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# An Application of Growth Analysis Method to Simple Correlation Analysis between Dry Matter Indigestibility and Lignin Content with Growth of a Forage

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This study was conducted to apply the growth analysis method to the simple correlation analysis between dry matter indigestibility [DMI] and lignin content [LC] with growth of a forage. The growth was set between each sampling day [$t_k$] and the day [$t_m$], estimated from the regression line, when the mean value was given for each of DMI and LC. Terms used in the growth analysis method were forage relative growth rate [RGRw], the formation rate of indigestible materials for measured data [FRI] and that for estimated data [fri] from the regression line between DMI and LC, the formation rate of lignin [FRL], and the formation of indigestible materials per unit increase in lignin for measured data [FIL] and that for estimated data [fil]. The following results were obtained: The correlation coefficient [r], regression coefficient [b] and standard error of estimates [SEE] in the simple correlation analysis between DMI and LC were described using RGRw, FRI, fri, FRL, FIL and fil. FIL, fil, and the ratio or the difference between them seemed to influence, in some degree, the determination of r, b or SEE. It was suggested that the simple correlation analysis between DMI and LC was described using growth analysis method, implying influences of FIL and fil on the determination of r, b and SEE.

## INTRODUCTION

There is a positive correlation between dry matter indigestibility [DMI] and lignin content [LC] in the growth of a forage, and this is a reverse expression of the negative correlation of dry matter digestibility [DMD] with LC (Van Soest, 1982; Minson, 1990).

In the simple correlation analysis between two items, differences between each observed value and the mean value of observed values in each item are used to evaluate the correlation (Snedecor and Cochran, 1967a, b). It seems in the case of DMI and LC that above differences are those occurring in the period between each sampling day and the day when the mean value is given for each of DMI and LC. We showed that the increase in DMI with growth of forages was described using forage relative growth rate and formation rates of lignin and indigestible materials (Shimojo *et al.*, 1995, 1997a, b, 1998a, b). These suggest, therefore, a possibility of an application of this growth analysis method to the simple correlation analysis between DMI and LC in the growth of a forage, provided that the day when the mean value is given for each of DMI, LC and their components is estimated.

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The present study was designed to suggest a procedure for the expression of the simple correlation analysis between DMI and LC with growth of a forage, using the method of growth analysis between each sampling day and the day when the mean value is given for each of DMI and LC, and followed by an application to three tropical grasses.

## ESTIMATING THE DAY WHEN MEAN VALUE IS GIVEN FOR EACH OF DMI AND LC IN THE SIMPLE CORRELATION ANALYSIS BETWEEN THEM

The DMI and LC measured for samples collected at time $t_k$ ($k$=1, 2, ..., $n$) in the growth of a forage are expressed as $Y_k$ and $X_k$, respectively. The dry matter indigestibility estimated from the regression line between $Y_k$ and $X_k$ is expressed as $y_k$ [dmi]. Then, the mean dmi (=mean DMI) and the mean LC that is common to the measured values and the estimated values are expressed as $y_m$ (=$Y_m$) and $X_m$, respectively.

Using $X_m$ and $y_m$ on the regression line, the following equality is suggested when ($X_m$, $y_m$) is found between ($X_k$, $y_k$) and ($X_{k+1}$, $y_{k+1}$),

$$\frac{X_m - X_k}{X_{k+1} - X_k} = \frac{y_m - y_k}{y_{k+1} - y_k}. \qquad (1)$$

In the present study, the time [$t_m$] when the mean value is given for each of $y_m$ and $X_m$ might be estimated as follows:

$$t_m = t_k + \frac{X_m - X_k}{X_{k+1} - X_k} \cdot (t_{k+1} - t_k), \quad \text{or} \quad t_m = t_k + \frac{y_m - y_k}{y_{k+1} - y_k} \cdot (t_{k+1} - t_k). \qquad (2)$$

Then, ($X_k$, $Y_k$), ($X_k$, $y_k$) and ($X_m$, $y_m$) are described as follows, respectively:

$$(X_k, Y_k) = \left(\frac{L_k}{W_k}, \frac{I_k}{W_k}\right), \qquad (3)$$

$$(X_k, y_k) = \left(\frac{L_k}{W_k}, \frac{i_k}{W_k}\right), \qquad (4)$$

$$(X_m, y_m) = \left(\frac{L_m}{W_m}, \frac{i_m}{W_m}\right), \qquad (5)$$

where $W_k$=measured dry weight of forage at $t_k$, $L_k$=measured amount of lignin at $t_k$, $I_k$=measured dry weight of indigestible materials at $t_k$, $i_k$=estimated dry weight of indigestible materials at $t_k$ using the regression line, $W_m$=estimated forage dry weight at $t_m$ {$\neq(\sum W_k)/n$}, $L_m$=estimated amount of lignin at $t_m$ {$\neq(\sum L_k)/n$}, $i_m$=estimated dry weight of indigestible materials at $t_m$ {$\neq(\sum i_k)/n$}.

$W_m$, $L_m$ and $i_m$ are considered difficult to estimate, but in the present study they are each estimated according to the following procedures. As ($X_m$, $y_m$, $t_m$) is set between ($X_k$, $y_k$, $t_k$) and ($X_{k+1}$, $y_{k+1}$, $t_{k+1}$) on the regression line, $W_m$ that is common to dmi, DMI and LC might be estimated as follows:

$$W_m = W_k + \frac{t_m - t_k}{t_{k+1} - t_k} \cdot (W_{k+1} - W_k). \qquad (6)$$

Then, $L_m$ and $i_m$ might be estimated as follows, respectively:

$$L_m = W_m \cdot X_m \,, \qquad (7)$$

$$i_m = W_m \cdot y_m \,. \qquad (8)$$

As $y_m = Y_m$ and $W_m$ is common to $y_m$ and $Y_m$, $i_m = I_m$. Thus,

$$(X_m, Y_m) = \left( \frac{L_m}{W_m}, \frac{I_m}{W_m} \right), \qquad (9)$$

where $I_m$=estimated dry weight of indigestible materials at $t_m$ $\{\neq(\sum I_k)/n\}$.
The following is also obtained,

$$I_m = W_m \cdot Y_m \,. \qquad (10)$$

We believe that there are other reliable methods of estimating $t_m$, $W_m$, $L_m$, $i_m$ and $I_m$, but unfortunately we do not know them for the present. The use of equations (1)～(10) should be limited to the cases where there are normal relationships between DMI and LC, otherwise there will occur the difficulty in estimating $t_m$ due to the large dispersion of data causing low coefficients of correlation.

Tables 1, 2 and 3 show an application of equations (1)～(10) to three tropical grasses, namely Rhodes grass [Rg] (*Chloris gayana* Kunth), dallis grass [Dg] (*Paspalum dilatatum* Poir.) and bermuda grass [Bg] (*Cynodon dactylon* (L.) Pers.), which were regrown at our experimental field with a dressing of a compound fertilizer ($N:P_2O_5:K_2O$=14:14:14%), after the first cut and discard, at a rate of 1.0 kg/a in Rg and 0.7 kg/a in Dg and Bg for each element. In these cases, $t_m$, $W_m$, $L_m$, $i_m$ and $I_m$ were estimated for each grass using corresponding regression line.

In the present study, $(X_m/W_m, i_m/W_m, t_m)$ and $(X_m/W_m, I_m/W_m, t_m)$ will be used as a set of mean values for the estimated values $(X_k/W_k, i_k/W_k, t_k)$ and the measured values $(X_k/W_k, I_k/W_k, t_k)$, respectively, in the application of growth analysis method to the simple correlation analysis between DMI and LC with growth of a forage.

**Table 1.** Characteristics of Rhodes grass [Rg] and estimation of $t_m$ when mean dry matter indigestibility [DMI], lignin content [LC] and their components are given.

| $t_k$ (days) | 25 | 41 | 74 | 37.19 ($t_m$) |
|---|---|---|---|---|
| $W_k$ (g/m²) | 223.85 | 398.98 | 593.32 | 357.24 ($W_m$) |
| $L_k$ (g/m²) | 8.81 | 29.36 | 49.45 | 23.37 ($L_m$) |
| $I_k$ (g/m²) | 67.87 | 190.55 | 326.49 | 158.50 ($I_m$) |
| $i_k$ (g/m²) | 67.33 | 194.86 | 321.50 | 158.50 ($i_m$) |
| $X_k$ (=$L_k/W_k$) | 0.0394 | 0.0736 | 0.0833 | 0.0654 ($X_m$) |
| $Y_k$ (=$I_k/W_k$) | 0.3032 | 0.4776 | 0.5503 | 0.4437 ($Y_m$) |
| $y_k$ (=$i_k/W_k$) | 0.3008 | 0.4884 | 0.5419 | 0.4437 ($y_m$) |

$t_k$=regrowth days, $W_k$=measured dry weight of forage, $L_k$=measured amount of lignin, $I_k$=measured dry weight of indigestible materials, $i_k$=estimated dry weight of indigestible materials using the regression line, $X_k$=measured lignin content [LC], $Y_k$=measured dry matter indigestibility [DMI], $y_k$=estimated dry matter indigestibility [dmi] using the regression line, $X_m$=mean LC, $Y_m$=mean DMI, $i_m$=mean dmi, $t_m$=the day when $X_m$ and $y_m$ (=$Y_m$) are given, $W_m$=$W$ at $t_m$, $L_m$=$W_m \cdot X_m$, $I_m$=$W_m \cdot Y_m$, $i_m$=$W_m \cdot y_m$.

**Table 2.** Characteristics of dallis grass [Dg] and estimation of $t_m$ when mean dry matter indigestibility [DMI], lignin content [LC] and their components are given.

| $t_k$ (days) | 20 | 59 | 80 | 60.87 ($t_m$) |
|---|---|---|---|---|
| $W_k$ (g/m$^2$) | 213.20 | 676.53 | 780.40 | 685.78 ($W_m$) |
| $L_k$ (g/m$^2$) | 6.20 | 28.35 | 46.36 | 29.81 ($L_m$) |
| $I_k$ (g/m$^2$) | 59.16 | 272.10 | 422.90 | 279.25 ($I_m$) |
| $i_k$ (g/m$^2$) | 60.21 | 266.33 | 425.71 | 279.25 ($i_m$) |
| $X_k$ (=$L_k/W_k$) | 0.0291 | 0.0419 | 0.0594 | 0.0435 ($X_m$) |
| $Y_k$ (=$I_k/W_k$) | 0.2775 | 0.4022 | 0.5419 | 0.4072 ($Y_m$) |
| $y_k$ (=$i_k/W_k$) | 0.2824 | 0.3937 | 0.5455 | 0.4072 ($y_m$) |

The explanation of symbols and terms are shown in the footnote of Table 1.

**Table 3.** Characteristics of bermuda grass [Bg] and estimation of $t_m$ when mean dry matter indigestibility [DMI], lignin content [LC] and their components are given.

| $t_k$ (days) | 20 | 59 | 80 | 50.68 ($t_m$) |
|---|---|---|---|---|
| $W_k$ (g/m$^2$) | 203.40 | 424.80 | 767.20 | 377.57 ($W_m$) |
| $L_k$ (g/m$^2$) | 5.45 | 19.16 | 39.66 | 15.55 ($L_m$) |
| $I_k$ (g/m$^2$) | 76.44 | 211.85 | 389.89 | 174.02 ($I_m$) |
| $i_k$ (g/m$^2$) | 77.29 | 205.11 | 398.84 | 174.02 ($i_m$) |
| $X_k$ (=$L_k/W_k$) | 0.0268 | 0.0451 | 0.0517 | 0.0412($X_m$) |
| $Y_k$ (=$I_k/W_k$) | 0.3758 | 0.4987 | 0.5082 | 0.4609 ($Y_m$) |
| $y_k$ (=$i_k/W_k$) | 0.3800 | 0.4828 | 0.5199 | 0.4609 ($y_m$) |

The explanation of symbols and terms are shown in the footnote of Table 1.

## DESCRIPTION OF CHANGES IN dmi, DMI AND LC BETWEEN $t_k$ and $t_m$

The changes in dmi and those in DMI between $t_k$ and $t_m$ are described on referring to our previous reports (Shimojo *et al.*, 1995, 1997a, b, 1998a, b). For the convenience of calculation, changes in dmi (estimated) are described as follows:

$$\text{Changes in dmi} = y_k - y_m$$

$$= \frac{i_k}{W_k} - \frac{i_m}{W_m}$$

$$= \left(1 - \frac{W_m}{W_k}\right) \cdot \left(\frac{\overline{\text{fri}}}{\overline{\text{RGR}_w}} - \frac{i_m}{W_m}\right), \qquad (11)$$

where fri=formation rate of estimated indigestible materials per unit $W$ [$(1/W)\cdot(di/dt)$], $\text{RGR}_w$=relative growth rate of forages [$(1/W)\cdot(dW/dt)$].

$\overline{\text{fri}}$ and $\overline{\text{RGR}_w}$ are approximated as follows:

$$\overline{\text{fri}} = \frac{\log_e W_k - \log_e W_m}{W_k - W_m} \cdot \frac{i_k - i_m}{t_k - t_m}, \qquad (12)$$

$$\overline{\text{RGR}_\text{w}} = \frac{\log_e W_k - \log_e W_m}{t_k - t_m}, \qquad (13)$$

where $e$=the base of natural logarithm.

Then, changes in DMI (measured) is expressed as follows:

$$\text{Changes in DMI} = Y_k - Y_m$$

$$= \frac{I_k}{W_k} - \frac{I_m}{W_m}$$

$$= \left(1 - \frac{W_m}{W_k}\right) \cdot \left(\frac{\overline{\text{FRI}}}{\overline{\text{RGR}_\text{w}}} - \frac{I_m}{W_m}\right), \qquad (14)$$

where FRI=formation rate of measured indigestible materials per unit $W$ $[(1/W)\cdot(dI/dt)]$. $\overline{\text{FRI}}$ is approximated as follows:

$$\overline{\text{FRI}} = \frac{\log_e W_k - \log_e W_m}{W_k - W_m} \cdot \frac{I_k - I_m}{t_k - t_m}. \qquad (15)$$

The comparison of equations (11) and (14) suggests that the difference between dmi changes and DMI changes is due to the difference between fri and FRI. Both fri and FRI are divided furthermore into two components as follows, respectively:

$$\text{fri} = \frac{1}{W} \cdot \frac{di}{dt} = \left(\frac{1}{W} \cdot \frac{dL}{dt}\right) \cdot \frac{di}{dL}, \qquad (16)$$

$$\text{FRI} = \frac{1}{W} \cdot \frac{dI}{dt} = \left(\frac{1}{W} \cdot \frac{dL}{dt}\right) \cdot \frac{dI}{dL}, \qquad (17)$$

where $(1/W)\cdot(dL/dt)$=formation rate of lignin [$L$] per unit $W$ [FRL], $di/dL$=formation of $i$ per unit increase in $L$ [fil], $dI/dL$=formation of $I$ per unit increase in $L$ [FIL].

Therefore, fil and FIL might make the difference between changes in dmi and those in DMI through the difference between fri and FRI. $\overline{\text{fil}}$ and $\overline{\text{FIL}}$ are approximated as follows:

$$\overline{\text{fil}} = \frac{i_k - i_m}{L_k - L_m}, \qquad \overline{\text{FIL}} = \frac{I_k - i_m}{L_k - L_m}. \qquad (18)$$

Likewise, changes in LC is described as follows:

$$\text{Changes in LC} = X_k - X_m$$

$$= \frac{L_k}{W_k} - \frac{L_m}{W_m}$$

$$= \left(1 - \frac{W_m}{W_k}\right) \cdot \left(\frac{\overline{\text{FRL}}}{\overline{\text{RGR}_\text{w}}} - \frac{L_m}{W_m}\right). \qquad (19)$$

$\overline{\text{FRL}}$ is approximated as follows:

$$\overline{\text{FRL}} = \frac{\log_e W_k - \log_e W_m}{W_k - W_m} \cdot \frac{L_k - L_m}{t_k - t_m}. \quad (20)$$

## APPLICATION OF EQUATIONS (11), (14) AND (19) TO SIMPLE CORRELATION ANALYSIS BETWEEN DMI AND LC

In the simple correlation analysis between two items, correlation coefficient, regression coefficient and standard error of estimates are determined at least to give a broad outline of the correlation (Snedecor and Cochran, 1967a, b).

### (A) Correlation coefficient

For pairs of $(X_k, Y_k)$, correlation coefficient [r] is described as follows:

$$\text{r} = \frac{\sqrt{\sum_{k=1}^{n}(y_k - y_m)^2}}{\sqrt{\sum_{k=1}^{n}(Y_k - Y_m)^2}}. \quad (21)$$

An application of equations (11) and (14) to the calculation of r gives

$$\text{r} = \frac{\sqrt{\sum_{k=1}^{n}\left\{\left(1 - \frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{fri}}}{\overline{\text{RGR}_\text{w}}} - \frac{i_m}{W_m}\right)\right\}^2}}{\sqrt{\sum_{k=1}^{n}\left\{\left(1 - \frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRI}}}{\overline{\text{RGR}_\text{w}}} - \frac{I_m}{W_m}\right)\right\}^2}}$$

$$= \frac{\sqrt{\sum_{k=1}^{n}\left\{\left(1 - \frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRL}}\cdot\overline{\text{fil}}}{\overline{\text{RGR}_\text{w}}} - \frac{i_m}{W_m}\right)\right\}^2}}{\sqrt{\sum_{k=1}^{n}\left\{\left(1 - \frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRL}}\cdot\overline{\text{FIL}}}{\overline{\text{RGR}_\text{w}}} - \frac{I_m}{W_m}\right)\right\}^2}}. \quad (22)$$

Equation (22) suggests that as $i_m = I_m$, the determination of r is influenced by the relationship between fil and FIL, roughly speaking, the ratio of fil to FIL.

### (B) Regression coefficient

The regression line for $(X_k, Y_k)$ is expressed as $Y = \text{a} + \text{b}X$ where b is the regression coefficient. Thus, b is described as follows:

$$\text{b} = \frac{\sqrt{\sum_{k=1}^{n}(y_k - y_m)^2}}{\sqrt{\sum_{k=1}^{n}(X_k - X_m)^2}}. \quad (23)$$

An application of equations (11) and (19) to the calculation of b gives

$$b=\frac{\sqrt{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{fri}}}{\text{RGR}_w}-\frac{i_m}{W_m}\right)\right\}^2}}{\sqrt{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRL}}}{\text{RGR}_w}-\frac{L_m}{W_m}\right)\right\}^2}}$$

$$=\frac{\sqrt{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRL}}\cdot\overline{\text{fil}}}{\text{RGR}_w}-\frac{i_m}{W_m}\right)\right\}^2}}{\sqrt{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRL}}}{\text{RGR}_w}-\frac{L_m}{W_m}\right)\right\}^2}}. \quad (24)$$

It is suggested in equation (24) that the determination of b is, roughly speaking, influenced by the presence of fil in the numerator and the ratio of $i_m/W_m$ to $L_m/W_m$.

### (C) Standard error of estimates

Standard error of estimates [SEE] is related to the accuracy with which DMI is estimated from LC on the regression line. This sort of evaluation is of importance to the prediction of forage digestibility from chemical components in forages, and in Australian studies residual standard deviation is used (Minson, 1990).

SEE is described as follows:

$$\text{SEE}=\sqrt{\frac{\sum_{k=1}^{n}(Y_k-y_k)^2}{n-2}}$$

$$=\sqrt{\frac{\sum_{k=1}^{n}\{(Y_k-Y_m)-(y_k-y_m)\}^2}{n-2}}, \quad (25)$$

where $Y_m = y_m$.

An application of equations (11) and (14) to the calculation of SEE gives

$$\text{SEE}=\sqrt{\frac{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRI}}}{\text{RGR}_w}-\frac{I_m}{W_m}\right)-\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{fri}}}{\text{RGR}_w}-\frac{i_m}{W_m}\right)\right\}^2}{n-2}}$$

$$=\sqrt{\frac{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRI}}}{\text{RGR}_w}-\frac{\overline{\text{fri}}}{\text{RGR}_w}\right)\right\}^2}{n-2}}$$

$$=\sqrt{\frac{\sum_{k=1}^{n}\left\{\left(1-\frac{W_m}{W_k}\right)\cdot\left(\frac{\overline{\text{FRL}}}{\text{RGR}_w}\right)\cdot\left(\overline{\text{FIL}}-\overline{\text{fil}}\right)\right\}^2}{n-2}}, \quad (26)$$

where $I_m/W_m = i_m/W_m$.

**Table 4.** An application of growth analysis method to simple correlation analysis between dry matter indigestibility [DMI] and lignin content [LC] in the growth of Rhodes grass [Rg].

| | |
|---|---|
| Correlation coefficient [r] | 0.9970 (P<0.05) |
| Regression coefficient [b] | 5.4804 ($y_k$=0.0851+5.4804·$X_k$) |
| Standard error of estimates [SEE] | 0.0139 |

$$\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{fri}}/\overline{\text{RGR}_\text{w}}-i_m/W_m)\}^2\right]^{0.5}/\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{FRI}}/\overline{\text{RGR}_\text{w}}-I_m/W_m)\}^2\right]^{0.5} = 0.9970$$

$$\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{fri}}/\overline{\text{RGR}_\text{w}}-i_m/W_m)\}^2\right]^{0.5}/\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{FRL}}/\overline{\text{RGR}_\text{w}}-L_m/W_m)\}^2\right]^{0.5} = 5.4804$$

$$\left[\Sigma\{(1-W_m/W_k)\cdot(1/\overline{\text{RGR}_\text{w}})\cdot(\overline{\text{FRI}}-\overline{\text{fri}})\}^2/(3-2)\right]^{0.5} = 0.0139$$

$W_k$=measured dry weight of forage, $X_k$=measured lignin content [LC], $Y_k$=measured dry matter indigestibility [DMI], $y_k$=estimated dry matter indigestibility [dmi] using the regression line, $X_m$=mean LC, $Y_m$=mean DMI, $i_m$=mean dmi, $W_m$=$W$ at $t_m$, $L_m$=$W_m$·$X_m$, $I_m$=$W_m$·$Y_m$, $i_m$=$W_m$·$y_m$, $\overline{\text{fri}}$=formation rate of estimated indigestible materials per unit $W$, $\overline{\text{FRI}}$=formation rate of measured indigestible materials per unit $W$, $\overline{\text{FRL}}$=formation rate of lignin per unit $W$, $\overline{\text{RGR}_\text{w}}$=forage relative growth rate.

**Table 5.** An application of growth analysis method to simple correlation analysis between dry matter indigestibility [DMI] and lignin content [LC] in the growth of dallis grass [Dg].

| | |
|---|---|
| Correlation coefficient [r] | 0.9984 (P<0.05) |
| Regression coefficient [b] | 8.6761 ($y_k$=0.0301+8.6761·$X_k$) |
| Standard error of estimates [SEE] | 0.0105 |

$$\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{fri}}/\overline{\text{RGR}_\text{w}}-i_m/W_m)\}^2\right]^{0.5}/\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{FRI}}/\overline{\text{RGR}_\text{w}}-I_m/W_m)\}^2\right]^{0.5} = 0.9984$$

$$\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{fri}}/\overline{\text{RGR}_\text{w}}-i_m/W_m)\}^2\right]^{0.5}/\left[\Sigma\{(1-W_m/W_k)\cdot(\overline{\text{FRL}}/\overline{\text{RGR}_\text{w}}-L_m/W_m)\}^2\right]^{0.5} = 8.6761$$

$$\left[\Sigma\{(1-W_m/W_k)\cdot(1/\overline{\text{RGR}_\text{w}})\cdot(\overline{\text{FRI}}-\overline{\text{fri}})\}^2/(3-2)\right]^{0.5} = 0.0105$$

The explanation of symbols and terms are shown in the footnote of Table 4.

Equation (26) suggests that the determination of SEE is influenced by the relationship between FIL and fil, roughly speaking, the difference between them.

An application of equations (22), (24) and (26) to the calculation of r, b and SEE using actual data is shown for Rg (Table 4), Dg (Table 5) and Bg (Table 6). This suggests that the simple correlation analysis between DMI and LC is reduced, in some degree, to the relationships between FIL and fil, if growth analysis method is applied between each sampling day and the day when the mean value is given for each of DMI and LC. FIL and fil are considered indices for the relationship between lignification and the formation of indigestible materials with growth of forages in the measured data and in the estimated data, respectively. This might give a sort of growth analytic explanation of the simple correlation analysis between DMI and LC.

**Table 6.** An application of growth analysis method to simple correlation analysis between dry matter indigestibility [DMI] and lignin content [LC] in the growth of bermuda grass [Bg].

| | |
|---|---|
| Correlation coefficient [r] | 0.9812 ($P>0.05$) |
| Regression coefficient [b] | 5.6166 ($y_k=0.2295+5.6166 \cdot X_k$) |
| Standard error of estimates [SEE] | 0.0201 |

$$\left[\Sigma\left\{\left(1-W_m/W_k\right)\cdot\left(\overline{\mathrm{fri}}/\overline{\mathrm{RGR}}_{\mathrm{w}}-i_m/W_m\right)\right\}^2\right]^{0.5}/\left[\Sigma\left\{\left(1-W_m/W_k\right)\cdot\left(\overline{\mathrm{FRI}}/\overline{\mathrm{RGR}}_{\mathrm{w}}-I_m/W_m\right)\right\}^2\right]^{0.5} = 0.9812$$

$$\left[\Sigma\left\{\left(1-W_m/W_k\right)\cdot\left(\overline{\mathrm{fri}}/\overline{\mathrm{RGR}}_{\mathrm{w}}-i_m/W_m\right)\right\}^2\right]^{0.5}/\left[\Sigma\left\{\left(1-W_m/W_k\right)\cdot\left(\overline{\mathrm{FRL}}/\overline{\mathrm{RGR}}_{\mathrm{w}}-L_m/W_m\right)\right\}^2\right]^{0.5} = 5.6166$$

$$\left[\Sigma\left\{\left(1-W_m/W_k\right)\cdot\left(1/\overline{\mathrm{RGR}}_{\mathrm{w}}\right)\cdot\left(\overline{\mathrm{FRI}}-\overline{\mathrm{fri}}\right)\right\}^2/\left(3-2\right)\right]^{0.5} = 0.0201$$

The explanation of symbols and terms are shown in the footnote of Table 4.

## Conclusions

It is suggested from this study that the simple correlation analysis between DMI and LC with growth of a forage is described using RGRw, FRI, fri, FRL, FIL and fil which are calculated between each sampling day and the day when the mean value is given for each of DMI and LC. This implies, roughly speaking, influences of FIL and fil on the determination of r, b and SEE.

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