Determination dry matter digestibility of tropical forage using nutrient composition

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Abstract. The objective of this study was to investigate the relationship between dry matter digestibility (DMD) and nutrient composition parameters in tropical forage (grass, legume, and a combination of both) and determining prediction equation for dry matter digestibility using nutrient composition variables as the predictor. The nutrient composition consists of 62 forages (31 grasses and 31 legumes), included of ash, crude protein (CP), ether extract (EE), crude fiber (CF), nitrogen-free extract (NFE), neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose, cellulose and DMD, all expressed as a percentage of dry matter. Multiple linear regression analysis was used to measure DMD estimated models. Models were validated with the coefficient of determination (R2), mean absolute deviation (MAD), root mean square error (RMSE), mean absolute percentage error (MAPE), were taken into consideration. Our result confirm that the nutrient composition can be efficiently used to determine the DMD of tropical forages, grasses, and legumes Prediction equation DMD in tropical forage, grass and legume were DMD = 104.267 - 0.918 ADF - 0.374 Hemicellulose, DMD = 110.409 - 1.363 ADF, DMD = 102.864 - 1.336 NDF + 0.602 Hemicellulose + 0.938 Cellulose, respectively.

1. Introduction

Forage is the main source of feed for ruminants for livestock farmers in Indonesia, so to increase ruminant livestock production must be followed by an increase in the supply of forage that is sufficient both in quantity and quality. Forage can be provided with a combination of grass and legume needed to complement the nutrient elements needed by livestock [1]. There is a difference in quality between tropical and subtropical forages, where the content of tropical forage fibers is higher and protein is lower than subtropical forages [2].

Chemical composition is based on the number of nutrients content (especially energy and protein) available that can be digested [3]. The quality of forage nutrition can be determined through the choice of forage, but environmental and management factors are the most influence on forage quality. Temperature and humidity are two environmental variables for plant growth which greatly affect the quality of forage [4]. In addition, it also depends on the level of maturity at the time of harvest and withering time to reach the right reserve of dry matter. With the growth phase increasing, the fiber fraction increases. The fiber fraction represents the more digestible parts of the plant that are needed on the digestibility.
Prediction equations of dry matter digestible (DMD) for different qualities of grass can differ depending on the combination of maturity parameters of the most influential agronomic parameters, namely fertilization rates, harvest times, and grass varieties [5]. The aim of the present study was to investigate the relationship between dry matter digestibility and nutrient composition parameters in forage, grass, and legume and determining prediction equation for dry matter digestibility using nutrient composition variables as the predictor.

2. Material and Methods

Multiple data sets were compiled to evaluated estimates of DMD and to relate DMD to nutrient composition. The database used in this study was from research published articles that were obtained from the thesis, dissertation, and journals. This database used is the composition of tropical forage nutrients (grass, legume, and combination of both) and DMD experiments are carried out directly on ruminants.

A total of 225 samples were identified had DMD data from 56 references obtained. After preprocessing the data, there are 62 samples were used for this experiment to be carried out in the next step. Data was comprised of 62 tropical forage, which consisted of grass/gramineae (n = 31), legume/leguminose (n = 31), and forage was combination of both. The variables included contents of ash, crude protein (CP), extract ether (EE), crude fiber (CF), nitrogen-free extract (NFE), neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose, cellulose and DMD, all expressed as a percentage of dry matter (%DM). The summary of the chemical composition of tropical forage, grass, and legume used in the database is presented in Table 1.

### Table 1. Summary of nutrient composition (%DM) and digestibility of tropical forage (n = 62), grass (n = 31) and legume (n = 31)

| Parameter | Forage | Grass | Legume |
|-----------|--------|-------|--------|
|           | Mean   | Min   | Max    | Mean   | Min   | Max    | Mean   | Min   | Max    |
| Ash       | 7.35±4.54 | 1.52  | 18.04  | 5.84±5.72 | 1.52  | 18.04  | 8.86±2.12 | 4.80  | 12.89  |
| CP        | 14.30±6.87 | 3.33  | 28.78  | 9.13±3.86 | 3.33  | 22.56  | 19.48±5.07 | 11.77 | 28.78  |
| EE        | 2.83±1.20 | 0.95  | 6.88   | 1.98±0.54 | 0.95  | 5.62   | 3.68±1.08 | 2.00  | 6.88   |
| CF        | 26.55±7.98 | 9.11  | 38.42  | 30.47±3.93 | 22.23 | 38.42  | 22.63±9.07 | 9.11  | 37.10  |
| NFE       | 46.12±4.78 | 36.00 | 59.59  | 46.89±5.15 | 36.00 | 59.59  | 43.35±4.33 | 36.32 | 54.48  |
| NDF       | 57.18±17.69 | 28.33 | 92.13  | 72.42±7.68 | 46.18 | 92.13  | 41.94±9.85 | 28.33 | 59.34  |
| ADF       | 34.65±9.09 | 17.32 | 52.70  | 31.80±6.04 | 29.94 | 52.76  | 28.69±7.62 | 17.32 | 43.45  |
| Hemicellulose | 22.52±10.65 | 3.69  | 45.99  | 28.72±5.59 | 15.02 | 45.99  | 13.25±4.63 | 3.69  | 30.09  |
| Cellulose | 23.51±8.48 | 4.89  | 39.24  | 27.83±8.03 | 4.89  | 39.24  | 19.20±6.59 | 5.11  | 32.48  |
| Ca        | 1.45±0.85 | 0.39  | 2.17   | 0.77±0.53 | 0.39  | 1.14   | 2.14±0.04 | 2.11  | 2.17   |
| P         | 0.49±0.21 | 0.33  | 0.79   | 0.63±0.23 | 0.47  | 0.79   | 0.34±0.01 | 0.33  | 0.35   |
| DMD       | 64.77±12.56 | 27.61 | 83.54  | 56.71±11.58 | 27.61 | 79.47  | 72.84±7.25 | 58.05 | 83.54  |

Note: CP, crude protein; EE, extract ether; CF, crude fiber; NFE, nitrogen-free extract; NDF, neutral detergent fiber; ADF, acid detergent fiber.

All covariates were jointly checked for Pearson correlations between the covariates were analyzed. To obtain equations to predict the dietary energy values, a model was used in which the DMD was
given as a function of nutrient composition variables, considering the adjustment of the multiple linear regression model [6].

\[ Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n + \varepsilon \]  

Where Y is the DMD (DMD forage, grass, and legume), \( \beta \) is the intercept, \( x \) is independent variables represented was determined in this study, and \( \varepsilon \) is the error. An internal evaluation, according to the method was carried out to validate the prediction equation, selected among the highest coefficient determination (R²) [6] for each predictor variable. The validation process consisted of comparing the DMD actual value with the DMD value predicted by the equation elaborated in the present study. The validation was undertaken using error value with mean absolute deviation (MAD) [7]; root mean square error (RMSE) [6]; mean absolute percentage error (MAPE) [8]. For each of the error values, equations with fewer errors were scored better and were considered the most appropriate. All statistical analyses were performed using IBM SPSS 22 version.

3. Results and Discussion

3.1. Relationships Between Forage, Grass and Legume Nutrient Contents and DMD

The correlation coefficients of the linear relationship between nutrient composition and DMD in tropical forage, grass, and legume presented in Table 2, Table 3 and Table 4, respectively. Relating forage, grass, and legume nutrient composition and DMD showed (1) higher correlation coefficient for fiber fraction with the other nutrient, (2) crude fiber and fiber fraction with DMD were negatively related.

|       | Ash   | CP    | EE    | CF    | NFE   | NDF   | ADF   | Hem   | Cel   | DMD   |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Ash   | 1     | 0.524** | 0.338* | -0.463** | -0.297* | -0.243 | 0.025 | -0.425** | -0.122 | -0.103 |
| CP    | 1     | 0.762** | -0.814** | -0.215 | -0.855** | -0.689** | -0.832** | -0.590** | 0.650** |
| EE    | 1     | -0.649** | -0.153 | -0.827** | -0.813** | -0.680** | -0.804** | 0.608** |
| CF    | 1     | -0.263* | 0.726** | 0.690** | 0.616** | 0.530** | -0.563** |
| NFE   | 1     | 0.059  | -0.108 | 0.191 | 0.133 | 0.003 |
| NDF   | 1     | 0.877** | 0.912** | 0.707** | -0.830** |
| ADF   | 1     | 0.604** | 0.808** | -0.829** |
| Hem   | 1     | 0.484** | -0.672** |
| Cel   | 1     | -0.609** |
| DMD   | 1     |       |       |       |       |       |

Note: CP, crude protein; EE, extract ether; CF, crude fiber; NFE, nitrogen-free extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; Hem, hemicellulose; Cel, Cellulose; *, P=0.05; **, P=0.01.

Forage digestibility especially grasses will decrease with increasing NDF and ADF because this part is difficult to digest in the rumen [9]. NDF contains lignin which cannot be digested as a digestive limiting factor that is very resistant to strong acids and microbial degradation, so it cannot be digested [10]. The ratio of lignin to fiber is greater in legumes compared to grass so it has more lignin than grass-based on DM [9]. Lignin in legumes is all concentrated in the xylem, whereas lignin in the grass is spread evenly in all tissues except phloem [9].

Xylem in legumes is almost completely indigestible, but the remaining tissue is very easily digested; therefore the legume trajectory rate is faster than grass because lower digestible fiber...
concentrations can inhibit grass digestibility [11; 12]. The cell wall content of a plant depends on the part of the plant and cutting edge which is one of the most important factors that can affect the nutrient content of forage [13]. Nevertheless, it does not mean that the other nutrients do not affect digestibility. The increase in digestibility can be caused by a protein degraded by microbes during fermentation activity in the rumen [14], fat in feed more than 5% will obtain digestive processes in the rumen in ruminants [15].

**Table 3.** Correlation coefficient between nutrient composition and DMD of tropical grass (n = 31)

|       | Ash | CP      | EE       | CF       | NFE      | NDF      | ADF      | Hem      | Cel      | DMD      |
|-------|-----|---------|----------|----------|----------|----------|----------|----------|----------|----------|
| Ash   | 1   | 0.541** | -0.189   | -0.327   | 0.357*   | -0.267   | 0.152    | -0.665** |          |          |
| CP    | 1   | 0.406*  | -0.503** | -0.685** | -0.269   | 0.166    | -0.550** | -0.130   | -0.011   |          |
| EE    | 1   | -0.001  | -0.608** | -0.485** | -0.272   | -0.374*  | -0.716** | 0.168    |          |          |
| CF    | 1   | 0.014   | 0.091    | -0.158   | 0.297    | -0.152   | 0.150    |          |          |          |
| NFE   | 1   | 0.330*  | 0.016    | 0.437*   | 0.437**  | -0.075   |          |          |          |          |
| NDF   | 1   | 0.693** | 0.626**  | 0.451*   | -0.658** |          |          |          |          |          |
| ADF   | 1   | -0.128  | 0.538**  | -0.768** |          |          |          |          |          |          |
| Hem   | 1   | 0.039   | -0.075   |          |          |          |          |          |          |          |
| Cel   | 1   | -0.369* |          |          |          |          |          |          |          |          |
| DMD   | 1   |         |          |          |          |          |          |          |          |          |

Note: CP, crude protein; EE, extract ether; CF, crude fiber; NFE, nitrogen-free extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; Hem, hemicellulose; Cel, Cellulose; *, P=0.05; **, P=0.01.

**Table 4.** Correlation coefficient between nutrient composition and DMD of tropical legume (n = 31)

|       | Ash | CP      | EE       | CF       | NFE      | NDF      | ADF      | Hem      | Cel      | DMD      |
|-------|-----|---------|----------|----------|----------|----------|----------|----------|----------|----------|
| Ash   | 1   | 0.475** | -0.228   | -0.469** | -0.121   | -0.374*  | -0.218   | -0.436*  | -0.216   | -0.453*  |
| CP    | 1   | 0.525** | -0.895** | 0.341    | -0.805** | -0.714** | -0.539** | -0.592** | 0.769**  |          |
| EE    | 1   | -0.592**| 0.266    | -0.659** | -0.819** | -0.055   | -0.848** | 0.445*   |          |          |
| CF    | 1   | -0.671**| 0.918**  | 0.829**  | 0.589**  | 0.715**  | -0.857** |          |          |          |
| NFE   | 1   | -0.634**| -0.591** | -0.376*  | -0.490** | 0.563**  |          |          |          |          |
| NDF   | 1   | 0.890** | 0.664**  | 0.798**  | -0.879** |          |          |          |          |          |
| ADF   | 1   | 0.250   | 0.945**  | -0.714** |          |          |          |          |          |          |
| Hem   | 1   | 0.143** | -0.697** |          |          |          |          |          |          |          |
| Cel   | 1   | -0.540**|          |          |          |          |          |          |          |          |
| DMD   | 1   |         |          |          |          |          |          |          |          |          |

Note: CP, crude protein; EE, extract ether; CF, crude fiber; NFE, nitrogen-free extract; NDF, neutral detergent fiber; ADF, acid detergent fiber; Hem, hemicellulose; Cel, Cellulose; *, P=0.05; **, P=0.01.

3.2. **Prediction of DMD**

The prediction equations of DMD of the ruminant are presented in Table 5. The prediction equation for DMD had higher R2 was obtain when ADF was considered. In the current study, ADF appeared
among the most important predictor DMD in the 3 equation shows the best fit. DMD equations in the published articles showed too the ADF is the defining factor [16], still used today to estimate DMD. Fibrous parameters, especially ADF (but also NDF), decrease the availability of nutrients in high fiber diets and tend to accelerate rumen filling and limit feed intake [10; 17]. The combination of ADF and hemicellulose; ADF; ADF, hemicellulose, and cellulose give the highest prediction for DMD tropical forage, grass, and legume, respectively. Digestibility is not only influenced by one nutrient composition but also is influenced by the composition of other nutrients that are consumed with the feed [18].

Table 5. Prediction equation DMD and validate with published equation of DMD

| Application       | Model                                | n  | $R^2$ | MAD | RMSE | MAPE (%) |
|-------------------|--------------------------------------|----|-------|-----|------|----------|
| Forage            | DMD = 103.840 – 0.920 ADF – 0.319 Hemicellulose | 62 | 0.733 | 5.94| 7.32 | 10%      |
| Grass             | DMD = 116.473 – 1.471 ADF            | 31 | 0.589 | 5.96| 7.30 | 12%      |
| Legume            | DMD = 102.838 – 1.335 ADF – 0.733 Hemicellulose + 0.939 Cellulose | 31 | 0.868 | 4.22| 5.90 | 6%       |
| Redfearn and Zhang (2016) | DMD = 88.9 – 0.779 ADF | 8.70 | 10.89 | 15% |

Note: n, sum of forages; MAD, mean absolute deviation; RMSE, root mean square error; MAPE, mean absolute percentage error; ADF, acid detergent fiber.

Figure 1. Relationship between observed DMD with predicted DMD (a) tropical forage (grass + legume), (b) grass, (c) legume, and (d) Redfearn and Zhang (2016).
The DMD prediction equation (Table 5) has the highest R2 value compared to the other equations for each category. In addition, it also has the lowest MAD, RMSE, and MAPE values. Error estimation is also an important validation tool [19] in the equation modeling stage. The lower the error estimation incidence, the closer the estimated value is to the observed value [20]. Lower error validation shows the prediction equation in this study can be used to determine the quality of DMD for tropical forages. Because prediction equation DMD of tropical forage, grass, legume show MAD, RMSE, and MAPE values are lower than the DMD equation \( = 88.9 - 0.779 \text{ADF} \) [16] so that this equation can be used to determine DMD quality in tropical forage.

Grass has a high variability of nutrient content due to different combinations of the most influential agronomic parameters (maturity stage, fertilization rate, harvest time, and grass variety) [5]. In tropical legumes, error validation shows the lowest error rate compared to the DMD equation [20], and also when compared to the forage and grass prediction models so that the equation is accurate in determining the DMD of tropical legumes. The relationship between observed DMD with predicted DMD tropical forage and Redfearn and Zhang (2016) is presented in Figure 1.

4. Conclusions

Equation DMD of tropical forage, grass and legume show can efficiently relate nutrient digestibility with nutrient composition and can be used to predict DMD. The equation for DMD in tropical forage, grass and legume were DMD = 104.267 - 0.918 ADF - 0.374 Hemicellulose, DMD = 110.409 - 1.363 ADF, DMD = 102.864 - 1.336 NDF + 0.602 Hemicellulose + 0.938 Cellulose, respectively.

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