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Net Assimilation Rate of Forages and Forage Intake of Ruminants as Related using a Hypothetic Equation Suggested to Growth Analysis of both Forages and Ruminants

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In this study another–type hypothetic equation with three parameters, which was slightly different in the form from the previous equation (Shimojo *et al.*, 1998b), was suggested to the growth analysis of both forages and ruminants. From the present hypothetic equation, absolute growth rate [AGR] and relative growth rate [RGR] of forages and those of ruminants were derived as special cases. In addition, when a certain substitution was made for parameters, AGR and RGR equations each were shown to be composed of daily forage intake [DFI] per animal or per unit body weight, net assimilation rate [NAR] per plant, and the term suggesting a sort of relationship between ruminant DFI and forage NAR. This relationship was suggested by adjusting growth period and yield of the forage to be equal to its feeding period and cumulative intake in the ruminant, respectively.

INTRODUCTION

The ruminant production from forages is considered of importance from the viewpoint of producing animal protein by the use of ruminant's ability to digest plant fibers that seem to be unsuitable for direct human consumption (Van Soest, 1982; Minson, 1990). Those who are interested in forage–ruminant complex pay attention to whether or not the meadow and pasture can produce enough amount of forages to meet their intake by ruminants. In that situation, therefore, forage production and ruminant production are the subject that cannot be separated.

We suggested a hypothetic equation from which growth analysis equations of forages and ruminants were derived as special cases (Shimojo *et al.*, 1998a, b, 1999). Those three reports also show, needless to say, that net assimilation rate and forage intake are essential to forage growth and ruminant growth, respectively. Then, there arises a question of whether forage intake of ruminants is related to net assimilation rate of forages, which is considered of interest from the viewpoint of relating ruminant growth to forage growth. This subject might be expected to suggest an analytic approach in the investigation into forage–ruminant complex.

The present study was designed to suggest a relationship between net assimilation rate of forages and forage intake of ruminants, using a hypothetic equation constructed newly for growth analysis of both forages and ruminants.

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CONSTRUCTING ANOTHER HYPOTHETIC EQUATION

A hypothetic equation for growth analysis of both forages and ruminants suggested previously

A hypothetic equation [H] suggested previously (Shimojo *et al.*, 1998b), from which absolute growth rate [AGR] and relative growth rate [RGR] of forages and those of ruminants are derived as special cases, is as follows:

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

where α, β and γ are a set of parameters related to AGR or RGR of forages or ruminants, W=dry weight per plant or body weight per animal, t=growth days.

Another hypothetic equation for AGR and RGR of forages and those of ruminants

In the present study another hypothetic equation [H*] is suggested to the deriving of AGR and RGR of forages and those of ruminants as special cases. Thus,

$$H^*=\left(\frac{1}{\alpha}\cdot\frac{d\beta}{dt}\right)\cdot\left(\frac{\alpha}{\gamma}+\frac{dW}{d\beta}-1\right), \qquad (2)$$

where α, β and γ are a set of parameters related to AGR or RGR of forages or ruminants, W=dry weight per plant or body weight per animal, t=growth days.

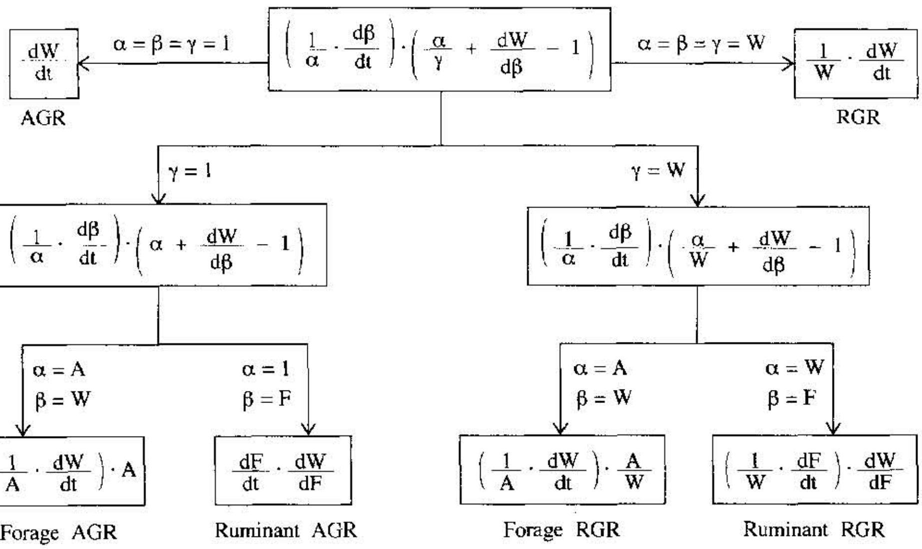

Fig. 1. A flowchart from a hypothetic equation to AGR and RGR of forages and those of ruminants (W=dry weight per plant or body weight per animal, A=forage leaf area, $(1/A)\cdot(dW/dt)$=forage net assimilation rate, A/W=leaf area ratio, F=cumulative feed intake per animal, dF/dt=daily feed intake per animal, dW/dF=feed efficiency, $(1/W)\cdot(dF/dt)$=daily feed intake per unit W).

As shown in Fig. 1, equation (2) gives almost the same results as those given by equation (1) (Shimojo *et al.*, 1998b). In the present study equation (2) will be used, in place of equation (1), to relate net assimilation rate of forages and forage intake of ruminants.

RELATING NET ASSIMILATION RATE OF FORAGES AND FORAGE INTAKE OF RUMINANTS

Forming a relationship

When $\gamma = 1$, equation (2) gives AGR equation [H^*_1] for forages and ruminants (Fig. 1). Thus,

$$H^*_1 = \left(\frac{1}{\alpha} \cdot \frac{d\beta}{dt}\right) \cdot \left(\alpha + \frac{dW}{d\beta} - 1\right). \qquad (3)$$

Leaves and feeds are indispensable to energy taking in by forages and ruminants, respectively. If $\alpha = A$ [leaf area per plant] and $\beta = F$ [cumulative forage intake per animal], equation (3) is rewritten as follows:

$$H^*_1 = \left(\frac{1}{A} \cdot \frac{dF}{dt}\right) \cdot \left(A + \frac{dW}{dF} - 1\right)$$

$$= \left(\frac{dF}{dt}\right) + \left(\frac{1}{A} \cdot \frac{dW}{dt}\right) - \left(\frac{1}{A} \cdot \frac{dF}{dt}\right). \qquad (4)$$

In the right–hand side of equation (4) the first two terms are interpreted easily, namely [dF/dt] denotes daily forage intake [DFI] per animal and $(1/A) \cdot (dW/dt)$ denotes net assimilation rate [NAR] per plant. However, what does the third term mean ? This term implies a sort of relationship between ruminant DFI and forage leaf area, and the detailed interpretation of $(1/A) \cdot (dF/dt)$ is the present subject.

The term in question also appears in the following procedures. When $\gamma = W$, equation (2) gives RGR equation [H^*_2] common to forages and ruminants (Fig. 1). Thus,

$$H^*_2 = \left(\frac{1}{\alpha} \cdot \frac{d\beta}{dt}\right) \cdot \left(\frac{\alpha}{W} + \frac{dW}{d\beta} - 1\right). \qquad (5)$$

Then, $\alpha = A$ and $\beta = F$,

$$H^*_2 = \left(\frac{1}{A} \cdot \frac{dF}{dt}\right) \cdot \left(\frac{A}{W} + \frac{dW}{dF} - 1\right)$$

$$= \left(\frac{1}{W} \cdot \frac{dF}{dt}\right) + \left(\frac{1}{A} + \frac{dW}{dt}\right) - \left(\frac{1}{A} \cdot \frac{dF}{dt}\right), \qquad (6)$$

where $(1/W) \cdot (dF/dt)$=DFI per unit body weight [DIFW], $(1/A) \cdot (dW/dt)$=NAR per plant, $(1/A) \cdot (dF/dt)$=the term in question.

Since [A] denotes leaf area and [F] denotes cumulative forage intake, it seems that interpreting $(1/A) \cdot (dF/dt)$ in equations (4) and (6) is the subject that lies between forage NAR and ruminant DFI or DFIW. One of the possible approaches to this subject seems to come from comparing $(1/A)\cdot(dF/dt)$ with $(1/A)\cdot(dW/dt)$, NAR, in the mean value over the interval t_1 to t_2. Thus,

$$\text{Mean } \frac{1}{A}\cdot\frac{dF}{dt}=\frac{\log_e A_2-\log_e A_1}{A_2-A_1}\cdot\frac{F_2-F_1}{t_2-t_1}, \qquad (7)$$

$$\text{Mean } \frac{1}{A}\cdot\frac{dW}{dt}=\frac{\log_e A_2-\log_e A_1}{A_2-A_1}\cdot\frac{W_2-W_1}{t_2-t_1}, \qquad (8)$$

where e=the base of natural logarithm.

The difference between equations (7) and (8) is due to the difference between $(F_2-F_1)/(t_2-t_1)$ and $(W_2-W_1)/(t_2-t_1)$. $(F_2-F_1)/(t_2-t_1)$ denotes DFI per animal and $(W_2-W_1)/(t_2-t_1)$ denotes AGR per plant. If these two terms are equalized in both between numerators and between denominators, respectively, then ruminant DFI will be related to forage AGR and result in the relationship with forage NAR, because forage AGR is the product of NAR and leaf area (Fig. 1). This will be achieved by the following two procedures: (a) adjusting the number of plants to make the forage yield $[(W_2-W_1)]$ equal to the cumulative forage intake per animal $[(F_2-F_1)]$, and (b) adjusting the forage feeding period to an animal $[(t_2-t_1)$ in $(F_2-F_1)/(t_2-t_1)]$ to be equal to the forage growth period $[(t_2-t_1)$ in $(W_2-W_1)/(t_2-t_1)]$. These two adjustments will allow $(1/A)\cdot(dF/dt)$ to be equal to $(1/A)\cdot(dW/dt)$.

For the calculation of $(1/A)\cdot(dW/dt)$ the following two conditions should be satisfied in the analysis of forage growth, namely (c) the plant at time t_1 has leaves, and (d) the plant height at t_1 is equal to the height above the ground at which the plant will be cut at t_2 for making hay. Satisfying the four requirements (a), (b), (c) and (d) will result in relating ruminant DFI or DFIW to forage NAR through $(1/A)\cdot(dF/dt)$, where forage yield is the same as cumulative forage intake per animal and forage feeding period to the animal (=animal growth period) is the same as forage growth period. Thus, $(1/A)\cdot(dF/dt)$ might be regarded as NAR that suggests a sort of relationship between ruminant DFI and forage NAR $[\text{NAR}_{(f-r)}]$.

Then, using $\text{NAR}_{(f-r)}$ $[(1/A)\cdot(dF/dt)]$ and leaf area $[A]$, DFI and DFIW are rewritten as follows:

$$\text{DFI}=\frac{dF}{dt}$$
$$=\left(\frac{1}{A}\cdot\frac{dF}{dt}\right)\cdot A\ , \qquad (9)$$

$$\text{DFIW}=\frac{1}{W}\cdot\frac{dF}{dt}$$
$$=\frac{1}{W}\cdot\left\{\left(\frac{1}{A}\cdot\frac{dF}{dt}\right)\cdot A\right\}. \qquad (10)$$

Since $(1/A)\cdot(dF/dt)=(1/A)\cdot(dW/dt)$, equations (9) and (10) are also derived from equations (4) and (6), respectively. Thus,

$$H^*_1 = \left(\frac{dF}{dt}\right) + \left(\frac{1}{A} \cdot \frac{dW}{dt}\right) - \left(\frac{1}{A} \cdot \frac{dF}{dt}\right)$$

$$= \frac{dF}{dt}$$

$$= \left(\frac{1}{A} \cdot \frac{dF}{dt}\right) \cdot A$$

$$= \mathrm{DFI}. \qquad (11)$$

$$H^*_2 = \left(\frac{1}{W} \cdot \frac{dF}{dt}\right) + \left(\frac{1}{A} \cdot \frac{dW}{dt}\right) - \left(\frac{1}{A} \cdot \frac{dF}{dt}\right)$$

$$= \frac{1}{W} \cdot \frac{dF}{dt}$$

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

$$= \mathrm{DFIW}. \qquad (12)$$

Thus, equations (9) ~ (12) show that ruminant DFI is expressed as the product of $NAR_{(f\,r)}$ and leaf area.

It seems to be of interest that equation (2), by a certain substitution made for parameters, is shown to be composed of three terms, namely DFI per animal or per unit body weight, NAR per plant, and $NAR_{(f\,r)}$ implying a sort of relationship between ruminant DFI and forage NAR, as shown in equations (4) and (6) which are derived from equation (2) as special cases. In brief, forages and ruminants seem to coexist in both equations (4) and (6) for the energy ingestion. This suggests, in other words, that the original style of ruminant production, 'Domestic ruminants are fed on forages', is derived from the unifying of growth analysis equations of forages and those of ruminants into an equation, though it is a hypothetic one.

Equations (9) and (10) are incorporated into AGR and RGR equations of ruminants, respectively. Thus,

$$\text{Ruminant AGR} = \frac{dW}{dt}$$

$$= \frac{dF}{dt} \cdot \frac{dW}{dF}$$

$$= \left\{\left(\frac{1}{A} \cdot \frac{dF}{dt}\right) \cdot A\right\} \cdot \left(\frac{dW}{dF}\right), \qquad (13)$$

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

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

$$=\left[\frac{1}{W}\cdot\left\{\left(\frac{1}{A}\cdot\frac{dF}{dt}\right)\cdot A\right\}\right]\cdot\left(\frac{dW}{dF}\right), \qquad (14)$$

where (dW/dF)=efficiency of forage intake for body weight gain.
Equations (13) and (14) show, therefore, that $NAR_{(C\text{-}r)}$ and leaf area are incorporated into the growth analysis of ruminants. This suggests a sort of relationship between forage production and ruminant production.

Problems in the examining of the present method

It goes without saying that there is a necessity for examining the present method by applying it to forages and ruminants in various conditions. There are problems as follows in the examining of this method: (a) there are forages and ruminants of many kinds, (b) the forage yield is influenced by cultivation management and environmental factors, (c) the forage intake of ruminants is influenced by plant, animal and environmental factors. Therefore, it is not too much to say that the relationship between forage NAR and ruminant DFI depends on individual cases.

If, in the local area, the forage of a kind grown under the appropriate management is given to growing ruminants of a kind kept under the controlled condition, this might be expected to suggest a sort of relationship between forage NAR and ruminant DFI in the particular case. In the cases where both forage NAR and ruminant DFI are expected to be normal due to favorable growth conditions for both forages and ruminants, they might be related easily. However, where forage NAR or ruminant DFI, or both inevitably becomes low due to unfavorable growth conditions, forming the relationship is considered difficult.

Forage NAR and ruminant DFI are usually different subjects, and the present method compulsorily relating them looks too complicated. Although it might give the viewpoint of mutual regulation between the area of meadow and the number of animals, adjusting forage NAR to be equal to ruminant DFI includes a very delicate problem. Actually, it is desirable that forage yield more than meets the intake by animals. Therefore, the mutual regulation in the forage–ruminant complex with proper surplus in the amount of forage is considered of importance, which might make a contribution to sustainable animal agriculture.

Conclusions

In the present study, another hypothetic equation with three parameters was suggested to the deriving of AGR and RGR of forages and those of ruminants as special cases. This hypothetic equation, when a certain substitution was made for parameters, was shown to be composed of DFI per animal or per unit body weight, NAR per plant, and the term suggesting a sort of relationship between ruminant DFI and forage NAR. This relationship was suggested by adjusting growth period and yield of the forage to be equal to their feeding period and cumulative intake in the ruminant, respectively.

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