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Two Different–Type Equations of Relative Growth Analysis for both Forages and Ruminants and Deriving of them from A Hypothetic Equation

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Two different–type equations of relative growth rate [RGR] for both forages and ruminants were taken up in the present study. Four equations of RGR each were composed of three or more components, and some features of them were summarized as follows: (1) forage RGR related to production analysis, (2) forage RGR related to utilization analysis, (3) ruminant RGR related to metabolic body size, and (4) ruminant RGR related to feed digestibility. Three of them, namely equations (2), (3) and (4) were discussed with data. Then, four equations were derived, as special cases, from a hypothetic equation for RGR suggested in the present study. This hypothetic equation was reduced to that suggested previously (Shimojo *et al.*, 1998a, b) from which RGR equation with two components for forages and that for ruminants had been derived as special cases.

INTRODUCTION

In a report (Shimojo *et al.*, 1998a, b) a hypothetic equation was suggested to the deriving of growth analysis equations for forages and ruminants as special cases. In one of those two papers (Shimojo *et al.*, 1998a) the equation of relative growth rate [RGR] for both forages and ruminants were made up of two components each, and the other paper (Shimojo *et al.*, 1998b) showed that the equation of absolute growth rate [AGR] and that of RGR for forages and ruminants, namely four equations, were made up of two components each.

Forage RGR equation with three components, which also deals with forage production analysis, is also known (Hunt, 1990a, b). In addition, another type of RGR equation, which is more complex in the form, was suggested from the viewpoint of forage utilization analysis (Shimojo *et al.*, 1998c). As for ruminants, RGR equation with three components was suggested to the growth analysis of beef cattle (Shimojo *et al.*, 1996, 1997). Another type of ruminant RGR equation with three components might be expected to be constructed by including feed digestion characteristics, and this is one of the subjects in the present study. Thus, we are now facing four equations of RGR with three or more components, namely two equations for forages and the other two for ruminants. It is also not known whether these four equations of RGR are derived from a

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hypothetic equation as special cases.

The present study was designed to take up two different–type equations for forage RGR and ruminant RGR, followed by deriving of them from a hypothetic equation as special cases.

TWO–DIFFERENT TYPE EQUATIONS FOR FORAGE RGR AND THOSE FOR RUMINANT RGR

Two–different type equations for forage RGR

(A) RGR equation for forage production analysis

RGR equation for forage production analysis [RGR_{f1}] with three components is described as follows (Hunt, 1990a, b):

$$RGR_{f1} = \frac{1}{W} \cdot \frac{dW}{dt}$$

$$= \left(\frac{1}{A} \cdot \frac{dW}{dt}\right) \cdot \left(\frac{A}{A_W}\right) \cdot \left(\frac{A_W}{W}\right), \qquad (1)$$

where W=forage dry weight, t=growth days, A=leaf area, A_W=leaf dry weight, $(1/A) \cdot (dW/dt)$=net assimilation rate [NAR], (A/A_W)=specific leaf area [SLA], (A_W/W)=leaf weight ratio [LWR].

It goes without saying that there have so far been a large number of studies, using equation (1), to analyze how the growth of forages of various genera, species, varieties and cultivars is related to the assimilation activity of leaves under various environmental and cultivation conditions. Thus, equation (1) has the validity of describing forage RGR from the viewpoint of production analysis.

(B) RGR equation for forage utilization analysis

RGR equation for forage utilization analysis [RGR_{f2}] suggested by Shimojo *et al.* (1998c) is as follows:

$$RGR_{f2} = \frac{1}{W} \cdot \frac{dW}{dt}$$

$$= \left(\frac{1}{W} \cdot \frac{d(D+I)}{dt}\right)$$

$$= \frac{1}{W} \cdot \frac{dD}{dt} + \frac{1}{W} \cdot \frac{dI}{dt}$$

$$= \left\{\frac{D + \frac{dW}{dt}}{W} \cdot \left(\frac{1}{D + \frac{dW}{dt}} \cdot \frac{dD}{dt}\right)\right\} + \left\{\frac{D + \frac{dW}{dt}}{W} \cdot \left(\frac{1}{D + \frac{dW}{dt}} \cdot \frac{dL}{dt}\right) \cdot \frac{dI}{dL}\right\}. \qquad (2)$$

where W=forage dry weight, t=growth days, D=dry weight of digestible materials, I=dry weight of indigestible materials, L=amount of lignin, (dW/dt)=new photosynthates (expressed in weight, not in rate), $(1/W)\cdot(dD/dt)$=accumulation rate of D per unit W [ARD], $(1/W)\cdot(dI/dt)$=formation rate of I per unit W [FRI], $(D+dW/dt)$=amount of source materials [S] for D accumulation or that for I formation, $(D+dW/dt)/W$=the ratio of S to W [S ratio], $\{1/(D+dW/dt)\}\cdot(dD/dt)$=accumulation rate of D per unit S [ARDS], $\{1/(D+dW/dt)\}\cdot(dL/dt)$=lignification rate of S [LRS], (dI/dL)=formation of I per unit increase in L [FIL].

Equation (2) was applied to a grass of tropical species in our previous report (Shimojo *et al.*, 1998c). In the present study the utilization analysis of two tropical forages, Rhodes grass (*Chloris gayana* Kunth) and Greenleaf desmodium (*Desmodium intortum* (Mill). Urb.), was conducted using equation (2). Rhodes grass [Rg] and Greenleaf desmodium [Gd] were cut at 35 and 63 days of regrowth with a compound fertilizer ($N:P_2O_5:K_2O$=14:14:14%) dressed at a rate of 1.0 kg/a for each element after the first cut and discard. Characteristic of Rg and Gd, and results of growth analysis are shown in Table 1. $\overline{RGR}$ was higher in Rg than in Gd. This was due to higher $\overline{FRI}$ and $\overline{ARD}$ of Rg compared with those of Gd, and the contribution of $\overline{FRI}$ was larger than that of $\overline{ARD}$. $\overline{ARD}$ of Rg was higher than that of Gd. This was mainly due to higher $\overline{ARDS}$ in Rg compared with Gd, because $\overline{\text{S ratio}}$ showed only a small difference between the two

Table 1. Relative growth rate [RGR] expressed as the sum of accumulation rate of digestible materials [ARD] and formation rate of indigestible materials [FRI] with growth of Rhodes grass [Rg] and Greenleaf desmodium [Gd].

Forages	Rg		Gd		Rg/Gd
Regrowth (days)	35	63	35	63	
Forage dry weight: W (g/m²)	225.56	515.00	190.00	315.28	
Dry weight of digestible materials: D (g/m²)	144.20	257.13	105.84	166.93	
Dry weight of indigestible materials: I (g/m²)	81.36	257.87	84.16	148.35	
Amount of lignin: L (g/m²)	6.93	30.26	13.41	24.33	
RGR = (ARD)+(FRI)					
$\overline{RGR}$ (g/g/day)	0.0295		0.0181		1.6302
$\overline{ARD}$ (g/g/day)	0.0115		0.0088		1.3044
$\overline{FRI}$ (g/g/day)	0.0180		0.0093		1.9403
ARD = (S ratio)·(ARDS)					
$\overline{ARD}$ (g/g/day)	0.0115		0.0088		1.3044
$\overline{\text{S ratio}}$ (g/g)	0.5864		0.5601		1.0470
$\overline{ARDS}$ (g/g/day)	0.0196		0.0157		1.2458
FRI = (S ratio)·(LRS)·(FIL)					
$\overline{FRI}$ (g/g/day)	0.0180		0.0093		1.9403
$\overline{\text{S ratio}}$ (g/g)	0.5864		0.5601		1.0470
$\overline{LRS}$ (g/g/day)	0.0041		0.0028		1.4398
$\overline{FIL}$ (g/g)	7.5658		5.8782		1.2871

RGR=relative growth rate, ARD=accumulation rate of D per unit W, FRI=formation rate of I per unit W, S ratio=the ratio of source materials [S] ($S=D+dW/dt$) to W, ARDS=accumulation rate of D per unit S, LRS=lignification rate of S, FIL=formation of I per unit increase in L.

forages. $\overline{FRI}$ was higher in Rg than in Gd, which was mainly due to higher $\overline{LRS}$ and $\overline{FIL}$ of Rg compared with those of Gd. It is suggested that this method accounts analytically for how forage RGR is related to the rate of D accumulation and that of I formation from the sum of digestible materials and new photosynthates with growth of forages. There is a necessity for examining this method by applying it to various forages grown under different conditions.

Two-different type equations for ruminant RGR

(A) RGR equation suggested to beef cattle

RGR equation of ruminants with three components [RGR_{r1}] suggested previously by Shimojo *et al.* (1996, 1997) to beef cattle is as follows:

$$RGR_{r1} = \frac{1}{W} \cdot \frac{dW}{dt}$$

$$= \left(\frac{1}{W^{0.75}} \cdot \frac{dF_{me}}{dt}\right) \cdot \left(\frac{W^{0.75}}{W}\right) \cdot \left(\frac{dW}{dF_{me}}\right), \qquad (3)$$

where W=animal body weight, t=growth days, $W^{0.75}$=metabolic body size [MBS], F_{me}=cumulative intake of metabolizable energy [CIM], $(1/W^{0.75})\cdot(dF_{me}/dt)$=daily intake of metabolizable energy per unit MBS [DIMM], $(W^{0.75}/W)$=metabolic body size ratio [MBS ratio] or maintenance requirements index [MR index], (dW/dF_{me})=efficiency of metabolizable energy for body weight gain [EEG].

A suggested feature of equation (3) is that $W^{0.75}/W$ has two meanings. One is MBS ratio which, if multiplied by DIMM, gives daily intake of metabolizable energy per unit W [DIMW], and the other is MR index that is an index associated with maintenance requirements per unit W in feeding standards or nutrient requirements where $W^{0.75}$ is adopted for the estimation of energy intake.

Table 2. Feeding and growth data of Japanese Black Cattle cited from Japanese Feeding Standard for Beef Cattle (1995) for Example (A).

Growth (kg)	Daily gain (kg/day)	Growth period (days)	Cumulative intake of metabolizable energy during the growth (MJ/head)
Castrate			
450→462	0.6	20	1463.68
450→462	1.2	10	986.15
Male			
450→462	0.6	20	1550.79
450→462	1.2	10	984.91
Female			
450→462	0.6	20	1585.28
450→462	1.2	10	1102.91

Table 3. Growth analysis of Japanese Black Catte using feeding and growth data in Example (A).

Growth (kg)	Period (days)	$\overline{\text{RGR}}$ (kg/kg/day)	$\overline{\text{DIMM}}$ (MJ/kg$^{0.75}$/day)	$\overline{\text{MBS ratio}}$ $\overline{\text{MR index}}$ (kg$^{0.75}$/kg)	$\overline{\text{EEG}}$ (kg/MJ)	$\overline{\text{DIMW}}$ (MJ/kg/day)
Castrate						
A: 450→462	20	0.0013	0.7417	0.2164	0.0082	0.1605
B: 450→462	10	0.0026	0.9994	0.2164	0.0122	0.2163
B/A	2.0	2.0000	1.3475	1.0000	1.4842	1.3475
Male						
A: 450→462	20	0.0013	0.7858	0.2164	0.0077	0.1701
B: 450→462	10	0.0026	0.9981	0.2164	0.0122	0.2160
B/A	2.0	2.0000	1.2702	1.0000	1.5745	1.2702
Female						
A: 450→462	20	0.0013	0.8033	0.2164	0.0076	0.1738
B: 450→462	10	0.0026	1.1177	0.2164	0.0109	0.2419
B/A	2.0	2.0000	1.3914	1.0000	1.4374	1.3914

RGR=relative growth rate, DIMM=daily intake of metabolizable energy per unit metabolic body size, MBS ratio=the ratio of metabolic body size to body weight, MR index=maintenance requirements index, EEG=efficiency of metabolizable energy for body weight gain, DIMW=daily intake of metabolizable energy per unit body weight.

In previous reports (Shinojo *et al.*, 1996, 1997) equation (3) was applied to Japanese Black Cattle using the data cited from Japanese Feeding Standard (Japan MAFF, 1995). In the present study feeding and growth data of Japanese Black Cattle were cited again from Japanese Feeding Standard (Japan MAFF, 1995). Feeding and growth data are shown in Table 2 and results of growth analysis are shown in Table 3. In three types of cattle $\overline{\text{RGR}}$ from 450 and 462 kg was higher when the growth period was 10 days than when it was 20 days (Table 3). This was due to higher $\overline{\text{DIMM}}$ and $\overline{\text{EEG}}$ in cattle of 10–day feeding compared with those in cattle of 20–day feeding, because $\overline{\text{MBS ratio}}$ or $\overline{\text{MR index}}$ was the same between the two feeding regimens. It is suggested that if maintenance requirements are the same, higher intake of metabolizable energy per day accelerates RGR through higher efficiency for gaining weight in three types of cattle.

(B) Suggesting another equation for ruminant RGR

In the present study, another equation for ruminant RGR [RGR_{r2}] with three components is suggested as follows:

$$\text{RGR}_{r2} = \frac{1}{W}\cdot\frac{dW}{dt}$$

$$= \left(\frac{1}{W}\cdot\frac{dF}{dt}\right)\cdot\left(\frac{dF_D}{dF}\right)\cdot\left(\frac{dW}{dF_D}\right), \qquad (4)$$

where W=animal body weight, t=growth days, F=cumulative intake of feed dry matter [CIF], F_D=cumulative intake of digestible dry matter [CIF_D], $(1/W)\cdot(dF/dt)$=daily intake of feed dry matter per unit W [DIFW], (dF_D/dF)=feed dry matter digestibility [DMD],

(dW/dF_D)=efficiency of digestible dry matter for body weight gain [EDG].
It is suggested that dF_D/dF in equation (4) is interpreted as a round estimate of feed DMD over the feeding period. Anyway, a suggested feature of equation (4) is that feed DMD is included in the analysis of ruminant RGR.

In the present study data on dry matter intake and total digestible nutrients [TDN] intake by Japanese Black Cattle were cited from Japanese Feeding Standard (Japan MAFF, 1995). Since TDN is used as the substitution for digestible dry matter, the following equation is used in place of equation (4). Thus,

$$\mathrm{RGR}_{r2} = \frac{1}{W}\cdot\frac{dW}{dt} = \left(\frac{1}{W}\cdot\frac{dF}{dt}\right)\cdot\left(\frac{dF_T}{dF}\right)\cdot\left(\frac{dW}{dF_T}\right), \qquad (5)$$

where F_T=cumulative intake of TDN [CITDN], (dF_T/dF)=TDN concentration of feed [TCF], (dW/dF_T)=efficiency of TDN for body weight gain [ETG].

Feeding and growth data are shown in Table 4 and results of growth analysis are shown in Table 5. In three types of cattle $\overline{\mathrm{RGR}}$ from 450 and 462 kg was higher in 10–day feeding regimen than in 20–day feeding regimen (Table 5). This was due to higher $\overline{\mathrm{DIFW}}$, $\overline{\mathrm{TCF}}$ and $\overline{\mathrm{ETG}}$ in cattle of 10–day feeding compared with those in cattle of 20–day feeding, and the contribution of $\overline{\mathrm{TCF}}$ is considered smaller than compared with $\overline{\mathrm{DIFW}}$ and $\overline{\mathrm{ETG}}$. It is suggested that higher intake of more digestible nutrients per day accelerates RGR through higher efficiency for gaining weight in three types of cattle.

To examine the two methods (A) and (B), namely RGR_{r1} and RGR_{r2}, there is a necessity for applying them to not only beef cattle of various breeds grown under different conditions but also other ruminants.

Table 4. Feeding and growth data of Japanese Black Cattle cited from Japanese Feeding Standard for Beef Cattle (1995) for Example (B).

Growth (kg)	Daily gain (kg/day)	Growth period (days)	Cumulative intake of dry matter during the growth (kg/head)	Cumulative intake of total digestible nutrients during the growth (kg/head)
Castrate				
450→462	0.6	20	138.20	96.64
450→462	1.2	10	86.38	65.11
Male				
450→462	0.6	20	169.21	102.39
450→462	1.2	10	94.49	65.03
Female				
450→462	0.6	20	154.00	104.67
450→462	1.2	10	97.17	72.82

Table 5. Growth analysis of Japanese Black Cattle using feeding and growth data in Example (B).

Growth (kg)	Period (days)	$\overline{\text{RGR}}$ (kg/kg/day)	$\overline{\text{DIFW}}$ (kg/kg/day)	$\overline{\text{TCF}}$ (kg/kg)	$\overline{\text{ETG}}$ (kg/kg)
Castrate					
A: 450→462	20	0.0013	0.0152	0.6993	0.1242
B: 450→462	10	0.0026	0.0189	0.7538	0.1843
B/A	2.0	2.0000	1.2501	1.0779	1.4843
Male					
A: 450→462	20	0.0013	0.0186	0.6051	0.1172
B: 450→462	10	0.0026	0.0207	0.6882	0.1845
B/A	2.0	2.0000	1.1168	1.1374	1.5745
Female					
A: 450→462	20	0.0013	0.0169	0.6797	0.1146
B: 450→462	10	0.0026	0.0213	0.7494	0.1648
B/A	2.0	2.0000	1.2619	1.1026	1.4374

RGR=relative growth rate, DIFW=daily intake of feed dry matter per unit body weight, TCF=TDN [total digestible nutrients] concentration of feed, ETG=efficiency of TDN for body weight gain.

DERIVING OF FOUR EQUATIONS FROM A HYPOTHETIC EQUATION AS SPECIAL CASES

Suggesting a hypothetic equation

It arises a question of whether there will be a common equation from which RGR_{f1}, RGR_{f2}, RGR_{r1} and RGR_{r2} might be expected to be derived as special cases. To this purpose we suggest the following hypothetic equation:

$$\mathrm{H}=\left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{\gamma}\cdot\frac{\gamma}{W}\right)\cdot\left(\frac{d\gamma}{d\beta}\cdot\frac{dW}{d\gamma}\right), \qquad (6)$$

where α , β and γ are a set of parameters related to RGR_{f1}, RGR_{f2}, RGR_{r1} or RGR_{r2}, W=forage dry weight or animal body weight.

Deriving two equations for forage RGR from equation (6)

(A) RGR_{f1} [equation (1)]

If α , β and γ in equation (6) are equal to A, W and A_W, respectively, then

$$\mathrm{H}=\left(\frac{1}{A}\cdot\frac{dW}{dt}\right)\cdot\left(\frac{A}{A_W}\cdot\frac{A_W}{W}\right)\cdot\left(\frac{dA_W}{dW}\cdot\frac{dW}{dA_W}\right)$$

$$=\left(\frac{1}{A}\cdot\frac{dW}{dt}\right)\cdot\left(\frac{A}{A_W}\right)\cdot\left(\frac{A_W}{W}\right)$$

$$=\mathrm{RGR}_{f1}\,. \qquad (7)$$

Thus, RGR_{f1} [equation (1)] was derived from equation (6).

(B) RGR_{f2} [equation (2)]

The following equation (8) is used, in place of equation (6), to derive RGR_{f2} [equation (2)]. Thus,

$$H^* = \left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{W}\right)\cdot\left\{1+\frac{d\gamma}{d\beta}\cdot\frac{d(W-\beta)}{d\gamma}\right\}. \qquad (8)$$

If $\alpha=(D+dW/dt)$, $\beta=D$ and $\gamma=L$ in equation (8), then

$$H^* = \left(\frac{1}{D+\frac{dW}{dt}}\cdot\frac{dD}{dt}\right)\cdot\left(\frac{D+\frac{dW}{dt}}{W}\right)\cdot\left\{1+\frac{dL}{dD}\cdot\frac{d(W-D)}{dL}\right\}$$

$$= \left(\frac{1}{D+\frac{dW}{dt}}\cdot\frac{dD}{dt}\right)\cdot\left(\frac{D+\frac{dW}{dt}}{W}\right)\cdot\left(1+\frac{dL}{dD}\cdot\frac{dI}{dL}\right) \qquad \text{(because } W=D+I\text{)}$$

$$= \left\{\frac{D+\frac{dW}{dt}}{W}\cdot\left(\frac{1}{D+\frac{dW}{dt}}\cdot\frac{dD}{dt}\right)\right\}+\left\{\frac{D+\frac{dW}{dt}}{W}\cdot\left(\frac{1}{D+\frac{dW}{dt}}\cdot\frac{dL}{dt}\right)\cdot\frac{dI}{dL}\right\}$$

$$= RGR_{f2}. \qquad (9)$$

Thus, RGR_{f2} [equation (2)] was derived from equation (8). Then, equation (8) is rewritten as follows:

$$H^* = \left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{W}\right)\cdot\left\{1+\frac{d\gamma}{d\beta}\cdot\frac{d(W-\beta)}{d\gamma}\right\}$$

$$= \left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{W}\right)\cdot\left\{1+\frac{d\gamma}{d\beta}\cdot\left(\frac{dW}{d\gamma}-\frac{d\beta}{d\gamma}\right)\right\}$$

$$= \left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{W}\right)\cdot\left(1+\frac{dW}{d\beta}-1\right)$$

$$= \left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{W}\right)\cdot\left(\frac{dW}{d\beta}\right)$$

$$= \left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{\gamma}\cdot\frac{\gamma}{W}\right)\cdot\left(\frac{d\gamma}{d\beta}\cdot\frac{dW}{d\gamma}\right)$$

$$= H. \qquad (10)$$

It was shown that equation (8) was equal to equation (6), suggesting the deriving of RGR_{f2} [equation (2)] from equation (6).

Deriving two equations for ruminant RGR from equation (6)

(A) RGR_{r1} [equation (3)]

In case of $\alpha = W^{0.75}$, $\beta = F_{me}$ and $\gamma = W$ in equation (6), then

$$H = \left(\frac{1}{W^{0.75}} \cdot \frac{dF_{me}}{dt}\right) \cdot \left(\frac{W^{0.75}}{W} \cdot \frac{W}{W}\right) \cdot \left(\frac{dW}{dF_{me}} \cdot \frac{dW}{dW}\right)$$

$$= \left(\frac{1}{W^{0.75}} \cdot \frac{dF_{me}}{dt}\right) \cdot \left(\frac{W^{0.75}}{W}\right) \cdot \left(\frac{dW}{dF_{me}}\right)$$

$$= RGR_{r1}. \qquad (11)$$

Thus, RGR_{r1} [equation (3)] was derived from equation (6).

(B) RGR_{r2} [equation (4)]

When $\alpha = W$, $\beta = F$ and $\gamma = F_D$ in equation (6), then

$$H = \left(\frac{1}{W} \cdot \frac{dF}{dt}\right) \cdot \left(\frac{W}{F_D} \cdot \frac{F_D}{W}\right) \cdot \left(\frac{dF_D}{dF} \cdot \frac{dW}{dF_D}\right)$$

$$= \left(\frac{1}{W} \cdot \frac{dF}{dt}\right) \cdot \left(\frac{dF_D}{dF}\right) \cdot \left(\frac{dW}{dF_D}\right)$$

$$= RGR_{r2} \qquad (12)$$

Thus, RGR_{r2} [equation (4)] was derived from equation (6).

Suggested relationships among RGR_{f1}, RGR_{f2}, RGR_{r1} and RGR_{r2}

It seems that RGR_{f1}, RGR_{f2}, RGR_{r1} and RGR_{r2} are mixed potentially in equation (6). Then, this equation can be reduced to respective RGRs by substituting, for parameters, the terms involved in each of four equations for RGR. In other words, equation (6) does not seem to separate four RGRs potentially, but actually the separation occurs and they seem to show different aspects of equation (6). This suggests, as it were, an indirect evidence of forage–ruminant complex, which might allow us to stand midway between forage production and ruminant production.

Simplifying equation (6)

Equation (6) is simplified by removing γ/γ and $d\gamma/d\gamma$ from the second and third parentheses, respectively. Thus,

$$H = \left(\frac{1}{\alpha} \cdot \frac{d\beta}{dt}\right) \cdot \left(\frac{\alpha}{\gamma} \cdot \frac{\gamma}{W}\right) \cdot \left(\frac{d\gamma}{d\beta} \cdot \frac{dW}{d\gamma}\right)$$

$$=\left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{W}\right)\cdot\left(\frac{dW}{d\beta}\right). \quad (13)$$

This suggests that equation (6) for RGR with three or more components can be reduced to equation (13) for RGR with two components taken up previously (Shimojo *et al.*, 1998a, b). Therefore, equation (13) has a potential for describing some aspects of RGR of both forages and ruminants.

Conclusions

Two different–type equations for both forage RGR and ruminant RGR were taken up and characteristics of them were discussed. These four equations showed some features, namely forage RGR related to production or utilization analysis, ruminant RGR related to metabolic body size or feed digestibility. Despite differences between four equations, they were derived from a hypothetic equation as special cases.

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