experiment	Cow	Treatment no.	Intake: Hay (kg/10 days)	Intake: Dry matter (kg/10 days)	Intake: Water drunk (kg/10 days)	Excretion: Faeces: Total (kg/10 days)	Excretion: Faeces: Dry matter (kg/10 days)	Excretion: Urine (kg/10 days)	Dry-matter content (%): Total intake	Dry-matter content (%): Faeces	Partial water balance (kg/10 days)
1	A	1 (unrestricted	81·6	69·9	340·7	173·5	29·8	110·7	16·6	17·2	+ 98·0
	C	water)	81·6	69·9	291·2	150·2	28·0	125·2	18·8	18·6	+ 55·5
	E		81·6	69·9	322·1	184·2	29·3	131·5	17·3	15·9	+ 47·4
		Mean	81·6	69·9	318·0	169·3	29·0	122·5	17·5	17·1	+ 67·0
2	A	1 (unrestricted	81·6	69·0	303·4	181·4	28·7	122·9	17·9	15·8	+ 40·4
	C	water)	81·6	69·0	264·9	153·0	28·0	123·4	19·9	18·3	+ 29·1
	E		81·6	69·0	309·8	190·7	28·4	137·0	17·6	14·9	+ 23·1
		Mean	81·6	69·0	292·7	175·0	28·4	127·8	18·4	16·2	+ 30·9
3	A	2 (restricted	78·6	66·0	204·6	115·8	24·8	96·6	23·3	21·4	+ 29·6
	C	water)	74·6	62·6	174·6	104·1	24·3	77·1	25·1	23·3	+ 29·7
	E		78·8	66·1	193·2	128·8	26·3	95·7	24·3	20·4	+ 7·7
		Mean	77·3	64·9	190·8	116·2	25·1	89·8	24·2	21·6	+ 22·3
1	B	1 (unrestricted	81·6	69·9	295·3	159·9	27·9	106·1	18·5	17·4	+ 68·9
	D	water)	81·6	69·9	335·7	168·1	29·1	113·9	16·8	17·3	+ 94·5
	F		81·6	69·9	337·9	196·3	30·3	155·1	16·7	15·4	+ 28·5
		Mean	81·6	69·9	323·0	174·8	29·1	125·0	17·3	16·6	+ 64·0
2	B	2 (restricted	69·9	59·1	177·4	110·3	23·5	68·5	23·9	21·3	+ 32·9
	D	water)	76·5	64·7	201·4	111·8	23·6	94·3	23·3	21·1	+ 30·7
	F		81·6	69·0	202·8	161·7	28·3	109·8	24·3	17·5	− 27·8
		Mean	76·0	64·3	193·9	127·9	25·1	90·9	23·8	19·6	+ 11·9
3	B	1 (unrestricted	81·6	68·5	318·4	174·2	27·1	77·1	17·1	15·6	+107·3
	D	water)	81·6	68·5	308·9	156·5	27·3	126·1	17·5	17·4	+ 66·7
	F		81·6	68·5	440·4	182·8	28·5	303·5	13·1	15·6	− 4·3
		Mean	81·6	68·5	355·9	171·2	27·6	168·9	15·6	16·1	+ 56·6

The partial water balance represents the difference between intake and the total of faecal and urinary excretion.

water intake. This increase was compensated by a fall in appetite, so that the mean daily intake of starch equivalent was 2·6–2·7 kg in all the periods. It is interesting to note that although this is below the accepted standard energy requirements for maintenance, e.g. those given by Woodman (1948), the cows did not lose flesh during

Table 3. *Percentage composition of the hay used in the digestibility trial*

Part of experiment	Dry matter	Crude protein	Ether extract	Nitrogen-free extract	Crude fibre	Ash	Total energy (Cal./g dry matter)
1	85·8	12·5	1·7	31·7	32·0	7·8	4·40
2	84·6	11·8	1·4	30·8	32·7	7·9	4·46
3	83·9	10·8	1·4	31·4	32·5	7·7	4·36
Mean	84·8	11·7	1·5	31·3	32·4	7·8	4·41

Table 4. *Digestibility of lucerne hay in six cows receiving unrestricted or restricted amounts of water*

Part of experiment	Cow	Treatment no.	Digestibility coefficient (%)					
			Dry matter	Crude protein	Ether extract	Nitrogen-free extract	Crude fibre	Total energy
1	A	1 (unrestricted	57·5	68·5	26·8	59·9	55·0	54·5
	C	water)	60·0	73·4	36·1	63·8	53·5	57·1
	E		58·2	70·5	29·4	60·9	54·3	54·7
		Mean	58·6	70·8	30·8	61·5	54·3	55·4
2	A	1 (unrestricted	58·5	67·6	17·4	58·2	60·2	56·0
	C	water)	59·5	71·0	24·7	59·9	58·4	58·3
	E		58·9	70·5	26·6	59·0	58·4	57·0
		Mean	59·0	69·7	22·9	59·0	59·0	57·1
3	A	2 (restricted	62·4	68·1	34·6	64·4	62·4	59·3
	C	water)	61·2	69·4	27·1	63·6	60·8	58·1
	E		60·2	68·4	35·3	63·1	59·1	56·9
		Mean	61·3	68·6	32·3	63·7	60·8	58·1
1	B	1 (unrestricted	60·1	70·2	31·3	62·4	57·8	58·0
	D	water)	58·4	69·6	29·7	61·3	54·6	55·2
	F		56·7	69·3	25·5	60·3	52·7	54·1
		Mean	58·4	69·7	28·8	61·3	55·0	55·8
2	B	2 (restricted	60·3	68·7	18·9	60·1	62·0	59·7
	D	water)	63·5	72·8	31·0	64·6	62·8	62·3
	F		59·0	70·3	28·6	59·3	57·8	56·4
		Mean	60·9	70·6	26·2	61·3	60·9	59·5
3	B	1 (unrestricted	60·5	68·8	32·9	63·5	59·1	59·3
	D	water)	60·2	68·1	29·3	62·7	59·2	59·2
	F		58·3	67·4	25·2	62·0	55·6	55·2
		Mean	59·7	68·1	29·1	62·7	58·0	57·9

the experiment, the loss in weight during treatment 2 being largely due to emptying of the digestive tract. However, as the experiment advanced, the cows, with the notable exception of cow B, were in increasingly negative nitrogen balance. This trend may have been due to the lower nitrogen content of the hay fed in the two later periods.

The effect of a restricted water intake on the rate of passage of hay

Curves were plotted showing the cumulative excretion in the faeces of undigested residues of stained hay. These curves had the typical sigmoid shape observed in earlier experiments (Balch, 1950). The time required for the excretion of 5% of the total undigested residues (called '5% excretion time') gives an index of the rate of passage of food through the omasum, the abomasum and the intestines, and the difference

Table 5. *The nutritive value of lucerne hay for six cows receiving unrestricted or restricted amounts of water*

Part of experiment	Cow	Treatment no.	Mean daily intake of hay (kg)	Starch equivalent of hay	Mean daily intake of starch equivalent (kg)	Mean daily intake of apparent digestible energy (Cal. × 10^3)	Nitrogen balance (g/day)
1	A	1 (unrestricted)	8·2	32·4	2·6	16·7	+ 2·3
	C	water)	8·2	34·3	2·8	17·5	+ 5·9
	E		8·2	32·8	2·7	16·8	− 0·4
		Mean	8·2	33·2	2·7	17·0	+ 2·6
2	A	1 (unrestricted	8·2	31·9	2·6	17·2	− 3·6
	C	water)	8·2	32·6	2·7	17·9	− 0·4
	E		8·2	31·3	2·6	17·5	+ 0·4
		Mean	8·2	31·9	2·6	17·5	− 1·2
3	A	2 (restricted	7·9	34·8	2·7	17·1	−11·3
	C	water)	7·5	34·1	2·5	15·8	−11·8
	E		7·9	33·7	2·7	16·1	− 5·0
		Mean	7·8	34·2	2·6	16·3	− 9·4
1	B	1 (unrestricted	8·2	35·0	2·9	17·8	+ 5·0
	D	water)	8·2	33·0	2·7	17·0	+ 2·7
	F		8·2	31·7	2·6	16·6	+ 5·0
		Mean	8·2	33·2	2·7	17·1	+ 4·2
2	B	2 (restricted	7·0	33·6	2·4	15·8	+19·5
	D	water)	7·6	36·5	2·8	17·9	− 5·9
	F		8·2	32·2	2·6	17·4	− 2·3
		Mean	7·6	34·1	2·6	17·0	+ 3·8
3	B	1 (unrestricted	8·2	33·3	2·7	17·1	+31·3
	D	water)	8·2	32·9	2·7	17·0	−11·8
	F		8·2	31·1	2·5	16·5	−11·8
		Mean	8·2	32·4	2·6	16·9	+ 2·6

between the time taken for the excretion of 5 and 80% of the total undigested residues ('80–5% excretion time') an index of the spread of the excretion curve and of the rate of passage of the stained particles through the reticulo-rumen.

Separate excretion curves were plotted for the red and green hay fed in each collection period, and in Table 6 mean values are given for the excretion of various percentages of the undigested residues. It is noticeable that in the second part of the experiment the 80–5% excretion time was longer than in part 1 in all the cows, although it was rather longer in the three receiving restricted water (cows B, D and F) than in the others. However, when these latter cows (A, C and E) received restricted water in part 3 there was no further slowing in this index of excretion, whereas values for

cows B, D and F receiving unrestricted water closely resembled those for cows A, C and E in part 2. These findings show that a considerable slowing of the rate of passage of hay may occur, possibly owing merely to the animals becoming thoroughly accustomed to the diet. It is unlikely that a restricted water intake produced any great change in the rate of passage of hay, although such differences as were found indicated a trend towards slower excretion.

Table 6. *Rate of excretion of undigested lucerne hay by six cows receiving unrestricted or restricted amounts of water*

Part of experiment	Cow	Treatment no.	Time (h) required for excretion of various proportions of total undigested residues from stained hay (mean values for red and green hay)				
			Initial appearance	5 %*	50 %*	80 %*	80–5 %*
1	A	1 (unrestricted	24	33	64	95	62
	C	water)	30	37	68	98	61
	E		27	33	67	92	59
		Mean	27	34	66	95	61
2	A	1 (unrestricted	24	35	71	103	68
	C	water)	30	40	75	112	72
	E		24	33	67	93	60
		Mean	26	36	71	103	67
3	A	2 (restricted	24	32	67	98	66
	C	water)	30	40	78	109	69
	E		24	37	70	100	63
		Mean	26	36	72	102	66
1	B	1 (unrestricted	27	28	56	84	56
	D	water)	27	35	70	93	58
	F		27	39	63	88	49
		Mean	27	34	63	88	54
2	B	2 (restricted	30	40	74	104	64
	D	water)	30	38	78	123	85
	F		24	32	69	101	69
		Mean	28	37	74	109	73
3	B	1 (unrestricted	24	33	64	89	56
	D	water)	24	40	84	121	81
	F		20	33	64	92	59
		Mean	23	35	71	101	65

* For explanation of these indices of the rate of excretion, see p. 218

Relationship between the rate of passage and digestibility of food

In Fig. 1 values for the digestibility of crude fibre are shown plotted against the index of the rate of passage of food through the reticulo-rumen (80–5 % excretion time). This shows that the larger period-to-period variations in rate of passage coincided with changes in the digestibility of crude fibre, but that the values for the digestibility of crude fibre in periods when the water intake was restricted were too high to be explained by a decreased rate of passage. The big increase in the digestibility of crude fibre by cows receiving unrestricted water in parts 2 or 3, compared with values for the same cows in part 1, may have been due largely to the slower rate of passage of the hay through the reticulo-rumen.

Changes in the reticulo-rumen during restricted intake of water

Results obtained with the fistulated cow are summarized in Table 7. During the initial control period the total weight of digesta in the reticulo-rumen at the four emptyings was very constant, varying only from 73·0 to 73·4 kg. The dry weight of digesta at these times varied from 6·3 to 8·2 kg, but the mean values for the dry-matter content of the digesta in the various compartments of the rumen were reasonably consistent for the 2 weeks.

Although sampling was discontinued for the week in which the change to a restricted water intake was made, and although the cow had received only 70% of its intake of water in part 1 on each of the 5 days preceding the first complete removal of digesta in part 2, it was clear that the recovery from the change was not completed by the

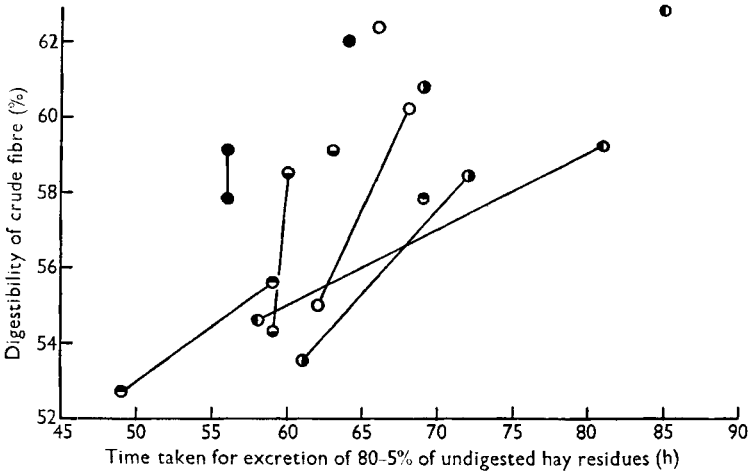

Fig. 1. Relationship, in cows A(○), B(●), C(◑), D(◐), E(◒) and F(◓) between the digestibility of crude fibre and the time required for the excretion of 80–5% of the residues of meals of stained hay. (For explanation of this index of the rate of excretion see p. 218.) The two values obtained for each cow while she was receiving unrestricted amounts of water are joined together by a line. The other values were obtained while the water intake was restricted.

time of the first sampling. At this time the reticulo-rumen contained 66·2 kg digesta with 10·2 kg dry matter. In the next 3 weeks there was a slight further fall in the total weight of digesta, so that in the last week of restricted water intake the mean content was 54·4 kg, or 18·8 kg less than in the initial control period. Accompanying this decrease there was a fall in the dry-matter content from 15·4% 1 week after the change to a mean of 11·5%. This value, only 0·3 percentage units higher than that found in the initial week of the control period, resulted partly from a voluntary decrease in the amount of hay eaten by the cow during the period in which her water intake was restricted. These findings were confirmed by analysis of samples taken from different parts of the reticulo-rumen, which showed that, although in weeks 5 and 6 the total weight of digesta in the reticulo-rumen was considerably less than in the initial control period, the dry-matter content was only slightly higher.

The rate of digestion of cellulose (cotton thread) in the dorsal sac of the rumen was

Table 7. *Effect of restricting the water intake of a fistulated cow on the dry-matter intake, the weight and dry-matter content of the digesta in the rumen and reticulum and on the rate of digestion of cotton thread in the rumen*

Part of experiment	Treatment	Week of experiment	Mean daily temperature in cowshed		Weight of cow (kg)	Mean daily intake			Dry-matter content				Weight of digesta in reticulo-rumen		Dry-matter content of total digesta in reticulo-rumen (%)	Mean reduction in weight of cotton after suspension in rumen for 24 h	
										Digesta							
			Max. (°F)	Min. (°F)		Hay (kg)	Water drunk (kg)	Dry matter* (%)	Faeces (%)	Dorsal sac of rumen (%)	Ventral sac of rumen (%)	Reticulum (%)	Total (kg)	Dry matter (kg)		Dorsal sac (%)	Ventral sac (%)
1	1 (unrestricted water)	1	71	61	571	7·3	26·3	18·5	18·5	14·7	5·7	5·1	73·0	8·1	11·1	—	—
													73·2	8·2	11·2		
		2	71	61	—	7·3	26·3	18·5	—	14·8	5·9	5·3	73·3	6·9	9·4	27·2	41·6
													73·4	6·3	8·6		
2	2 (restricted water)	4	73	63	536	6·9	18·6	24·1	22·1	16·5	7·3	6·1	66·2	10·2	15·4	—	—
													59·4	7·2	12·1		
		5	70	61	—	6·7	18·6	23·5	22·3	16·2	8·0	6·3	59·7	6·5	10·9	16·2	45·8
													59·5	6·5	10·9		
		6	78	67	534	6·1	18·6	21·8	25·3	17·1	7·0	8·2	58·0	6·7	11·6	—	—
													50·8	5·8	11·4		
3	1 (unrestricted water)	7	74	65	568	7·3	31·7	16·4	—	16·0	7·0	5·7	78·3	8·6	11·0	22·7	54·3
													75·8	7·5	9·9		

* $\frac{\text{Dry matter intake} \times 100}{\text{Total food intake} + \text{total water intake}}$

lower during the 2nd full week of water restriction than during the control periods. The rate of digestion in the ventral sac increased throughout the experiment. Digestion was again very much more rapid in the ventral sac than in the dorsal sac (cf. Balch & Johnson, 1950).

DISCUSSION

The main experiment confirmed the findings of Larsen *et al.* (1917) about the digestibility of the dry matter and crude fibre of hay, both of which were slightly increased when the water intake of the cows was limited. The water intake was limited to 60% of that voluntarily drunk in the preliminary control period and, because of a fall in environmental temperature, probably supplied about 65% of the water that would have been drunk by the cows had their intake been unlimited. The digestibility of crude protein, ether extract and nitrogen-free extract was not altered by the changes in water intake. In some of their experiments Larsen *et al.* (1917) found that the digestibility of crude protein and nitrogen-free extract was also increased, but in the present work no such increase was found. The cows tended to eat less on restricted intake of water, another observation that agrees with the findings of Larsen *et al.* There was consequently no change in the average daily intake of starch equivalent, as determined from amounts of digestible nutrients, and the animals gained no advantage from the small increases in digestibility. From the practical viewpoint, therefore, no advantage can be gained by restricting the water intake of cattle.

In view of the importance of water for the proper functioning of the reticulo-rumen, it was of interest to find what measures were taken by the animal's body to overcome a moderate shortage of water. Determinations of the rate of passage of hay through the cows had shown that the changes in the digestibility of crude fibre could not adequately be explained by changes in the rate of passage of the hay through the reticulo-rumen. A second experiment was therefore conducted on a fistulated cow. The results suggest that when the water intake of this cow was restricted she reacted similarly to the six cows on the larger experiment.

During periods in which the water intake was restricted, the six cows in the main experiment lost from 21 to 58 kg in weight, the mean loss being 38 kg. Larsen *et al.* (1917) found under comparable circumstances a mean loss of weight of 45 kg per cow when water intake was restricted to 50% of normal. In the fistulated cow the loss was 35 kg, of which about 20 kg was due to a reduction in the weight of material present in the reticulo-rumen.

The results of the experiment suggest that when the intake of water was restricted adjustments took place in the water economy of the cow favouring the maintenance of a water to dry-matter ratio in the reticulo-rumen similar to that present when water was freely available. This accounts for the fact that, contrary to the implications of the findings of Balch (1950) and Balch & Johnson (1950), the digestibility of crude fibre was not decreased by restricting water intake. In comparison with control periods, the adjustments may be summarized as a reduction in the excretion of water, amounting on average in six cows to 32·7% in faeces and 33·6% in urine, and a reduction in the amount of hay consumed. The reduced intake of hay was probably

responsible for the smaller amounts of digesta found in the reticulo-rumen. Simultaneous changes in the rate of passage of the hay were insufficient to explain the small increases in the digestibility of the crude fibre. It must therefore be concluded that although the digesta in the reticulo-rumen neither were more fluid nor remained for a sufficiently longer time when water intake was restricted, conditions were more favourable for the breakdown of fibre. This conclusion was confirmed by the rate of breakdown of cotton threads in the ventral sac of the rumen, but not by those for threads in the dorsal sac. It is suggested that during the shortage of water production of saliva was increased, and that this provided more favourable conditions for fermentation in the ventral sac. Preliminary results, obtained partly in the course of the experiment on the fistulated cow (Balch, unpublished results) showed that during eating the fistulated cow produced saliva at the rate of 5·8 kg/kg hay dry-matter when receiving limited amounts of water, but that the same cow produced only 4·6 kg/kg, and two other cows 4·8 kg/kg when receiving water at will.

SUMMARY

1. Six cows were given 8·2 kg lucerne hay daily and allowed unrestricted water during control periods. During experimental periods the amount of water was reduced to 60% of the amount drunk in the first control period; owing to a decrease in the mean cowshed temperature this amount was about 65% of the cows' probable intake had they not been restricted.

2. During the periods of restricted intake of water, five of the cows refused part of the hay and they all lost weight. The cows that received treatment 1 after treatment 2 regained their original weight during the experimental period. Production of urine fell to 66·4% and of water in the faeces to 67·3% of the excretion during the control periods, but there was no consistent change in the nitrogen balance.

3. During periods of restricted intake of water the digestibility of dry matter and of crude fibre rose slightly but, because of the decreased intake of hay, this did not affect the intake of apparently digestible energy and starch equivalent. No changes could be detected in values for crude protein, ether-extractable substances or nitrogen-free extract. It was concluded that no advantage could be gained by restricting the water intake of cattle.

4. When the water intake was similarly restricted, a fistulated cow made adjustments in her water economy favouring the maintenance of optimum water levels in the digesta in the reticulo-rumen. Although fewer digesta of a slightly drier consistency were found in the reticulo-rumen, it is likely that the secretion of saliva was increased and that the increased amounts of saliva favoured fermentation.

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Evidence of an Inherited Factor in Trophopathic Hepatitis

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It is well known that dietary insufficiency in experimental animals can produce necrosis of the liver parenchyma, with subsequent development of fibrous tissue (Himsworth, 1947). It was, therefore, not surprising to find evidence of permanent liver damage in service personnel who had been prisoners of war in Japanese hands. No evidence, however, could be found of any correlation between the presence of liver damage and of other more obvious signs of malnutrition. Such damage did not bear any apparent relationship to the overall degree of malnutrition. It might have been expected that liver damage would have been widespread in the various prison camps, but in fact this was not so. The condition occurred apparently at random, and whereas a few men in each camp developed it, the majority—presumably on the same diet—did not do so. In an attempt to find an explanation of this curious distribution, all possible facts relating to these cases were recorded, and it was found that the only factor that appeared to have any relationship to the incidence of liver damage was the degree of pigmentation of the eyes and hair of the individual. This implies an inherited liver abnormality linked in some way with pigmentation.

METHODS

Collection of data. Information was being collected as part of a general programme for the investigation of the possibility of an association between susceptibility to disease and eye and hair colour. An attempt has been made to include all available cases of the diseases under discussion in which the eye and hair colours of the patient were recorded. The data are taken from the records of service personnel in the possession of the Ministry of Pensions. They are not entirely unselected as they refer to the male sex only and are necessarily limited to the service age groups; the men concerned were considered to be of a standard of physical fitness suitable for service in the Armed Forces. All the men were born in the United Kingdom, and their age