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Optimized feed planning for a grazing horse production systems

José Evandro Gervásio de Oliveira[1, 4], João Batista Soares[2], Luis Gustavo Barioni[3], Gilberto Gonçalves Leite[2, 3], Auro César Braga[4], Marcelo Espellet Menezes[4]

[1] *Mestrando em Agronegócios da Faculdade de Agronomia e Medicina Veterinária da Universidade de Brasília.*
[2] *Faculdade de Agronomia e Veterinária - FAV/UnB.*
[3] *Embrapa Cerrados, Brasília-DF.*
[4] *Exército Brasileiro, Brasília, DF.*

ABSTRACT - The objective of this study was to develop an economically optimal plan for pasture production and supplementary feeding of horses. The plan was based on the optimization of a multiperiodic linear programming model with the objective of minimizing overall feeding costs, subject to the nutritional constraints of each horse category. The model encompasses a period of one year, from January to December, divided in bimonthly periods. Technical coefficients varied among periods based on local information regarding productivity of the forage crops, taking into account the local climatic conditions and seasonality of production. Literature data on feed nutritional value (crude protein and digestible energy), dry matter intake and nutritional requirements of the horses were also used as technical coefficients. Optimization results allow concluding that it is possible to reduce significantly the feeding costs in the horse production system by decreasing supplementation and substituting the commercial concentrate by the oat grain produced in the local.

Key Words: linear programming, modeling, ration balancing

Planejamento otimizado da alimentação em um sistema de produção de equinos em pastejo

RESUMO - Objetivou-se planejar e otimizar economicamente a produção de forragem e a alimentação de equinos, visando reduzir os custos de um sistema de produção de equinos em pastejo. O planejamento foi desenvolvido a partir da otimização de um modelo de programação linear multiperiódico com o objetivo de reduzir as despesas com alimentação, sujeita às restrições de exigência nutricional de cada categoria. O modelo contemplou o período de um ano, de janeiro a dezembro, dividido em bimestres. Os coeficientes técnicos variaram entre períodos com base em informações locais sobre a produtividade dos cultivos forrageiros e valores nutricionais dos alimentos (proteína bruta e energia digestível) sugeridos na literatura, considerando as condições climáticas e a sazonalidade de produção, observados na Coudelaria. De acordo com os resultados, é possível reduzir os custos no sistema de produção de forragem e na alimentação de equinos, bem como substituir o uso de concentrado comercial por aveia produzida no local.

Palavras-chave: balanceamento de dieta, modelagem, programação linear

Introduction

Horse breeding occupies a nationally prominent position, however, it can still be better known and exploited, particularly with regards to its contribution to employment and income generation.

According to CEPEA data (2006), total Brazilian horse breeding amounts to about 5.8 million animals, raising the need for studies aimed at the development of this activity and for its related economic sectors responsible for generating about 3.2 million direct and indirect jobs. This may positively rise such an important agribusiness segment.

In Brazil, horses are most widely used in agriculture, but they are also used in sports, leisure, therapeutic riding, and military activities. The potential of this species for meat production is still incipient; however, it presents itself as a new agribusiness opportunity.

Not long ago, rarely horses received concentrated feed, grass or legume hay or even grains. Pasture has always been the natural ration for horses. Typically, good-quality pastures are sufficient for maintaining good physical conditions of horses. However, feed represents a significant share of costs involved in horse breeding. According to Cunha (2001), feed represents about 60% to 80% of the total horse raising production costs.

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Corresponding author: evandro.gervasio@gmail.com; gg.leite@hotmail.com

In this sense, the aim of this work was to plan forage production and to optimize the costs of feeding animals in a horse production system through linear programming techniques.

Material and Methods

According to Alves (2004), in their habitat conditions, horses spend up to 75% of the day chewing. The volume of feed eaten per day, according to NRC (1989), ranges from 1.5 to 3.5% of body weight, depending on the age and category of the animal and the work carried out. However, Silva et al. (1998) emphasizes that the volume ingested should not be less than 1% of body weight.

The use of concentrates (commercial mixtures, corn, oats, etc.) in horse diets should be in accordance with a bulk pasture ratio (hay, pasture and grazing), which may vary from 40% to 60% and from 60% to 40% and might, exceptionally, reach up to 70% of concentrate in the diet of high-performance horses, when these are stabled (NRC, 1989).

Generally, in Horse Farms, animals are raised in the field, with supplementary feeding, on a half-stable regime. Stallions are stabled and fed concentrate rations twice a day and mineral salts once a day. For the rest of the day, they remain loose in the native or cultivated pasture, with a limitless supply of common salt. The different horse categories are raised in different areas, according to the management type.

Except for non-pregnant mares and females at 2 to 4 years of age, which are raised exclusively on natural and cultivated pastures, and breeding stallions, which get 7.5 kilograms of concentrated feed, animals are fed 5.0 kg of commercial concentrated mixes (Table 1).

The nutritional requirements estimated for the categories at the Coudelaria do Rincão, in terms of energy and protein, were calculated according to the NRC (1989) (Table 2). These quantities are taken to be the minimum requirements for calculating the nutritional diet of each category.

The existence of a variety of forage species (grasses and legumes) and the absence of specific surveys, such as dry matter production, rainfall and average annual temperature on site, make it difficult to accurately determine forage quality (crude protein and digestible energy) for the Horse Farm region. Therefore, it was in this work the average rates recommended by the Fundação Estadual de Pesquisa Agropecuária (FEPAGRO) from the station in São Borja, Rio Grande do Sul, the setting for the study, considering that the quality of the pasture offered is identical to the one consumed by the animals.

Table 1 - Summary of feeding management and consumption at the Horse Farm[a]

Time	At 5 a.m.	Between 7 a.m. and 8 a.m.	Between 8 a.m. and 12 p.m.	Between 12 p.m. and 1 p.m.	Between 1 p.m. and 4 p.m.	Between 4 p.m. and 5 p.m.	At 8 p.m.
Category							
Stallion	2.5 kg of concentrate	Loose in the paddocks		2.5 kg of hay/ green pasture	Loose in the paddocks	2.5 kg of concentrate	2.5 kg of hay/ green pasture
Breeding stallion	2.5 kg of concentrate	Loose in the paddocks		2.5 kg of hay/ green pasture	Loose in the paddocks	2.5 kg of concentrate	2.5 kg of hay/ green pasture with a supplement of 2.5 kg of oat grain
Pregnant mare or unpregnant dam with foal		2.5 kg of concentrate	Loose in the native pastures	Set loose in the pasture as of 1pm		2.5 kg of concentrate	Set loose in the native pasture
Pregnant mare		2.5 kg of concentrate	Loose in the pasture	Set loose in the native pasture as of 1pm		2.5 kg of concentrate	Set loose in the native pasture
Weaning foal of up to 24 months		2.5 kg of concentrate	Loose in the pasture	Set loose in the native pasture as of 1pm		2.5 kg of concentrate	Set loose in the native pasture
Mare 2 to 4 years old /Unpregnant foals			Are raised exclusively on native pastures and artificial pastures				

[a] Source: Coudelaria do Rincão (2005).
The price obtained for 1 (one) kg of feed in a public procurement process, on March, 2006, was US$ 0.39.
All categories receive 50g of mineral salt and limitless common salt in an open feedlot and in the field. Total estimated amount for feeding is US$ 484,769.66.

Animal Science indices seen in the management system used at the Coudelaria do Rincão are within the standards described for semi-extensive management, observed by Santos et al. (2004), which served as a parameter to establish the monthly evolution of the assets in the present work (Table 3). Observing Table 3 and considering the number of existing mares (240) and the animal sciences indexes observed as pregnancy (76%), birth rate (90%), weaning rate (90%) and, mortality rate of weaned animals (5%), it is possible to calculate the evolution of assets during the year. As such, stallions enter the breeding season in August and remain in it until January. The number of unpregnant mares stems from the mentioned pregnancy rate.

An inventory of pastures was carried out and compiled in a spreadsheet on the productivity and energy density of forage (Tables 4 and 5). The months of pasture use and the seasonal production of dry matter, energy and protein production of each forage species were also calculated (Table 6). Tables 7 and 8 show the required amounts of energy and protein calculated based on animal requirements and the population dynamics of the herd.

In order to carry out a strategic plan for the productivity of dry matter , crude protein and digestible energy, 6 (six) periods of forage production were established based on weather conditions and the seasonality of the existing forage productivity in the Horse Farm.

Considering the horse assets at the Horse Farm, (Table 3), the daily energy needs in M Cal (Table 7) and the daily crude protein demand in kg (Table 10) were possible of being calculated. They were both were used in this work as minimum restrictions to be met in the optimized diet.

Table 2 - Daily nutritional energy and protein requirements, per category

Animal category	Nutritional requirement	
	Digestible energy (Mcal/day)	Crude protein (g/day)
Stallion[1]	19.4	776
Breeding stallion[1]	24.3	970
Unpregnant mare[2]	16.4	656
Unpregnant mare w/ foal (lactating)[2]	28.3	1.427
Pregnant mare[2]	19.7	866
Pregnant mare with foal[2]	28.3	1.427
Weaned foal	15.0	750
1 year of age foal	18.9	851
2 years of age foal	18.8	800
3 – 4 years of age female (maintenance)	16.4	656

Source: NRC (1989).
[1] Stallions were considered with an average weight of 600 kg.
[2] Mares were considered with an average weight of 500 kg.

Table 3 - List of animals, by category

Animal category	Monthly number of animals											
	January	February	March	April	May	June	July	August	September	October	November	December
Stallion	0	20	20	20	20	20	20	0	0	0	0	0
Breeding stallion	20	0	0	0	0	0	0	20	20	20	20	20
Unpregnant mare	18	18	18	18	18	18	18	18	18	18	18	18
Unpregnant mare with foal	40	40	40	40	40	40	40	40	40	40	40	40
Pregnant mare	0	0	50	100	182	182	182	182	182	0	0	0
Pregnant mare with foal	182	182	132	82	0	0	0	0	0	182	182	182
Weaned foal	0	0	50	100	150	150	150	150	150	150	150	150
1 year of age foal	150	150	150	150	150	150	150	150	150	150	150	150
2 years of age foal	150	150	150	150	150	150	150	150	150	150	150	0
3 to 4 years of age female	30	30	30	30	30	30	30	30	30	30	30	30
Total	590	590	640	690	740	740	740	740	740	740	740	590

Source: Coudelaria do Rincão, 2005.

Table 4 - Inventory of pasture areas and productivity spreadshee

Forage	Planted area	Dry matter productivity	Dry matter production	Usage period		Cost
	(ha)	(t/ha)	(t)	From	To	(R$/ha)[4]
Ryegrass	290	4,00	1.160	Jun	Nov	480,00
White oat (grain)	100	2,00[1]	200	Jan	Dec	587,50
Millet	50	20,00[2]	1.000	Dec	Apr	510,40
Native field	900	4,20[3]	3.780	Jan	Dec	00,00[5]

[1]MAPA/CONAB (2005); [2]Kichel (2000); [3]Fundação Estadual de Pesquisa Agropecuária – FEPAGRO (2005).[4]Costs calculated based on the work of Kichel (2000) and De Mori (2004), indexed by the IGP-DI, based on Jan/2007. [5]Cost of native pastures not estimated because it is Federal land. The total cost of pasture/production areas (millet, ryegrass, oat grain is US$ 125,533.70. Total cost (pasture and grazing areas) is US$ 163,924.41.
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Table 5 - Energy density and protein of the forages used in the feeding management of Horse Farm animals

Forage	Scientific name	Energy density (Mcal/kg DM/DE)	Crude protein level (%)	Bibliographic reference
Ryegrass (100% DM)	*Lolium multiflorum Lam.*	2.2	17.9	NRC (1989)
White oat (grain)	*Avena sativa L.*	3.2	13.3	NRC (1989)
Millet	*Pennisetum americanum L.*	2.81	20.0	PB winter and summer, adapted from Frizo (2001) and Travi (2002)
Native field summer	Several species	2.64[1]	10.0	
Native field winter	Several species	2.16[1]	4.0	UFRGS[1]

[1] Oral information from Professor Miguel D'Allgnol/UFRGS.

Table 6 - Crop, energy and protein productivity

Forage	Annual total	Period 1 Jan./Feb.	Period 2 March/April	Period 3 May/June	Period 4 July/Aug.	Period 5 Sept./Oct.	Period 6 Nov./Dec.
Crop productivity (kg DM/ha)							
Ryegrass	4,000	0	0	667	1,334	1,334	667
Millet	10,000	4,000	4,000	0	0	0	2,000
Native field winter	1,800	0	300	600	600	300	0
Native field summer	2,400	800	400	0	0	400	800
Energy productivity (Mcal)							
Ryegrass	8,800	0	0	1,466	2,934	2,934	1,467
Millet	28,100	11,240	11,240	0	0	0	5,620
Native field winter	4,752	0	792	1,584	1,584	792	0
Native field summer	5,184	1,728	864	0	0	864	1,728
Protein productivity (kg)							
Ryegrass	716,000	0	0	119,334	238,667	238,667	119,334
Millet	2,400,000	960,000	960,000	0	0	0	480,000
Native field winter	126,000	0	21,000	42,000	42,000	21,000	0
Native field summer	160,800	53,600	26,800	0	0	26,800	53,600

Table 7 - Energy requirements

Animal category	Energy demand (Mcal/day)											
	Jan.	Febr.	Marc	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stallion	0	388	388	388	388	388	388	0	0	0	0	0
Breeding stallion	486	0	0	0	0	0	0	486	486	486	486	486
Unpregnant mare	295	295	295	295	295	295	295	295	295	295	295	295
Unpregnant mare with foal	1,132	1,132	1,132	1,132	1,132	1,132	1,132	1,132	1,132	1,132	1,132	1,132
Pregnant mare	0	0	985	1,970	3,586	3,586	3586	3586	3586	0	0	0
Pregnant mare with foal	5,150	5,150	3,735	2,320	0	0	0	0	0	5,150	5,150	5,150
Weaned foal	0	0	750	1,500	2,250	2,250	2,250	2,250	2,250	2,250	2,250	2,250
1 year of age foal	2,835	2,835	2,835	2,835	2,835	2,835	2,835	2,835	2,835	2,835	2,835	2,835
2 years of age foal	2,820	2,820	2,820	2,820	2,820	2,820	2,820	2,820	2,820	2,820	2,820	0
3 to 4 years of age female	492	492	492	492	492	492	492	492	492	492	492	492
Total per day	13,210	13,112	13,432	13,752	13,797	13,797	13,797	13,895	13,895	15,460	15,460	12,640
Total per month	396,324	393,384	402,984	412,584	413,928	413,928	413,928	416,868	416,868	463,824	463,824	379,224
Total per year	4,987,668											

The production cost for cultivated pastures (millet, ryegrass and oat grain) is US$ 125,533.70 and, for native pastures, it is US$ 32,865.17 (Table 4). So, to plan the optimal feeding scheme for horse raising in grazing pastures, an investment of around US$ 163,924.41 will be required to provide the pasture areas needed for the implementation of the proposed change from commercial concentrate mixes to oat grain. Considering the consumption of the animal (Table 1) and considering the value of the commercial mixture, the current cost of feeding horses at the Horse Farm is US$ 484,769.66, therefore, in order to minimize costs, animal feeding is possible to be optimized by replacing ration for oats.

In order to address the seasonality of forage production, a multiperiod linear programming model was developed, in which forage production is represented on a bimonthly

Table 8 - Crude protein demand (kg/day)

Animal category	Protein demand (kg/day)											
	Jan.	Febr.	Marc	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stallion	0	15.52	15.52	15.52	15.52	15.52	15.52	0	0	0	0	0
Breeding stallion	19.4	0	0	0	0	0	0	19.4	19.4	19.4	19.4	19.4
Unpregnant mare	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
Unpregnant mare with foal	57	57	57	57	57	57	57	57	57	57	57	57
Pregnant mare	0	0	43.3	86.6	157.6	157.6	157.6	157.6	157.6	0	0	0
Pregnant mare with foal	259.7	259.7	188.4	117.0	0	0	0	0	0	259.7	259.7	259.7
Weaned foal	0	0	37.5	75	112.5	112.5	112.5	112.5	112.5	112.5	112.5	112.5
1 year of age foal	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6	127.6
2 yr.-old foal	120	120	120	120	120	120	120	120	120	120	120	0
3 to 4 years of age female	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8	16.8
Total per day	612	608	618	627	619,0	619	619	622	622	725	725	605
Total per month	18,373	18,257.2	18,540	18,824	18,569	18,569	18,569	18,685	18,685	21,748	21,748	18,148
Total year	228,719											

basis, as well as the number of animals per category and nutritional requirements of the animals. The technical coefficients related to forage production considered typical conditions of the location (inter-year variability was not considered).

The model was established to minimize feeding costs, i.e., the sum of the product of the quantities of feed supplied and its respective price, for each period and category, during the period of one year (January to December). A period of one year was chosen to accommodate the typical seasonality of forage production in the Horse Farm. The amount of feed, in bulk pasture or concentrate, was expressed in kilograms of dry matter.

Mathematically, the objective function can be described as:

$$Min \sum_{ij} A_{ij} \cdot P_{ij}, \qquad (1)$$

where, A_{ij} = daily quantity of dry matter of the j-th feed, bulk or concentrate, consumed (kg/day), in the i-th period, and; P_{ij} = the price of dry matter of the j–th feed in the i-th period (R$/kg) (Table 4).

The minimization problem is subject to restrictions related to the nutritional requirements of animals. To balance the diets, we considered crude protein and digestible energy requirements (inequalities 2 and 3), assuming that the other nutrients are supplied in adequate amounts.

$$RPB_k \leq \sum_{ij} \left(PB_{ij} \cdot C_{ijk} \right) \text{ for every } k \qquad (2)$$

$$RED_k \leq \sum_{ij} \left(ED_{ij} \cdot C_{ijk} \right) \text{ for every } k \qquad (3)$$

where RPB_k = the requirement for crude protein of the k-th animal category (g/day); RED_k = the requirement for digestible energy of the k-th category (Mcal/day); PB_{ij} = the concentration of crude protein of the j-th feed, in the i-th period (g/day); ED_{ij} = the concentration of digestible energy of the j-th feed, in the i-th period (Mcal/day); C_{ijk} = dry matter ingestion of the j-th feed, in the i-th period, by the k–th category (kg/day).

The nutritional restrictions described above do not establish minimum levels for the concentration of nutrients in the diet, only the total amount of nutrient to be consumed. Since it is known that the amount of food consumed by animals is limited by physiological issues, it was established a restriction to the maximum amount of dry matter being consumed (Inequality 4).

$$A_{ij} \leq \sum_{ij} \left(C_{ijk} \cdot N_{ik} \cdot D_i \right), \text{ for every } k \qquad (4),$$

where N_{ik} = the number of animals in the k-th category, in the i-th period and D_i = the number of days in the i-th period. The number of days for each period was determined by the number of days of each two-month period, i.e., 59, 61, 61, 62, 61 and 61 days, respectively, for periods 1 to 6. The intake of dry matter (C_{ijk}, kg/day) is the response-variable of optimization.

The maximum amount of the offered bulk forage considered productivity and the area allocated for each grass species in each period. Also, the supply of feed concentrates generally obeyed the constraint imposed by Inequation 5, where O_{ij} = the amount of dry matter of the i-th feed (kg/day) offered in the j-th period. The values of O_{ij} were obtained by multiplying the expected productivity of crops in each period (Table 6) by the area of each crop (Table 4).

$$A_{ij} \leq O_{ij} \text{ for every } i \text{ and } j \qquad (5)$$

Some categories have specific constraints on the amount of allocated feed, Inequality 6. Stallions, for example, have no access to the native pasture and, therefore, the consumption of this feed is restricted to zero.

$C_{ijk} \le O_{ijk}$ for every i, j and k (6)

According to the NRC (1989), bulk forages should be included in the diet of horses in a defined ratio (usually 60%) compared to the total intake of dry matter. To address this technical criterion, the constraint described by Inequality 7 was established.

$$\alpha_{ik} \cdot \sum_{n} V_{ink} \ge \beta_{ik} \cdot \sum_{m} CN_{imk}\text{, for every } i \text{ and } k \quad (7)$$

where V_{ink} = the amount of the n-th bulk forage feed consumed by the k-th category (kg/day), in the i-th period; CN_{imk} = the quantity of the m-th concentrate feed consumed by the k-th category (kg/day), in the i-th period; α_{ik} = the maximum ratio of concentrated feed (adimensional) of the k-th category, in the i-th period; β_{ik} = the minimum ratio of bulk forage feed in the diet of the k-th category (adimensional), in the i-th period. Both CN_{imk} and V_{ink} correspond to subsets of A_{ijk}, defined by the following correspondence between the indices (Equations 8 and 9).

$A_{ijk} = V_{ink}$, for j=1..nv; j=n; (8)

$A_{ijk} = CN_{imk}$, for j=nv+1...na, j=nv+m; (9)

where *nv* corresponds to the number of bulk forages and *na* corresponds to the total number of feeds. Since these are all subsets, the sum of the quantities and ratios of bulk forage and concentrates should cater to equations 10 and 11.

$\alpha_{ik} + \beta_{ik} = 1$, for any i (10)

$$A_{ij} = \sum_{n} V_{in} + \sum_{m} CN_{im} \quad (11)$$

The use of forage from annual crops was subject to a constraint (Inequality 12) so that the area (turf) grown, which is not considered explicitly by the model, remained constant in subsequent periods for which crop production persists. To achieve this, the production ratio of each feed grown in subsequent periods was considered (Table 6).

$V_{ni} = \gamma_{ni} \cdot V_{n(i-1)}$ (12),

where γ_{ni} = the production ratio of the n-th bulk forage in the i-th period in relation to the same forage in the previous period (i-1).

The linear programming model described above was implemented using a spreadsheet in Microsoft Office Excel 2003 solved by Microsoft Excel Solver, using the Primal Simplex method (SOLVER.COM, 2007; DANTIZG, 1951).

Results and Discussion

The results provide suggestions for the optimal use of existing forage resources and proposals for economically optimal diets for the Horse Farm. The values found (Tables 9 to 12) below, shown in brackets, refer to the diets currently applied in the Horse Farm (Table 1). The proposal for the diet being considered is expressed as the daily food intake (kg / day DM), by horse category, for six periods throughout the year.

It has to be noted that in the first evaluation period (Table 9) there is no need to supply commercial concentrate, in accordance with the management type. This is because of the optimization in the use of millet, oat grain and pasture. As highlighted by Kichel (2000), millet is a type of forage with excellent nutritional value of up to 24% of crude protein as pasture, good palatability and 60% to 78% digestibility. Similarly, oat grain has a high nutritional value, good palatability and 60 to 80% digestibility (NRC, 1989; Kichel, 2000). The optimized model proposes the following feeding program for the categories under consideration:

- For stallions, optimized management dictates the use of oats in grain instead of concentrate and use of millet. The nutritional needs of stallions in this period are met by the consumption of 8.3 kg of dry matter per animal/day, distributed as the following: 6 kg DM of millet offered in the feedlot and / or in the picket and 2.3 kg DM of oats beans. It shall be noted that the amount of oat offered is less than 5.0 kg/day of concentrates fed in the current management. This smaller quantity of oats is due to the high nutritional value of the millet selected by the model as a forage alternative for this category. As highlighted by Frizo (2001) and Travi (2002), millet is a type of grass with high levels of crude protein and digestible energy, and partially meets the nutritional needs of stallions, according to NRC (1989).

- For unpregnant mares, optimized management dictates that only open fields are used. The amount of dry matter intake is 6.6 kg per day. It is emphasized that the nutritional requirements of this category are low, according to NRC (1989), when compared to other categories. The proposed optimal plan does not differ from the current system used

Table 9 - Daily feed intake in the 1st period, January/February

Category	Daily feed intake (kg DM)				
	Millet	Native field	Oat gain	Ryegrass	Total per horse
Stallion	6.0	0.0	2.3	0.0 (5.0)	8.3
Unpregnant mare	0.0	6.6	0.0	0.0 (0.0)	6.6
Mare with foal	4.5	3.5	2.0	0.0 (5.0)	10.0
Foal + 1 year	1.9	4.9	0.2	0.0 (5.0)	7.0

Numbers in parentheses represent the current feeding practice.

at the Horse Farm, which does not feed supplements to unpregnant mares.

- Mares with foal is a category with high nutritional requirements (NRC, 1989), when compared to the others. Thus, the optimized plan proposes about 4.5 kg of millet dry matter, 3.5 kg of native pasture dry matter and 2.0 kg oat grain dry matter, amounting to 10.0 daily kilograms of dry matter.

- For foals at more than a year of age, the optimized model proposes the use of millet, grain oat and native fields, in the respective amounts of 1.9, 4.9 and 0.2 kg of dry matter, totaling 7.0 kg DM/day. The current management scheme uses 5.0 kg of balanced feed per day. In the optimized plan, nutritional needs are met by using oats in conjunction with millet and native pasture.

The weaned foal and pregnant mare categories do not exist in the Horse Farm during the considered period, since foals are weaned in May/June at seven months of age and, in this period, they are more than one year of age; also, the breeding season is not yet complete and mare requirements in early pregnancy stages are the same as unpregnant females (NRC, 1989).

It was also observed that in the second assessment period (Table 10) there is no need to provide a commercial concentrate, according to the employed management type.

This period differs from the previous period in terms of the quantities offered by the optimized model. In this period a smaller amount of millet will be offered, because of the end of harvesting (Table 4). To compensate that, the model adds a larger amount of oat grain; this supplies all the nutritional requirements of the animals in the existing categories (Table 5).

In the third assessment period there is no need to supply the commercial concentrate, according to management type (Table 11). In this period, there is an increase in the use of ryegrass in animal nutrition. According to Kichel (2000), ryegrass is one of the most widely-cultivated winter grasses in Rio Grande do Sul, both for cutting and for grazing. This grass has up to 2.2% of digestible energy/kg of dry matter and 17.9% of crude protein/kg dry matter (NRC, 1989). Ryegrass has dry matter productivity of 2 to 6 t/ha, and the period of use occurs from June to November (Table 4).

For the categories considered by this study, the optimized model establishes the following feeding proposal for the 4th assessment period:

- For stallions, it is proposed the use of oat grain to replace commercial concentrate and the use of ryegrass. The nutritional need for stallions in this period is a total of 8.3 of kg dry matter, being provided as the following: 6 kg of ryegrass dry matter per day, offered in the feedlot and/ or the picket and 2.3 kg of oat grain. The amount of oat to be used is less than the 5.0 kg/day of concentrate used in the current management scheme due to the nutritional quality of ryegrass (Kichel, 2000).

- For unpregnant mares, the optimized management proposes the use of native and cultivated ryegrass pasture in quantities of 3.1 kg/DM of ryegrass and 3.6 kg/DM of native pasture, totaling 6.6 kilograms of dry matter per day. At Coudelaria do Rincão, this category is raised in native pastures. Due to the low quality of native pasture during winter, the optimal management proposes that this category has to be supplemented with ryegrass.

- Mares with foals have higher nutritional requirements than other categories (NRC, 1989). Thus, the optimized management scheme proposes 9.5 kg of ryegrass dry matter and 0.5 kg of oat grain dry matter, amounting to 10.0 kg of dry matter. The ryegrass has a high level of crude protein and high energy density (NRC, 1989) and it is available during this period (Tables 4 and 6). The current practice at the Horse Farm differs because it does not provide concentrate, which is replaced by oat grain in smaller quantities.

- For weaned foals, during the period of July and August, the proposed scheme is composed of 2.6 kg of ryegrass dry matter and 2.5 kg of oat grain dry matter,

Table 10 - Daily feed intake in the 2nd period (March/April)

Category	Daily feed intake (kg DM)				
	Millet	Native pasture	Oat grain	Ryegrass	Total per horse
Stallion	3,9	0	2,6	0 (5,0)	6,5
Unpregnant mare	0,1	3,3	2,3	0 (0,0)	5,7
Mare with foal	4,2	1,7	3,8	0 (5,0)	9,6
Weaned foal	2,5	0	2,5	0 (5,0)	5,0
Foal + 1 year	2,2	1,8	2,6	0 (5,0)	6,5
Pregnant mare	1,2	2,9	2,7	0 (5,0)	6,8

Numbers in parentheses represent the current feeding practice.

Table 11 - Daily feed intake in the 3rd period (May/June)

Category	Daily feed intake (kg DM)				
	Ryegrass	Native pasture	Oat grain	Comercial concentrate	Total per horse
Stallion	4.0	0.0	2.5	0.0 (5.0)	6.5
Unpregnant mare	0.0	8.1	1.9	0.0	10.0
Mare with foal	4.6	1.4	4.0	0.0 (5.0)	10.0
Weaned foal	2.5	0.1	2.5	0.0 (5.0)	5.0
Foal + 1 year of age	2.1	2.1	2.8	0.0 (5.0)	7.0
Pregnant mare	1.7	6.5	1.8	0.0 (5.0)	10.0

Numbers in parentheses represent the current feeding practice.

amounting to 5.0 kg per day of dry matter. The proposed scheme differs from the current practice, by replacing 5.0 kg of concentrate with 2.5 kg of oat grain. This category, with medium growth, has low nutritional requirements (NRC, 1989) when compared to the others. Unlike the current management type, which uses 5.0 kg of concentrate, the optimized management proposes to supply about 50% of dry matter needs in the form of oat grain while other needs are met by ryegrass.

- For foals at more than a year of age, it is proposed by the optimized plan the use of 5.8 kilograms of ryegrass dry matter and 1.2 kg of native pasture dry matter, totaling 7.0 kg of dry matter per day. The current management scheme uses 5.0 kg of concentrate per day, in addition to pasture. In planning the optimal nutritional, the needs are met with total replacement of concentrate by artificial ryegrass pasture and native pasture. The nutritional requirements of this category are met due to the nutritional quality of ryegrass (NRC, 1989).

- For pregnant mares, the use of native pasture and ryegrass to meet nutritional requirements is what the optimized management proposes. Although this category may have high nutritional requirements (NRC, 1989), they are achieved because of the good quality of the ryegrass (Kichel, 2000). The optimized plan proposes around 3.6 kilograms of ryegrass dry matter and 4.5 kg of native pasture dry matter, totaling 8.0 kg of dry matter daily. The proposed scheme differs from the current regime at the Coudelaria do Rincão because it does not include the use of concentrate in the diet of this animal category.

In the 5th assessment period (Table 12), what is proposed differs from the earlier period, primarily in the quantities of winter native pastures and ryegrass for the categories of unpregnant mares, pregnant mares and foals older than a year of age.

Ryegrass and millet are available in the 6th period (November/December) , and at the end of winter production and beginning of summer forage production, respectively. Forage production is optimized by annual pastures, as evidenced by the optimization results of the models. The availability of these forages prevents forage emptiness, i.e., a period of insufficient production of pasture dry matter. It is observed that the nutritional needs of various categories are completely met by pastures and the use of oat grain, with no need to use the industrial feed.

According to the model implemented, the amount oat grain needed for optimization is 352,750 kg. On an annual basis, Coudelaria do Rincão uses about 1,232,700 kg of commercial concentrate in the animal feed, at a cost of US$ 484,769.66 (Table 1). The total production cost of

Table 12 - Daily feed intake in the 5th period (September/October)

Category	Daily feed intake (kg DM)				
	Ryegrass	Native pasture	Oat grain	Comercial concentrate	Total per horse
Stallion	6.0	0.0	2.3	0.0 (5.0)	8.3
Unpregnant mare	0.5	5.7	0.0	0.0	6.2
Mare with foal	9.5	0.0	0.5	0.0 (5.0)	10.0
Weaned foal	2.6	0.0	2.4	0.0 (5.0)	5.0
Foal + 1 year	6.7	0.1	0.0	0.0 (5.0)	6.8
Pregnant mare	1.6	5.7	0.0	0.0 (5.0)	7.3

Numbers in parentheses represent the current feeding practice.

artificial pastures, oat grain and native pasture is US$ 163,924.41 (Table 4).

With the results obtained, we can completely replace commercial concentrate with oat grain, together with ryegrass, millet and native pasture grazing. The optimized feeding plan for raising horses in pastures saw a reduction in costs by around US$ 326,370.78.

Conclusions

The use of the optimized plan allows for a forage management plan, and the amount of forage needed to meet the nutritional requirements of each category over a year can be calculated. It is proved to be an effective tool in planning the use of forage resources with a potentially favorable impact on the development of agribusiness, particularly in breeding stock.

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