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Formation of Indigestible Materials and Increase in Dry Matter Indigestibility in the Growth of Two Tropical Forages

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This study was conducted to analyze the formation of indigestible materials [equation (A)] and the increase in dry matter indigestibility [equation (B)] in the growth of Rhodes grass (Rg) and Greenleaf desmodium (Gd).

$$\frac{1}{W} \cdot \frac{dI}{dt} = \frac{C}{W} \cdot \left(\frac{1}{C} \cdot \frac{dL}{dt} \right) \cdot \frac{dI}{dL}, \qquad \text{(A)}$$

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

$$\frac{I_2}{W_2} - \frac{I_1}{W_1} = \left(1 - \frac{W_1}{W_2} \right) \cdot \left(\frac{\overline{\mathrm{FRI}}}{\overline{\mathrm{RGR_w}}} - \frac{I_1}{W_1} \right), \qquad \text{(B)}$$

where $(I_2/W_2 - I_1/W_1)$ = increases in dry matter indigestibility [IDMI], $W_1 \neq W_2$, $(1 - W_1/W_2)$ = forage growth index [FG index], $\overline{\mathrm{RGR_w}}$ = mean relative growth rate of forage, $(\overline{\mathrm{FRI}}/\overline{\mathrm{RGR_w}} - I_1/W_1)$ = index for dry matter partition into indigestible materials [DMP index]. Each attribute was given a bar on it to show mean value over the interval t_1 to t_2.

The results obtained were as follows.

1. $\overline{\mathrm{FRI}}$ was higher in Rg than in Gd and this was due to both higher $\overline{\mathrm{CWC\ ratio}}$ and higher $\overline{\mathrm{FIL}}$ in Rg.
2. IDMI was larger in Rg compared to Gd, which was due to higher DMP index with some contribution by FG index.

It was suggested that this method was available for a macro analysis of the change in dry matter indigestibility occurring in the growth of forages.

INTRODUCTION

Those people who are engaged in the production of ruminants from forages should pay attention to the forage quality which affects the intake and productivity in animals (Van Soest, 1982; Minson, 1990a). Among the forage qualities dry matter digestibility is one of the major concerns to be taken up in the forage breeding programs.

As a forage plant grows its dry matter digestibility generally falls due to a increase in the proportion of indigestible materials. A study by Masuda (1985) is probably a pioneering one in which the process of changes in forage indigestibility during growth was

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analyzed using simple equations. This sort of analytical approach is considered important from a practical point of view, though in a micro level investigation there are complicated relationships between cell wall components and digestibility in forages (Jung and Allen, 1995). Shimojo *et al.* (1995) also presented a simple method for analyzing the formation of indigestible materials and increases in dry matter indigestibility, and applied it to some tropical grasses.

The present study was designed to apply this analytical method to a grass and a forage legume of tropical species which might be expected to show different tendencies in the formation of indigestible materials and in the increase in dry matter indigestibility during growth.

MATERIALS AND METHODS

Forage samples and their characteristics

Forages used in the present study were Rhodes grass (*Chloris gayana* Kunth) and Greenleaf desmodium (*Desmodium intortum* (Mill.) Urb.). They were regrowth forages cut at 35 and 63 days after the first cut and discard followed directly 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.

The characteristics of Rhodes grass (Rg) and Greenleaf desmodium (Gd) are shown in Table 1. The contents of cell wall constituents and lignin in forages were determined using the method by Goering and Van Soest (1970). The effects of silica on forage digestibility (Van Soest, 1982; Minson, 1990b) were not taken into account.

Table 1. Characteristics of Rhodes grass (Rg) and Greenleaf desmodium (Gd).

Forages	Rg		Gd	
Regrowth (days)	35	63	35	63
Dry matter digestibility[1] (%)	63.93	49.93	55.71	52.95
Dry matter indigestibility[1] (%)	36.07	50.07	44.29	47.05
Cell wall constituents: CWC (%)	73.80	77.89	51.49	57.02
Lignin[2] (%)	3.07	5.88	7.06	7.72
Dry weight (DW) of forage: W (g/m^2)	225.56	515.00	190.00	315.28
DW of indigestible materials: I (g/m^2)	81.36	257.87	84.16	148.35
Amount of CWC: C (g/m^2)	166.47	401.14	97.84	179.76
Amount of lignin: L (g/m^2)	6.93	30.26	13.41	24.33

1) *In vitro* determination using rumen fluid of goats and pepsin.
2) Acid detergent lignin.

Analytical methods

(1) Formation of indigestible materials in the growth of forage

According to our previous paper (Shimojo *et al.*, 1995) the following equation was used to analyze the formation of indigestible materials.

$$\frac{1}{W} \cdot \frac{dI}{dt} = \frac{C}{W} \cdot \left(\frac{1}{C} \cdot \frac{dL}{dt} \right) \cdot \frac{dI}{dL} , \qquad (1)$$

where W = dry weight of forage, I = dry weight of indigestible materials, L = amount of lignin, C = amount of cell wall constituents [CWC], $(1/W) \cdot (dI/dt)$ = formation rate of I per unit W [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].

In equation (1) lignin was related to both cell wall lignification and formation of indigestible materials with forage growth, which is based on the strong negative correlations between lignin content and cell wall digestion in forages sampled at a range of maturities (Jung and Allen, 1995). Thus, FRI was evaluated using CWC ratio, specific FRL and FIL.

The mean value over the interval t_1 to t_2 for each of FRI, CWC ratio, Specific FRL and FIL was approximately as follows:

$$\overline{\text{FRI}} = \frac{log_e W_2 - log_e W_1}{W_2 - W_1} \cdot \frac{I_2 - I_1}{t_2 - t_1}, \quad (2)$$

$$\overline{\text{CWC ratio}} = \frac{C_2 - C_1}{log_e C_2 - log_e C_1} \cdot \frac{log_e W_2 - log_e W_1}{W_2 - W_1}, \quad (3)$$

$$\overline{\text{Specific FRL}} = \frac{log_e C_2 - log_e C_1}{C_2 - C_1} \cdot \frac{L_2 - L_1}{t_2 - t_1}, \quad (4)$$

$$\overline{\text{FIL}} = \frac{I_2 - I_1}{L_2 - L_1}, \quad (5)$$

where e is the base of natural logarithm.

(2) Increase in dry matter indigestibility with forage growth

The increase in dry matter indigestibility [IDMI] over the interval t_1 to t_2 that incorporated FRI into it was described as follows:

$$\text{IDMI} = \frac{I_2}{W_2} - \frac{I_1}{W_1} = \left(1 - \frac{W_1}{W_2}\right) \cdot \left(\frac{\overline{\text{FRI}}}{\text{RGR}_w} - \frac{I_1}{W_1}\right), \quad (6)$$

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

It was suggested in equation (6) that IDMI was divided into growth part and indigestible part of a forage, and thus, IDMI was evaluated using FG index and DMP index.

RESULTS AND DISCUSSION

Analysis of the formation of indigestible materials in the growth of two forages

The results for the analysis of the formation of indigestible materials in Rg and Gd in the growth from 35 to 63 days are shown in Table 2a.

$\overline{\text{FRI}}$ over 28 day-growth for Rg was almost twice as high as that for Gd. $\overline{\text{CWC ratio}}$ was higher in Rg than in Gd, which was associated with higher content of CWC in Rg compared to Gd. $\overline{\text{Specific FRL}}$ showed only a small difference between two forages, implying that Rg and Gd were similar in the extent of cell wall lignification from the analytical point of view. $\overline{\text{FIL}}$ for RG was higher than that for Gd, and this suggested that

Table 2. Analysis of formation of indigestible materials and of increases in dry matter indigestibility in the growth of Rhodes grass (Rg) and Greenleaf desmodium (Gd).

a) Analysis of formation of indigestible materials.

Forages	Rg	Gd	Rg/Gd
Interval (days)	28	28	
$\overline{\text{FRI}}$ (g/g/day)	0.0180	0.0093	1.9403
$\overline{\text{CWC ratio}}$ (g/g)	0.7611	0.5444	1.3980
$\overline{\text{Specific FRL}}$ (g/g/day)	0.0031	0.0029	1.0783
$\overline{\text{FIL}}$ (g/g)	7.5658	5.8782	1.2871

FRI: formation rate of indigestible materials per unit of forage dry weight,
CWC ratio: the ratio of cell wall constituents to forage dry weight ,
Specific FRL: formation rate of lignin per unit of cell wall constituents,
FIL: formation of indigestible materials per unit increase in lignin.

b) Analysis of increase in dry matter indigestibility (IDMI).

Forages	Rg	Gd	Rg/Gd
IDMI	0.1400	0.0276	5.0755
FG index	0.5620	0.3974	1.4144
DMP index	0.2491	0.0694	3.5885

IDMI: increases in dry matter indigestibility,
FG index: forage growth index,
DMP index: index for dry matter partition into indigestible materials.

the extent to which indigestible materials was formed per unit increase in lignin was higher for Rg than for Gd.

Therefore, higher $\overline{\text{FRI}}$ in Rg than in Gd is mainly due to both higher $\overline{\text{CWC ratio}}$ and higher $\overline{\text{FIL}}$ in Rg. These results are associated with implications by Jung and Allen (1995) that reducing cell wall concentration is a target for improvement of grasses, whereas improving cell wall digestibility is a more important target for forage legumes.

Analysis of increase in dry matter indigestibility with growth of two forages

The results for the analysis of the increase in IDMI are shown in Table 2b. There was a larger IDMI for Rg compared to Gd. FG index was higher in Rg than in Gd. DMP index of Rg was much higher than that in Gd. Larger IDMI in Rg compared to Gd was due to higher DMP index with some contribution by FG index. Thus, the difference in IDMI between Rg and Gd may be probably related to the difference in $\overline{\text{FRI}}$ between two forages.

The underestimation of lignin content caused by the use of acid detergent lignin is somewhat larger in grasses than in forage legumes (Shimojo and Goto, 1987; Jung and Allen, 1995). The content of silica is generally higher in grasses compared to legumes (Wilson, 1982). There will be, therefore, some modifications in the results of analyses if there occurs a selection for the method of lignin determination and/or an incorporation of the effects of silica (Van Soest, 1982; Minson, 1990b).

In the present study using FRI and IDMI an analytical explanation was given to the

formation of indigestible materials and the dry matter indigestibility increases during the growth which showed different tendencies between a grass and a forage legume of tropical species. It is suggested that this method is available for a macro analysis of the change in dry matter indigestibility occurring in the growth of forages.

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