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<https://doi.org/10.5109/24224>

出版情報：九州大学大学院農学研究院紀要. 42 (3/4), pp.361-364, 1998-03. Kyushu University
バージョン：
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Relationship between Two Different-Type Equations Analyzing Increase in Dry Matter Indigestibility with Growth of Forages

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(Received November 28, 1997 and accepted December 3, 1997)

This study was planned to relate two different-type equations analyzing the increase in dry matter indigestibility (IDMI) in the growth of forages. The following equation showed the relationship between two equations, namely, the left-hand side equation by Masuda (1985) and the right-hand side equation which was a changed form of the original equation by Shimojo *et al.* (1995).

$$\frac{I_1}{W_1} \cdot \left[\exp \left\{ (\overline{\text{RGR}}_i - \overline{\text{RGR}}_w) \cdot (t_2 - t_1) \right\} - 1 \right] = \left(1 - \frac{W_1}{W_2} \right) \cdot \left(\frac{\overline{\text{SFR}}}{\overline{\text{RGR}}_w} \cdot \frac{D}{W} - \frac{I_1}{W_1} \right),$$

where W = forage dry weight ($W_1 \neq W_2$), I = dry weight of indigestible materials, D = dry weight of digestible materials ($D_1 \neq D_2$), $\overline{\text{RGR}}_w$ = mean relative growth rate of forage, $\overline{\text{RGR}}_i$ = mean relative growth rate of I , $(1 - W_1/W_2)$ = forage growth index [FG index], SFR = mean specific formation rate of I per unit D , D/W = the ratio of D to W [D ratio], $\{(\text{SFR}/\overline{\text{RGR}}_w) \cdot (D/W) - I_1/W_1\}$ = a changed form of DMP index (DMP index: index for dry matter partition into D).

The following results were obtained:

RGR , was found to be related to SFR from their positions in the equation, and this might support the suggestion by Masuda (1985) about the close relation of RGR_i to SFR . SFR might substantially relate the equation by Masuda (1985) and the equation by Shimojo *et al.* (1995). It was suggested that there was a close relationship between two different-type equations analyzing the increase in dry matter indigestibility with growth of forages.

INTRODUCTION

There usually occurs the increase in the proportion of indigestible materials with growth of forages. This results in the increase in dry matter indigestibility, namely, the decrease in dry matter digestibility (Van Soest, 1982; Minson, 1990).

In a pioneering study on the analysis of the change in forage digestibility (Masuda, 1985), the increase in dry matter indigestibility was expressed using an equation including two factors which were relative growth rate of forage and that of indigestible materials. Subsequent reports (Shimojo *et al.*, 1995; Shimojo *et al.*, 1997a; Shimojo *et al.*, 1997b; Shimojo *et al.*, 1998) showed another equation in which indigestibility increases were expressed using relative growth rate of forage and formation rate of indigestible materials per unit dry weight of forage. These two different-type equations do not seem

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to be related in their original forms, but might be expected to be related by changing the form of equations.

This study was planned to relate the equation for analyzing indigestibility increases by Masuda (1985) and another equation (Shimojo *et al.*, 1995) by changing the form of the latter one.

TWO ANALYTICAL EQUATIONS AND THE RELATION

Equation by Masuda (1985)

The equation reported by Masuda (1985) for analyzing the increase in dry matter indigestibility [IDMI] with growth of forage is as follows:

$$\begin{aligned} \text{IDMI} &= \frac{I_2}{W_2} - \frac{I_1}{W_1} \\ &= \frac{I_1}{W_1} \cdot \left[\exp \{ (\overline{\text{RGR}}_i - \overline{\text{RGR}}_w) \cdot (t_2 - t_1) \} - 1 \right], \end{aligned} \quad (1)$$

where W = dry weight of forage, I = dry weight of indigestible materials, $\overline{\text{RGR}}_i$ = mean relative growth rate of I over the interval t_1 to t_2 , $\overline{\text{RGR}}_w$ = mean relative growth rate of forage over the interval t_1 to t_2 .

Equation (1) is considered very simple and easy to treat with.

In the same work (Masuda, 1985) the formation rate of I per unit weight of digestible materials was taken up and called specific formation rate [SFR] of I . Thus, SFR is as follows:

$$\text{SFR} = \frac{1}{D} \cdot \frac{dI}{dt}, \quad (2)$$

where D = dry weight of digestible materials.

SFR is considered a factor of importance to the analysis of the formation of I , because it is suggested that there is a close relationship between SFR and RGR_i (Masuda, 1985), though SFR is not included in equation (1).

$\overline{\text{RGR}}_i$ and $\overline{\text{RGR}}_w$ are approximately as follows:

$$\overline{\text{RGR}}_i = \frac{\log_e I_2 - \log_e I_1}{t_2 - t_1}, \quad (3)$$

$$\overline{\text{RGR}}_w = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}, \quad (4)$$

where e = the base of natural logarithm.

Equation by Shimojo *et al.* (1995)

Another equation reported by Shimojo *et al.* (1995) for the analysis of IDMI is as follows:

$$\begin{aligned} \text{IDMI} &= \frac{I_2}{W_2} - \frac{I_1}{W_1} \\ &= \left(1 - \frac{W_1}{W_2} \right) \cdot \left(\frac{\overline{\text{FRI}}}{\overline{\text{RGR}}_w} - \frac{I_1}{W_1} \right), \end{aligned} \quad (5)$$

where W = dry weight of forage ($W_1 \neq W_2$), I = dry weight of indigestible materials, $\overline{\text{FRI}}$ = mean formation rate of I per unit W over the interval t_1 to t_2 , $(1 - W_1/W_2)$ = forage growth index [FG index], $(\overline{\text{FRI}}/\overline{\text{RGR}_w} - I_1/W_1)$ = index for dry matter partition into indigestible materials [DMP index].

$\overline{\text{FRI}}$ is approximately as follows:

$$\overline{\text{FRI}} = \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1} \cdot \frac{I_2 - I_1}{t_2 - t_1} \quad (6)$$

Relating two equations

The form of equation (1) seems to be different from that of equation (5). In order to relate equation (1) and equation (5), some changes are made for the form of equation (5) as follows:

$$\begin{aligned} \frac{\overline{\text{FRI}}}{\overline{\text{RGR}_w}} &= \frac{\frac{1}{W} \cdot \frac{dI}{dt}}{\frac{1}{W} \cdot \frac{dW}{dt}} \\ &= \frac{\frac{1}{D} \cdot \frac{dI}{dt}}{\frac{1}{W} \cdot \frac{dW}{dt}} \cdot \frac{D}{W}, \end{aligned} \quad (7)$$

where $(1/D) \cdot (dI/dt) = \text{SFR}$, $(1/W) \cdot (dW/dt) = \text{RGR}_w$, D/W = the ratio of D to W [D ratio]. Then, equation (7) is rewritten as follows:

$$\frac{\overline{\text{FRI}}}{\overline{\text{RGR}_w}} = \frac{\overline{\text{SFR}}}{\overline{\text{RGR}_w}} \cdot \frac{D}{W}, \quad (8)$$

where $\overline{\text{SFR}}$ = mean SFR over the interval t_1 to t_2 .

$\overline{\text{SFR}}$ and D ratio over the interval t_1 to t_2 are approximately as follows:

$$\overline{\text{SFR}} = \frac{\log_e D_2 - \log_e D_1}{D_2 - D_1} \cdot \frac{I_2 - I_1}{t_2 - t_1}, \quad (9)$$

$$\text{D ratio} = \frac{D_2 - D_1}{\log_e D_2 - \log_e D_1} \cdot \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1} \quad (10)$$

where $D_1 \neq D_2$, $W_1 \neq W_2$.

Inserting equation (8) into equation (5) gives

$$\text{IDMI} = \left(1 - \frac{W_1}{W_2}\right) \cdot \left(\frac{\overline{\text{SFR}}}{\overline{\text{RGR}_w}} \cdot \frac{D}{W} - \frac{I_1}{W_1}\right), \quad (11)$$

where $\{(\overline{\text{SFR}}/\overline{\text{RGR}_w}) \cdot (D/W) - I_1/W_1\}$ is a changed form of DMP index.

Thus, relating two equations (1) and (11) leads to the following equation (12).

$$\frac{I_1}{W_1} \cdot [\exp \{(\overline{\text{RGR}_i} - \overline{\text{RGR}_w}) \cdot (t_2 - t_1)\} - 1] = \left(1 - \frac{W_1}{W_2}\right) \cdot \left(\frac{\overline{\text{SFR}}}{\overline{\text{RGR}_w}} \cdot \frac{D}{W} - \frac{I_1}{W_1}\right). \quad (12)$$

Equation (12) shows relationships among RGR_i , RGR_w and SFR. RGR_i is found to be related to SFR from their positions in this equation, and this may support the suggestion by Masuda (1985) about the close relation of RGR_i to SFR. Therefore, the analytical approach by Masuda (1985) to *I* formation and IDMI may prove to be of reasonableness. In other words, SFR may substantially relate equation (1) by Masuda (1985) and equation (5) by Shimojo *et al.* (1995) which seem to be different in type. This is why RGR_i , RGR_w and SFR are considered the essential elements required for constructing the method that analyzes, as simply as possible, the formation of *I* and IDMI in the pioneering work of Masuda (1985).

As shown in the following equation (13), there are cases in which the method for analyzing *I* formation and IDMI is transferred from the left-hand side equation (Masuda, 1985) to the right-hand side equation in the original form (Shimojo *et al.*, 1995).

$$\frac{I_1}{W_1} \cdot [\exp \{(\overline{RGR_i} - \overline{RGR_w}) \cdot (t_2 - t_1)\} - 1] = \left(1 - \frac{W_1}{W_2}\right) \cdot \left(\frac{\overline{FRI}}{\overline{RGR_w}} - \frac{I_1}{W_1}\right). \quad (13)$$

In such cases FRI in the right-hand side equation is found to be expressed using two different ways (Shimojo *et al.*, 1998) to give more detailed analysis of the formation of *I*.

Conclusions

It is suggested from this study that there is a close relationship between two different-type equations analyzing the increase in dry matter indigestibility with growth of forages.

ACKNOWLEDGEMENTS

We wish to thank Dr. Mitsuhiro Furuse who encouraged us during the writing this paper.

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