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Elephant grass, rice straw and maize silage as feeds: a dynamic modelling approach on their degradation kinetics

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Abstract. This study aimed to evaluate nutritive value of elephant grass, rice straw and maize silage by using a dynamic modelling approach. Data on dry matter (DM) degradation characteristics were compiled, i.e., soluble (S), degradable (D) and undegradable (U) fractions, and rate of degradation of the degradable fraction (k_d). Each of the S, D or U fraction was assumed to have a specific rate of passage (k_p). The S, D and U fractions are dynamically changed over time. Degraded S and D fractions form a pool namely cumulative S and D (CSD) and it dynamically increases over time. Integration of all the dynamic models was performed in Vensim software version 7.3.5 using the Euler method. Results revealed that soluble fraction present in elephant grass, rice straw and maize silage disappeared within early hours in the rumen. The degradable fraction of maize silage was degraded more rapidly than that of elephant grass and rice straw. Maize silage had the highest potential CSD as compared to those of elephant grass and rice straw. It can be concluded that, based on the dynamic modelling approach, maize silage has higher nutritive value for ruminant livestock, followed by elephant grass and then rice straw.

1. Introduction

Ruminant livestock depends on fibrous materials as feeds to sustain life and to produce quality foods for human such as meat and milk. The commonly used fibrous materials are, for instance, grasses and various agricultural residues. Elephant grass (*Pennisetum purpureum*) has been the commonest grass species fed to ruminants in Indonesia [1,2], apparently due to its high biomass production and high nutritive value comparatively among the tropical grasses. On the other hand, rice straw as an agricultural residue is abundantly available in the country since the main staple food for Indonesians is rice. It is, however, generally known to have a low nutritive value when being fed to ruminants as indicated by its low crude protein content, high lignocellulose fraction and low digestibility [3]. Maize silage is a common forage mainly in temperate countries. It is typically ensiled together with the maize grains and therefore contains a high concentration of starch [4]. This study aimed to evaluate and to compare nutritive values of elephant grass, rice straw and maize silage by using a dynamic modelling approach.

2. Material and methods

Chemical composition and dry matter (DM) degradation characteristics of elephant grass, rice straw and maize silage were compiled from literatures [5–7] and summarized in Table 1. Chemical composition data included were crude protein (CP), neutral detergent fiber (NDF) and acid detergent



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fiber (ADF). Degradation characteristics of DM compiled were soluble (S), degradable (D) and undegradable (U) fractions, and rate of degradation of the degradable fraction (k_d). These values were originated from *in situ* rumen data that were fitted with the Orskov's equation [8]: $y = a + b(1 - e^{-ct})$, where y is the DM disappearance in the rumen at time t , a is S, b is D and c is k_d . The U fraction was determined as follow: $U = 100 - (S + D)$.

Table 1. Chemical composition and dry matter degradation characteristics of elephant grass, rice straw and maize silage*

Item	Elephant grass	Rice straw	Maize silage
Chemical composition (%DM)			
Crude protein	8.9	2.7	7.1
NDF	75.7	75.6	37.8
ADF	45.2	45.7	21.2
DM degradation characteristics (%)			
Soluble	29.0	0.02	27.1
Degradable	39.0	35.1	55.9
Undegradable	32.0	64.8	17.0
k_d (/h)	0.027	0.041	0.041

DM= dry matter; NDF= neutral detergent fiber; ADF= acid detergent fiber; k_d = degradation rate constant of degradable fraction.

* Compiled from literatures [5–7].

Each of the S, D or U fraction was assumed to have a specific rate of passage (k_p). The k_p for S fraction was assumed to be similar with liquid phase, i.e., 10%/h, whereas the k_p values for D and U fractions were both 3%/h. The S fraction is typically degraded before it has the chance of leaving the rumen and here was assumed to have the k_d of 200%/h. The S, D and U fractions are dynamically changed over time according to the following equations:

$$\begin{aligned} dS/dt &= -k_{dS} \times S - k_{pS} \times S \\ dD/dt &= -k_{dD} \times D - k_{pD} \times D \\ dU/dt &= -k_{pU} \times U \end{aligned}$$

Degraded S and D fractions form a pool namely cumulative S and D (CSD); this pool dynamically increases over time:

$$dCSD/dt = k_{dS} \times S + k_{dD} \times D$$

The degraded component is used by rumen microbes as an energy source and as building block to generate microbial biomass for further utilization by the host animal. Such degraded component is also partially converted into various volatile fatty acids (VFA), primarily acetate, propionate and butyrate. It was assumed that the conversion efficiency of degraded component into microbial biomass was 15% and the rate of passage of microbial biomass flows out the rumen was 3%/h. Meanwhile, conversion efficiency of degraded component into VFA was assumed to be 70%. Proportions of acetate, propionate and butyrate were modelled to be 65, 20 and 15%, respectively. Since VFA is water soluble, the compound leaves out the rumen with a rate of passage similar to that of liquid material. Further, acetate, propionate and butyrate are also absorbed through rumen wall and here they were assumed to have absorption rates of 20, 30 and 40%/h, respectively.

Integration of all the above dynamic models was performed in Vensim® PLE software version 7.3.5 (Ventana Systems, Inc., Harvard, MA, USA) using the Euler method. Simulation was performed for 100 h with a time step of 0.1 h.

3. Results and discussion

Soluble fraction present in elephant grass, rice straw and maize silage disappeared within early hours in the rumen (Table 2). It disappeared completely after 4 h for elephant grass and maize silage, and

after 1 h for rice straw, apparently due to its small amount in the straw. Feed soluble components in the rumen may be in the form of soluble carbohydrate or soluble nitrogen [9,10]. These fractions are rapidly degraded into various monomers or other smaller molecules and absorbed in the digestive tract of ruminants or flows to the subsequent digestive organ.

Table 2. Ruminal degradation kinetics of soluble (S) fraction of elephant grass, rice straw and maize silage (% feed dry matter).

Time (h)	Elephant Grass	Rice Straw	Maize Silage
0	29.0	0.020	27.1
1	2.75	0.002	2.57
2	0.260	0	0.243
3	0.025	0	0.023
4	0.002	0	0.002
5	0	0	0

The degradable fraction of maize silage was degraded more rapidly than that of elephant grass and rice straw (Figure 1). Apparently the high concentration of non-fiber carbohydrate like starch in maize silage causes its high degradation rate [4]. It was also confirmed by the much lower NDF and ADF contents of maize silage in comparison to the other two forages. This fraction in all forage sources had been mostly depleted after 40 h of incubation period. Rice straw contained the highest undegradable fraction among the feeds, followed by elephant grass and maize silage. High proportion of undegradable fraction (particularly lignocellulose) present in rice straw is confirmed by other studies [11,12]. The disappearance of this fraction depends only on rate of passage since it is not degraded nor fermented in the rumen. In this study, rate of passage of the undegradable fraction in all forages was assumed to be similar, i.e., 3%/h.

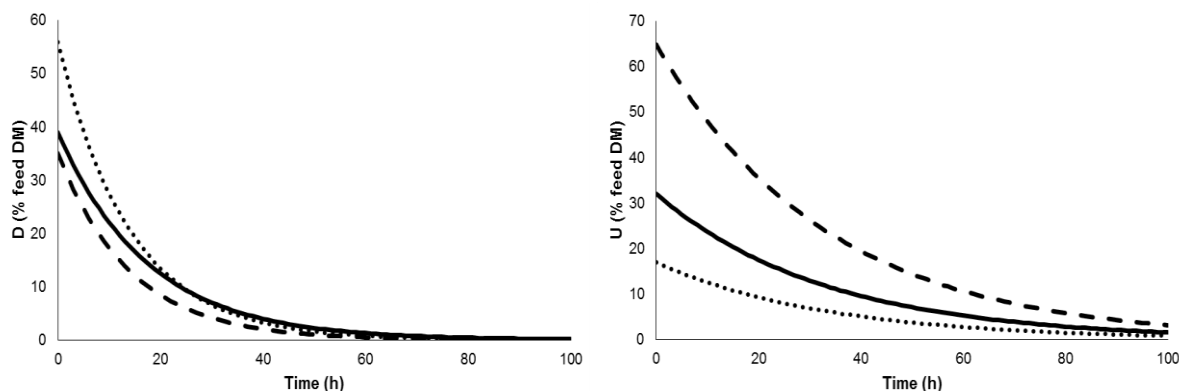


Figure 1. Ruminal degradation kinetics of degradable (D, figure left) and undegradable (U, figure right) fractions of elephant grass (full line), rice straw (dash line) and maize silage (dot line).

Cumulative soluble and degradable pool for elephant grass and maize silage had a rapid increase during early hours in the rumen, whereas it was not the case for rice straw (Figure 2). The potential value of CSD pool was achieved starting from 40 h for all forages. Maize silage had the highest potential CSD as compared to those of elephant grass and rice straw. Microbial biomass production rate between elephant grass and maize silage was relatively similar, and it reached the maximum production rate within the first 1 h and then declined rapidly with a curvilinear pattern. Its production rate was quite low for rice straw. This microbial biomass is an important source of protein for ruminants and it determines their production performance for generating valuable foods for human. Its synthesis in the rumen is primarily determined by ruminally available energy and nitrogen [13]. Since

rice straw contains low levels of ruminally available energy and nitrogen, it is not surprising that the forage results in a low microbial biomass production.

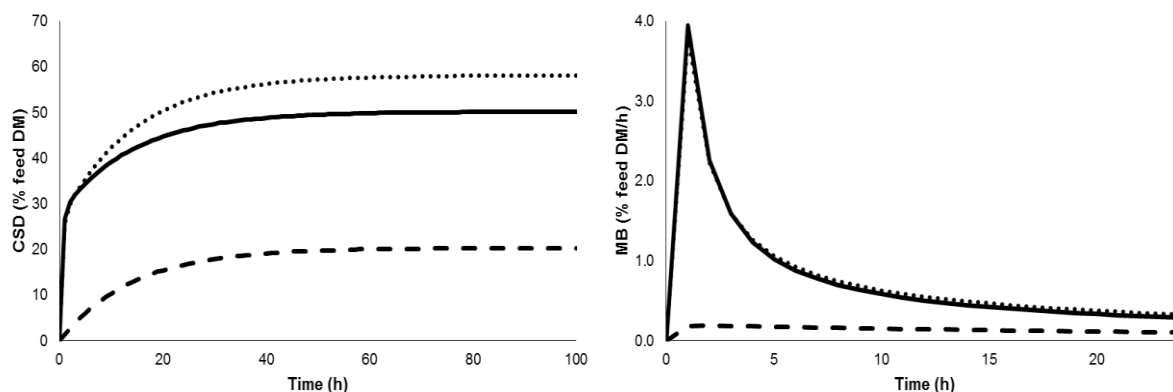


Figure 2. Cumulative soluble and degradable pool (CSD, figure left) and microbial biomass production rate (MB, figure right) of elephant grass (full line), rice straw (dash line) and maize silage (dot line).

Total VFA production was higher in elephant grass as compared to maize silage during early 2 h in the rumen, but started to be the opposite after then (Table 3). Its production was above 30% (from feed dry matter) in 24 h for elephant grass and maize silage, but remained low, i.e., approximately 10% for rice straw. The VFA itself is an essential energy source for ruminants and may contribute up to 70% of their total energy requirement [14]. Its production in the rumen is largely determined by microbial fermentation on fiber and non-fiber carbohydrate.

Table 3. Total volatile fatty acid (VFA) production (% feed dry matter) of elephant grass, rice straw and maize silage

Time (h)	Elephant Grass	Rice Straw	Maize Silage
0	0	0	0
1	17.4	0	16.7
2	20.1	0.698	19.7
4	22.0	2.33	22.5
8	25.0	4.98	26.7
12	27.2	6.97	29.9
16	28.9	8.46	32.2
24	31.0	10.4	35.4

4. Conclusion

Maize silage has higher nutritive value for ruminant livestock, followed by elephant grass and then rice straw based on the dynamic modelling approach. Such dynamic modelling approach is a useful tool for integrating available experimental data on animal feed and nutrition.

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