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WATER ECONOMY IN RUMINANTS

IV. Effects of feed intakes on water consumption and balance

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Introduction

Water takes one of priorities in the nutrients that the animal requires for maintaining its homeostasis and for developing and producing a material, whatever it might be. Water has been considered to have several functions to perform in the animal body.

Investigations on water consumption in farm animals have been concentrated on the study in adult animals. Little work has been done on the consumption of water and its balance in growing animals. RADOSTITS and BELL¹⁰⁾ stated that milk-replacer-fed calves would drink water if it were available between feedings, but the daily allowances have not been known. ATKESON *et al.*⁴⁾ studied water consumption of growing calves fed skim milk for 6 months, and concluded that the total water requirement of dairy calves was to be rather definite at various ages up to six months. Drinking water became increasingly more important as calves grow older than eight weeks. Results also showed that the relationship was quite constant between total water intake and body weight, and also between total water intake and dry-matter consumption, especially after the tenth weeks.

In several reviews on water consumption rates,^{8,18,6,13)} water intake has been considered to relate quantitatively to feed intake, namely an amount of dry matter ingested. Statistical analyses of relations between water consumption and dry-matter intake in the adult cows revealed that there were highly significant positive correlations between water intake and dry-matter intake ($r=0.873$ for dry cows, $r=0.610$ for lactating cows), nitrogen intake ($r=0.671$), and energy intake ($r=0.830$).^{11,12)} When a weaned-lamb was allowed free access to drinking water, the ratio of water consumption to dry-matter intake was found to be 2 to 4 g./g. of dry-matter intake.²⁾ The

relationship between water consumption and dry-matter intake has been considered to be nearly constant.

Taking considerations of results reported, water intake is a function of feed intake with expecting other factors. Little informations have been published so far on water consumption and its balance in growing calves.

The present study was undertaken to determine the relationship in water intake, its balance and feed intake with statistical analyses on the data obtained in several experiments.

Materials and Methods

In five experiments on water balance, data obtained from 17 Holstein male calves were used in the analyses. Calves were fed either milk replacer or whole milk for seven to eleven weeks with calf starter and second-cutting hay. Fresh water was available all the time of a day throughout the experiments. Daily records were maintained on amounts of feed ingested, drinking water consumption and amounts of urine and feces excreted.

Dry-matter and nitrogen contents of feeds, feces and urine were analyzed by the method described in the Official Methods of Analysis of the Association of Official Analytical Chemists⁹⁾. Gross energy contents of feeds were measured with an automatic adiabatic oxygen bomb calorimeter (SHIMADZU-NENKEN Co.).

Statistical analyses were done with the methods described by either SNEDECOR¹⁰⁾ or STEEL and TORRIE¹⁷⁾. Correlation and regression coefficients were calculated.

Intakes of dry-matter, nitrogen and energy are the total of those consumed by calves. Total water obtained is the sum of water drunk, water contained in feeds and metabolic water calculated from the amount of nutrients digested using figures presented by ABRAMS.¹⁾

Results

Average amounts of water ingested and excreted

Amounts of total water obtained for calves fed milk replacer averaged 6493 g./day with the range from 3098 g. to 11620 g./day up to 8 weeks of age. Those for calves weaned from milk replacer averaged 11034 g./day and ranged from 5235 to 30973 g./day up to 25 weeks of age. Those for whole-milk-fed calves were 7325 g./day with the range from 5057 to 9965 g./day up to 7 weeks of age. The average of total water obtained for calves weaned from whole milk was 6214 g./day with range from 3933 to 10056 g./day up

to 12 weeks of age.

Averages of drinking water consumption were 1366 g./day and 585 g./day for replacer-fed and whole-milk-fed calves, respectively. The ranges were from 20 to 6080 g./day and from 30 to 3610 g./day for calves fed the replacer and whole milk, respectively. After weaning, amounts of free water drunk averaged 9718 g./day with the range from 3910 to 28070 g./day for those weaned from the replacer up to age of 25 weeks and 5527 g./day with the range from 3300 to 9490 g./day for those weaned from whole milk up to 12 weeks of age.

Calves fed milk replacer consumed dry matter on the average of 1047 g./day with the range from 355 to 2076 g./day up to 8 weeks of age. Those fed whole milk consumed dry matter on the average of 998 g./day with the range from 518 to 1631 g./day up to 7 weeks of age. After the weaning, dry-matter intake averaged 21718 g./day with range from 905 to 5747 g. for the replacer-weaned calves up to 25 weeks of age.

Calves weaned from whole milk consumed dry matter on the average of 1701 g./day with range from 1096 to 2934 g./day up to 12 weeks of age.

Averages of nitrogen intakes for calves fed milk replacer and whole milk were 51.73 g./day with range from 21.61 to 79.31 g./day and 41.85 g./day with the range from 20.79 to 65.90 g./day, respectively. After the weaning, calves weaned from milk replacer ingested nitrogen on the average of 88.26 g./day with the range from 32.73 to 176.1 g./day up to 25 weeks of age. Those from whole milk ingested nitrogen on the average of 65.57 g./day with the range from 39.29 to 111.8 g./day up to 12 weeks of age.

Average intakes of gross energy were 5148 kcal./day with the range from 1920 to 9522 kcal. and 5636 kcal./day with the range from 2940 to 7531 kcal. for calves fed milk replacer and whole milk, respectively. After the weaning, gross energy intakes averaged 12946 kcal./day with the range from 3924 to 2447 kcal. up to 25 weeks of age for calves weaned from milk replacer and 7368 kcal./day with the range from 4282 to 12682 kcal. up to 12 weeks of age for those weaned from whole milk.

Water excreted through feces was on the average of 804 g./day with the range from 29 to 2153 g. for calves fed milk replacer. Whole-milk-fed calves excreted water through feces on the average of 340 g./day with the range from 21 to 1971 g. The average of water excreted through feces was on the average of 3414 g./day with the range from 152 to 10059 g. up to 25 weeks of age for calves weaned from milk replacer. Water excreted in feces averaged 641 g./day with the range from 163 to 2248 g. for calves weaned from whole milk for only 7 weeks of age.

Water excreted in urine averaged 3616 g./day with the range from 628 to 7270 g. for replacer-fed calves. That for whole-milk-fed calves was 4571 g./day with the range from 1993 to 6706 g. After the weaning, amounts of water excreted in urine averaged 3401 g./day with the range from 1073 to 9090 g. for calves weaned from milk replacer up to 25 weeks of age. For calves weaned from whole milk, water excreted in urine averaged 2263 g./day with the range from 775 to 7560 g. for only 7 weeks of age.

The correlations among parameters

Statistical analyses were made among such parameters as total water obtained by animals (TWI), drinking water consumption (FWI), dry-matter intake (DMI), nitrogen intake (NI), gross energy intake (GEI), water excreted in feces (Wf) and water excreted in urine (Wu). Analyses among parameters were separately done in calves fed either milk replacer or whole milk and those weaned either from the replacer or the milk. Of the results of statistical analyses, coefficients of correlations were shown in Table 1.

The suckling period

Water intake

In liquid diet feeding period, total water obtained correlated significantly with drinking water consumption and nitrogen intake at 0.1% level and with dry-matter intake and gross energy intake at 5% level in calves receiving milk replacer, while correlations were neither significant between total water obtained and drinking water consumption nor dry-matter intake in calves fed whole milk. Drinking water consumption correlated with intakes of dry matter, nitrogen and gross energy in replacer-fed calves at 0.1% level of significance. In calves fed whole-milk diet, drinking water consumption had a correlation with dry-matter and nitrogen intakes at a level of 5% significance.

Water output

When calves received a liquid diet, water excreted in urine increased as total water obtained and amounts of water drunk increased in replacer-fed calves, but decreased in whole-milk-fed calves. Water excreted in feces, however, was not correlated with total water obtained in calves receiving replacer, while it was negatively correlated with total water obtained in calves receiving whole milk. With an increase in drinking water consumption, water excreted in feces and urine increased significantly both in replacer and whole milk feeding. Fecal water excretion correlated with dry-matter intake in calves fed either replacer or whole milk.

TABLE 1. Coefficients of correlations calculated among parameters⁴⁾

Parameter	TWI	FWI	DMI	NI	GEI
Calves fed liquid feed					
Milk replacer fed, 2-8 weeks of age					
TWI	1	.615*** ¹⁾	.197*	.395***	.165*
FWI		1	.380***	.358***	.327***
DMI			1	.888***	.949***
Wf	.080	.184*	.538***	— ²⁾	—
Wu	.743***	.301***	—	.004	—
Whole milk fed, 2-7 weeks of age					
TWI	1	-.099	.114	.251*	.367***
FWI		1	.254*	.250*	.138
DMI			1	.924***	.900***
Wf	-.558***	.596***	.661***	—	—
Wu	.878***	-.358***	—	.019	—
Calves fed a dry feed as a ration					
After weaned from milk replacer feeding, 7-25 weeks of age					
TWI	1	.997***	.916***	.870***	.922***
FWI		1	.889***	.869***	.894***
DMI			1	.962***	.997***
Wf	.861***	.849***	.909***	—	—
Wu	.638***	.650***	—	.560***	—
After weaned from whole milk feeding, 7-12 weeks of age					
TWI	1	.997***	.940***	.917***	.940***
FWI		1	.950***	.942***	.950***
DMI			1	.985***	.999***
Wf	-.315 ³⁾	-.251 ³⁾	-.645*** ³⁾	—	—
Wu	-.064 ³⁾	-.003 ³⁾	—	.193	—

1) *, significant at 5% level; ***, significant at 0.1% level

2) Not calculated

3) The data for 7 weeks of age were only available.

4) Abbreviated notations are shown in the text

The dry ration feeding period

Water intake

When calves were changed to a feeding of a dry feed ration after the weaning, total water obtained highly significantly correlated with drinking water consumption, and intakes of dry matter, nitrogen and gross energy regardless of a kind of liquid feed fed before weaning ($P < .001$).

Water output

Amounts of water excreted in feces and urine increased as amounts of total water obtained and drinking water consumed augmented in calves after weaning from milk replacer. In calves weaned from whole milk feeding, there were no correlations between fecal water and total water obtained or drinking water consumption, except with dry-matter intake. Water excreted in urine did not correlate with total water obtained, drinking water consumption and nitrogen intake. In the case of calves weaned from whole milk feeding, however, data were only available during a week just after weaning.

The regressions among parameters

Coefficients of regression among parameters were shown in Table 2 with each of confidence interval at 5% of significance.

*The suckling period**Water intake*

Total water obtained in replacer-fed calves would have increased in 0.81 parts as drinking water consumption increased one part. The difference of 0.19 parts indicates the decrease in amounts of water ingested with milk replacer which was purposely withdrawn gradually in the course of liquid diet feeding period. With an increment of intakes of dry matter, nitrogen and gross energy, amounts of total water obtained increased at a rate of 2.57 g./g., 55.7 g./g. and 0.17 g./kcal., respectively. Amounts of free water drunk increased at a rate of 1.25 g./g., 36.3 g./g. and 0.26 g./kcal., respectively as intakes of dry matter, nitrogen and gross energy increased. In whole-milk-fed calves, intakes of nitrogen and gross energy influenced to the amounts of total water obtained. Drinking water consumption was significantly affected with dry-matter and nitrogen intakes.

Water output

In replacer-fed calves, fecal water excretion has not related to the amount of total water obtained, while it was influenced a little in amount by an increment of free water intake. On the other hand, dry-matter intake increased water excreted in feces at a rate of 0.71 g./g. of the intake. Water excreted in urine increased in larger amounts than fecal water output when total water obtained and free water consumption increased.

In whole-milk-fed calves, water excreted in feces was inversely influenced by the amount of total water obtained. The amount of free water drunk, however, increased fecal water output at a rate of 0.34 g./g. of free water. The amount of dry matter eaten also increased the excretion of fecal water

TABLE 2. Coefficients of simple regression calculated among parameters⁵⁾

Parameter	TWI	FWI	DMI	NI	GEI
Calves fed liquid feed					
Milk replacer fed, 2-8 weeks of age					
TWI	1	.81 ^{b,1)} ± .17 ²⁾	2.57 ^a ± .72	55.7 ^b ± 20.2	0.17 ^a ± .16
FWI		1	1.25 ^b ± .47	36.3 ^b ± 14.7	0.26 ^b ± .11
DMI			1	.029 ^b ± .002	4.23 ^b ± .22
Wf	X ⁴⁾	.07 ^a ± .06	.71 ^b ± .17	— ³⁾	—
Wu	.69 ^b ± .10	.37 ^b ± .18	—	X	—
Whole milk fed, 2-7 weeks of age					
TWI	1	X	X	39.1 ^a ± 36.8	0.55 ^b ± .35
FWI		1	.74 ^a ± .66	19.6 ^a ± 18.3	X
DMI			1	.041 ^b ± .004	4.33 ^b ± .52
Wf	— .14 ^b ± .05	.34 ^b ± .11	1.16 ^b ± .32	—	—
Wu	.88 ^b ± .12	— .79 ^b ± .55	—	X	—
Calves fed a dry feed as a ration					
After weaned from milk replacer feeding, 7-25 weeks of age					
TWI	1	1.10 ^b ± .02	3.99 ^b ± .34	134.8 ^b ± 15.6	0.89 ^b ± .08
FWI		1	3.19 ^b ± .31	108.5 ^b ± 11.6	0.73 ^b ± .07
DMI			1	.028 ^b ± .001	4.36 ^b ± .06
Wf	.38 ^b ± 0.5	.42 ^b ± .06	1.72 ^b ± .17	—	—
Wu	.19 ^b ± .05	.22 ^b ± 0.6	—	26.8 ^b ± 8.6	—
After weaned from whole milk feeding, 7-12 weeks of age					
TWI	1	.96 ^b ± .0004	2.73 ^b ± .36	66.5 ^b ± 10.6	0.63 ^b ± .04
FWI		1	2.88 ^b ± .35	71.7 ^b ± 9.4	0.67 ^b ± .04
DMI			1	.039 ^b ± .0002	4.32 ^b ± .001
Wf	X	X	— 2.15 ^b ± 1.11 ⁶⁾	—	—
Wu	X	X	—	X	—

1) Superscripts show statistical significance; a, at 5% level and b, at 0.1% level.

2) Confidence interval at 5% level of significance.

3) Not calculated.

4) Coefficients of regression were not calculated because of non significant correlation.

5) Abbreviated notations are shown in the text.

6) The data for 7 weeks of age were only available.

at a rate of 1.16 g./g. of dry-matter intake. Urinary excretion of water increased at a rate of 0.88 g./g. of total water obtained, while an increase in free water intake decreased urinary water output at the rate of 0.79 g./g. of free water.

The dry ration feeding period

Water intake

When animals were weaned to a dry ration, amounts of total water obtained by calves increased almost one part with an increase in drinking water consumption regardless of a kind of liquid feed fed before weaning.

The amounts of total water obtained by calves fed a dry ration after the weaning from replacer feeding increased with an increase in intakes of dry matter, nitrogen and gross energy at the respective rate of 3.99 g./g., 34.8 g./g. and 0.89 g./kcal. Consumption of drinking water also increased at the rate of 3.19 g./g., 108.5 g./g. and 0.73 g./kcal. for an increase in intakes of dry matter, nitrogen and gross energy, respectively.

In animals on a dry ration changed from whole-milk feeding, the increment rates of water consumptions to intakes of dry matter, nitrogen and gross energy were not significantly different between total water obtained and free water intake. Thus, the rate of water consumption turned out to be at around 2.8 g./g. for dry-matter intake, at about 70 g./g. for the amount of nitrogen consumed and at about 0.65 g./kcal. for gross energy intake.

Water output

Fecal water excretion augmented at the respective rate of 0.38 g./g. of total water obtained, 0.42 g./g. of drinking water consumption and 1.72 g./g. of dry-matter intake. Water excreted in urine increased with an increase in amounts of total water obtained by animals, of free water drunk and of nitrogen ingested at the rate of 0.19 g./g., 0.22 g./g. and 26.8 g./g., respectively. Tests of homogeneity of regression, however, revealed that there were no significant differences in the rates of fecal or urinary water excretions to the amounts of total water obtained and of free water drunk by calves on a dry ration after the weaning from replacer-feeding. Thus, water would have excreted in feces at about the rate of 0.4 g. to an increase of one gram of water consumption. The rates of water excretion to water consumption were significantly different ($P < .001$) between feces and urine.

The relationships between water intakes and body weight

Drinking water consumption

There were significant exponential relationships between water consumptions and body weight in animals on whatever feeding regime might be ($P < .05$). Equations for regression of free water intake (Y) to body weight (X) in different feeding-regimes were obtained as follows;

$$Y = 0.2197 X^{1.988} \text{ for calves fed milk replacer,}$$

$Y = 0.03446 X^{2.239}$ for calves fed whole milk,

$Y = 56.481 X^{1.109}$ for calves on a dry ration after weaned
from milk replacer,

$Y = 4.990 X^{1.588}$ for calves on a dry ration after weaned
from whole milk.

Total water obtained

Those of total water obtained (Y) to body weight (X) were calculated as following equations ;

$Y = 15352/X^{0.214}$ for calves fed milk replacer,

$Y = 142070/X^{0.727}$ for calves fed whole milk,

$Y = 1032.5 X^{0.510}$ for calves on a dry ration after weaned
from milk replacer,

$Y = 19.307 X^{1.308}$ for calves on a dry ration after weaned
from whole milk.

The inverse relationships were found between total water obtained and body weight for calves in liquid-diet feeding period. In the period for feeding on a dry ration, water consumption exponentially related to the body weight.

The relationship between drinking water consumption and intakes of dry matter and nitrogen

As in the period for feeding of a dry ration, total water obtained were paralleled with an increase in free water intake, and as the consumption of free water is a parameter measurable in a practical operation involved, relations of free water intake to dietary parameters were analyzed. When drinking water consumption (Y) regressed on intakes of dry matter and nitrogen, the following equation was obtained ;

$$Y = 2.57 X_1 + 22.2 X_2 + 542 ,$$

where X_1 represents dry-matter intake and X_2 represents intake of nitrogen. The equation was significant at 1% level and each of the coefficients of regression was also found to have a 0.1% level of significance.

Thus, the amount of free water consumed for a growing calves up to 6 months of age is estimated as the sum of 2.57 times of dry-matter intake and 22.2 times of the amounts of nitrogen ingested.

Then, after the analysis was further made with calculating each standard

partial regression coefficient of the regression, it was found that dry-matter intake had a standard partial regression coefficient of 0.718 for free water intake and that of nitrogen intake was calculated for 0.178. These figures show that the amount of dry matter consumed was more responsible for increasing the intake of drinking water.

The relationship between drinking water consumption and intakes of dry matter and gross energy

When the multiple regression of free water consumption (Y) was calculated to dry-matter intake and gross energy intake the equation was obtained as follows ;

$$Y = 0.815 X_1 + 0.541 X_2 + 957 ,$$

where X_1 represents dry-matter intake and X_2 represents gross energy intake. Although the equation showed 0.5% level of significance, each of the coefficient of regression had no significance. It means intakes of dry matter and gross energy are not independent variables for each other to free water consumption. It might be assumed from the simple regression coefficients shown in Table 2 that coefficients of regression between dry-matter intake and gross energy intake were in the range of 4.23 to 4.36 kcal./g. in any feeding regimes.

Discussion

Water intake in the suckling period

It was found that significant correlations between water consumptions and nutrient intakes in calves receiving milk replacer, while in animals fed whole milk, dry-matter intake had no effect on total water obtained. Thus, in calves receiving milk replacer, intakes of dry matter and such other nutrients as nitrogen and energy had an influence upon water consumption, as many workers have indicated in mature animals.^{8,18,6,13)}

In whole-milk-fed calves, however, there was no relationship between dry-matter intake and total water obtained. Amount of total water obtained by calves fed whole milk averaged 7288 g./day. In the course of liquid diet feeding period, amounts of whole milk offered have been purposely reduced. The consumption of drinking water has significantly related to dry-matter intake, although a rate of increment has been 0.74 g./g. of dry-matter intake which was about a half rate of that found in replacer-fed calves.

Coefficients of regression for dry-matter intake on body weight resulted to be 13.9 g./kg. for whole-milk-fed calves and 26.6 g./kg. for replacer-fed

calves. The average total water obtained amounted to a fairly larger quantity, with smaller rates of increases in dry-matter intake regressed on body weight and in free water intake regressed on dry-matter intake. Thus, an increase in free water intake could have compensated a decrease of water supplied from whole milk which was withdrawn gradually. Amounts of the increment in free water, however, might have been not enough to affect the amount of total water obtained in the period of whole milk feeding.

Water output in the suckling period

Fecal water excretion was not affected with total water obtained in replacer-fed calves, while in those fed whole milk decreased at the rate of 0.14 g. per gram increase in total water obtained. The dry matter voided as feces has been about 15% of the intake in replacer-fed calves, while in those fed whole milk, it has been about 5% or less of the intake.⁷⁾ RADOSTITS and BELL¹⁰⁾ have studied digestibilities in calves fed milk replacer as a ration from 6 to 24 days of age, and have found that coefficients of digestibility of dry matter have been 74% for 6-9 days of age and 88 to 89% for 19-24 days of age. PORTER¹⁰⁾ reviewed on a digestion in the pre-ruminant animal and has concluded that certain digestive abilities of the pre-ruminant calf have been likely to be more limited, when nutrients have been supplied from the sources other than whole milk. Considering the difference in the digestibility between whole milk and milk replacer, animals fed whole milk might excrete less amount of feces in younger stage than in the period when calves began to ingest calf starter to compensate decreased supply of nutrients from whole milk which was purposely limited with an advance of age. Thus, the negative relationship was found between fecal water excretion and total water obtained in calves fed whole milk.

Drinking water consumption, however, positively correlated with fecal water excretion. It regressed on drinking water consumption at the rate of 0.07 g./g. increase in replacer-fed calves and of 0.34 g./g. increase in animals fed whole milk. Coefficients of regression for fecal water excretion on dry-matter intake were found to be 0.71 for replacer-fed calves and 1.16 for those offered whole milk. Increased feeding level of whole milk resulted in an increase in feces output¹⁰⁾. MARSH⁹⁾ showed that digestibility of dry matter decreased as the level of feeding increased. When it was considered that drinking water consumption increased with dry-matter intake and feces excretion increased with the level of feeding, the relationship between fecal water excretion and drinking water consumption was mediated through the dry-matter intake. Thus, it was not considered for free water *per se* to be responsible for a cause of diarrhea in animals on the liquid ration.

Urinary water excretion positively regressed on total water obtained in calves fed liquid diet and on free water intake in calves fed milk replacer, while it negatively related to drinking water consumption in whole-milk-fed animals. Coefficients of regression show that urine would take a larger part than feces as a route of excretion of water. In animals fed whole milk, total water obtained did not relate to free water intake. Increase in amounts of water drunk, therefore, might not exceed over the amount of water supplied with whole milk decreased purposely. It was assumed that animals decreased water excretion in urine to maintain the amount of water required with their body in calves fed whole milk.

Water intake and output in the dry ration feeding period

Animals on a dry ration consume water with a respective relation to the parameters studied. Total water obtained in calves on a dry ration is almost completely dependent on free water intake. The rate of water excretion in feces, therefore, is the same to total and free water consumption. That of urine is also similar to the results obtained in feces. Coefficients of regression, however, show that water excretion through feces is larger than urine. Therefore, feces take a larger part as a route for excretion of water than urine unlike in the case of the liquid feed feeding period.

JOHNSON *et al.*⁵⁾ reported that free water intake in Holstein calves fed whole milk related exponentially to body weight at the rate of 1.43 for animals kept at the constant temperature of 10°C and 1.99 for those at 26.7°C. As data were mostly obtained in summer season in the present study, the relationship of drinking water to body weight was well agreeable to that obtained at a higher ambient temperature reported by JOHNSON *et al.*⁵⁾ Total water obtained inversely related to body weight in the period of liquid diet feeding. Relationship between total water obtained and free water intake show incomplete compensation of water in the course of declining supply of liquid feed, thus, an increase in body weight exceeds the increment of total water obtained.

The relationships between water intake and the intakes of dry matter, nitrogen and gross energy

Analysis of multiple regression shows that dry-matter intake is more responsible to an increase in free water consumption than nitrogen intake. Energy intake is dependent on dry-matter intake in the present study. Thus, dry-matter intake might be a better index in practical use for estimating drinking water consumption in growing calves when the content of gross energy in a ration is almost identical. Furthermore, nitrogen intake is effec-

tive on free water intake when the amount of dry matter consumed is equal for calves in hand. Thus, simple regression of free water intake (Y) on dry-matter intake (X) is calculated as follows;

$$Y = 3.19 X + 821 \text{ for calves weaned from milk replacer } (P < .001),$$

$$Y = 2.88 X + 629 \text{ for calves weaned from whole milk } (P < .001).$$

The test of homogeneity of regression revealed that there was no significant difference in the rate of water intake to dry-matter intake between calves weaned from milk replacer and from whole milk. The rate of water intake to dry-matter intake is, thus, calculated with pooled data for calves on a dry ration, whatever the previous ration might be. The regression equation is as follows;

$$Y = 3.27 X + 441 \text{ (} P < .001 \text{) for calves on a dry ration up to 25 weeks of age, where } X \text{ is dry-matter intake (g./day) and } Y \text{ is free water intake (g./day).}$$

Therefore, water requirement of calves on a dry ration up to 25 weeks of age could be predicted by applying the equation above.

Summary

The results of water balance obtained from 17 Holstein male calves were statistically analyzed to determine the relationships among water intake, its balance and feed intake. In liquid diet feeding period, total water obtained significantly correlated with drinking water consumption, nitrogen intake, dry-matter intake and gross energy intake in calves receiving milk replacer. Significant correlations were found between total water obtained and nitrogen intake or gross energy intake in whole-milk-fed calves. Drinking water consumption significantly correlated with intakes of dry matter and nitrogen in both groups. Water excreted in feces significantly correlated with dry-matter intake and free water intake in both groups. Water excreted as urine significantly correlated with total water obtained in both groups. In a dry ration feeding period, water intake significantly correlated with feed intakes regardless of a kind of liquid feed fed before weaning. Water output in calves weaned from milk replacer significantly correlated with water intakes, but not in calves weaned from whole milk.

Analyses in regression coefficients revealed that dry-matter intake was to be the most responsible for water intake. Water excreted in feces was affected by water intake and dry-matter intake. Water excreted as urine increased as water intake and nitrogen intake increased. In a dry ration feeding period, drinking water intake accounted for the most part of total

water obtained. Following equation was postulated for water requirement of calves on a dry ration up to 25 weeks of age ;

$$Y = 3.27 X + 441 \quad (P < .001),$$

where X is dry-matter intake (g./day) and Y is free water intake (g./day).

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