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COMPARISON OF MODELS AND ESTIMATION OF MISSING PARAMETERS OF SOME MATHEMATICAL MODELS RELATED TO *IN SITU* DRY MATTER DEGRADATION

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ABSTRACT

The aim of this study was to estimate missing parameters of the models such as the Orskov, Gompertz, Logistic and Richard models. These missing parameters for some models were estimated on the rapidly soluble fraction, the insoluble but potentially degradable fraction and the partial potentially degradable fraction. No difference was found among the values of these parameters ($P>0.05$), except for the constant rate of degredation. Besides, other missing parameters of the models studied were: partial dry matter disappearance in rumen for the percent rate at time t (t_p) and Rt_p, rate of the partial dry matter disapparance in rumen at the time t_p (t_0, t_{25}, t_{50}, t_{75} and t_{95}). These values and formulas for these values in different time intervals were also obtained. The second objective was especially on the comparison of the results of all t_p\`s ($t_{25}$, $t_{50}$, $t_{75}$ and $t_{95}$) and $Rt_p$\`s (Rt_0, Rt_{25}, Rt_{50}, Rt_{75} and Rt_{95}) in the models. The results of all t_p\`s and $Rt_p$\`s in the models were compatible with each other ($P>0.05$). The thirth objective was to investigate the fit performance of the models for *in situ* degradation studies. Some criteria used with the purpose of evaluating performances of models studied were on the analysis of residual (The Runs test and Durbin Watson) and goodness-of-fit (Residual Mean Square, the coefficient of determination and F-ratio). As a result of this study, while the Orskov model showed the best statistical performance and goodness of fit, the Richard model showed the worst. it is determined that the Gompertz model showed a systematic deviation from the data and is not appropriate for describing *in situ* data.

Key words: *in situ* degradation; mathematical models; exponential shape; sigmoidal shape

INTRODUCTION

The nylon bag technique (*in situ*) has been widely used for many years in order to estimate both rate and the extent of Dry Matter (DM) degradation in forages *in situ* (Mehrez and Orskov, 1977; Orskov *et al.*, 1980). Recently, *in situ* digestion technique was commonly used to determine the kinetics of digestion of feedstuffs by using convenient mathematical models as recommended by numerous researchers such as Schofield *et al.*, (1994); Rossi *et al.*, (2003); Blummel *et al.*, (2005); Calbro *et al.*, (2005); Pirmohammadi *et al.*, (2006); Gurbuz, (2007); Milis *et al.*, (2007); Taghizadeh *et al.*, (2008); Rodrigues *et al.*, (2009); Uckardes, 2010; Wang *et al.*, (2011). The most preferred five models *in situ* techniques suggested by some researchers are the Orskov, Gompertz, Logistic, France and Richard models (Orskov and McDonald, 1979; Blummel and Orskov, 1993; Getachew *et al.*, 1998; Lopez *et al.*, 1999; Topal *et al.*, 2004; Kamalak *et al.*, 2005; Kupai *et al.*, 2009; Uckardes, 2010; Wang *et al.*, 2011). On the other hand, some researchers preferred to use the France model instead of the other models since Maximum Likelihood packet program allows the calculation t_{50} and t_{95} when the data is fitted to France model $(y=a(1-\exp(-b(t-T) -c(\sqrt{t}-\sqrt{T}))$ (Ross, 1987); Theodorou *et al.*, 1994; Lopez *et al.*, 1999; Kamalak *et al.*, 2004; 2005; Sallam *et al.*, 2007). With a similar study, Sahin *et al.*, (2011) found the partial gas production times, t_{25}, t_{50}, t_{75} and t_{95} of the exponential model in their study.

In the digestion kinetics, the missing of some of the parameters of widely used models causes the loss information. More information on the digestion kinetics of feeds is reached as a result of the knowledge of these parameters. It was shown how to obtain important parameters not included in this study. In addition, it was also shown how to obtain the equations of t_p ve Rt_p for the digestion kinetics. As a result of obtaining of these equations, the preference of the other models could be increased according to the France model.

There are three main purposes of this study. The first purpose is to obtain the important parameters of the degradation kinetics such as the rapidly soluble fraction, the insoluble potentially degradable fraction, the total degradable fraction and the constant rate of degradation of models. The second purpose is to find the equations of t_p and Rt_p of the models. The thirth purpose is to determine the best model with the residual analysis and the goodness- of- fit of the models in a wide perspective.

MATERIALS AND METHODS

***In situ DM disappearance*:** Commercially available and widely used two forages consisting of *Gleditsia Triacanthos* and *Alfalfa hay (Medicago sativa L.)* were used in this experiment. Three ruminally fistulated sheep (two years old and with body weight of average 60 kg), maintained on a 900g good quality alfalfa hay and 300g concentrate diet according to their requirements were used. The sheep were fed twice a day with forage *Alfalfa hay* and concentrate diet.

The in situ DM degradation analysis was carried out according to the procedure described by Mehrez and Orskov (1977). Polyster bags were 12.5 x 10 cm in size with a pore size of 50 x 27µm. 5 gram *Gleditsia Triacanthos* samples dried and milled through a 1-mm sieve were weighed into nylon bags and incubated in three rumen fistulated sheep for 3, 6, 12, 24, 48, 72 and 96h. As soon as the bags were removed from the rumen, the nylon bags were thoroughly washed with cold running water, until no further coloured liquid could be extruded, and dried at 60 ^{0}C for 48h. The DM degradation losses (%) for each incubation time were determined. The DM degredation data were fitted to the models.

The equations of the four models used in this study were given in Table 1. In Table 1, some parameters of the models were missing to describe the kinetics of digestion. Therefore, the various mathematical transformations to find the missing parameters were applied and the results were given in Table 2. As an example, to obtain of these missing parameters of the Orskov model was shown below step by step. The Orskov model is written as the Eq. (1).

$y= a+b(1-\exp(-ct))$ (1)

where, a is the rapidly soluble fraction, b is the insoluble but potentially degradable fraction, c is the constant rate of degradation. The Orskov model does not directly include in the total degradable fraction. The total degradable fraction gives maximum dry matter disappearance in rumen when time goes to infinity. In other words, when time goes to infinity, the value of the limit of the model gives the total degradable fraction.

Since $y_\infty = \lim_{t\to\infty} y$, y_∞ of the Orskov model is found as :

$$y_\infty = \lim_{t\to\infty}\left(a+b\left(1-\exp\left(-ct\right)\right)\right)=a+b$$

where: y_∞ is maximum dry matter disappearance in rumen, a+b : the total degradable fractions. The missing parameters of the other models were found with a similar approach and then the results were given in Table 2.

The t_p can be found using the Eq. (2).

$$y_0 + (y_\infty - y_0)p/100 = y(t_p) \qquad (2)$$

where: p is percent rate of partial dry matter disappearance in rumen, t_p is time (h) to produce p % of partial dry matter disappearance in rumen, y_0 is partial dry matter disappearance in rumen in the initial time, y_∞ is maximum dry matter disappearance in rumen, $y(t_p)$ is partial dry matter disappearance in rumen for the percent rate at time t.

The values of y_0 and y_∞ are a and (a+b), respectively. If these values are written in Eq. (2), the following Eq. (3) is found.

$a+bp/100=a+b(1-\exp(-c\,t_p))$ (3)

By solving the Eq. (3) for t_p, t_p is found that

$t_p=-\ln(-1/100p+1)/c$ (4)

where: p may have any value in the range 0-100 using a percentage scale.

So, the desired t_p values can be found by using the Eq. (4). In this study, t_{25}, t_{50}, t_{75} and t_{95} are only given. The results of the other models are obtained by using the same method. These results are given in Table 3. The Rt_p at the time t_p can be found by taking the first derivative of the models. For example, the Orskov model can be expressed as;

$$Rt_p = \partial y/\partial t_p = bc\exp(-ct_p)$$

and at the t_0, Rt_0 is reached on the maximum rate of the partial dry matter disappearance such as Rt_0= bc

The Rt_p formulas of all models at the t_p were given in Table 4.

Model Comparison: Goodness-of-fit of each model was evaluated using Residual Mean Square (RMS), The coefficient of determination (R^2) and F ratio.

Residual Mean Square (RMS) is defined as the residual sum of square divided by its degress of freedom. As well-known, a model with the smallest RMS is more favourable. For RMS, the following equations were used

$$RSS = \sum (y_i - \hat{y}_i)^2,$$

$$RMS = RSS/(n-p),$$

$$R^2 = 1 - RMS/(S_y^2),$$

where:

RSS is the residaul sum of square; p is the number of parameters of the model and S_y^2 is the partial variance of the y-variable (Bibby and Toutenberg, 1977).

F ratio test was used for pair wise comparisions statistical significance of the difference between models in terms of goodness-of-fit to the same set of data was assessed using F test for comparing two models as described by Motulsky and Ransnas, (1987).

To compare models with the same number of parameters, the following equation was used,

$$F = \left(RSS_1\right) / \left(RSS_2\right) \sim F_{\left(\left(n-p,n-p\right),\alpha\right)}, \qquad \left(p_1 = p_2\right)$$

If you expect to get an F ratio near 1.0, RSS_1 model is correct. If you expect to get an F ratio much greater than 1.0, RSS_2 model is correct (Motulsky and Christopoulos, 2003).

and to compare the models with different number of parameters, the following equation was used

$$F=\left(\left(RSS_1-RSS_2\right)/\left(p_2-p_1\right)\right)/\left(\left(RSS_2\right)/\left(n-p_2\right)\right)\sim F_{\left(\left(p_2-p_1\right),\left(n-p_2\right),\alpha\right)}$$

$$\left(p_1 \neq p_2\right),$$

where: the subscript 1 refers to bigger RSS model. A small P value indicates that the more parameters model fits better than fewer parameters model (Motulsky and Ransnas, 1987; Bilgin *et al.*, 2004).

All models were fitted to the data by nonlinear regression using algorithm of the Levenberg Marquardt and the NLIN procedure of SAS package (SAS, 1999). The initial values were defined as different for each data set and each model. Several possible starting values were selected for each parameter and the starting value which has the smallest residual sum of squares was accepted.

The t_{25}, t_{50}, t_{75} and t_{95} of partial dry matter disappearance in rumen and Rt_{25}, Rt_{50}, Rt_{75} and Rt_{95}, the rate of the partial dry matter disapparance in rumen were subjected to standart analysis of variance using the general linear model. Statistical analysis used the GLM produce in SAS, (1999). Significance between individual means was identified using Tukey's multiple range test (Pearse and Hartley, 1966; Uckardes, 2006). Mean differences were considered significant at $P<0.05$.

Examination of Residuals: The Runs test is a robust and simple for determining whether data differ systematically from a theoretical curve (Lopez *et al.*, 1999, 2004; Uckardes, 2010; Wang *et al.*, 2011). A run is defined as a series of positive values or a series of negative values. The number of positive, or negative, values is the length of the run. The Run test was determined as described by Motulsky and Ransnas, (1987). Durbin Watson (DW) statistics was used to determine serial correlation or autocorrelation of residuals. The DW statistics and its level of significance were determined as described by Draper and Smith, (1981).

RESULTS

All the models were fitted to data set as seen in Figure 1. They exhibited similar behaviour in Figure 1 and no fitting problem was encountered.

The values calculated for old and new parameters of the models used are given in Table 5. The differences among the parameter values of the rapidly soluble fraction, potentially degradable fraction and the total degradable fraction were not found significant ($P>0.05$). The difference among the values of the constant rate of degradation of models was found significant ($P<0.01$). The value of the constant rate of degradation of the Orskov model was slower than the Logistic model. The proportion of the variation explained was usually very high in all models. The average R^2 values for all the models had a narrow range of 0.9814 to 0.9854 (Table 6). The R^2 values were very close to unity in most cases. The Orskov model had the highest average R^2 (0.9854), whereas the Richard model had the smallest average (0.9814). The Gompertz and the Logistic models had the intermediate average R^2 (0.9852; 0.9850), respectively. According to these results, the Orskov model was the non-linear model giving the best fit and the Richard model was determined to be the worst model. A similar tendency showed for the RMS values that took into account the number of parameters contained in each model (Table 6). The Orskov model yielded the smallest average RMS value (14.433). The Gompertz and Logistic were the non-linear models with the intermediate RMS (14.797; 15.279). The Richard model had the highest average RMS value (17.982). While the highest maximum RMS value was recorded in the Richard model (77.054), the lowest maximum RMS value was obtained in the Logistic model (1.062). Whereas, the Gompertz model (6.262) had a value of the lowest RMS median in the other model (Table 6). Whereas, the Richard model had the highest average median (8.250) and maximum RMS value (77.054). According to the RMS ranked value, while the Orskov model is the best model, the Richard model is the worst model. To comparison the pair-wise among the models F ratio test was used. For R^2 ve RMS, similar results occured. The Orskov and the Logistic models showed the best performance in F ratio. The Richard model had the worst performance. However, the Gompertz model showed performance at the intermediate level.

For serial correlation or autocorrelation of the errors, the Durbin Watson test (DW) was employed to test whether the errors are scattered randomly around the zero line. The DW values estimated for the models are given in Table 7. In Table 7, the DW values of the Orskov and Logistic models are non-significant meaning that the errors are scattered randomly around the zero line. The DW values of the Gompertz and Richard models showed respectively, six times and one time significant ($P<0.05$),

The distribution of number of runs of sign was given in Table 7. The distribution of the 12 curves for each fitted models was illustrated by diving them into four groups, which were the number of curves with ≤ 3, 4, 5 and ≥ 6 runs of sign, respectively (Table 7). According to the Runs test, if the model is inappropriate for the data, the positive residuals may tend to cluster together at some parts, whereas negative residuals cluster together at other parts. Such clustering indicates that the data points differ systematically from the predictions of the curve. The Gompertz model had the smallest number of runs of sign among the models used. In conclusion, the Gompertz model indicates that the data points differ systematically from the predictions of the curve according to the other models.

The t_p (t_{25}, t_{50}, t_{75} and t_{95}) and Rt_p (Rt_0, Rt_{25}, Rt_{50}, Rt_{75} and Rt_{95}) results of all models were given in Tables 8 and 9, respectively. According to these results, the results of t_p ve Rt_p were not found as significant ($P>0.05$).

DISCUSSION

The curve of *in situ* digestion had generally an exponential shape as seen in Figure 1. For that reason, the most appropriate model has the exponential form. However, a few researchers have used some sigmoidal shape by transforming the models for *in situ* degradation due to fact that these models are consistent with microbial activity of the rumen. The microbial activity which is dependent on the feed increases during the first time and then on the inflection point, it reaches the maximum rate. After this inflection point, it was reported that the rate of the microbial activity gradually decreased. While comparing the Gompertz, Richards, Logistic models *in vitro* or *in situ* studies, many researchers did not include the Orskov model (Lopez *et al.,* 1999; Calabro *et al.,* 2005; Wang *et al.,* 2011). They emphasized on the alternative models. The Gompertz and Logistic models from these models have been used widely *in vitro* gas production and *in situ* degreabilitiy.

Both the Gompertz and Logistic models *in vitro* gas production were firstly used by Schofield *et al.,* (1994). During the last few decades, these models were developed in different forms (Lopez *et al.,* 1999; Calabro *et al.,* 2005; Wang *et al.,* 2010). It was also reported that the Logistic, Gompertz and Richard models could be used for rumen digestibility (Lopez *et al.,* 1999, 2004). These researchers declared that these models were appropriate to define degradation kinetics.

These researchers have not done any study on determining the missing parameters of the models when they were studying on the development of the goodness-of -fit of these models. These missing parameters are very important since they give more information about the kinetics of digestion. The equations of the missing parameters of the models used and their analysis results were given in Table 2 and Table 5, respectively.

There is not only one method to determine the similarities and differences among the nonlinear models (Lopez *et al.,* 2004). Comparison of the nonlinear models is made on the basis of the goodness-of-fit techniques and residual analysis (Motulsky and Ransnas, 1987; Lopez *et al.,* 2004).

Lopez *et al.,* (2004) and Motulsky and Ransnas, (1987), emphasized that it is necessary to use a few criterias to determine the differences between models in terms of goodness-of-fit which have the same data set. The coefficient of determination (R^2) of all the models has been found to be convenient for *in situ*. The Orskov and Gompertz models were found as more appropriate than other models (Table 6). The R^2 values of the Gompertz and the Logistic models were found agreement with Wang *et al.,* (2011).

Comparing any two models by taking into account the RMS values, highest rank RMS values are obtained respectively by the Orskov model (27 times), the Gompertz model (24 times) and the Logistic model (18 times) while the lowest RMS value is obtained by the Richard model (3 times).

According to these results, the Orskov and the Gompertz models, compared with the other models, showed a better fit to the curve in terms of the RMS criteria. Zwitering *et al.,* 1990 reported that the models with a greater number of parameters usually give a lower RMS. Therefore, data fits obtained by using the various models were compared statistically by the use of F-ratio test. While the Orskov model which was compared pairwise with all other models was found as the best statistically fitting model ($P<0.05$), the Gomperz model and the Richard models exhibited on the lowest performance in terms of F-ratio. In conclusion, while the Orskov model showed the best performance in terms of goodness-of-fit, the Richard model showed the worst performance.

According to residual analysis, the Orskov and the Gompertz models showed the best and the worst tendency, respectively. While the serial correlation of the Orskov and the Logistic models were found non-significant ($P>0.05$), the serial correlation of the Gompertz and the Richard models were found significant 6 times and 1 time, respectively ($P<0.05$). Some authors concluded that the systematic errors of the Gompertz equation were observed (Baranyi *et al.,* 1993; 1994; Dalgaard, 1995; Membre *et al.,* 1999; Schepers *et al.,* 2000).

Table 1. Candidate models

Model	y =
1.Orskov (ORS)	a+b(1-exp(-ct))
2.Gompertz (GMP)	mexp(log(k/n)exp(-ct))
3.Logistic (LOG)	a/(1+exp(b-ct)
4. Richard (RCH)	$a(1+b\exp(-ct))^m$

exp, exponential

Table 2. Meanings of old and new parameters of the models used

Model	The rapidly soluble fraction (y_0)	The insoluble but potentially degradable fraction	The total degradable fraction (y_∞)	The constant rate of degradation	Shape parameters
1.ORS	a	b	a+b	c	-
2.GMP	mk/n	m- (mk/n)	m	c	k, n
3.LOG	a/(1+exp(b))	a-a/(1+exp(b))	a	c	b
4.RCH	a(1+b)^m	a-a(1+b)^m	a	c	m, b

Table 3. The formulas of the time (h) to produce p % of partial dry matter disappearance (t_p)

Model	t_p =
1.ORS	-ln(-1/100p+1)/c
2.GMP	-ln(ln(-1/100(-100k-pn+pk)/n)/ln(k/n))/c
3.LOG	-ln(-(p-100)/(100+exp(b)p))/c
4.RCH	-ln((exp(ln((1+b)^m+1/100p-1/100p(1+b)^m)/m)-1)/b)/c

Table 4. The general and the initial rate formulas of the partial dry matter disapparance in rumen at the time t_p of the models

Model	Rt_p =	Rt_0 =
1. ORS	bcexp(-ct_p)	bc
2. GMP	-mln(k/n)cexp(-ct_p)exp(ln(k/n)exp(-ct_p))	-mln(k/n)ck/n
3. LOG	acexp(b-ct_p)/((1+exp(b-ct_p))^2)	acexp(b)/((1+exp(b))^2)
4. RCH	-a(1+bexp(-ct_p))^mmbcexp(-ct_p)/(1+bexp(-ct_p))	-a(1+b)^mmbc/(1+b)

Sqrt=square root; exp=exponential

Table 5. The values of old and new parameters of the models used (Mean ± Standart Error)

Model	The rapidly soluble fraction (y_0)	The insoluble but potentially degradable fraction	The partial potentially degradable fraction (y_∞)	The constant rate of degradation	Shape parameters
1.ORS	46.108 ± 3.107	32.638 ± 4.916	78.795 ± 1.979	0.053 ^{b} ± 0.003	-
2.GMP	46.898 ± 2.748	31.381 ± 4.355	78.279 ± 6.275	0.063 ^{ab} ± 0.012	k=0.0003 ± 0.000, n=0.001 ± 0.000
3.LOG	47.390 ± 2.740	30.507 ± 4.331	77.897 ± 1.695	0.073 ^{a} ± 0.005	-0.534 ± 0.205
4.RCH	46.562 ± 3.054	31.838 ± 4.809	78.699 ± 6.583	0.062 ^{ab} ± 0.015	m= -182.882 ± 595.835, b=0.043 ± 0.511
Sig.	ns	ns	ns	**	-

Sig= Significance level; ns= non-significance ($P>0.05$); ** = $P<0.01$; the same column superscripts are significantly different ($P<0.05$).

The DW statistics is a robust method for determining whether data differ systematically from a theorical curve. That the DW statistic is significant shows that the model is not appropriate (Lopez *et al.*, 2004). Similarity, the Runs test is another test which shows that the errors are distributed independently and randomly. Motulsky and Ransnas, (1987) reported that the curve deviates systematically from the points in case of the small number of runs. The results of the DW statistics and the Runs tests were given in Table 7. The Gompertz model indiacated more systematic errors and autocorrelation according to the other models. In conlusion, the Gompertz model is not appropriate and it has autocorrelation.

The t_p and Rt_p values of all models were found non-significant in Table 8 ($P>0.05$). Thus, the results of all models are compatible with each other. In this study, t_{25}, t_{50}, t_{75} and t_{95} of partial dry matter disappearance of all models were slightly higher than t_{25}, t_{50}, t_{75} and t_{95} of partial dry matter disappearance of the exponential model reported by Sahin *et al.*, (2011). The values of t_{50} in the Logistic and Gompertz models are compatible with the values by Wang *et al.*, (2011). However, general t_p of the partial dry matter disappearance was not included in the study of these researchers. Only t_{50} was included in their study. In this study, the estimation of Rt_{50} was slightly higher than the the values reported by Wang *et al.*, (2011).

As a result, the estimations of "t_p" and "Rt_p", in addition to the parameters (a, b, c.., etc) using the Orskov, the Gompertz, the Logistic and the Richard models were provided more useful data to compare feedstuffs in terms of both *in situ* degradation and *in vitro* fermentation studies. Thus, these models, widely used for *in situ* studies could be used as an alternative to the France model.

Table 6. Goodness-of-fit and Pair-wise comparisions among the models to the *in situ*

	ORS	GMP	LOG	RCH
Average R^2 values	0.9854	0.9852	0.9850	0.9814
Residual Mean Square				
Average	14.433	14.797	15.279	17.982
Median	6.288	6.263	6.678	8.250
Minumum	1.098	1.079	1.062	1.440
Maximum	58.103	57.879	58.844	77.054
Ranking of models according to RMS				
No. of cases where with smallest RMS	27	24	18	3
No. of cases where with largest RMS	9	12	18	33
Comparision of models according to F ratio test				
No. of cases where the model was better than others	30	11	28	1
No.of cases where the model was worse than others	6	25	8	35

RMS: residual mean square values, total number of cases the RMS (smallest = rank 1, etc.) for which the model showed the smallest and largest RMS and total number of cases where each model was either better or worse than the others according to the pair-wise F-ratio.

Table 7. Durbin-Watson (DW) values and run test after fitting models

	ORS	**GMP**	**LOG**	**RCH**
Distribution of curves according to Durbin Watson (DW) values (partial curve =12)				
Significant	0	6	0	1
Non -significant	12	6	12	11
Distribution of curves according to number of runs of sign (partial curve =12)				
≤ 3	1	9	1	1
4	2	3	1	2
5	5	0	8	5
≥ 6	4	0	2	4

Table 8. The t_{25}, t_{50}, t_{75} and t_{95} of partial dry matter disappearance of the models (Mean ± Standart Error)

	ORS	**GMP**	**LOG**	**RCH**	**Sig**
t_{25}	5.662 ± 0.340	6.013 ± 0.346	6.269 ± 0.351	5.943 ± 0.360	ns
t_{50}	13.642 ± 0.819	13.795 ± 0.764	13.858 ± 0.719	13.858 ± 0.815	ns
t_{75}	27.284 ± 1.638	26.228 ± 1.436	25.322 ± 1.315	26.436 ± 1.594	ns
t_{95}	58.961 ± 3.540	53.626 ± 2.975	49.469 ± 2.776	54.611 ± 3.513	ns

t_{25} = time to produce 25 % of partial dry matter disappearance; t_{50} = time to produce 50 % of partial dry matter disappearance; t_{75} = time to produce 75 % of partial dry matter disappearance; t_{95} = time to produce 95 % of partial dry matter disappearance; ns = non-significance (P>0.05); Sig.= significance level

Table 9. The rate of the partial dry matter disapparance in rumen at the time t_p of the models (Mean ± Standart Error)

	ORS	GMP	LOG	RCH	Sig
Rt_0	1.699 ± 0.277	1.411 ± 0.177	1.250 ± 0.137	1.554 ± 0.265	ns
Rt_{25}	1.275 ± 0.202	1.193 ± 0.171	1.147 ± 0.158	1.249 ± 0.203	ns
Rt_{50}	0.850 ± 0.135	0.873 ± 0.136	0.905 ± 0.143	0.886 ± 0.141	ns
Rt_{75}	0.425 ± 0.067	0.471 ± 0.078	0.523 ± 0.091	0.469 ± 0.074	ns
Rt_{95}	0.085 ± 0.013	0.099 ± 0.017	0.116 ± 0.021	0.098 ± 0.015	ns

Rt_0 = The rate of the partial dry matter disapparance for t_0; Rt_{25} = The rate of the partial dry matter disapparance for t_{25}; Rt_{50} = The rate of the partial dry matter disapparance for t_{50}; Rt_{75} The rate of the partial dry matter disapparance for t_{75}; Rt_{95} = The rate of the partial dry matter disapparance for t_{95}; ns = non-significance (P>0.05); Sig. = significance level .

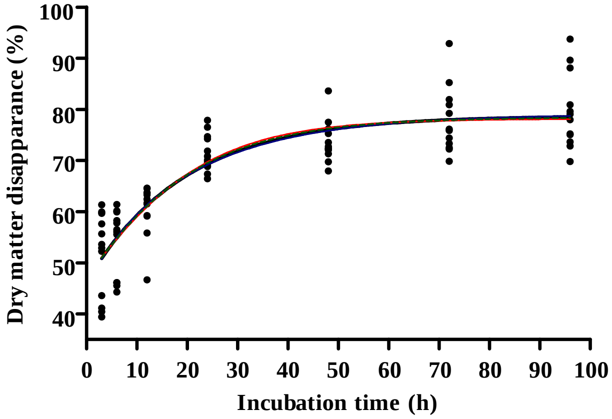

Figure 1. The general fit to data set of the all models (the curves of all the models coincided)

Conclusions: In this study, four mathematical models which are widely used in animal feeding have been used. Some parameters which are important in animal feeding were found and the equations t_p and Rt_p of models were obtained. More information about the feedstuff can be obtained by knowing these parameters and equations. As a result of this study, while the Orskov model showed the best statistical performance and goodness of fit, the Richard model showed the worst one. It is determined that the Gompertz model showed a systematic deviation from the data and is not appropriate for describing *in situ* data.

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