MANAGEMENT STRATEGIES, RISK CONSIDERATIONS AND HERD SIZE ANALYSIS FOR OPTIMAL RESOURCE ALLOCATION IN ARGENTINE DAIRY FARMS

Ariadna M. Berger, Wayne A. Knoblauch and James E. Pratt

Department of Agricultural, Resource, and Managerial Economics
College of Agriculture and Life Sciences
Cornell University
Ithaca, New York 14853-7801

ABSTRACT

After a rapid expansion of the Argentine dairy sector, lower producer prices are expected. As a means of preventing an excessive reduction in dairy farmers' profitability, an analysis of current profitability and an evaluation of possible improved resource allocation are warranted.

This study aims to: 1- establish an optimal plan for dairy farms located in the Santa Fe Sur region, and determine if and how it differs from the current plan; 2- determine if the current resource allocation is efficient in terms of the return-risk tradeoff; 3- evaluate 'nearly optimal' plans; and 4- determine the role of herd size in profitability improvement.

The comparison of current practices on a representative dairy farm in the Santa Fe Sur region and the optimal solutions obtained for different scenarios with a linear programming model show that there is room for improvement in resource allocation.

The model was modified, simulating several scenarios and including various sources of risk, to evaluate return-risk tradeoffs. When different choice models are applied to determine the best production plan, none of the seven optimal plans analyzed is the best one under all six choice models. The production plans that are the best ones under at least two different choice models are the plans for years 1996 and 1997, and the current plan is not the best under any choice model.

The analysis of multiple goals, included through additional constraints or activities, to evaluate nearly optimal solutions indicates that the economic performance of these farms is higher when corn for grain is included in the crop sequence, heifers are first bred at fifteen months of age, and higher production levels are achieved, despite the higher total feeding expenses.

The herd size analysis for years 1996 and 1997 suggests that there is room for growth, especially if heifers need not to be raised on the farm. Even if most of the potential profitability increase due to larger herds is lost when all replacements are raised on the farm, the herd can still be enlarged by thirty-forty percent. However, larger herds do not necessarily lead to higher profitability.

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INTRODUCTION

The Argentine dairy sector has expanded rapidly over the past few years. As a consequence of a stable economy, no government intervention, and increased domestic consumption, dairy has become one of the most dynamic agricultural sectors at both the farm and processor level. In 1991, total milk production was 5,937 million liters (SAGPyA, 1997), while in 1998 it was expected to be 9,700 million liters[1] (USDA, 1998).

Many observers have suggested that one factor could slow longer term production: the proportion of production devoted to the export market. Overall, exports achieve lower prices because dairy products and not fluid milk are exported. On the other hand, due to the high level of consumption already reached, it will probably be difficult to sustain the recent growth in domestic demand achieved during the past few years (Depetris de Guiguet and Cappellini, 1997). Therefore, higher percentages of the production will have to be exported, at lower prices, thus lowering producers' returns.

In Argentina, most of the milk production and dairy industry is located in the "Pampa Region". The Argentine pampa is a flat level plain of fertile soils with a warm/temperate climate and adequate to less than adequate rainfall (Solbrig, 1997). Overall, the climate and production resources of this region are very good for milk production under a grazing system.

Argentine milk production takes place on a forage basis. Milk cows graze planted pastures during the four seasons of the year, and fresh forage is the main component of their diet. Even if some diversity exists among production regions and among farms in the same region, a general description of milk production at the national level can be easily attempted. The average Argentine dairy farm has a herd of 107 cows, produces 1,104 liters per day, has a stocking rate of around one cow per hectare, and a lactation period of 225 to 330 days (SAGPyA, 1996). Different soils permit successful growth of different forage crops. However, alfalfa is the most common species used in planted pastures. The amount of supplementary feed is, in general, low: one to three kilograms per cow per day as a yearly average. Corn, wheat

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[1] No official final data for 1998 were available at the time this paper was completed.

bran, sunflower expeller and cotton seed are among the most used supplemental feeds. Depending on the lactation length, total production per cow fluctuates from 3,700 and 5,000 liters per year. Productivity measured in kilograms of milkfat per hectare ranges from 90 to 140 kilograms per hectare.

Currently, Argentine dairy farms' profitability is in general higher than other traditional agricultural enterprises. Dairy farms have benefited from improved genetics and production practices, and from relatively stable milk prices. Profitability of dairy farms in 1997 would range from 4.4 to 7.4 percent on total assets, without appreciation (Agromercado, 1998). However, these figures are based on theoretical models, and no official data are available. Further, due to the forecasted relatively slow growth in domestic demand and shrinking export markets, net returns for Argentine dairy farmers could decline in the future.

Variability in economic results occurs between years, due to the pasture-based nature of Argentine milk production. Forage production by planted pastures greatly fluctuates according to the weather, especially rainfall. Also, fluctuations in output and input (especially grains and byproducts) prices and other market conditions are important to define the economic result of these farms.

There are several tools that could be used in order to improve profitability. One strategy, probably the easiest one, consists of better allocating the resources already available in the farm. Another strategy is the introduction of new and/or different activities on the farm. In this case, we refer only to activities related to milk production, excluding from the analysis any activity that would mean a complete change of the farm. Finally, a third strategy implies the growth of the farm, in terms of land and/or number of cows, in order to reach economies of scale for smaller farms.

The overall objective of this study is to determine if the profitability of Argentine dairy farms can be improved, either via a better allocation of current resources, or via the firms' growth. Specific objectives are: 1- establish an optimal production plan, and determine if and how the current plan deviates from it; 2- if the current resource allocation is not optimal, determine if at least it is efficient in terms of the trade-off between return and risk; 3- evaluate 'nearly optimal' solutions, consistent with the goals or objectives of decision makers, and assess its sensitivity to changes in prices of milk and inputs; and 4- determine if profitability can be improved by enlarging the farm's size.

METHODOLOGY AND DATA

The region analyzed in this study is the Santa Fe Sur region. This region is representative of the Argentine dairy sector, and has a central location in the Pampa region briefly described in the previous section.

A linear programming (LP) model was constructed to reflect production practices and resource constraints of a representative farm in the selected region. In the model, the standard resources available and the most common constraints were included in order to represent the current production system characteristics. The model thus obtained is a decision aid that can rapidly calculate the optimal production plan

by matching number of cows and their requirements through time with available forages and other feed resources, and labor requirements of the herd and of other activities in the farm with labor availability.

In an uncertain framework, such as the one farmers face, in which only a few prices can be determined in advance and the effects of weather on yields and field time availability are unknown, it is difficult to conclude that the certainty assumption[2] holds. Therefore, the existing risk has to be included through some modifications of the basic model. If the relative riskiness of the enterprises being considered is not incorporated in the model, the optimal solution may result in higher income and more risky enterprise choices than observed in real situations. According to the farmer's attitude toward risk, a farm plan with less than maximum income, but lower income variability, may be preferred.

All sources of uncertainty (objective function, technical and right-hand side (RHS) coefficients) were modeled following the approach proposed by Pope and Shumway (1984)[3]. This approach consists in modifying the original LP model in order to represent different possible years, or "states of nature". Each state of nature includes all the possible relationships between variables such as rainfall, forage production, and prices, thus accounting for a_{ij}, b_i and c_j coefficient uncertainty. For each state of nature, the return-maximizing plan is obtained. Then, each of these plans is simulated in the other states of nature. Finally, the plan with the highest expected net return could be identified. Multiple objectives were evaluated by including them in the models as additional constraints. Increases in the farm's size were analyzed with parametric modifications of RHS coefficients.

The activities considered in this study are among the commercially implementable practices currently carried on in dairy farms of this region belonging to the farm management association that provided the data. Physical performance reflects the one that is currently achievable. Land, field time and the milking parlor capacity are the main restrictive factors in the model. The constraints included in the model refer to crop rotations, and accounting constraints to balance monthly demand and supply of labor and field time, dry matter, metabolizable energy, crude protein, fiber, calcium, herd dynamics and milkfat. Herd dynamics constraints account for the probability associated with a lactating cow being culled or starting another lactation. Milkfat constraints balance the supply of milkfat by lactating cows and the demand of milkfat by the monthly selling activities.

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[2] LP has four basic assumptions: proportionality, divisibility, additivity and certainty. Only if these assumptions hold, will the problem be valid and the solution useful. When they do not hold, some modifications can be adopted. Regarding the certainty assumption, average values are often used, even if they are not necessarily the best estimates of any coefficient. Or, modifications of the original LP problem, like stochastic or quadratic programming, allow for the inclusion of variability measures.

[3] Mean-Variance (E-V) programming was not used because objective function risk was already included in the reruns of the model. Also, the importance of this source of risk depends on the activities a farm is engaged in, and it may be more important in a cash crop farm than in a dairy farm. For instance, while the price of corn had a variation coefficient of eighteen percent over the period 1992-1997, milkfat price had a variation coefficient of only eight percent over the same period.

The representative farm used in this study was derived from data provided by an Argentine farm management association[4]. The main sources of information were the reports kept by technicians working in this region and personal communications with them. Emphasis is on farms belonging to a farm management association just because they keep accurate records over time. In this study *representative* does not mean *average* but, rather, *modal*.

The term *farm management association* defines a region-wide business development association that groups several *consortiums*. Consortiums are groups of neighboring farmers who hire a professional agronomist or veterinarian, and run their farms under his/her guidance. They act as a group, and hold frequent meetings in which information and ideas are exchanged.

It could be argued that only the "special" farms belonging to this association, generally supposed to be larger and, especially, better managed (thus being considered "top farms") are used in the study, and therefore no general results can be obtained. However, there is no empirical evidence on a better performance of these farmers. In fact, studies by Gallacher (1988), and Gallacher, Goetz and Debertin (1994) on the efficiency of both beef and mixed (cash crops-livestock) farms belonging to farm management associations in Argentina indicate that these farms do not show a significantly better performance when compared to other farms. There are no studies similar to these on dairy farms.

On the other hand, it would probably be impossible to conduct a study involving a sample of all Argentine dairy farms, or of all farms within a specific region, as the lack of records would become an important obstacle. It is not common to find well-documented farms, and big farms and farms belonging to farm management associations are almost the only exception.

The meteorological information was obtained from farm records and the National Meteorological Service (for the years 1992 to 1997), for the meteorological station located in the city of Laboulaye. Some additional information on forage production variability was obtained from the experiment stations of the National Institute of Agricultural Technology[5] located in Marcos Juárez and Rafaela (INTA, 1996b).

CONSTRUCTION OF THE MODEL

Table 1 summarizes the characteristics and average resources of the representative farm modeled in this study.

Nutrient sources are forage crops, grains, concentrates and byproducts. Forage crops include perennial pastures and winter and warm season annuals (oats and corn). Total yields and their variances for all forage crops are detailed in table 2. Other feedstuffs include corn, cotton seed, sunflower expeller, and wheat bran.

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[4] AACREA (Asociación Argentina de Consorcios de Experimentación Agrícola, or Argentine Association of Regional Consortiums for Agricultural Experimentation).
[5] INTA, Instituto Nacional de Tecnología Agropecuaria.

Table 1: Characteristics of a representative farm in the Santa Fe Sur region

Characteristic		Source
Total land (hectares)	600	a
Milk cows (head)	500	a
Heifers (head)	300	a
Milk production (liters/lactating cow/day)	18	b
Milk production (liters/lactating cow/year)	5310	b
Milkfat production (kg/cow)	186	b
Supplemental feed (kg/cow)	1570	b
Feed ratio (kg feed/liters of milk)	0.29	b
Calving interval (months)	13.5	b
Culling rate	25%	b

Sources: a) Piola (1998), b) López Sauque and Piola (1997)

Table 2: Total yields and variance of forage crops

	Corn silage	Pasture			Oats
		year 1	year 2	year 3	
Total production (1)	28.0	5.0	7.5	3.5	4.0
Variance	5.4	2.0	2.3	1.1	0.9

(1) Except for the corn silage, production is measured in metric tons of dry matter per hectare.
Source: Piola (1998).

The farm is assumed to be self-sufficient in production of fresh forage and silage. Therefore, no provision is made for buying or selling any kind of conserved forage. The crop sequence is four years long: after three years of pasture, land is cultivated with oats and/or corn. After the harvest of corn, another three-year-pasture is started. Machinery needed for field operations belongs to the farm. The only exception is the harvest of corn for silage, which is custom-hired.

The chemical composition of every forage and feed was specified. To determine the nutrient content of forages and feeds, priority was given to the local information summarized by Lafontaine (1994) and experimental data released by the National Institute of Agricultural Technology (INTA, 1996a). The tables on composition of feeds published by the NRC (1988) were used to cover any lack of local information. Dry matter percentage, and metabolizable energy, neutral detergent fiber (NDF), crude protein and calcium contents were considered. Nutritional constraints ensure a balance among all the feed sources available in order not to modify the chemical composition of milk or the total production that can be expected from the herd. The right acetate-to-propionate ratio in ruminal content has to be kept not to depress milkfat percentage. This is obtained by limiting the amount of grains fed to the animals. Finally, intake of byproducts with a high NDF content is limited to

no more than twenty percent of the total dry matter intake in the summer to not decrease milk production.

The dairy herd consists of Holstein-type (known as *Holando Argentino*) cattle with an average mature structural size of 550 kg. Cows are culled after five lactations or because of udder or reproduction diseases, injuries or other sickness. A heifer can first calve in any of the twelve months of the year. Male calves are sold as soon as they are born. Heifer calves, on the other hand, can be either sold at birth or kept on the farm and grown as replacement heifers. Replacement heifers can be either purchased or grown on the farm. If they are grown on the farm, two different systems are possible: a forage-based rearing and a forage/concentrate-based rearing. The herd dynamics are established according to the pregnancy, calving and mortality rates of each animal class.

Different nutritional requirements are defined for cows in their first lactation and for cows in their second to fifth lactations ("adult cows"). These requirements include the monthly intake of dry matter, metabolizable energy, NDF, crude protein and calcium. All of them, except the NDF requirements, are determined according to the tables published by the NRC (1988). For the NDF intake, the equation presented by Mertens (1994) is used. Live weight, milk production, milkfat content, daily weight target gain or loss, and stage of gestation are considered to determine the nutritional requirements. Milkfat content is 3.5 percent during the first lactation, and 3.6 percent during the other lactations. Table 3 shows the monthly milk production. Two different lactation curves were defined for cows in their first lactation and cows in their second to fifth lactation ("adult cows").

Table 3: Milk production (liters of milk/day) by cows
in their first lactation and adult cows

Month of lactation	First lactation cow	Adult cow
1	20	22
2	25	28
3	21	25
4	18	22.6
5	17	20
6	15	18
7	13	16
8	12	15
9	10	13.5
10	-	12

Source: Piola (1998)

Labor is formulated as another activity, with a negative c_j coefficient and a supply of labor hours during each month of the year. There are two different kinds of

labor, with different constraints for each of them: labor for cattle management and labor for crop management.

Field time hours available for each month were calculated based on the number of days with rainfall according to the information recorded by the National Meteorological Service[6] (1992-97). Availability of field time hours is influenced by soil type and meteorological conditions. For each rainy day, two days were deducted, meaning that one whole day after the rain is necessary before being able to carry on field operations. Soils in the Santa Fe Sur region are rather sandy, and therefore two days are usually enough for them to drain in each season of the year.

Based on the above paragraphs describing activities and constraints, the final model was obtained. The general structure of the linear programming model is represented in figure 1. There are 237 activities and 249 constraints. The model maximizes profit subject to a set of constraints that dispose the use of all resources available. An original model with average values was obtained in a first stage. The model was then solved with different values for the coefficients describing the monthly availability of forage dry matter and of field time, and prices, in order to represent different possible scenarios.

Monthly data of forage production under each state of nature, necessary for this approach, were not available. Results of forage variety trials carried on by the experimental stations located in Rafaela and Marcos Juárez are not applicable because they do not really belong to the Santa Fe Sur region, and because they are not representative of yields obtained under field production conditions. Information for the region was limited to an average value and its expected standard deviation. Therefore, monthly dry matter production of forage crops was calculated for years 1992 to 1997 applying to it the same normal distribution of the number of days with rainfall.

Input price information was obtained from Agromercado (1997), AACREA (1997), and Piola (1998). Output prices were obtained from AACREA (1998) and Piola (1998). Prices are in December 1997 Argentine pesos ($). At the time, the exchange rate was one Argentine peso for one American dollar.

The model was validated by setting all forage activities and the herd size at their current levels, and all feed sources at their current level plus/minus three percent[7]. Differences between the current plan and the plan obtained in the validation process were overall insignificant.

RESULTS AND DISCUSSION

Optimal production plan

The first objective of this study was to establish an optimal plan for a representative dairy farm in the Santa Fe Sur region, and determine if -and how- the

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[6] SMN, Servicio Metereológico Nacional.

[7] The reason of this procedure was to give some more flexibility to the model in obtaining a solution, especially because the current values are average values, and not necessarily being used at the same time.

Figure 1: Structure of the model
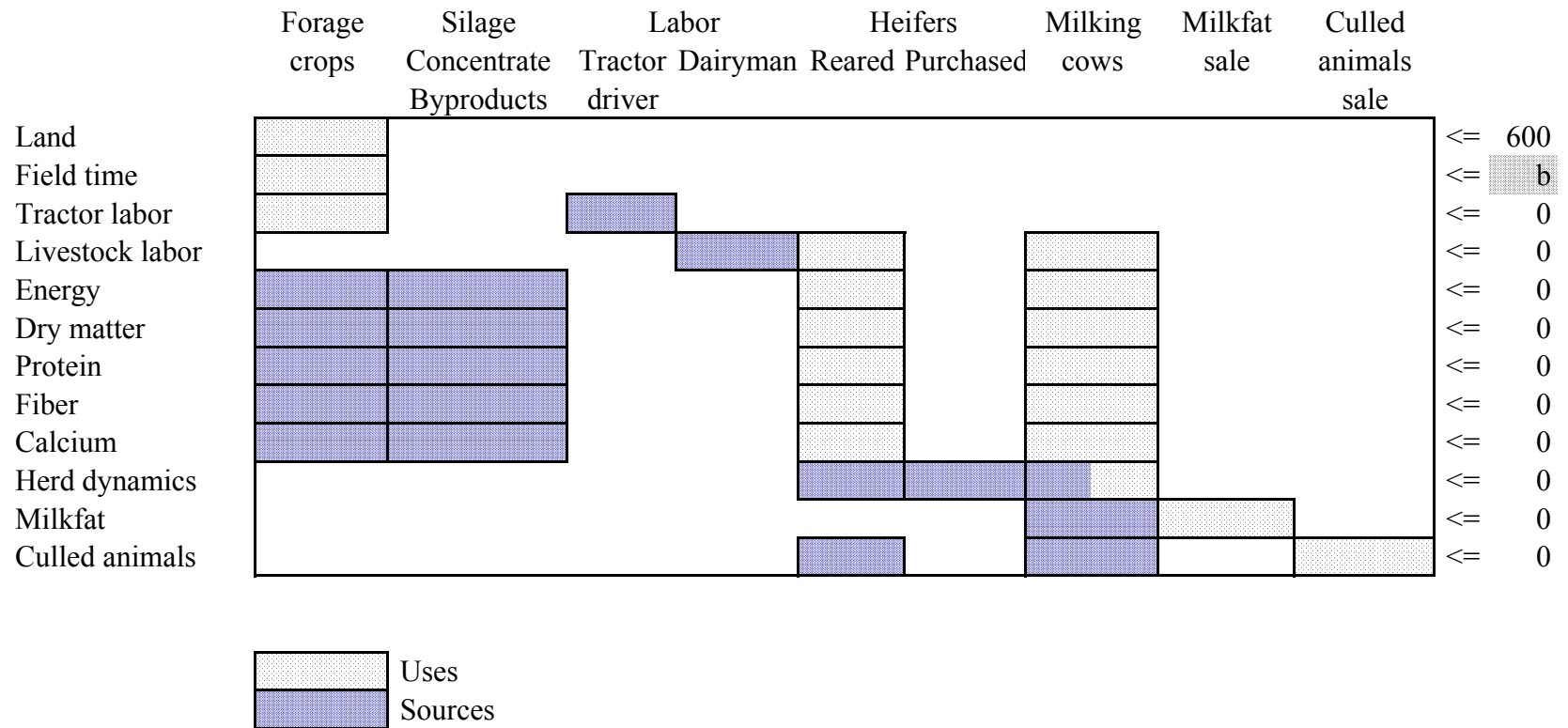
current plan deviates from it. This was achieved by modeling the representative farm with average coefficients, that is to say that prices, yields and field time availability used were the averages for the 1992-97 period. Results indicate that there is room for improvement, especially in the allocation of land to different forage crops and in the amounts and sources of supplemental feed used.

Table 4 summarizes some of the principal variable levels for both the current plan and the optimal plan with average resources.

Table 4: Current and optimal production plans

Use of land (1)	Current Plan (2)	Validation Plan (3)	Optimal Plan
Pasture year 1 (ha)	135	135	150
Pasture year 2 (ha)	135	135	150
Pasture year 3 (ha)	135	135	150
Oats (ha)	120	120	150
Corn for silage (ha)	120	120	50
Herd composition			
Herd size (cows)	500	498	500
Raised heifers	300 (4)	338 (5)	338 (5)
Purchased heifers	0	0	0
Supplemental feed			
Corn silage (ton) (6)	1200	1212	509
Wheat bran (ton) (6)	200	205	624
Corn (ton) (6)	365	370	97
Sunflower expeller (ton) (6)	190	185	0
Cotton seed (ton) (6)	72	74	44
Animal performance and production			
Total milk production (l)	2655000	2644952	2656213
Milkfat production per hectare (kg ha^{-1})	186	186	186
Economic performance			
Returns over variable cost ($)		312060	369961
Profit above all costs (%) (7)	5	5.2	8.4

(1) A total amount of hectares higher than the total available (600) may originate because in a twelve-month period the same land can be cultivated twice (e.g.: oats plus corn for silage).
(2) Values based on data available for the region.
(3) Values obtained in the validation of the model.
(4) Mostly reared with forage and concentrate.
(5) All of them reared with forage and concentrate.
(6) Metric tons as fed.
(7) Profit above all costs calculated over market value of total assets.

In the optimal plan with average resources (which will be referred to as "average plan"), more land is cultivated with pasture and oats, and fewer hectares are

devoted to corn silage production. As for the purchased feeds, more wheat bran is consumed, while less corn grain and cotton seed are purchased, and sunflower expeller is not included in the plan. With a higher availability of feeds, the maximum number of cows is reached, and this is the only change in the herd. The distribution of calving dates is the same. The addition of two cows slightly increases production indices.

Profit above all costs, however, rises from 5.2 to 8.4 percent of the market value of total assets. The main reason for this increase in profit is the lower average price paid for feed. In fact, average feed cost (including forage and purchased feed) is $ 0.048 per kilogram of dry matter, $ 0.0198 per Mcal, $ 0.323 per kilogram of crude protein, and $ 0.112 per kilogram of NDF in the average plan. These costs in the validation plan are 0.063 $/kg of dry matter, 0.026 $/Mcal, 0.323 $/kg of crude protein, and 0.148 $/kg of NDF. This means that the validation plan uses a combination of feed sources that is twenty-five to thirty percent more expensive. The lower cost combination of feeds in the average plan is possible because more hectares with pasture and oats, which are the cheapest feed sources in terms of cost per unit of dry matter, energy and protein, are cultivated. Also, more wheat bran, which is the cheapest byproduct feed in terms of cost per unit of dry matter and energy, is used. At the same time, less corn, sunflower expeller, cotton seed and corn silage, all of which are more expensive, are used.

On the other hand, there is a very little (0.4 percent) increase in milk sale income due to the slight enlargement of the herd. Because the distribution of calving dates is not modified, there is no effect of milk price in total income[8]. Both the validation and the average plan, with a maximum of cows calving in winter, have the highest production in spring, due to the fact that the peak in milk production occurs during the second month of lactation, even if price is not highest.

It is not surprising, however, that the largest amount of milkfat is not sold during the months of highest prices. In fact, even if the price is higher in winter, the cost of producing milk is also higher in winter, when less forage is produced, and more supplemental feed is necessary. Land is binding (i.e. all land is utilized), with a dual price of 104 $ ha. The only nutritional constraint that is binding is the maximum imposed on NDF for the summer. The milking parlor capacity is binding, and its dual price is very high (496 $ cow).

Risk considerations

The second objective was to determine if the current resource allocation, if not optimal, was at least efficient in terms of the tradeoff between returns and risk. By simulating different states of nature, corresponding to different years, the most important sources of risk and the interactions among them were considered together. In this way, the evaluation of returns could be performed conjointly with risk analysis.

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[8] As milk price is seasonal, with a minimum in spring and a maximum in winter, different calving dates distributions could lead to improvements in returns over variable costs just because of a milk price effect.

Some climatic and market conditions observed during the 1992-97 period are summarized in tables 5 and 6. For each year, the number of rainy days and the price of the most important outputs and inputs are compared to the average values for all the period. Because forage production was calculated following the same probability distribution of days with precipitation, table 5 also applies to forage production.

Table 5: Number of rainy days compared to the 1992-97 average

	Total	Summer	Autumn	Winter	Spring
1992	x	x	-	++	+
1993	++	+	+	+	++
1994	-	--	x	+	--
1995	--	++	-	-	-
1996	x	+	++	--	x
1997	-	x	--	x	x

Legend: x = average, - = below average, -- = minimum, + = above average, ++ = maximum.

Table 6: Output and input prices compared to the 1992-97 average

	Milkfat	Beef (1)	Corn	Wheat bran	Sunflower expeller
1992	+	++	-	--	--
1993	++	x	x	x	+
1994	x	-	+	-	++
1995	--	--	+	+	-
1996	-	-	++	++	-
1997	-	+	--	-	x

(1) Price of heifers ($/kg).
Legend: x = average, - = below average, -- = minimum, + = above average, ++ = maximum.

Table 7 summarizes the most important characteristics of the optimal solution for each state of nature. By setting the amount of hectares used for pasture as a fixed value[9], only oats and corn for silage can vary. The proportion of land cultivated with

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[9] The hectares of pasture being planted every year were set at a level of 150 hectares because the total hectares with pasture are not easily adjustable in the short run, as they depend on decisions made in the two previous years. Likewise, any decision on how many hectares of new pasture to plant in one year will influence resource availability in the future. Also, for soil conservation purposes, the four-year crop rotation cannot be changed. Even if longer periods of annual crops could be sustained by these soils, input use and production levels would be different from the ones used in the model and new variables (activities) should be defined.

Table 7: Optimal production plans for each state of nature

State of nature	1992	1993	1994	1995	1996	1997
Return over variable costs ($/year)	396443	410173	377071	275451	277512	310595
Herd size (cows)	500	500	500	500	500	500
Reared heifers (1)	132	132	133	103	96	132
Purchased heifers	0	0	0	27	33	0
Pasture (total) (ha)	450	450	450	450	450	450
Oats (ha)	150	150	150	150	138	150
Corn silage (ha)	64	41	57	63	49	62
Forage and silage (tons of DM)	2581	2731	2336	2146	2219	2178
Concentrate (tons) (2)	95	83	53	105	71	68
By products (tons) (2)	627	521	655	545	551	761

(1) All the reared heifers are reared with forage and concentrate, and first bred when they are fifteen months old.
(2) Dry matter.

oats fluctuates much less than the land cultivated with corn for silage. The herd size does not vary from its original value of 500 cows. The purchase of replacement heifers is more profitable than rearing heifers only when low prices for heifers combine with average or below average forage production and high supplemental feed prices (years 1995 and 1996). Even then, only twenty to twenty-five percent of the heifers are purchased, while the others are reared in the farm.

The optimal plan obtained for each year was evaluated under all other states of nature (years). This was achieved by constraining activities to each year's level, but using the forage production, field time availability and prices of all other years. There are forty-nine possible combinations of production plans and states of nature.

If all variables had been fixed, some models could have had no solution, because the feeding activities set for a year with high forage production could have not covered the herd requirements in a year in which a lower forage production was obtained. Therefore, land use, herd size, replacement rearing and/or purchase, and calving patterns were set at each year's optimal values, while supplemental feed distribution was allowed to adapt to the changing forage supply. This actually reflects the decisions farmers make. In fact, some decisions are made in advance and cannot be modified quickly (for example the distribution of calving dates, the method of obtaining replacements, or the land planted with perennial crops), while others are more easily modified in order to conform to weather or price conditions (for example the amount of supplemental feed purchased).

Table 8 shows the return over variable costs that could be obtained with each plan under each state of nature. As the last row of table 8 shows, the difference between the highest and the lowest returns for each state of nature is in general small, and always less than ten percent of the highest possible return. Table 8 also indicates which plans are the best ones according to several choice models that are usually cited

in the literature. A detailed description of these models can be found in Suter (1963) and Agrawal and Heady (1972).

According to the maximax principle, a decision maker will choose the plan that maximizes his/her maximum gains, regardless of the losses that may take place. If this is the only criterion to be applied, the 1993 plan will be the best one, because $ 410,200 is the highest possible return over variable costs for all combinations of plans and states of nature. The 1993 plan, however, is designed to outperform all others only in a year with high forage production and favorable price relationships, which does not occur frequently.

If the maximin model is used, only the minimum possible outcomes are considered. The minimum outcome is then maximized. A farmer choosing a management plan with this criterion would be more risk averse than a "maximaxer" farmer. The most suitable plan for a "maximiner" farmer is the 1996 plan, designed for a year with unfavorable price relationships. The minimum return for the 1996 plan occurs under the 1995 scenario ($ 270,600), while all other plans achieve their minimum return under the 1996 scenario, and their returns are all below $ 270,600.

The "minimum regret" choice model considers disutility in the decision making process. With this method, a production plan that is not highly disappointing is preferred to all others. Such a plan does not miss large gains and at the same time it does not cause large losses. With this criterion, a regret matrix is obtained by subtracting from each return of the payoff matrix the highest return possible in its own state of nature. For each plan, the minimum regret is considered, and the best production plan is the one with the smallest regret. Under this criterion, the 1995 plan is preferred to the others. This plan, as the one chosen under the maximin model, is also designed for a bad year, characterized by low forage production and adverse price relationships.

Under the optimism-pessimism model (or Hurwicz model), both the best and the worst possible payoffs of every plan are taken into consideration. A weight is attached to each one, according to the decision maker's beliefs, and the optimal strategy is the one with the largest sum of products. Weights of 0.5 to each return and of 0.7 to the lowest and 0.3 to the highest were used to choose the best plan under this criterion. Equal weights of 0.5 represent a naive approach, while weights of 0.7 for the lowest return and 0.3 for the highest represent a more risk averse farmer. Calculated with these two different weights, the best plan is the 1996 plan.

Another model frequently used in decision making is Laplace's criterion, which considers all possible outcomes, giving equal probabilities to each state of nature. Equal probabilities may be a naive approximation to real probabilities. Nonetheless, there are not enough data to assign a probability to each of these years, as both climatic and price probabilities should be used to compute it. Hence, the "principle of insufficient reason" (Agrawal and Heady, 1972, p. 138) is implemented to assign equal probabilities. The 1997 plan has the highest expected return when equal probabilities are used. However, it has to be noticed that differences in expected returns among all production plans

Table 8: Return over variable costs for different plans under different scenarios (thousand December 1997 $)

State of nature / Production plan	Average	1992	1993	1994	1995	1996	1997	Expected returns (1)
Average	370.0	394.5	409.4	376.6	271.5	256.5	308.4	336.1
1992	368.1	396.4	407.4	376.8	272.8	253.9	309.6	336.2
1993 (2)	368.7	393.2	410.2	375.3	270.2	256.2	306.1	335.2
1994	368.2	395.3	407.8	377.1	271.0	255.8	308.5	335.9
1995 (4)	362.0	387.7	397.6	367.8	275.5	266.6	306.6	333.6
1996 (3),(5),(6)	360.9	384.4	396.9	364.3	270.6	277.5	304.3	333.0
1997 (7),(8)	369.0	395.9	408.2	376.6	273.0	256.3	310.6	336.8
Validation	348.9	383.5	393.0	361.9	256.6	259.2	294.9	324.9
Highest minus lowest return (9)	9.0	12.0	13.3	12.8	5.3	23.6	6.3	3.8

Each number in the table indicates the returns over variable costs (in thousand $) that are obtained with a given production plan under a given scenario.
(1) Calculated with equal weights for each state of nature, 1992 through 1997.
(2) Best plan under the maximax choice model.
(3) Best plan under the maximin choice model.
(4) Best plan under the minimum regret choice model.
(5) Best plan if the average of both highest and lowest possible outcomes (Hurwicz with equal weights) criterion is used.
(6) Best plan under the Hurwicz choice model with a weight of 0.7 for the lowest return and 0.3 for the highest.
(7) Best plan under the maximum expected return choice model.
(8) Best plan under the excess benefit choice model.
(9) Only returns for optimal plans are considered (e.g.: the return for the validation plan is not considered).

are really small, and therefore the choice of the best plan using this criterion may be difficult.

The regret and the maximin models are combined in the "excess benefit" criterion. Under this criterion, a benefit matrix is calculated by subtracting the lowest return for each state of nature to all possible returns for that state of nature. This difference is the "benefit" resulting from choosing one strategy other than the worst under a given state of nature. The best strategy is the one with the maximum minimum benefit. According to this criterion, the 1997 plan is the best one.

From the analysis in the above paragraphs, it is clear that none of the seven production plans is the best one under all choice models. Two plans (1993 and 1995) are the best ones under one decision making model each, while two others (1996 and 1997) are the best ones under two decision making models each[10]. Still, the 1996 plan reported the lowest returns four out of the six years considered. These results indicate that there is not actually a production plan that dominates all others, and that farmers with different goals may face risk in different ways, and still be efficient. Recalling that differences among different plans under the same state of nature are small, this is even more true. This can be partially explained by the fact that the use of most of the land was not allowed to vary because of the fixed number of hectares with pasture. Another factor explaining this fact is that the milking parlor capacity is strongly binding all plans, and therefore the optimal herd size is the same in all production plans.

Nevertheless, these results show that the optimal plan with average resources is not necessarily the best one. Also, and more importantly, the current plan (evaluated through the validation model) is not optimal under any of the analyzed scenarios. Even if the differences between the return for the validation solution and all other optimal solutions are not very large, the fact that returns for the current plan are lower is still an indication that there is room for improvement in resource allocation.

The most probable reason why the current plan has a lower return is the fact that not all the land is used, while all of it is allocated to at least one crop per year in all other plans. Also, another rather big difference between the current plan and all optimal plans is the amount of corn silage fed to the cattle. The current plan, in fact, includes two to three times the hectares of corn for silage that optimal plans do. Corn silage, due to the costs of planting and the rather high dry matter losses in silage production, is an expensive feed source. Calving dates distribution does not seem to be very important in determining lower returns, because the distribution in the current plan is the same one as some of the optimal plans (1993 and 1997).

Differences in expected returns among all production plans are really small, and therefore the choice of the best plan may be difficult. Besides, as the characteristics of each farmer in terms of risk aversion are not always the same, the optimal plan may not be the same one for all farmers. This is interesting, as it gives farmers a possibility to choose among similar results. Using the model individually

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[10] The Hurwicz criterion, even if used with two different weights, is considered as only one decision making model.

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may turn into a time consuming but precise and perfectly focused tool in helping farmers in their decision making process.

Profit above all costs was positive for every plan under every scenario. This might be the case because, as it was mentioned in the *Methodology and data* section, the data for this analysis were obtained from well-managed farms.

The two production plans that are the best ones under a higher number of decision models are the optimal plans for two of the three worst years of the period analyzed. That might indicate that farmers are better off planning for "bad" years, which coincides with the generally recognized assumption that farmers are rather risk averse.

Multiple goals

The third objective was to assess the impact of multiple goals on profitability. This was studied by including some additional variables or constraints to the original model, under more than one scenario. The options analyzed were: a) corn for grain grown on the farm, b) replacement heifers first bred at two years of age, and c) different milk production levels.

For most of the analysis of multiple objectives, the 1996 and the 1997 scenarios were chosen to run the simulations. Years 1996 and 1997 are two of the three worst years of the period analyzed in this study, in terms of the combination of weather and price relationships. Even if they were two of the three worst years in the 1992-97 period, the probabilities of occurrence of their levels of prices and rainfall are not too low, and therefore it is still reasonable to analyze them. That is, it is not highly improbable that years like these could happen[11].

Corn is a rather expensive feed, and its price may fluctuate largely and without correlation with the local weather or national market conditions because it depends on the international market. If more stability is desired in the feeding plan, an alternative to be considered is introducing corn for grain in the crop sequence. The original model was modified by including corn for grain, with yields of 80.87, 66.82, and 67.26 hundred kilos per hectare in 1995, 1996 and 1997 respectively. Storing costs were added to the distribution cost of corn in every month other than the harvest month. The corn harvested can only be consumed on the farm. No allowance for sale of corn grain is made.

Corn grown for grain has a positive effect on returns over variable costs. This effect can be rather small if purchased feed prices are not high, but there still is an improvement in profit (see table 9). The optimal amount of hectares to be cultivated with corn for grain does not vary significantly from one year to the other[12] (among the years analyzed), despite different yields. Sensitivity analysis of corn yields that justify

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[11] When precipitation and price distributions for this period were analyzed, precipitation levels observed in 1996 and 1997 turned out having a probability of 31 and 81 percent respectively. Prices observed in 1996 and 1997 have a probability of 81 and 78 percent (milkfat), 78 and 30 percent (beef), 97 and 18 percent (corn), 95 and 29 percent (wheat bran), and 34 and 42 percent (sunflower expeller) respectively.

[12] 45 hectares are the optimal amount to be cultivated with corn for grain.

growing this crop show that it is profitable to grow corn for grain even with very low yields for the region, and if the land allows for it, this crop should be included in the crop sequence.

Table 9: Returns over variable costs with and without corn grown on the farm
(thousand December 1997 $)

Year	1995	1996	1997
Without corn	275.5	277.5	310.6
With corn	289.0	288.7	314.1

Replacement heifers may be first bred when they are fifteen or twenty-four months old. If heifers are bred at fifteen months of age, they must be fed with pasture and concentrate; if they are bred at two years of age, they can be fed pasture only. Although most of the replacement heifers are currently bred at fifteen months of age, which is in agreement with the optimal solutions obtained for every scenario, it may be interesting to assess the profitability of this practice.

The effect of this choice is larger under the 1996 scenario, in which feed prices were higher. With this scenario, if heifers are first bred at two years of age, profit above all costs drops from 4.3 to 0.5 percent, while with the 1995 scenario it drops from 5.6 to 2.6 percent (see table 10).

Table 10: Returns over variable costs with two different heifer rearing systems
(thousand December 1997 $)

Year	1996	1997
Pasture+Concentrate (15 months of age)	277.5	310.6
Pasture (24 months of age)	223.8	266.1

Also, different production levels were studied. Higher production levels, despite the higher total feeding expenses, can improve the return on variable costs (see table 11). On the other hand, a decrease in production aiming to reduce feeding expenses is not profitable, because the reduction in production is more than proportional to the reduction in nutritional requirements. These last results indicate that higher milk production levels, even with a slight decrease in milkfat percentage, can be considered a means of increasing profitability.

Herd size

The fourth objective of this study was to determine the relationship between the herd size and profitability, in order to evaluate the possibilities of improving the latter by increasing the former. The effect of larger herds was studied under three alternatives: the original model, without purchased heifers, and without purchased heifers and corn grown on the farm. According to the dual solution, both land and the milking parlor are binding. While the milking parlor was binding over the whole

Table 11: Returns over variable costs with different production levels
(thousand December 1997 $)

Year	1996	1997
Original	277.5	310.6
10% lower	227.6	269.1
10% higher	316.9	350.0
20% higher	342.0	375.2

period, that was not the case for land. Therefore, a more important increase in returns over variable costs can be originated by allowing a larger herd size rather than by increasing the farm in terms of hectares available.

The herd size analysis (tables 12 and 13) shows that the herd can be significantly increased, especially if heifers need not to be raised on the farm. In this case, the herd can be doubled before the nutritional constraints regarding maximum protein and fiber in the diet and field time availability become binding. If the farm adopts a production system such that all replacements are purchased, even if the herd can be doubled, maximum profit is reached with a six hundred cow herd in 1996, and with an eight hundred cow herd in 1997. After those levels, returns do not increase proportionally to investment in facilities and livestock, and profit decreases. Return over variable cost per additional cow decreases when the herd is increased because of

Table 12: Return over variable cost (thousand December 1997 $),
profit above all costs (%) and return over variable costs per additional
cow at different herd sizes under the 1996 scenario

Herd size	500	600	700	800	900	1000
Original model						
Returns over variable costs	277.5	304.0	324.8	340.1	349.9	351.7
Profit (%)	4.3	4.8	4.4	3.5	2.5	1.4
$/additional cow		265	208	153	98	37
No purchased heifers						
Returns over variable costs	277.5	290.5	292.7	292.7	292.7	292.7
Profit (%)	4.3	2.6	1.4	0.4	-0.5	-1.5
$/additional cow		130	53	0	0	0
Corn cultivated on the farm and no purchased heifers						
Returns over variable costs	288.2	307.9	309.5	309.5	309.5	309.5
Profit (%)	4.5	3.5	2.3	1.3	0.3	-0.6
$/additional cow		197	57	0	0	0

Maximum herd sizes are: 950 cows in the original model, 643 cows with no purchased heifers and 631 cows with corn for grain grown on the farm and no purchased heifers.

Table 13: Return over variable cost (thousand December 1997 $),
profit above all costs (%) and return over variable cost per additional
cow at different herd sizes under the 1997 scenario

Herd size	500	600	700	800	900	1000
Original model						
Returns over variable costs	310.6	346.3	376.6	404.1	430.7	445.3
Profit (%)	5.6	5.6	5.9	6.3	6.2	5.3
$/additional cow		357	303	275	267	146
No purchased heifers						
Returns over variable costs	310.6	343.7	367.1	367.1	367.1	367.1
Profit (%)	5.6	5.2	4.4	3.4	2.4	1.5
$/additional cow		331	246	0	0	0
Corn cultivated on the farm and no purchased heifers						
Returns over variable costs	314.1	350.3	367.3	367.3	367.3	367.3
Profit (%)	5.7	5.5	4.6	3.5	2.5	1.6
$/additional cow		362	203	0	0	0

Maximum herd sizes are: 1002 cows in the original model, 695 cows with no purchased
heifers and 684 cows with corn for grain grown on the farm and no purchased heifers.

higher feeding expenses. In fact, once the forage production is maximized according
to the land available, more purchased feed is necessary for the herd, at an average
higher cost.

Although most of the potential profitability increase due to larger herds is lost
when all replacements are raised on the farm, the herd can still be enlarged by thirty-
forty percent. Maximum herd size with this option is between six and seven hundred
cows. However, both in 1996 and 1997, profit decreased with any enlargement of the
herd. This might indicate that the current size is the best one farmers could have,
assuming that they want to rear the replacement heifers on the farm. The inclusion of
corn for grain in the crop sequence associated with larger herds significantly increases
returns over variable costs only if supplemental feed is expensive, which was the case
in 1996.

CONCLUSIONS

The principal implication of this study is that, overall, there is room for
improvement in these farms in terms of resource allocation and management
strategies. Although the results obtained are applicable to this group of supposedly
above average farms[13], they may still be useful for more far-reaching results. In fact, if

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[13] Recall, however, that there is no statistical evidence of a higher efficiency or a better economic
performance for these farms belonging to a farm management association.

in these farms there still is room for improvement, in all others there might be a real need to improve resource allocation and management strategies. The results originated by such adjustments in the whole dairy sector could be considerable.

The current land distribution among forage crops and the current purchases of supplemental feed may be changed to significantly reduce feed costs. Contrastingly, calving date distribution and the rearing of heifers are close to optimal.

The current plan is not optimal when risk is considered. In fact, simulations of different scenarios lead to several optimal plans, all of them different from the current one, and with higher returns over variable cost. None of the plans, nonetheless, clearly outperforms all others, which gives farmers the possibility of choosing from different plans while still being efficient in terms of the risk-return tradeoff.

The analysis of multiple goals (alternative operating methods) indicates that the inclusion of corn for grain in the crop sequence can improve the economic performance of the farm, by lowering feeding costs. The decrease in returns when heifers are first bred when they are two years old (compared to first breeding them at the age of fifteen months) shows that farmers are currently efficient in this aspect. Also, higher production levels, despite the higher total feeding expenses, can improve the return on variable costs.

From the herd size analysis, it can be concluded that there is room for growth, especially if heifers need not to be raised on the farm. In this case, the herd can be doubled before other constraints (regarding maximum protein and NDF in the diet, and field time availability) become binding. Even if most of the potential profitability increase due to growth is lost when all replacements are raised on the farm, the herd can still be enlarged by thirty-forty percent. However, maximum profitability occurs at herd sizes not much larger than the current one.

The model built with average coefficients did not maximize returns under any of the different scenarios simulated. This is a further demonstration that whenever a linear programming model is used to determine the optimal plan, the use of average coefficients is not necessarily the best approach, and it can lead to conclusions different from the ones obtained with simulations of several possible scenarios.

One of the major strengths of this study lays in its data, which were obtained directly in the region of interest and permitted the construction of an accurate model for a representative dairy farm in the Santa Fe Sur region. Use of good data is extremely important, as the results obtained are critically dependent on the coefficients with which the models are built. Also, both herd size and distribution of calving dates were not treated as fixed factors, but left to the solution, which gave more flexibility to the model. The accurate data and the complete consideration of activities and constraints contributed to a model that performed well in its validation.

Despite the strength of most of its coefficients, the model could have had more flexibility if different crop rotations were defined, instead of including only one. If more rotations had been considered, greater differences could have arisen among scenarios. Nonetheless, lack of data did not permit that. Another feature of the model that limited its flexibility is that the milk production level was set in advance, and no possibility for the program to choose which production level to select was included.

Some sensitivity analysis to different milk production levels, however, was done in the *Multiple goals* section, when modeling lower and higher production levels.

Regardless of its limitations, this study covers an almost unexplored research area for Argentine dairy farms, thus furnishing some useful information. Optimization techniques and risk analysis were used together to analyze profitability improvement possibilities in detail, and the results obtained give some interesting guidelines.

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