Contrastive or Interconvertible Relationships between Forage and Ruminant Growth Analysis Equations – A Simple Description using a Symmetry-like Characteristic –

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https://doi.org/10.5109/24329

出版情報：九州大学大学院農学研究院紀要. 44 (3/4), pp.279-285, 2000-02. Kyushu University

J. Fac. Agr., Kyushu Univ., 44 (3·4), 279–285 (2000)

Contrastive or Interconvertible Relationships between Forage and Ruminant Growth Analysis Equations – A Simple Description using a Symmetry–like Characteristic –

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(Received October 29, 1999 and accepted November 5, 1999)

The present study suggested (1) a symmetry–like characteristic hidden in the hypothetic equation unifying the forage and ruminant growth analysis equations, and (2) the breakdown of symmetry–like characteristic and corresponding resultants. The monistic breakdown of symmetry–like characteristic, which was shown by inserting either forage factors or ruminant factors into parameters, gave the contrastive relationship where the autotrophic characteristic of forage RGR (relative growth rate) and the heterotrophic characteristic of ruminant RGR were derived as special cases. The dualistic breakdown of symmetry–like characteristic, which was shown by inserting both forage factors and ruminant factors into parameters, gave the interconvertible relationship between forage RGR and ruminant RGR.

INTRODUCTION

In the ruminant production based on meadows or pastures, forages are not end products but are indispensable to the feeding of ruminant animals (Van Soest, 1982; Wheeler, 1987; Minson, 1990a; Humphreys, 1991). Forages and ruminants are equally important in the forage–ruminant production complex.

In our recent reports (Shimojo *et al.*, 1998a, b, 1999) growth analysis equations of forages and those of ruminants were unified into a hypothetic equation with parameters, and then were derived again from the unified equation as special cases. Forage growth and ruminant growth might show, in a manner, two aspects of the forage–ruminant production complex (Shimojo *et al.*, 1999). This suggests that a sort of symmetric characteristic is hidden in the unified equation and the breakdown of symmetry–like characteristic derives forage and ruminant growth analysis equations as special cases. The concept of symmetry and its breakdown is considered one of the tools to relate systematically things which seemingly look different, but we have not yet referred to this point in our previous reports (Shimojo *et al.*, 1998a, b, 1999).

The present study was designed to investigate (1) the symmetry–like characteristic that might be expected to be hidden in the hypothetic equation unifying forage and ruminant growth analysis equations (Shimojo *et al.*, 1998a, b, 1999), and (2) the way of its breakdown and corresponding resultants.

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SYMMETRY–LIKE CHARACTERISTIC AND ITS BREAKDOWN

Unifying forage and ruminant growth analysis equations and symmetry–like characteristic

(A) Reasons for unifying equations

The main reason why RGR [relative growth rate] equation with its components for forages (Hunt, 1990) and that for ruminants (Shimojo *et al.*, 1996, 1997) were unified into a hypothetic equation [H] (Shimojo *et al.*, 1998a, b) comes from the fact that both forages and ruminants grow by taking the outside energy in. In other words, the hypothetic equation was constructed in order to deal with both forages and ruminants in the analysis of energy taking in.

The simple process of unifying forage RGR and ruminant RGR is described as follows:

$$\text{Forage RGR} = \frac{1}{W_F} \cdot \frac{dW_F}{dt} = \left(\frac{1}{A} \cdot \frac{dW_F}{dt}\right) \cdot \left(\frac{A}{W_F}\right), \quad (1)$$

where W_F=forage dry weight, A=leaf area, $(1/A) \cdot (dW_F/dt)$=net assimilation rate [NAR], A/W_F=leaf area ratio [LAR], t=time.

$$\text{Ruminant RGR} = \frac{1}{W_R} \cdot \frac{dW_R}{dt} = \left(\frac{1}{W_R} \cdot \frac{dF}{dt}\right) \cdot \left(\frac{dW_R}{dF}\right), \quad (2)$$

where W_R=ruminant body weight, F=cumulative forage intake, $(1/W_R) \cdot (dF/dt)$=forage ingestion rate per unit W_R [FIRW$_R$], dW_R/dF=feed efficiency [FE] , t=time.

Unifying equations (1) and (2) gives the following equation as an example (Shimojo *et al.*, 1998a, b),

$$\text{H} = \left(\frac{1}{\alpha} \cdot \frac{d\beta}{dt}\right) \cdot \left(\frac{\alpha}{W}\right) \cdot \left(\frac{dW}{d\beta}\right), \quad (3)$$

where W=W_F or W_R, α and β are parameters, t=time.

(B) Symmetry–like characteristic of the unified equation

Equation (3) was given by two procedures: (i) uniting equations (1) and (2), and (ii) replacing forage and ruminant factors with common parameters. The unified equation (3) has four features. (a) The number of terms has increased by one to three. (b) α and β are exchangeable each other. (c) The choice is not made between forage and ruminant growth analyses. (d) Whichever analysis is related to W, α and β, RGR equation is inevitably given as follows:

$$\text{H} = \left(\frac{1}{\alpha} \cdot \frac{d\beta}{dt}\right) \cdot \left(\frac{\alpha}{W}\right) \cdot \left(\frac{dW}{d\beta}\right) = \frac{1}{W} \cdot \frac{dW}{dt}. \quad (4)$$

These four features suggest that a symmetry–like characteristic is hidden in the unified equation (3), though this estimation seems to be inaccurate.

Breakdown of symmetry–like characteristic

What are inserted into W, α and β will give the way of breakdown and corresponding resultants. The following two ways of breakdown are suggested in the present study: (i) the breakdown where either forage or ruminant factors are inserted, which is temporarily called monistic breakdown, (ii) the breakdown where both forage and ruminant factors are inserted, likewise called dualistic breakdown. The monistic breakdown will give a distinction between forage RGR and ruminant RGR, a sort of contrastive relationship between them. The dualistic breakdown will give a sort of interconvertible relationship between forage and ruminant RGRs. These two relationships will be described in the following two sections, respectively.

Monistic breakdown of symmetry–like characteristic and contrastive relationships

(A) Monistic breakdown of symmetry–like characteristic

The monistic breakdown of symmetry–like characteristic is given by inserting only forage factors or only ruminant factors into W, α and β of equation (3). This was already shown in our previous papers (Shimojo *et al.*, 1998a, b), where detailed descriptions of contrastive relationships were not shown. There are two monistic breakdowns: one is the breakdown into forage RGR and the other is the breakdown into ruminant RGR.

(B) Monistic breakdown into forage RGR

In equation (3) $\alpha=A$ and $\beta=W=W_F$, then there occurs the monistic breakdown into forage RGR [$\mathrm{H_F}$] as follows:

$$\mathrm{H_F}=\left(\frac{1}{A}\cdot\frac{dW_F}{dt}\right)\cdot\left(\frac{A}{W_F}\right)\cdot\left(\frac{dW_F}{dW_F}\right)$$

$$=\left(\frac{1}{A}\cdot\frac{dW_F}{dt}\right)\cdot\left(\frac{A}{W_F}\right), \tag{5}$$

$$=\frac{1}{W_F}\cdot\frac{dW_F}{dt}, \tag{6}$$

where $(1/A)\cdot(dW_F/dt)$=NAR, A/W_F=LAR, $(1/W_F)\cdot(dW_F/dt)$=forage RGR. The reduction in the number of terms occurs, from three (equation (3)) to two (equation (5)). The term, $(1/A)\cdot(dW_F/dt)$, in equation (5) shows that using leaves forages synthesize, mainly from carbon dioxide, water and solar radiation, the organic matter that is used for the growth (equation (6)). The important role of leaf area in the forage growth is shown analytically by NAR and LAR in equation (5). This is a sort of analytic description of the autotrophic characteristic of the forage growth.

(C) Monistic breakdown into ruminant RGR

In equation (3) $\alpha=W=W_R$ and $\beta=F$, then we get the other monistic breakdown, namely that into ruminant RGR [$\mathrm{H_R}$]. Thus,

$$\mathrm{H_R}=\left(\frac{1}{W_R}\cdot\frac{dF}{dt}\right)\cdot\left(\frac{W_R}{W_R}\right)\cdot\left(\frac{dW_R}{dF}\right)$$

$$=\left(\frac{1}{W_R}\cdot\frac{dF}{dt}\right)\cdot\left(\frac{dW_R}{dF}\right), \tag{7}$$

$$=\frac{1}{W_R}\cdot\frac{dW_R}{dt}, \tag{8}$$

where $(1/W_R)\cdot(dF/dt)$=$\mathrm{FIRW_R}$, dW_R/dF=FE, $(1/W_R)\cdot(dW_R/dt)$=ruminant RGR. The number of terms decreased from three (equation (3)) to two (equation (7)). The term, $(1/W_R)\cdot(dF/dt)$, in equation (7) shows that ruminants have to ingest forage organic matter for the growth (equation (8)). The important role of forage intake in the ruminant growth is shown analytically by $FIRW_R$ and FE in equation (7). This is a sort of analytic description of the heterotrophic characteristic of the ruminant growth.

(D) Contrastive relationships

The reduction in the number of terms from three to two is associated with the monistic breakdown. The atutotrophic characteristic of forage RGR (equation (5)) is in contrast to the heterotrophic characteristic of ruminant RGR (equation (7)). It is suggested that the contrastive relationship in the way of taking the outside energy in for growth results from the monistic breakdown of symmetry-like characteristic hidden in the hypothetic equation unifying forage and ruminant RGRs.

Dualistic breakdown of symmetry-like characteristic and interconvertible relationships

(A) Dualistic breakdown of symmetry-like characteristic

We take up the dualistic breakdown that will suggest an interconvertible relationship between forage RGR and ruminant RGR. This is given by inserting both forage and ruminant factors into W, α and β of equation (3). There are two dualistic breakdowns: one is the conversion of forage RGR into ruminant RGR and the other is the conversion of ruminant RGR into forage RGR.

(B) Conversion of forage RGR into ruminant RGR

In equation (3) $\alpha=\beta=W_F$ and $W=W_R$, then there occurs the dualistic breakdown into the following equation that is a mixture of forage and ruminant growth analyses [H_{F-R}]. Thus,

$$H_{F-R}=\left(\frac{1}{W_F}\cdot\frac{dW_F}{dt}\right)\cdot\left(\frac{W_F}{W_R}\right)\cdot\left(\frac{dW_R}{dW_F}\right). \tag{9}$$

There is no reduction in the number of terms, namely three for both equations (3) and (9). The form of equation (9) is changed as follows to get mean H_{F-R} over the interval t_1 to t_2 [$\overline{H_{F-R}}$]. Thus,

$$\overline{H_{F-R}}=\left(\frac{\log_e W_{F2}-\log_e W_{F1}}{t_2-t_1}\right)\cdot\left(\frac{W_{F2}-W_{F1}}{\log_e W_{F2}-\log_e W_{F1}}\cdot\frac{\log_e W_{R2}-\log_e W_{R1}}{W_{R2}-W_{R1}}\right)\cdot\left(\frac{W_{R2}-W_{R1}}{W_{F2}-W_{F1}}\right). \tag{10}$$

The essential point of equation (10) is that $(W_{F2}-W_{F1})$ is regarded as not only the harvested forage weight but also the cumulative forage intake by ruminants on condition that there is a complete consumption of the harvested forage. The first parenthesis in the right-hand side shows mean forage RGR. The second parenthesis shows the ratio of mean W_F to mean W_R [(mean W_F)/(mean W_R)]. The third parenthesis, $(W_{R2}-W_{R1})/(W_{F2}-W_{F1})$, is regarded as feed efficiency [FE]. Actually, the complete ingestion of harvested forages by ruminants may occur when forages are young and immature and low in the concentration of anti-quality components. Equation (10), therefore, suggests an issue of importance in the forage breeding and cultivation programs, particularly when tropical forages are targeted due to the lower intake (Minson, 1990b) that is generally related to lower digestibility (Minson, 1990c) and lower protein concentration (Minson, 1990d) compared with those of temperate forages.

The right–hand side of equation (10) has a structure of multiplying mean forage RGR by the product of (mean W_F)/(mean W_R) and FE. This will lead to the following conversion on condition that ruminant growth period (= the period of forage feeding to ruminants) is equalized to forage growth period. Thus,

$$\overline{H_{F-R}} = (\text{Mean forage RGR}) \cdot \left\{ \left(\frac{\text{Mean}\, W_F}{\text{Mean}\, W_R} \right) \cdot (\text{FE}) \right\}$$

$$= \left(\frac{\log_e W_{F2} - \log_e W_{F1}}{t_2 - t_1} \right) \cdot \left\{ \left(\frac{W_{F2} - W_{F1}}{\log_e W_{F2} - \log_e W_{F1}} \cdot \frac{\log_e W_{R2} - \log_e W_{R1}}{W_{R2} - W_{R1}} \right) \cdot \left(\frac{W_{R2} - W_{R1}}{W_{F2} - W_{F1}} \right) \right\}$$

$$= \frac{\log_e W_{R2} - \log_e W_{R1}}{t_2 - t_1} = \text{Mean ruminant RGR}. \qquad (11)$$

Equation (11) suggests a sort of procedure with which mean forage RGR is converted into corresponding mean ruminant RGR, provided that forages are completely eaten by ruminants and forage growth period and ruminant growth period are equalized.

(C) Conversion of ruminant RGR into forage RGR

In equation (3) $\alpha = \beta = W_R$ and $W = W_F$, then there is the other dualistic breakdown [H_{R-F}] as follows:

$$H_{R-F} = \left(\frac{1}{W_R} \cdot \frac{dW_R}{dt} \right) \cdot \left(\frac{W_R}{W_F} \right) \cdot \left(\frac{dW_F}{dW_R} \right). \qquad (12)$$

The reduction in the number of terms does not occur between equations (3) and (12). Changing the form of equation (12) gives mean H_{R-F} over the interval t_1 to t_2 [$\overline{H_{R-F}}$] as follows:

$$\overline{H_{R-F}} = \left(\frac{\log_e W_{R2} - \log_e W_{R1}}{t_2 - t_1} \right) \cdot \left(\frac{W_{R2} - W_{R1}}{\log_e W_{R2} - \log_e W_{R1}} \cdot \frac{\log_e W_{F2} - \log_e W_{F1}}{W_{F2} - W_{F1}} \right) \cdot \left(\frac{W_{F2} - W_{F1}}{W_{R2} - W_{R1}} \right). \qquad (13)$$

In equation (13) ($W_{F2} - W_{F1}$) is regarded as the cumulative forage intake by ruminants as well as the harvested forage weight on condition that there is a complete forage consumption. The first parenthesis in the right–hand side shows mean ruminant RGR. The second parenthesis shows the ratio of mean W_R to mean W_F [(mean W_R)/(mean W_F)]. The third parenthesis, ($W_{F2} - W_{F1}$)/($W_{R2} - W_{R1}$), is regarded as feed conversion [FC].

The right–hand side of equation (13) has a structure of multiplying mean ruminant RGR by the product of (mean W_R)/(mean W_F) and FC. This will lead to the following conversion on condition that there is a complete forage consumption by ruminants and growth periods are equalized between forages and ruminants. Thus,

$$\overline{H_{R-F}} = (\text{Mean ruminant RGR}) \cdot \left\{ \left(\frac{\text{Mean}\ W_R}{\text{Mean}\ W_F} \right) \cdot (\text{FC}) \right\}$$

$$= \left(\frac{\log_e W_{R2} - \log_e W_{R1}}{t_2 - t_1} \right) \cdot \left\{ \left(\frac{W_{R2} - W_{R1}}{\log_e W_{R2} - \log_e W_{R1}} \cdot \frac{\log_e W_{F2} - \log_e W_{F1}}{W_{F2} - W_{F1}} \right) \cdot \left(\frac{W_{F2} - W_{F1}}{W_{R2} - W_{R1}} \right) \right\}$$

$$= \frac{\log_e W_{F2} - \log_e W_{F1}}{t_2 - t_1} = \text{Mean forage RGR}. \qquad (14)$$

Equation (14) shows a sort of procedure for converting mean ruminant RGR into corresponding mean forage RGR, provided that ruminant growth period and forage growth period are equalized and ruminants eat forages completely.

(D) Interconvertible relationships

No reduction in the number of terms is associated with the dualistic breakdown. Forage RGR and ruminant RGR are related equivalently on condition that there is a complete consumption of harvested forages by ruminants and growth periods are equalized between forages and ruminants. The dualistic breakdown has two issues that should be discussed. (1) Forage RGR and ruminant RGR are forcedly related, but this will lead to the necessity of breeding forages that can be completely eaten by ruminants, an issue of great importance in ruminant agriculture. (2) In actual cases the forced equalization of growth periods between forages and ruminants will lead to a segmental treatment of ruminant growth period, because growth period is usually longer for ruminants than for harvested forages. However, this may give an image of the increase in meadow area with the growth of or the increase in the number of ruminants, when the forage harvested at once from the meadow is being fed to ruminants. The interconvertibility is associated with a sort of equivalent status between forage and ruminant production.

It is suggested that the interconvertible relationship between forage RGR and ruminant RGR results from the dualistic breakdown of symmetry–like characteristic hidden in the hypothetic equation unifying forage and ruminant RGRs.

Suggestions from the present analyses

The forage growth and the ruminant growth are different things, because forages are autotrophic and ruminants are heterotrophic. On one hand this emphasizes the distinction between them; on the other hand, the close relationship is formed due to the important role of forages as a major source of ruminant feeds.

This distinction and the close relationship are described systematically by the two ways of breakdown of symmetry–like characteristic hidden in the hypothetic equation that unifies forage and ruminant growth analysis equations: namely (1) the monistic breakdown suggesting the autotrophic characteristic of forage growth analysis and the heterotrophic characteristic of ruminant growth analysis, and (2) the dualistic breakdown suggesting the equivalent status between forage RGR and ruminant RGR through the interconvertible relationship between them. The present analyses might give a sort of unified viewpoint to the forage–ruminant production complex, but require further investigation.

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