UNIVERSIDAD AUTÓNOMA DEL ESTADO DE MÉXICO

MAESTRÍA Y DOCTORADO EN CIENCIAS

AGROPECUARIAS Y RECURSOS NATURALES

"MODELO MATEMÁTICO PARA PREDECIR LA INGESTA DE MATERIA SECA DE VACAS LECHERAS DE PASTOREO"

T E S I S

QUE PARA OBTENER EL GRADO DE
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P R E S E N T A :

MAT. ROSARIO SÁNCHEZ PÉREZ

El Cerrillo Piedras Blancas, Toluca, Estado de México, Julio de 2017

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P R E S E N T A :

MAT. ROSARIO SÁNCHEZ PÉREZ

COMITÉ DE TUTORES

Tutor Académico
DR. ABDELFATTAH ZEIDAN MOHAMED SALEM

Tutores Adjuntos
DRA. MARÍA DOLORES MARIEZCURRENA BERASAIN
DRA. MONA MOHAMED MOHAMED YASSEEN ELGHANDOUR

El Cerrillo Piedras Blancas, Toluca, Estado de México, Julio de 2017

DEDICATORIA

A mis padres con mucho cariño, gracias a ellos logro subir un escalón más.
A mi familia que de una u otra forma me apoya en mis proyectos.
A mis amigas incondicionales, Juanita y Eli.

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RESUMEN

En un sistema de pastoreo en vacas lecheras existe una relación directa entre la producción de leche y la ingesta de materia seca (DMI), de ahí la importancia de medir esta última, sin embargo, esta labor es complicada por los altos costos y el trabajo que implica. El objetivo de este estudio es diseñar un modelo matemático para predecir la ingesta de materia seca de vacas lecheras en un sistema de pastoreo. Dicho modelo se basa en el principio básico fill-unit system. En este sistema las vacas y los alimentos son descritos en términos de la capacidad de ingesta de alimento (FIC) (fill-units/d) y Fill (fill-units/amount of feed), respectivamente. La FIC está determinada por la capacidad del animal para procesar la ingesta del alimento que pende de factores como tamaño, edad y estado de lactación. El Fill está determinado por las propiedades del alimento tales como digestibilidad, proteína cruda, entre otros. En el diseño del modelo se asume una alimentación *ad libitum. Se* consideran características del animal como paridad, estado de lactación y gestación para obtener su capacidad de ingesta; para determinar el valor de saciedad (SV), de cada alimento; f*estuca arundinacea* y *lolium multiflorum* son los alimentos que considera el modelo, descritos por materia seca (DM), proteína cruda (CP), fibra detergente neutro (NDF), digestibilidad *in vitro* de la materia orgánica (dOM). Los parámetros fijos del modelo se determinaron aplicando regresión polinomial a datos de tres experimentos en vacas lecheras de pastoreo de Baja California México. El modelo permite predecir la ingesta de materia seca, usando como entradas, datos de fácil medición y que no requieren del conocimiento de la producción de leche (MY) o peso corporal (BW), por lo que el modelo es consistente.

Los resultados del modelo son satisfactorios, ya que son similares a los obtenidos experimentalmente debido a que la ingesta de materia seca, en promedio, es de 21.68 kg/d en un grupo y en el otro de 23.44 kg/d, y al aplicar el modelo se obtiene una estimación de 22.826 kg/d para una vaca con características semejantes a las de las vacas en estudio.

Palabras clave: Vacas lecheras, ingesta de materia seca, pastoreo, modelo.

ABSTRACT

In a grazing system in dairy cows, there is a direct relationship between milk production and dry matter intake (DMI), hence the importance of measuring them, however, its hard work and high costs. The objective of this study is to design a mathematical model to predict the dry matter intake of dairy cows in a grazing system. This model based on the basic principle of fill-unit system. In this system, cows and feed are described in terms of feed intake capacity (FIC) and fill (units / amount of feed), respectively. The FIC determined by the animal's ability to process feed intake that depends on factors such as size, age and lactation status. The Fill determined by the properties of the feed such as digestibility, crude protein, among others. In the design of the model, an ad libitum feed assumed. Characteristics of the animal are considered as parity, state of lactation and gestation to obtain its capacity of ingestion; To determine the Satiety value (SV) of each forage; *Festuca arundinacea* and *Lolium multiflorum* are the forage s considered by the model, described by dry matter (DM), crude protein (CP), neutral detergent fiber (NDF), in vitro digestible organic matter (dOM). The fixed parameters of the model were determined by applying polynomial regression to data from three experiments in lactating dairy cattle from Baja California Mexico. The model allows predicting dry matter intake, using as inputs, easily measured data and does not require the knowledge of milk yield (MY) or body weight (BW), so the model is consistent. The results of the model are satisfactory, since they are similar to those obtained experimentally because the dry matter intake, on average, is 21.68 kg / d in one group and in the other of 23.44 kg / d, and when applying the model we obtain an estimate of 22,826 kg / d for a cow with characteristics similar to those of the cows under study.

Keywords: Dairy cows, dry matter intake, grazing, model.

INTRODUCCIÓN

En un sistema de pastoreo en vacas lecheras, existe una relación directa entre la producción de leche y la ingesta de materia seca. Determinar la ingesta de alimento y las características de la dieta en un sistema de pastoreo en rumiantes sigue siendo uno de los principales retos en la investigación (Coleman, 2005).

Una gran proporción de la producción de leche en regiones cálidas está basada principalmente en sistemas de pastoreo (Dilon, 2006). La producción de leche en México está cimentada esencialmente en sistemas de pastoreo. Además el alimento representa uno de los principales costos en sistemas de producción de leche (Berry *et al*., 2014, Vallimont *et al*., 2011, Connor *et al*., 2012). Sin embargo, predecir la ingesta de materia seca (DMI) en vacas lecheras es de suma importancia, pero estimarla es difícil y costosa sobre todo en un sistema de pastoreo (Zom et al., 2012, Vazquez y Smith, 2000, Coleman, 2005).

Medir la ingesta de materia seca es difícil debido a que intervienen factores tanto físicos como fisiológicos del animal. En confinamiento es posible medir DMI contario a lo que sucede en un sistema de pastoreo. Los modelos de predicción pueden ser una guía para medir DMI en distintos esquemas.

Un modelo matemático describe un proceso natural en términos matemáticos, realiza una simplificación de la realidad ya que se ignoran detalles secundarios y se centra en sucesos esenciales que rigen el proceso, por lo que se pueden hacer inferencias acerca de la situación real, lo que conlleva a un menor costo, ya que se requiere menor tiempo y es más fácil experimentar con la situación real. Se debe tener cuidado con las interpretaciones de resultados que están fuera de la realidad debido a la sensibilidad que presentan los modelos ante pequeños cambios de la información.

¿Podemos modelar el desarrollo de los animales tomando en cuenta características genéticas y fisiológicas del animal, así como las propiedades de los alimentos que consumen para maximizar su rendimiento y desarrollo?, ¿Es posible predecir la

ingesta de alimento en los animales para complementar su alimentación y mejorar su rendimiento?

El propósito del proyecto consiste en un análisis de ecuaciones que describen a las vacas lecheras en términos fisiológicos y ecuaciones que caracterizan a los alimentos para diseñar y desarrollar un modelo matemático que nos permita predecir la ingesta de materia seca y mediante la programación del modelo implementada en Matlab (Matriz Laboratory) construir una Graphic User Interface (GUI) para que el modelo sea amigable al usuario.

En los primeros capítulos del trabajo se da un panorama general de la modelación y antecedentes de modelos matemáticos para predecir DMI. Los capítulos subsecuentes presentan una descripción general del modelo programado en Matlab y los resultados obtenidos mediante gráficas.

Mathematical model to predict the intake of dry matter in grazing system of dairy cows

Rosario Sánchez Pérez[1], Mona M.M.Y. Elghandour[1], María D. Mariezcurrena[2], Miguel Mellado[3], Luis M. Camacho[4], Peter Adeniyi Alaba [5], Abdelfattah Z.M. Salem[1*]

[1]*Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma del Estado de México, Estado de México, México*

[2]*Facultad de Ciencias Agrícolas, Universidad Autónoma del Estado de México. Instituto Literario 100, C.P. 50000, Estado de México.*

[3]*Department of Animal Nutrition, Autonomous Agrarian University Antonio Narro, Saltillo, Mexico*

[4]*Unidad Académica de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Guerrero, Cd. Altamirano, Guerrero, México*

[5] *Department of Chemical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia.*

*Corresponding authors: Abdelfattah Z.M. Salem, Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma del Estado de México, Estado de México, México. asalem70@yahoo.com

Mathematical model to predict the intake of dry matter in grazing system of dairy cows

This study aims to design a mathematical model to predict the dry matter intake (DMI) of dairy cows in a grazing system based on the basic principle of the fill-unit system. In this system, cows and feed are described in terms of feed intake capacity (FIC) and fill (units/amount of feed), respectively. The FIC is determined by the ability of the animal to process feed intake depending on factors such as size, age and lactation status. The fill is determined by feed properties such as digestibility, crude protein (CP), among others. This model assumed ad libitum feed. Characteristics of the animal are considered as parity, state of lactation and gestation to obtain its capacity of ingestion; To determine the Satiety value (SV) of each forage; Festuca arundinacea and Lolium multiflorum are the forages considered by the model, described by DM, CP, neutral detergent fiber (NDF), in vitro digestible organic matter (dOM). The fixed parameters of the model were determined by applying polynomial regression to data from three experiments in lactating dairy cattle from Baja California Mexico. The model consistently predicts DMI using parity, days in lactation, days of gestation and gestation rate as inputs, without requiring the knowledge of milk yield (MY) or body weight (BW). Moreover, the model gives satisfactory results, which are similar to the experimental. For instance, one group exhibits average DMI of 21.68 kg/d and the other, 23.44 kg/d, while the model gives an estimate of 22,826 kg/d for a similar sample.

Keywords: Dairy cows; dry matter intake; grazing; model.

Introduction

Milk production based on the grazing system mainly depends to a large extent on the voluntary consumption of the animal. The age, size, and pregnancy of the animal, as well as the chemical composition and nutritive value of the forage, among others, are characteristics that influence play a vital role in the forage intake. The purpose of this work

is to design a mathematical model that estimates the dry matter intake of dairy cows in a grazing system. Development of a model for estimation of dry matter intake (DMI) is important towards relating the contemplate characteristics of both animal and forage. In the literature, there are models that take into accountSeveral models have been developed considering these traits (Doole, Romera, 2013, Gregorini et al., 2013, Halachmi et al., 2004). However, most of the traitsse remain constant, so it is not possiblemaking it difficult to apply existing models to predict DMI without taking into account that there areconsidering certain differences in each grazing system, such as plant species, grazing organization, among others (Mármol, 2006).

There are other models to predictfor DMI (Avond et al., 2002, Baudracco et al., 2006, Baudracco et al., 2010a, Krizsan et al., 2014, Berry et al., 2014), however, theybut are either based on milk yield (MY) or body wWeight (BW) (Zom et al., 2012) or do not contemplate characteristics of the animal or forage. The formulas models proposed by Zom et al., (2012) were simplified by taking fewer constants that were obtained by polynomial regression from of the experimental data obtained from three individual experiments in dairy cows in Baja California, Mexico. The inputs related to the animal are age, parity, lactation status, gestational state and gestational rate whose measurement is feasible. Inputs related to the inputs depend on the grazing system such as the type of forage, digestibility and nutritional value. The model has more freedom to describe its qualities by the satiety value that could be described by dry matter (DM), as input. Crude protein (CP), neutral detergent fiber (NDF), in vitro digestible organic matter (dOM) were estimated from dry matter (DM).

The purpose of this work is to design a mathematical model that estimates the dry matter intake of dairy cows in a grazing system. The DMI model proposed by Zom et al. (2012) is based on fundamental principle fill-unit system (Jarriage et al., 1986) and contemplates the main genetic and physiological characteristics that describe the animal in terms of feed intake capacity (FIC). The model proposed in this research based on the same system and, therefore, we contemplate these formulas.

Materials and Methods

Essential Principles of the Model

The model for predicting the DMI of dairy cows in a grazing system is based on the fundamental principle of the fill-unit system. "The fill unit, by definition, 1 kg DM of a reference young pasture grass has a fill value (FV) of one fill unit both in sheep (1 FUS) and in cattle (1 FUC). Its VDMI (in g / kg .75) amounts to 75 by the standard sheep (SS) and 122.6 by the standard lactating cow (SLC; 600 kg live weight, 17 kg milk)" (Jarriage et al., 1986). In the fill-unit system, an animal is described by the FIC (fill-units/d) and feed in terms of fill (fill-units/amount of feed) (Zom et al., 2012). Zom et al. (2012) expressed DMI by means of the ratio between FIC and fill given by

$$DMI\left(\frac{kg}{day}\right) = \frac{FIC\left(fill-unit/day\right)}{Fill\left(fill-unit/kgDM\right)} \qquad (1)$$

For the model, the same formula was chosen since it is possible to include and modify characteristics of both the animal and the forage and there is no relationship between the two. The FIC determined by the ability of the animal to process forage, which depends on factors such as size, age and lactation status. The Fill established by forage properties such as digestibility and its chemical composition. An ad libitum feed assumed, i.e. the cow will eat until the total amount of the fill-units is equal to that of FIC.

Two types of forage that may be present in a grazing system in Mexico are considered. They grazed predominantly on pasture containing two native grasses (*Festuca arundinacea* and *Lolium multiflorum*). Each type of feed has its own qualities:

$$DMI = \frac{FIC}{\sum_{i=1}^{n} f_i SV_i}, \qquad (2)$$

Where $FIC = \alpha + \beta(1 - e^{m})(re^{n})$, and considering *n* types of feed present in the grazing system, f_i represents the feed fraction *i,* and SV_i, its respective satiety value. Thus, $\sum_{i=1}^{n} f_i SV_i$ is the total satiety value.

The formula is given is based on the work done in Zom et al. (2012a) where α is a constant that describes the average base capacity of forage intake, β determines the change in intake capacity with respect to the days in lactation, $1 - e^{m}$ represents the behavior of the forage intake and e^{n} describes the behavior of forage intake during gestation. As for the qualities of the feed $f_i SV_i$ determined by the chemical composition and digestibility of the forage. For the type of forage, *i*, dry matter (DM) is considered crude protein (CP), neutral detergent fiber (NDF) and in vitro digestible organic matter (dOM) from DM contained in each type of forage. The age of the cow is calculated as *(p-1) + d/365*. Cows are assumed dry at day 220 of gestation.

To obtain the constant parameters, we applied the interpolation method with Lagrange polynomials to the data provided by individual experiments in dairy cows in Baja California, Mexico. The implementation of the algorithm was executed in mathematical software, MATLAB (Matrix laboratory). To obtain the FIC, the input parameters are parity, days in lactation, days of gestation and gestation rate.

To obtain $SV = \sum_{i=1}^{n} f_i SV_i$ are considered as inputs; DM, y, CP, NDF and, dOM are estimated from each forage, which was obtained by an adjustment of Data in the following table:

[Insert Table 1]

When executing the program, the following window appears (Figure 1), where the inputs of the animal were requested, the dry matter of each forage and the proportion of each forage in the grazing system. The characteristics of the animal that are contemplated are parity, days of lactation, days of gestation and rate of gestation. The characteristics of the forage are DM of *Fescue arundinacea* and of *Lolium multiflorum* and their respective proportion in the meadow where the cows graze.

[Insert Figure 1]

The model provides the intake capacity of each animal, the satiety value of *Fescue arundinacea* and *Lolium multiflorum*. Finally, it provides the amount of DM that the animal ingests in kg (Figure 2).

[Insert Figure 2]

Program model validation

Data from three experiments of grazing dairy cows (race, age, lactation season, and gestation state and gestation rate) carried out in low California, Mexico was used to validate the generated program of DMI prediction. The data collected was the DMI, daily milk production, and diet

ingredients and composition. The data was inserted in the generated model program for the validation results. Table 2 shows the DM consumption averages obtained experimentally.

[Insert Table 2]

Results and Discussion

The model contemplates two types of forage, however, due to the prototype structure, it has the potential to predict the intake of dry matter in different grazing systems, and it is enough to add the corresponding inputs. Since it predicts the intake for each individual animal and in various grazing systems, the model is robust.

Figure 3 presents the relationship between FIC and the parity number (p). The direct relationship can be attributed to the correlation between age and cow size. At higher animal size, the capacity of the digestive tract increases (Allison, 1985; Doreau et al., 1985). On the other hand, Boudon et al., (2009) suggests that rumen fill depends on maturity. In fact, Figure 3. Shows that the animal's ingestion capacity increases as the lactation days increase to an asymptotic level. It can also be observed that increasing parity has a greater capacity of forage intake.

[Insert Figure 3]

Figure 4 presents the DMI as a function of physiological changes of the sample. As the days in lactation increase, the dry matter intake increases, in addition to the increase in the number of parity (p), there is also an increase in dry matter intake.

The age of the cow described in terms of parity and days in lactation, represents the physiological state of the animal, which generates changes in FIC and DMI (Figures 3 and 4). Therefore, as parity and day in lactation increase, the value of FIC increases, leading to increase in DMI. However, the value of FIC tends to be the same for parities greater than or equal to three.

In Berry et al., (2014), dry matter intake ranges from 15.6 to 24.9 kg/d and our model estimates a dry matter intake of between 16 and 25 kg / d (Figure 4), showing a similarity with the model in this study. On the other hand, Volden et al., (2011) reported a minimum intake of 9.7 kg/d and a maximum intake of 32.3 kg/d, which shows significant differences with the proposed model. These differences can be attributed to metabolic regulation (Volden et al., 2011) and to the fact that environmental factors that influence DMI are not considered (Ingvartsen, 1994).

[Insert Figure 4]

Conclusions

This study contemplates characteristics of both animal and forage; although not considered environmental characteristics, the model estimates are consistent and do not differ significantly

from the results of other studies. Another prevailing advantage of this model is that only DM is the required input that characterize the forage, CP, NDF and dOM are not necessary. The developed model is consistent since the average DMI of group 2 is 21.68 kg/d and that of group 1 is 23.44 kg/d, while the model estimates a DMI of 22,826 kg/d based on the average characteristics of the cows under study.

References

Allison, C.D. (1985). Factors affecting forage intake by range ruminants — a review. J. Range Manage. 38, 305–311.

Berry, D. P., Coffey, M. P., Pryce, J. E., De Haas, Y., Løvendahl, P., Krattenmacher, N., Crowley, J. J., Wang, Z., Spurlock, D., Weigel, K., Macdonald, K., and Veerkamp, R. F. (2014). International genetic evaluations for feed intake in dairy cattle through the collation of data from multiple sources. Journal of Dairy Science, 97(6), 3894-3905.

Boudon, A., Peyraud, J.L., Faverdin, P., Delagarde, R., Delaby, L., Chaves, A.V., (2009). Effect of rumen fill on intake of fresh perennial ryegrass in young and mature dairy cows grazing or zero-grazing fresh perennial ryegrass. Animal 3, 1706–1720.

Doole, G.J., and A. J. Romera. (2013). Detailed description of grazing systems using nonlinear optimisation methods: A model of a pasture-based New Zealand dairy farm. Agricultural Systems 122: 33-41.

Doreau, M., Robelin, J., Lestrade, A. (1985). Effects of physiological-state and body fatness on digestive-tract weight and composition in the dairycow. Livest. Prod. Sci. 12, 379–385.

Gregorini, P, E. M. K. Minnee, W. Griffiths, and J. M. Lee. (2013). Dairy cows increase ingestive mastication and reduce ruminative chewing when grazing chicory and plantain. Journal of Dairy Science 96: 7798-7805.

Ingvartsen, K. L. (1994). Models of voluntary food intake in cattle. *Livestock Production Science*, *39*(1), 19-38.

Jarrige, R., Demarquilly, C., Dulphy, J. P., Hoden, A., Robelin, J., Beranger, C., Geay, Y., Journet, M., Malterre, C., Micol, D., and Petit, M. (1986). The INRA "Fill Unit" system for predicting the voluntary intake of forage-based diets in ruminants: a review. *Journal of Animal Science*, *63*(6), 1737-1758.

Krizsan, S. J., Sairanen, A., H¨ojer, A., and Huhtanen, P. (2014). Evaluation of different feed intake models for dairy cows. Journal of dairy science, 97(4), 2387-2397.

Mármol, J. F. (2006). Manejo de pastos y forrajes en la ganadería de doble propósito. Memorias X Seminario de Pastos y Forrajes. Fac. Ciencias Veterinarias, La Universidad de Zulia, 4, 20-22.

Miguel, M. F., Ribeiro Filho, H. M. N., Crestani, S., Ramos, F. D. R., and Genro, T. C. M. (2012). Pasture characteristics of Italian ryegrass and milk production under different management strategies. *Pesquisa Agropecuária Brasileira*, *47*(6), 863-868.

Van Rensburg, M. J. (2013). Nutritive value of tall fescue (Festuca arundinacea) established on rehabilitated mineland for grazing cattle (Doctoral dissertation, University of Pretoria).

Volden, H., Nielsen, N. I., Åkerlind, M., Larsen, M., Havrevoll, Ø., and Rygh, A. J. (2011). Prediction of voluntary feed intake. In *NorFor-The Nordic feed evaluation system* (pp. 113-126). Wageningen Academic Publishers.

Zom, R. L. G., André, G., and Van Vuuren, A. M. (2012). Development of a model for the prediction of feed intake by dairy cows: 1. Prediction of feed intake. Livestock Science, 143(1), 43-57.

Table 1. Chemical composition of *Fescue arundinacea* and *Lolium multiflorum*

	DM g kg^{-1}	CP g kg^{-1} DM	NDF g kg^{-1} DM	dOM g kg^{-1} DM
Festuca Arundinacea[a]	386.9	105.1	623.8	605.3
	400.3	90.8	604.1	653.3
	438.3	78.7	592.6	668.9
	461.4	74.1	567.8	659.7
	546	73.6	627.6	618.7
Lolium multiflorum[b]	165	216	331	0.76
	178	258	332	0.75
	222	147	453	0.70
	174	196	378	0.75
	205	148	504	0.68

Source: [a]Van Rensburg, M.J. (2013), [b] Miguel et al. (2012)

Table 2. Dry matter consumption kg/d

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Average
Group 1	23.7	24.5	24.16	24.33	24.57	21.33	21.5	23.44143
Group 2	20.6	21.8	19.16	20.66	23.71	21.83	24	21.68

Figure 1. Graphic User Interface (GUI) of MATLAB where the user types inputs from the model.

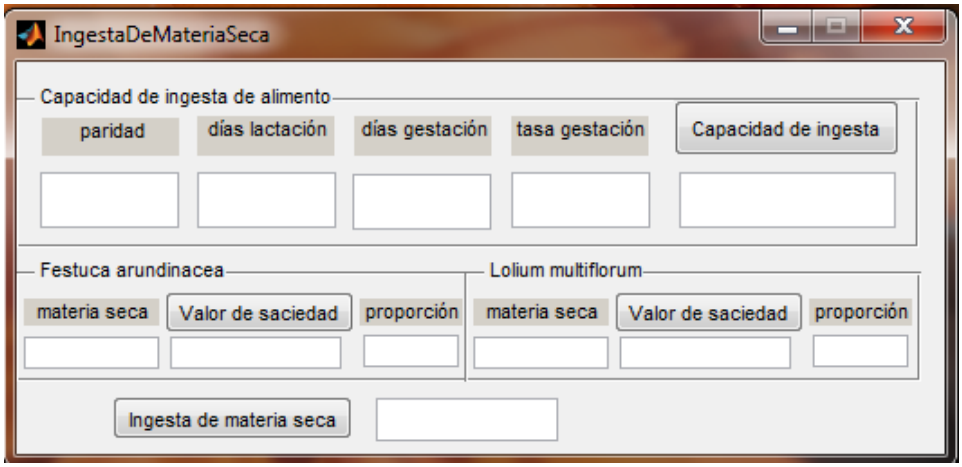

Figure 2. The execution of the model estimates an intake of 22,826 kg. Of dry matter for a cow in its second parity.

Figure 3. Feed intake capacity (FIC) in the course of lactation days for different parities.

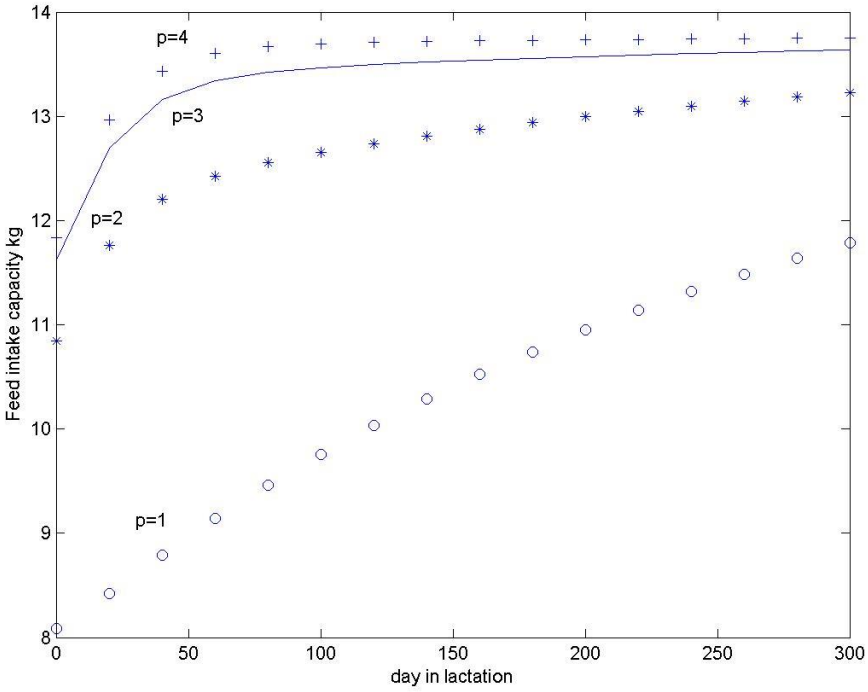

Figure 4. Feed intake depending on lactation days and parity (p).