Formation of Indigestible Materials from Digestible Materials and Photosynthates in the Growth of Rhodes grass (Chloris gayana Kunth)

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Formation of Indigestible Materials from Digestible Materials and Photosynthates in the Growth of Rhodes grass (*Chloris gayana* Kunth)

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This study was conducted to analyze the formation of indigestible materials from digestible materials and new photosynthates in the growth of Rhodes grass, using the following equation.

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

where W = forage dry weight (W_1+W_2), I = dry weight of indigestible materials, L = amount of lignin, D = dry weight of digestible materials (D_1+D_2), dW/dt = new photosynthates, ($D+dW/dt$) = amount of source materials [S] for I formation, $(1/W)\cdot(dI/dt)$ = formation rate of I [FRI], $(D+dW/dt)/W$ = the ratio of S to W [S ratio], $\{1/(D+dW/dt)\}\cdot(dL/dt)$ = lignification rate of S [LRS], dI/dL = formation of I per unit increase in L [FIL].

This equation was applied to samples from Rhodes grass (Rg) cut at 25, 41 and 74 days of regrowth. Each attribute in the equation was given a bar on it to show mean value over the 1st interval of 16 days and over the 2nd interval of 33 days, respectively. The following results were obtained:

Higher $\overline{\text{FRI}}$ in the 1st interval than in the 2nd interval was mainly due to higher $\overline{\text{LRS}}$ in the 1st interval with some contribution by higher $\overline{\text{S ratio}}$. This suggested that lignification of source materials composed of digestible materials and new photosynthates was the main factor promoting the formation of indigestible materials in the comparison between the 1st and 2nd intervals. It was suggested that the new equation presented in this study gave a macro analysis of the formation of indigestible materials from digestible materials and new photosynthates with growth of tropical grasses.

INTRODUCTION

The forage digestibility is considered of primary importance to ruminant nutrition when forages are a main source of energy, and dry matter digestibility generally falls with growth of forage due to the increase in the proportion of indigestible materials (Van Soest, 1982; Minson, 1990). Following a pioneering study of Masuda (1985) on the analysis of the formation of indigestible materials, there were some reports (Shimojo *et al.*, 1995; Shimojo *et al.*, 1997a; Shimojo *et al.*, 1997b) in which simple equations were presented to relate the formation of indigestible materials with lignin and cell wall constituents.

The indigestible materials are actually formed from digestible materials present in

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forage and new photosynthates (Balasko *et al.*, 1981; Masuda, 1985), but this forming process does not appear to be elucidated analytically.

The present study was designed to make an analytical approach to the formation of indigestible materials from digestible materials present in forage and new photosynthates, and followed by an application to Rhodes grass (*Chloris gayana* Kunth).

METHOD FOR ANALYZING THE FORMATION OF INDIGESTIBLE MATERIALS FROM DIGESTIBLE MATERIALS AND PHOTOSYNTHATES

New method

First, the formation rate of indigestible materials [FRI] in forage is taken up and its instantaneous value is described in the same way as the production rate of leaf, stem or root in plant (Hunt, 1990).

Thus,

$$\mathrm{FRI} = \frac{1}{W} \cdot \frac{dI}{dt} \qquad (1)$$

where W = dry weight of forage, I = dry weight of indigestible materials.

The source materials [S] used for the formation of I are composed of digestible materials present in forage and new photosynthates.

Thus,

$$\mathrm{S} = D + \frac{dW}{dt}, \qquad (2)$$

where D = dry weight of digestible materials present in forage, dW/dt = amount of new photosynthates.

Then, lignification rate of S [LRS] is taken up as follows:

$$\mathrm{LRS} = \frac{1}{D + \frac{dW}{dt}} \cdot \frac{dL}{dt}, \qquad (3)$$

where L = amount of lignin.

Combining equations (1) and (3) leads to

$$\frac{1}{W} \cdot \frac{dI}{dt} = \frac{D+\frac{dW}{dt}}{W} \cdot \left(\frac{1}{D+\frac{dW}{dt}} \cdot \frac{dL}{dt} \right) \cdot \frac{dI}{dL}, \qquad (4)$$

where $(D+dW/dt)/W$ = the ratio of S to W [S ratio], dI/dL = formation of I per unit increase in L [FIL].

Thus, equation (4) shows that FRI is expressed as the product of S ratio, LRS and FIL.

Mean value over the interval t_1 to t_2 for each of FRI, S ratio, LRS and FIL is approximately as follows:

$$\overline{\mathrm{FRI}} = \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1} \cdot \frac{I_2 - I_1}{t_2 - t_1}, \qquad (5)$$

$$\overline{\mathrm{S\ ratio}} = \left(\frac{D_2 - D_1}{\log_e D_2 - \log_e D_1} + \frac{W_2 - W_1}{t_2 - t_1} \right) \cdot \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1}, \qquad (6)$$

$$\overline{\mathrm{LRS}} = \frac{1}{\dfrac{D_2 - D_1}{\log_e D_2 - \log_e D_1} + \dfrac{W_2 - W_1}{t_2 - t_1}} \cdot \frac{L_2 - L_1}{t_2 - t_1}, \qquad (7)$$

$$\overline{\mathrm{FIL}} = \frac{I_2 - I_1}{L_2 - L_1}, \qquad (8)$$

where e = the base of natural logarithm, $W_1 \neq W_2$, $D_1 \neq D_2$.

Previous method

To compare the new method with the previous method, a brief description of the previous method (Shimojo *et al.*, 1995) is made as follows:

$$\begin{aligned} \mathrm{FRI} &= \frac{1}{W} \cdot \frac{dI}{dt} \\ &= \frac{C}{W} \cdot \left(\frac{1}{C} \cdot \frac{dL}{dt}\right) \cdot \frac{dI}{dL}, \qquad (9) \end{aligned}$$

where W = dry weight of forage, I = dry weight of indigestible materials, C = amount of cell wall constituents, L = amount of lignin, $(1/W) \cdot (dI/dt)$ = FRI, C/W = the ratio of C to W [CWC ratio], $(1/C) \cdot (dL/dt)$ = formation rate of L per unit C [Specific FRL], dI/dL = formation of I per unit increase in L [FIL].

Specific FRL is associated with lignification rate of CWC. Thus, equation (9) shows that FRI is expressed as the product of CWC ratio, Specific FRL and FIL.

Mean value over the interval t_1 to t_2 for each of FRI and FIL was already shown by equation (5) and equation (8), respectively, therefore, that for each of CWC ratio and Specific FRL is approximately as follows:

$$\overline{\text{CWC ratio}} = \frac{C_2 - C_1}{\log_e C_2 - \log_e C_1} \cdot \frac{\log_e W_2 - \log_e W_1}{W_2 - W_1}, \qquad (10)$$

$$\overline{\text{Specific FRL}} = \frac{\log_e C_2 - \log_e C_1}{C_2 - C_1} \cdot \frac{L_2 - L_1}{t_2 - t_1}, \qquad (11)$$

where $W_1 \neq W_2$, $C_1 \neq C_2$.

APPLICATIONS OF NEW AND PREVIOUS METHODS TO RHODES GRASS

Characteristics of Rhodes grass (Rg) are shown in Table 1. Rg was a regrowth grass cut at 25, 41 and 74 days after the first cut and discard followed immediately by the dressing of a compound fertilizer ($N:P_2O_5:K_2O$ = 14:14:14 %) at a rate of 1.0 kg/a for each element.

Analysis using new method

Analytical results obtained using the new method over the 1st interval of 16 days (25 to 41 days) and over the 2nd interval of 33 days (41 to 74 days) are shown in Table 2a.

Table 1. Characteristics of Rhodes grass.

Regrowth (days)	25	41	74
Dry matter indigestibility: (%)	30.32	47.76	55.03
Dry weight of forage: W (g/m^2)	223.85	398.98	593.32
Dry weight of indigestible materials: I (g/m^2)	67.87	190.55	326.49
Dry weight of digestible materials: D (g/m^2)	155.98	208.43	266.83
Amount of lignin: L (g/m^2)	8.81	29.36	49.45
Amount of CWC: C (g/m^2)	162.93	313.17	472.00

Dry matter indigestibility: determined *in vitro* using rumen fluid of goats and pepsin.
Lignin: acid detergent lignin.
CWC: cell wall constituents.

Table 2. Analysis of the formation of indigestible materials in the growth of Rhodes grass (Rg) using the new and previous methods.

a) Analysis using the new method (formation from digestible materials and new photosynthates).

Interval Length of interval (days)	1 st (A) 16	2 nd (B) 33	 A/B
$\overline{\text{FRI}}$ (g/g/day)	0.0253	0.0084	3.0082
$\overline{\text{S ratio}}$ (g/g)	0.6332	0.4948	1.2798
$\overline{\text{LRS}}$ (g/g/day)	0.0067	0.0025	2.6642
$\overline{\text{FIL}}$ (g/g)	5.9698	6.7666	0.8823

FRI : formation rate of I per unit W.
S ratio : the ratio of S (source materials $= D + dW/dt$) to W.
LRS : lignification rate of S.
FIL : formation of I per unit increase in L.

b) Analysis using the previous method (Shimojo *et al.*, 1995).

Interval Length of interval (days)	1 st (P) 16	2 nd (Q) 33	 P/Q
$\overline{\text{FRI}}$ (g/g/day)	0.0253	0.0084	3.0082
$\overline{\text{CWC ratio}}$ (g/g)	0.7588	0.7906	0.9598
$\overline{\text{S pecific FRL}}$ (g/g/day)	0.0056	0.0016	3.5525
$\overline{\text{FIL}}$ (g/g)	5.9698	6.7666	0.8823

FRI : formation rate of I per unit W.
CWC ratio : the ratio of C to W.
S pecific FRL : formation rate of L per unit C.
FIL : formation of I per unit increase in L.

$\overline{\text{FRI}}$ in the 1st interval (0.0253) was higher than that in the 2nd interval (0.0084). $\overline{\text{S ratio}}$ was higher in the 1st interval compared to the 2nd interval (0.6332 versus 0.4948). $\overline{\text{LRS}}$ in the 1st interval (0.0067) was much higher than that in the 2nd interval (0.0025). $\overline{\text{FIL}}$ was slightly lower in the 1st interval compared to the 2nd interval (5.9698 versus 6.7666). Therefore, higher $\overline{\text{FRI}}$ in the 1st interval than in the 2nd interval was mainly due to higher $\overline{\text{LRS}}$ in the 1st interval with some contribution by higher $\overline{\text{S ratio}}$. This suggests that lignification of source materials composed of digestible materials and new photosynthates is the main factor promoting the formation of indigestible materials in the comparison made between the 1st and 2nd intervals in Rg.

Analysis using previous method

Analytical results obtained by the use of previous method over the 1st interval and over the 2nd interval are shown in Table 2b.

Higher $\overline{\text{FRI}}$ in the 1st interval than in the 2nd interval (0.0253 versus 0.0084) was due to higher $\overline{\text{Specific FRL}}$ in the 1st interval (0.0056) compared to that in the 2nd interval (0.0016), because both $\overline{\text{CWC ratio}}$ and $\overline{\text{FIL}}$ were slightly lower in the 1st interval than in the 2nd interval (0.7588 versus 0.7906, 5.9698 versus 6.7666, respectively). This suggests that lignification of cell wall is the main factor promoting the formation of indigestible materials in the comparison made between two growths of Rg.

Comparisons between new and previous methods

Cell wall constituents in the previous method [equation (9)] is replaced, in the new method [equation (4)], by the sum of digestible materials and new photosynthates. This replacement suggests that the new analysis refers more directly to the materials which are a target of lignification, when compared to the previous analysis. The contribution of lignification to the formation of indigestible materials is found to be large in both analyses. Two methods also include a common term FIL that is easy to calculate when estimating the effect of lignification on the formation of indigestible materials. Thus, using the new and previous methods, some information may be obtained for the macro analysis of the formation of indigestible materials with growth of tropical grasses.

Incorporation of FRI into the equation for increase in dry matter indigestibility

Either of the equations (4) and (9) for FRI can be incorporated into the following equation (12) that analyzes the increase in dry matter indigestibility [IDMI] in the growth of forages.

$$\begin{aligned}\text{IDMI} &= \frac{I_2}{W_2} - \frac{I_1}{W_1} \\ &= \left(1 - \frac{W_1}{W_2}\right) \cdot \left(\frac{\overline{\text{FRI}}}{\overline{\text{RGR}_\text{w}}} - \frac{I_1}{W_1}\right), \qquad (12)\end{aligned}$$

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

IDMI is originally a difference between initial and final indigestibilities of dry matter over the period, and this is expressed using a complex of W and I which are connected inseparably (equation (12)). As FG index refers only to the forage production factor that is taken compulsorily out of the complex, DMP index as the partition factor inevitably includes RGR_w to complete the inseparable connection.

Conclusions

It is suggested from this study that the new method gives a macro analysis of the formation of indigestible materials from digestible materials and new photosynthates in the growth of tropical grasses. The new and previous analytical methods should be applied to other tropical and temperate forages.

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