

UNIVERSIDADE FEDERAL DE VIÇOSA

JARDESON DE SOUZA PINHEIRO

**PRODUCTION COSTS, ECONOMIC VIABILITY, AND RISKS ASSOCIATED
WITH COMPOST BEDDED PACK, FREE STALL, AND DRYLOT SYSTEMS
IN TROPICAL DAIRY FARMS**

**VIÇOSA - MINAS GERAIS
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Dissertation submitted to the Universidade Federal de Viçosa as partial fulfillment of the requirements of the Animal Science Graduate Program for the degree of *Magister Scientiae*.

Adviser: Marcos Inácio Marcondes

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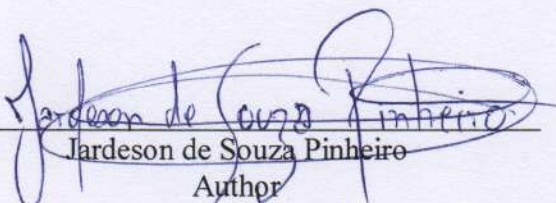
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Assent:



Jardeson de Souza Pinheiro
Author



Marcos Inácio Marcondes
Adviser

DEDICATION

This work is dedicated to all the people that had encouraged and supported me in one way or another along the way.

To my family, Ednaldo, Alzira and Jonathan, who always gave me all the support to keep going on this journey.

To my canine sons, Valadão and Taurus.

And to my soul brothers, Edna and Dhones for all their companionship and loyalty during the challenges of life.

This is for you!

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BIOGRAPHY

JARDESON DE SOUZA PINHEIRO, son of Francisco Ednaldo Ferreira Pinheiro and Alzira de Souza Pinheiro, was born on July 27, 1995, in the city of Fortaleza, Ceará.

He started the undergraduate degree in Animal Science at the Federal University of Ceará on August 2013 and graduated on January 18, 2018. During his undergraduate studies he received a scientific initiation scholarship from CNPq (PIBIC / CNPq) and FUNCAP under the guidance of Ana Cláudia Nascimento Campos and Carla Renata Gadelha.

In the first semester of 2018, he got the internship in the Dairy Cattle Department at the University of Minnesota, USA.

And in August 2018, he started the master's degree in Animal Science in the post-graduate program in Animal Science at the Federal University of Viçosa under the guidance of Professor Marcos Inácio Marcondes, where he concentrated his studies in the area of Production and Ruminants Nutrition. He obtained the title of master's in animal science on July 20, 2020.

ABSTRACT

PINHEIRO, Jardeson de Souza, M.Sc., Universidade Federal de Viçosa, July, 2020. **Production costs, economic viability, and risks associated with Compost Bedded Pack, Free Stall, and Drylot systems in tropical dairy farms.** Adviser: Marcos inácio Marcondes.

We aimed to compare production costs, economic outcomes, and risk of dairy operations in CB, FS, and DL systems. We collected data from 2,181 Brazilian farms over 120 consecutive months; 960 farms met our selection criteria. All costs were modeled for two animal production categories: milking cows and non-milking animals. We used a regression model that included linear and quadratic parameters, and we added the production system as a fixed variable for all parameters tested with this model. Consultant, year, herd, and herd \times system interaction were included in the model as random variables. Further, we simulated annual technical and economic indexes per farm. In addition, we developed a risk analysis to measure the probability of negative profit of the farms based on a 14-year historical series of milk prices. All production costs were affected by the system. Feeding, medicines, sundry, and labor costs per farm per year were greater in DL compared to CB and FS in farms with greater milk yield (MY). Milk yield (MY/cow and MY/ha), assets per liter (\$/L), asset turnover rate (%), return on assets (%), operational profit (%), and profit per cow (\$/yr) and per liter of milk (\$/L) were greater in CB and FS with a higher MY ($> 3,000$ L/d) when compared to DL. Nonetheless, DL had greatest economic indexes with a lower MY ($< 3,000$ L/d), with lower operating costs and greater economic outcomes. The risk analysis indicated that the probability of negative profit (risk) was reduced for CB and FS as MY increased, but DL had the lowest risk (35.5%) with low MY levels. In conclusion, we suggest DL as the most attractive system for tropical farms with a MY between 150 and 3,000 L/d, once the DL had lowest risk and greatest profit in this production scale. Despite similar outcomes for CB and FS in most of the farms, the profit per cow (\$/yr), assets turnover rate (%), risk (%) and expected profit (\$/L) analysis indicated that CB can be recommended for farms with MY greater than 3,200 L/d, whereas based on risk (%) and expected profit (\$/L) FS would be the most profitable system in dairies producing more than 8,000 L/d of milk.

Keywords: Dairy operations. Indexes. Efficiency. Milk yield. Profitability.

RESUMO

PINHEIRO, Jardeson de Souza, M.Sc., Universidade Federal de Viçosa, julho de 2020. **Custos de produção, viabilidade econômica e riscos associados aos sistemas Compost Bedded Pack, Free Stall e Drylot de fazendas leiteiras tropicais.** Orientador: Marcos inácio Marcondes.

O objetivo desse trabalho foi comparar os custos de produção, resultados econômicos e risco das fazendas leiteiras nos sistemas CB, FS e DL. Foram coletados dados de 2.181 fazendas brasileiras ao longo de 120 meses consecutivos; 960 fazendas atenderam aos nossos critérios de seleção. Todos os custos foram modelados para duas categorias de produção animal: vacas leiteiras e animais não leiteiros. Usamos um modelo de regressão que incluiu parâmetros lineares e quadráticos e adicionamos o sistema de produção como uma variável fixa para todos os parâmetros testados neste modelo. Consultor, ano, rebanho e interação rebanho \times sistema foram incluídos no modelo como variáveis aleatórias. Além disso, simulamos índices técnicos e econômicos anuais por fazenda. Desenvolvemos também, uma análise de risco para medir a probabilidade de lucro negativo das fazendas com base em uma série histórica de preços do leite de 14 anos. Todos os custos de produção foram afetados pelo sistema. Os custos de alimentação, medicamentos, diversos e mão de obra por fazenda por ano foram maiores em DL em comparação com CB e FS em fazendas com maior produção de leite (PL). A produção de leite (PL / vaca e PL / ha), estoque de capital por litro (\$ / L), taxa de giro do estoque de capital (%), retorno sobre o estoque de capital (%), lucro operacional (%), lucro por vaca (\$ / ano) e por litro de leite (\$ / L) foram maiores em CB e FS com maior PL (> 3.000 L / d) quando comparados a DL. No entanto, DL teve melhores índices econômicos em uma menor PL (<3.000 L / d), com menores custos operacionais e melhores resultados econômicos. A análise de risco indicou que a probabilidade de lucro negativo (risco) foi reduzida para CB e FS conforme a PL aumentou, mas DL teve o risco mais baixo (35,5%) em baixos níveis de PL. Em conclusão, sugerimos o DL como o sistema mais atraente para fazendas tropicais com PL entre 150 e 3.000 L / d, uma vez que o DL apresentou menor risco e maior lucro nesta escala de produção. Apesar de resultados semelhantes entre CB e FS na maioria das fazendas, o lucro por vaca (\$ / ano), taxa de giro do estoque de capital (%), análise de risco (%) e lucro esperado (\$ / L) indicaram que CB pode ser recomendado para fazendas com PL maior que 3.200 L / d, enquanto com base no risco (%) e lucro esperado (\$ / L) o FS seria o sistema mais lucrativo em fazendas que produzem mais de 8.000 L / d de leite.

Palavras-chave: Eficiência. Fazendas leiteiras. Índices. Lucratividade. Produção de leite.

SUMMARY

PRODUCTION COSTS, ECONOMIC VIABILITY, AND RISKS ASSOCIATED WITH COMPOST BEDDED PACK, FREE STALL, AND DRYLOT SYSTEMS IN TROPICAL DAIRY FARMS.....	9
1 ABSTRACT.....	9
2 INTRODUCTION.....	10
3 MATERIAL AND METHODS.....	12
3.1 Database.....	12
3.2 Technical indexes.....	14
3.3 Economic data.....	14
3.4 Modeling.....	15
3.5 Simulation.....	16
3.6 Risk analysis.....	17
4 RESULTS.....	18
4.1 Descriptive statistics.....	18
4.2 Fit models.....	18
4.3 Simulation.....	21
5 DISCUSSION.....	22
REFERENCES.....	28

Production costs, economic viability, and risks associated with compost bedded pack, free stall, and drylot systems in tropical dairy farms

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Abstract

The adoption of intensive production systems, such as compost bedded pack (CB) and free stall (FS), has increased recently in tropical regions, mainly replacing drylot system (DL). Thus, our objectives were to compare production costs, economic outcomes, and risk of dairy operations in CB, FS, and DL systems. We collected data from 2,181 Brazilian farms over 120 consecutive months; 960 farms met our selection criteria. All costs were modeled for two animal production categories: milking cows and non-milking animals. We used a regression model that included linear and quadratic parameters, and we added the production system as a fixed variable for all parameters tested with this model. Consultant, year, herd, and herd × system interaction were included in the model as random variables. Further, we simulated annual technical and economic indexes per farm. In addition, we developed a risk analysis to measure the probability of negative profit of the farms based on a 14-year historical series of milk prices. All production costs were affected by the system. Feeding, medicines, sundry, and labor costs per farm per year were greater in DL compared to CB and FS in farms

with greater milk yield (MY). Milk yield (MY/cow and MY/ha), assets per liter (\$/L), asset turnover rate (%), return on assets (%), operational profit (%), and profit per cow (\$/yr) and per liter of milk (\$/L) were greater in CB and FS with a higher MY (> 3,000 L/d) when compared to DL. Nonetheless, DL had greatest economic indexes with a lower MY (< 3,000 L/d), with lower operating costs and greater economic outcomes. The risk analysis indicated that the probability of negative profit (risk) was reduced for CB and FS as MY increased, but DL had the lowest risk (35.5%) with low MY levels. In conclusion, we suggest DL as the most attractive system for tropical farms with a MY between 150 and 3,000 L/d, once the DL had lowest risk and greatest profit in this production scale. Despite similar outcomes for CB and FS in most of the farms, the profit per cow (\$/yr), assets turnover rate (%), risk (%) and expected profit (\$/L) analysis indicated that CB can be recommended for farms with MY greater than 3,200 L/d, whereas based on risk (%) and expected profit (\$/L) FS would be the most profitable system in dairies producing more than 8,000 L/d of milk.

Keywords: Dairy operations. Indexes. Efficiency. Milk yield. Profitability.

1. Introduction

Over the years, production systems have been developed to improve dairy operations; however, the more technological the system, the greater the use of inputs, and the higher the production costs (Breitenbach, 2018). Dairy farm economic information that is available in the literature is usually based on empirical knowledge or simulations (Black et al., 2013; Munir et al., 2016; Calsamiglia et al., 2018). Furthermore, there are few studies that evaluated production costs and efficiency from dairy farms in tropical conditions (de Oliveira et al., 2007; Camilo Neto et al., 2012; Oliveira et al., 2016). Additionally, most literature data are based on a small number of farms (83 farms) and financial comparison among the production systems are limited (Gomes, 2005; Magalhães and Campos, 2006; Yamaguchi et al., 2009; Moura et al.,

2013; Oliveira et al., 2016). Thus, these studies may not represent the dynamic conditions of dairy production systems throughout the years and more complete economic comparison among dairy production systems is warranted.

According to De Assis (2005), more intensive dairy production systems, such as compost bedded pack (CB) and free stall (FS), tend to have greater costs when compared to less intensive systems, such as open lots or dry lots (DL). In contrast, CB and FS have greater productivity and annual farm revenue than less intensive systems (Breitenbach, 2018).

Besides the revenue from milk production, other indirect factors such as risks associated with cow health and longevity play an important role in farms profitability (De Vries and Marcondes, 2020). In addition, all the outcomes related with MY and the risks associated to the animals may aid to determine a specific production system according to the intensification objective of the farmer. For instance, CB provides greater udder health and longevity to the cows (Wagner, 2002; Galama, 2011), improve milk production per cow (Marcondes et al., 2019), reducing the risk of negative profit in farms. In FS, the herds are more susceptible to mastitis and lameness, which increases production costs and decreases the MY and fertility. (Green et al., 2002; Cha et al., 2010; Firth et al., 2019; Jewell et al., 2019). Lastly, less intensive systems, such as DL, are known for having low production costs. However, this system has frequent health issues, mainly associate to environmental hazards, such as radiation and rain (Chen et al., 2017). Thus, all those problems may result in low MY per cow and low cow longevity (Esteban and Anderson, 1995), increasing the risk of negative profit.

Over the years, several models have been developed to understand the economic dynamics of dairy operations (Congleton, 1984; Enevoldsen et al., 1995; Bailey et al., 1997; Tess and Kolstad, 2000; Bruijnis et al., 2010; Munir et al., 2016), but a robust profitability analysis with a large data set is missing for tropical areas. Thus, we aimed

to evaluate production costs, economic results, milk production, and risks involved in dairy farms operating in more intensive (CB and FS) and less intensive (DL) systems. We hypothesized that DL will be less profitable than CB and FS, mainly due to lower annual revenue per year. We also hypothesized that intensive systems (CB and FS) have lower probability of negative profit (risk) than DL, mainly due to greater annual revenue and net profit.

2. Material and methods

2.1 Database

In this retrospective study, we evaluated financial and production records (indexes) of dairy farms located in the state of Minas Gerais, Brazil. Data were collected monthly for 120 consecutive months (from August 2008 to July 2018). The characteristic climate of the region is the tropical wet and dry (Aw Köppen -Geiger, Reboita et al., 2016), with warm and rainy summers, and cold and dry winters. Throughout the year, the average temperature is 21°C and the annual rainfall is 1450 mm.

The initial database was comprised of 2,181 farms assisted by the Sebrae Educampo® Project. In brief, the project provides technical support for farm management and standardize economic evaluation by monthly records.

Before analysis, the farms used in this study were selected following the criteria: *i)* farms should have been in the EduCampo® Project for at least 2 years; *ii)* farms should have a DL, CB, or FS system; *iii)* farms should have all technical and economic records; *iv)* farms should produce at least 150 L/d and at maximum 10,000 L/d, once farms below and above those limits did not presented reliable records based on visual analysis. Thus, out of 2,181 farms, 960 fulfilled the selection criteria (Table 1). The

selected farms are geographically located between 16°S and 22° S and 42°W and 52°W, and with average altitude of 703 m.

The production systems can be characterized as: DL) animals managed in large open areas ($> 55 \text{ m}^2$ per animal), covered by little vegetation, shading area of at least 4.00 m^2 per animal, and a feed alley with at least 0.70 m per animal; CB) use of collective bedding (average of 15 m^2 per animal) composed of coffee hulls and shavings mixed twice daily, and fans distributed throughout the bedding area and at least 0.70 m of feed bunk and 0.06 m of water trough per animal; FS) same characteristics of CB farms; however, the animals were handled in individual beds made of mattresses or filled with sand, and a longer circulation corridor.

Feeding systems were as similar as possible across farms, with corn silage being the main roughage source, and concentrate based mostly on fine ground corn, soybean meal, and cottonseed. Additionally, in most farms the lactating cows were fed about 1 kg of concentrate for every 3 kg of milk yield (MY). On farms with lower MY ($< 2,000 \text{ L/d}$), Holstein x Gyr crossbred animals predominated, while in farms with greater MY ($> 2,000 \text{ L/d}$), the herd was mostly characterized by Holstein animals.

The technical and economic information from the farms databank were collected once a month by the various consultants of the EduCampo® Project to determine the cost for two production categories: costs for non-milking animals (NMA), composed of heifers and dry cows, and costs for milking cows (MC)

Land values were not included in the assets due to the high variation in land price of the different regions in Minas Gerais state. Family labor costs were calculated as the salary of a person who could perform the same tasks that the producer performs and converted into full time equivalent labor (FTE). Depreciation was calculated as the initial value minus the residual value, divided by the recovery period in years. The residual value was dependent on each item and treated individually.

2.2 Technical indexes

The following technical indexes were obtained each year per farm:

- Milk Yield per cow (MY_C) = Farm milk yield per lactating cow (L/cow/d);
- Milk Yield per area (MY_A) = Farm milk yield per hectare (L/ha);
- Milk Yield per labor (MY_{FTE}) = Milk Yield per full time equivalent labor days (L/FTE);
- Herd size (HS) = comprises all animals in the herd, such as cows, heifers, bulls, etc.);
- *Milking cost* (MC_{HS}) = $\frac{\text{average number of lactating cows}}{\text{herd size}} \times 100$ (%).

2.3. Economic data

The economic data were adjusted for inflation to January 2019, according to the General Price Index of the Brazilian Institute of Economics of the Getúlio Vargas Foundation – Brazil (IGP-DI), in national currency (real R\$). Then, the values were converted to US dollars (\$) using a conversion rate of 3.88 R\$ per \$, provided by the same institute for the same date (January 2019).

The costs for each farm was divided in two production categories: costs for NMA, and costs for MC, calculated as follows (Matsunaga et al., 1976):

MC costs with Y = farm cost with Y $\times \frac{\text{annual milk revenue}}{\text{annual farm revenue}}$, and

$$\text{NMA costs with Y} = \text{farm cost with Y} \times \frac{\text{annual beef}_{eq} \text{ revenue}}{\text{annual farm revenue}},$$

where Y indicates the expenses for concentrate, roughage, hired labor, medicines, sundry, family labor, or depreciation. Annual farm revenue was calculated as the sum of annual milk revenue and annual beef equivalent revenue (beef_{eq}, income with surplus animals).

Costs with roughage and concentrate, medicines, hired labor, and sundry characterized the total operating cost (TOC). The accrual operating cost (AOC) was

calculated as TOC plus cost for family labor and depreciation. Net margin was calculated as annual farm revenue minus TOC. Profit was calculated as annual farm revenue minus AOC (Marcondes et al., 2019).

2.4. Modeling

Production cost models were created using regressions based on the equivalent milk yield (MY_{eq}). According to De Araujo et al., (2004), the MY_{eq} may be more significant than total milk yield when there are non-milk revenues (such as surplus animals' sales) because AOC include costs to generate these non-milk revenues. Thus, MY_{eq} was calculated by converting revenue beef sales (surplus animals) to the equivalent amount of milk with the same revenue as suggested by De Araujo et al., (2004). The MY_{eq} was calculated as follows:

- Sales beef equivalent ($Beef_{eq}$, L/d) = Annual revenue with beef sales/Milk price/365 (L/\$/d);
- Milk yield equivalent (MY_{eq} , L/d) = Milk yield + $Beef_{eq}$.

Then, economic data (expenses from concentrate, roughage, medicines, family and hired labor, depreciation, and sundry) and herd data (total area, number of cows, number of milking cows, number of heifers, number of employees, and total assets) were modeled using the approach suggested by Tomaszewski et al. (2000). We used a quadratic model to fit all listed variables, and production system was tested in all parameters of the model. Interactions and quadratic parameters (fixed) were removed when non-significant. Consultant, year, herd, and herd \times system interaction were included in the model as random effects as follows:

$$Y_{ijkl} = \beta_0 + \beta_1 \times PS_i + \beta_2 \times MY_{eq} + \beta_3 \times MY_{eq} \times PS_i + \beta_4 \times MY_{eq}^2 + \beta_5 \times MY_{eq}^2 \times PS_i + Consultant_j + Year_k + Herd_l + \psi \times (PS \times Herd)_{il} + e_{ijkl}.$$

The regression model estimates Y_{ijkl} , with the following main independent variables: MY_{eq} , consultant “j”, year “k”, herd “l”, and PS ($i = 1 \sim CB$; $i = 2 \sim FS$; $i = 3 \sim DL$). The consultant, size of the herd (total number of animals in the herd), and the term $PS \times Herd$ were included as random effects, as they represent only a random sample of all Brazilian farms. As farms might have changed their consultants or production system over the years, this information was accounted for in all our modelling procedures. The interaction was added to explain the differences in the effect of production system among herds. Lastly, as the benefits of adopting a specific production system can vary between herds, we superimposed a random $PS \times Herd$ interaction in the model (Tomaszewski et al., 2000).

The results and discussion sections will be focused on system results, with a mention of parameters only when necessary. For all parameters, differences from 0 were declared when $P < 0.10$.

2.5. Simulations

From the results obtained by the regression models, new TOCs and AOCs were simulated at different MY_{eq} levels for CB, FS, and DL. Then, the following indexes were simulated for farms with 150 to 10,000 L/d of MY_{eq} , for each production system:

- Assets per liter (A_L) = $\frac{\text{assets } (\$)}{\text{farm milk yield}} (\$/L/d)$;
- Assets turnover rate (ATR) = $\frac{\text{annual farm revenue } (\$)}{\text{assets } (\$)} \times 100 (\%)$;
- Return on assets (ROA) = $\frac{\text{annual profit } (\$)}{\text{assets } (\$)} \times 100 (\%)$;
- Operational profit (OP) = $\frac{\text{annual profit } (\$)}{\text{annual farm revenue } (\$)} \times 100 (\%)$;
- Unitary profit (Up) = $\frac{\text{net margin } (\$)}{\text{Milk Yield equivalent (L)}} (\$/L)$;
- Profit/cow = $\frac{\text{net margin } (\$)}{\text{average number of cows in the herd}} (\$/cow/yr)$;

2.6. Risk analysis

The main objective of risk analysis is to estimate the probability of a future event based on historical price series (Monte Carlo analysis; Metropolis and Ulam, 1949). In this study, we evaluated the probability of negative profit for each farm, using the historical series of prices (expected milk price) and AOC per liter of MY_{eq} (AOC_L) for MC. Therefore, the risk is the probability of a milk price lower than the AOC_L , which means a negative profit, with the basis of the price frequency milk obtained from the time series, as described below.

Farm milk prices were obtained from 169 months (January 2005 to January 2019) from the database of the Center for Advanced Studies in Applied Economics (Center for Advanced Studies in Economics [CEPEA], Esalq, University of São Paulo). The data were corrected to January 2019, according to the General Price Index of the Brazilian Economic Institute, and then converted to US dollars (\$).

The software used to obtain risk data was @RISK (Palisade Corporation, Ithaca, USA, 1995). Fifty-thousand interactions were tested, using the Latin hypercube sampling method, as described by McKay et al. (1979), in all risk analyses. When the standard deviation of each output variable did not change by more than 3% after a new interaction, convergence was achieved. For this analysis, we used 90% as the confidence level to estimate the most likely milk price. Thirty-seven probability distributions were tested when running the analysis, and the best fit for the data was a Weibull distribution.

Finally, actual milk prices, $Beef_{eq}$ data, and AOC were used to estimate the annual profit ($\text{Profit} = \text{annual yield sales} \times \text{actual milk price} + \text{Beef}_{eq} \times \text{actual milk price} - \text{AOC}$ [in \$/yr]) for each farm.

Then, the following risk indexes were obtained:

- Risk (%), the probability of negative profit, using actual revenue and costs, but considering the simulated farm milk prices using historical series of prices (Monte Carlo analysis) instead of actual farm milk price; and
- Expected profit (\$/yr) = annual profit obtained using the most likely milk price.

3. Results

3.1 Descriptive statistics

Based on the technical indexes of the farms in our database (Table 1), DL was the system with lower number of animals (78.6) when compared with CB (114.3) and FS (113.9). For milk yield per cow, FS was the system with the greatest production (26.05 L/cow/d), followed by CB (25.55 L/cow/d). The greatest milk revenue per farm per yr was observed in FS farms, \$ 403,968.84; whereas CB had greatest annual beef revenue (\$ 26,290.85). Additionally, FS had the greatest AOC (\$ 377,260.54), driven mainly by greater concentrate, roughage, medicine, sundry, hired labor and depreciation costs. Although FS had greatest AOC, it had also greater revenue per yr when compared with CB and DL, which resulted in greater profit per yr (Table 1).

3.2 Fit models

The regression equations for predicting farms characteristic and production costs (for MC and NMA) are described in Tables 2 to 4. Total cows and milking cows were quadratically (concave) related to MY_{eq} . The system affected β_1 and β_2 of the equation ($P < 0.10$). DL had, on average, more animals than CB and FS at the same MY_{eq} (Figure 1A, B). The number of heifers was linearly related to MY_{eq} (Table 2) and was not affected by the system ($P > 0.10$). Labor was quadratically (concave) related to MY_{eq} (Table 2, Figure 1D). The system affected β_0 and β_1 ($P < 0.10$), and FS demanded the most FTE, followed by CB. Area (ha) was quadratically (concave) related to MY_{eq}

($P < 0.10$) (Table 2). The system affected the parameters β_1 and β_2 . For MY_{eq} below 1,000 L/d, DL demanded the greatest area, followed by FS and CB that needed similar areas (Figure 1E). Assets without land (\$) were also quadratically (concave) related to MY_{eq} (Table 2). The system affected β_0 , β_1 and β_2 of this model ($P < 0.10$). FS demanded the most assets (\$) when MY_{eq} was below 4,000 L/d (Figure 1F). From this point on, CB and DL had greater demands for assets when compared with FS.

Concentrate costs (\$/farm/yr) were linearly affected by MY_{eq} for MC and NMA (Tables 3 and 4). The production system affected the β_0 , β_1 , and β_2 parameters of the MC model. In the NMA model, the production system only affected the β_1 parameter ($P < 0.001$). Among the systems, DL had the greatest use of concentrate for both MC and NMA, followed by CB. Concentrate costs increased approximately \$50,000 and \$5,000 per year for every 1,000 L/d of MY_{eq} for MC and NMA in DL, respectively (Figure 2A, H). The concentrate cost per year was approximately \$7,000 less in the CB and FS systems compared to the DL at the same MY_{eq} level.

Roughage costs (\$/farm/yr) for MC were affected quadratically (concave) by MY_{eq} and were also affected by production system ($P < 0.10$) (Table 3). The system only affected the β_1 of the regression ($P < 0.001$). The three systems had similar roughage costs until 1,000 L/d of MY_{eq} , but in a situation with a MY_{eq} above 3,000 L/d, DL had the greatest roughage costs (Figure 2B). Roughage costs for NMA increased linearly according to MY_{eq} ($P < 0.001$). DL had the greatest roughage costs, followed by CB and FS.

Medicine costs (\$/farm/yr) were quadratically (convex) related to MY_{eq} for MC (Table 3). Both parameters, β_1 and β_2 , were affected by production system ($P < 0.10$). DL had the most demand for medicines in MC, followed by CB. In farms where milk production surpasses 5,000 L/d (Figure 2C), costs for medicine with MC, in CB, exceeded those in FS. For NMA, medicine costs were quadratically (convex in FS and

DL; concave in CB) related to MY_{eq} ($P < 0.10$) (Table 4). Both parameters, β_1 and β_2 , were affected by production systems ($P < 0.10$). DL had the most demand for medicines, followed by FS. When considering NMA, with MY_{eq} above 4,000 L/d (Figure 2J), there was greater medicine use in FS when compared to CB.

Hired labor costs (\$/farm/yr) for MC were quadratically (convex) related to MY_{eq} ($P < 0.001$) (Table 3). The hired labor cost of the three systems was similar for MY_{eq} up to 5,000 L/d. When MY_{eq} was greater than 7,100 L/d, DL costs increased sharply and surpassed other systems. For NMA, hired labor were linearly affected by MY_{eq} and the production system affected the regression slope ($P < 0.001$). FS required the most hired labor, followed by DL and CB (Figure 2K).

Sundry expenses (\$/farm/yr) were quadratically (convex in CB and DL; concave in FS) related to MY_{eq} for MC, and all parameters of the equations were affected by the system ($P < 0.10$) (Table 3). The FS had the greatest sundry costs with MY_{eq} up to 7,000 L/d (Figure 2E). Above 7,000 L/d, DL had the greatest sundry expenses. The system did not influence sundry expenses for NMA ($P > 0.10$) (Table 4; Figure 2L).

Family labor expenses (\$/farm/yr) for MC were linearly and NMA were quadratically (convex in CB and FS; concave in DL) affected by MY_{eq} , and the system affected β_1 and β_2 in NMA ($P < 0.10$) (Table 3 and 4). For MC, DL required the greatest use of family labor, followed by CB (Figure 2F). For NMA, from 300 to 5,000 L/d, CB and DL had similar family labor costs (Figure 2M); however, with higher MY_{eq} , family labor costs were greater in CB compared to DL. FS had the lowest family labor costs regardless of MY_{eq} .

Depreciation expenses (\$/farm/yr) with MC were quadratically (convex) affected by MY_{eq} , and the system only affected the slope of the regression ($P < 0.001$). FS exhibited the greatest depreciation expenses, followed by CB (Figure 2G). Depreciation expenses for NMA were linearly related to MY_{eq} and the system affected

the slope of the regression ($P < 0.006$) (Table 4). In MY_{eq} up to 1,000 L/d, FS and DL had the greatest expenses. Between these two systems, FS had the greater costs. There was a lower depreciation cost in CB for NMA.

3.3 Simulation

Regarding simulation data, the MC_{HS} increased linearly (Figure 3A) with MY_{eq} . DL demanded the most animals, followed by CB and FS, as MY_{eq} increased. MY_C and MY_A increased exponentially with MY_{eq} (Figure 3B and C). DL had the lowest MY_C and MY_A . When comparing FS and CB, FS showed a greater MY_C when MY_{eq} was greater than 4,000 L/d, and both systems had a similar MY_A .

Assets/L (A_L) decreased exponentially as MY_{eq} increased (Figure 4A). When MY_{eq} was lower than 4,050 L/d, FS had the greatest A_L . In MY_{eq} greater than 4,050 L/d, the systems had similar A_L . ATR increased exponentially as MY_{eq} increased (Figure 4B). FS had the lowest ATR when MY_{eq} was lower than 4,300 L/d, but the greatest ATR when MY_{eq} was higher than 4,950 L/d. DL and CB had similar ATR.

The ROA had a quadratic relationship with MY_{eq} (Figure 4C). DL had the greatest ROA when MY_{eq} was between 700 and 3,700 L/d. From this point on, CB had the greatest ROA. At the edge of our data range ($MY_{eq} = 10,000$ L/d), FS and CB had a similar ROA. OP had an exponential behavior as MY_{eq} increased (Figure 4D). DL had the highest OP with MY_{eq} up to 3,150 L/d. From this point on, CB had the highest OP.

All profitability indexes (unitary profit, \$/L; and profit per cow, \$/yr) exhibited an exponential behavior (Figure 5A and C). DL had the greatest unitary profit and profit per cow when MY_{eq} was below 3,400 L/d and 2,300 L/d, respectively. From this point, profit was decreased in DL. CB had the greatest unitary profit and profit per cow when MY_{eq} was greater than 3,400 L/d and 2,300 L/d, respectively.

The frequency of milk price distribution is presented in Supplementary Figure 1. We fit the data with a Weibull distribution, and the expected milk price was \$0.35/L. DL had the lowest risk when MY_{eq} was below to 3,500 L/d (Figure 5B). In this level of MY_{eq} , DL had 35.5% risk of obtain negative profit. With a MY_{eq} from 3,500 to 8,950 L/d, CB had the lowest risk (37%). Finally, when MY_{eq} was greater than 8,950 L/d, FS had the lowest risk (Figure 5B). In other words, the risk of having negative profit in FS was 38.9%. All systems had negative expected unitary profit (\$/L) when MY_{eq} was lower than 1,250 L/d (Figure 5D). DL, CB, and FS started to have positive expected profit with MY_{eq} of 1,250, 1,950, and 4,950 L/d, respectively. We should highlight that when MY_{eq} was greater than 5,400 L/d, DL expected profit returned to being negative.

4. Discussion

The aim of this study was to evaluate the effect of production systems (CB, FS, or DL) on costs, economic results, milk production, and the risk. As expected, the results indicate that MY_{eq} is a key point for comparison of the systems and for selection of them by the farmers. Both hypotheses are clearly supported by the costs modelling and risk analysis, mainly at higher MY_{eq} values. Off course our data deal with an specific region and all interpretations of specific numerical values should be cautiously compared to other regions. However the behavior of the estimates among MY_{eq} can be useful for supporting future research aiming to compare these production systems. Most of the results were similar among MC and NMA and they were discussed together with specific remarks when relevant.

Farm characteristics data showed that the greatest production cost in DL, especially at high MY_{eq} levels, is likely linked to the greater demand for animals (total cows and milking cows) and area within the same MY_{eq} (Figure 1A, B and E). In DL, as the number of animals increase, more area, feeding, medicines, materials, and labor

were demanded (Figure 2). Although labor cost was the highest in DL, FTE was greater in FS and CB, respectively (Figure 1D). Farms based on FS and CB are probably more technological and need fewer employees. In Brazil, most facilities are not upgraded for labor efficiency, and it is known that poorly planned facilities increase the demand for animal handling. We speculate that this might be the reason for greater FTE in more intensive systems, mainly for FS, which was popularized in Brazil in the 1990s and probably lack in proper design for labor efficiency.

Comparing the more intensive systems (CB and FS) with DL, it was clear that CB and FS required greater input (costs with feeding and medicines) within the same MY_{eq} range, especially for lower MY_{eq} (Figure 2). In contrast, CB and FS were more economically efficient with greater MY_{eq} . Feeding management is known to be the greatest production cost and is directly linked to the farm net revenue (De Oliveira and Pereira, 2009). In our conditions, CB and FS had reduced feeding costs within the same MY_{eq} level when compared with DL (Figure 2). We speculate that CB and FS, are likely to be more specialized systems may also be more efficient in production and storage of roughage and concentrate feedstuffs, and in shrink control, leading to a reduced feeding costs and AOC (Breitenbach, 2018). Additionally, due to its structural characteristics, animals in DL are often more exposed to climatic factors and parasites. As a result, both reduction in intake by heats stress and feed losses in feed bunks and management may occur (Keller, 2009), and consequently increasing feeding costs. Heat stress can also result in greater incidence of physiological disorders. Sick animals also demand more medicines, bedding material, and labor for sanitary procedures. For instance, cows in CB and FS had a lower mastitis incidence when compared with less intensive systems (Barberg et al., 2007). This phenomenon can also be seen in our results, where more intensive systems such CB and FS had reduced medicine, sundry, and labor costs, all of which might represent more efficient health management.

Overall, DL farms had greater TOC when compared with CB and FS with higher MY_{eq} . However, the depreciation costs were greater in more intensive systems, especially FS. The FS facility has more complex structures, such as individual beds, machinery for cleaning the stalls, and manure treatment system (Von Keyserlingk et al., 2012). This structure intensively depreciates and requires repairs and maintenance (affecting sundry costs); hence, there are greater depreciation and sundry costs when compared with CB and DL. In addition, FS has a greater cost with regard to manure treatment systems when compared with CB, which produces 80% less manure (Black et al., 2013). Lastly, we observed that DL had the lowest cost with depreciation, considering those costs involve at a minimum animal waterers and feeders, fences, and shaded areas. Additionally, DL has mostly solid manure; thus, the facility used for manure treatment is less expensive compared to those used in FS and CB.

In summary, greater depreciation costs did not abruptly increase the TOC and AOC from more intensive farms (FS and CB). Although the production costs were somewhat similar among the intensive farms, the FS had higher AOC compared with CB in all MY_{eq} levels, driven mostly by costs associated with roughage, hired labor, and depreciation (Figure 2). However, when we grouped CB and FS, greater AOC was observed for DL. Although DL had a lower cost/animal, it required more animals within the same MY_{eq} level, when MY_C was lower in DL (Figure 2).

MY_{eq} (L/cow or L/ha) and profitability indexes were greater on FS and CB farms compared to DL when there was higher MY_{eq} . These results have also been observed in temperate countries (Fontaneli et al., 2005; Astiz et al., 2014). In this case, FS and CB had a lower MC_{TH} , but there was greater MY_C in FS and MY_A in CB compared with DL (Figure 3) (Breitenbach, 2018; Marcondes et al., 2019). In a recent study, Breitenbach (2018) observed similar results where FS reached a greater MY_C than CB, but both systems were larger than semi-confined systems. Although some heat

abatement strategies are observed in DL farms, CB and FS farms are usually more efficient (Leso et al., 2020), and the use of modern ventilation systems is directly linked to improved MY_C and MY_A (Lobeck et al., 2011).

The CB and FS farms had an average MY_{eq} of 25.5 L/cow/d and 26.6 L/cow/d, respectively, while DL farms had an average of MY_{eq} of 21.9 L/cow/d. Additionally, we believe that diets were very similar across the evaluated systems. In Brazil, the majority of dairy farms use corn silage as a primary roughage source, and they use ground corn, soybean meal, whole cottonseed, soybean hulls, and citrus pulp as primary feedstuffs for concentrate mixtures (Marcondes et al., 2014). Thus, the dietary factor is less influential here than heat stress control and quality of management practices. In personal communications with the farm consultants involved in this study, we noticed low variability in genetics across farms. Nevertheless, there was high variation in management. Comparing the quality of management across farms might be a challenging task. However, when associated with heat abatement technologies and cow comfort (Black et al., 2013), they might explain the differences observed in MY_C and MY_A among systems (De Oliveira and Pereira, 2009).

MY_C is highly linked to A_L , ATR, OP and ROA because they represent a measurement of production scale in a farm (Figure 4). In this study, the A_L demonstrated that all systems were less efficient below 4,050 L/d MY_{eq} (Figure 4A). In this case, more intensive systems demanded more assets per liter (3.59 \$/L in FS and 2.57 \$/L in CB) than DL (2.36 \$/L), likely due to high investment in animals, infrastructure, and machinery in FS and CB systems. Therefore, DL was the most efficient system when MY_{eq} was below 4,050 L/d, followed by CB and FS (Figure 4A). This situation makes DL more attractive for small producers due to underinvestment, resulting in low assets per produced liter. Nevertheless, we noticed that the cost of unitary milk production (\$/L) was reduced as MY_{eq} increased, mainly for CB and FS

systems. In this case, the more technological the system, the more efficient, due to the compensation of MY_c and MY_A , diluting the unitary milk production cost.

In agreement with the A_L results, ATR showed that FS generated more income (\$) per stocked dollar when MY_{eq} was greater than 4,950 L/d (Figure 4B). Nevertheless, DL was the most profitable system (ROA = 0.134, \$/L) when MY_{eq} was between 700 and 3,700 L/d, followed by CB ($MY_{eq} > 3,700$) (Figure 4C), mainly because of a lower production cost within that MY_{eq} range. Brazilian DL producers possibly focused their budget management on reducing costs instead of maximizing profits. This approach would reduce the cost per animal, but at the end would increase total costs in large herds, because they would have to have more animals to produce the same MY_{eq} as CS or FS.

All profitability indexes (annual profit, profit per cow, OP, and ATR) were higher in CB and FS ($MY_{eq} > 3,000$ L/d) when compared with DL (Figure 4 and 5). Those indexes were influenced by annual farm revenue due to higher MY per cow and per area, besides lower AOC_L , resulting in a better (lower) risk and expected profit. The greater risk for DL at higher MY_{eq} was influenced by greater annual AOC_L leading to an intense negative expected profit. According to Marcondes et al. (2019), when a system has a negative expected profit there is an intense depreciation of assets, non-remuneration of family labor, and the viability of the production system is only maintained in the short term, considering positive net margin.

Although DL had the greatest fixed and variable costs, with increased AOC_L as MY_{eq} increase, it had better profitability at low production levels ($MY_{eq} < 3,500$ L/d). These data indicate that for small farmers, this system is the most adequate (expected profit = 0.0102 \$/L and 35.5% of risk). Nevertheless, at higher MY_{eq} levels ($> 3,600$ L/d), CB had the best expected profit (0.0101 \$/L) and lower risk (37%). Thus, the choice between DL and CB should be made with care because an improvement in the

farm production level might change the best fit for that dairy farm. Finally, FS had the greatest expected profit (0.0079 \$/L) and lowest risk (38.9%) when MY_{eq} was greater than 8,000 L/d. These findings indicate that management of large CB is still a challenge in Brazil.

In conclusion, we suggest DL is the most attractive system for farms with MY_{eq} between 150 and 3,000 L/d (based mainly on Cost per cow, A_L , ATR, ROA, OP, FTE, profit, and risks). Even though CB and FS had somewhat similar outcomes in the majority of cases (MC_{TH} , MY_C , MY_A , ROA, OP, FTE, and annual farm revenue), the risk and expected profit analyses demonstrated that CB ($MY_{eq} > 3,200$ L/d) is an intermediate system, followed by FS, which is the most profitable system (MY_C , risk, and expected profit) for larger dairies ($MY_{eq} > 8,000$ L/d). It is worth noting that the combination of technical and economic outcomes significantly impacted unitary production cost (\$/L), and these results explain why most dairies are focusing on CB and FS, instead of DL, in tropical countries. However, the producers must consider that the combination of elements such as feeding, genetics, welfare, and efficient farm management may change the outcomes of the results reported herein.

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Declaration of interest

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Ethics committee statement

This study did not directly involve contact with animals, therefore an evaluation by the ethics committee was not necessary.

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Table 1. Technical and economic descriptive outcomes per farm in dairy production systems

Item	Compost bedded pack, N = 144			Drylot, N = 683			Free Stall, N = 133		
	Mean \pm sd	Min	Max	Mean \pm sd	Min	Max	Mean \pm sd	Min	Max
MYeq, L/d	2,871.1 \pm 2111.3	331.4	11,614.2	1524.0 \pm 1152.2	155.8	7928.4	3043.6 \pm 2427.8	376.1	10311.1
Milking Cow, N	114.3 \pm 75.0	16.9	404.3	78.6 \pm 51.7	10.3	350.1	113.9 \pm 78.1	10.7	327.3
Heifers, N	124.5 \pm 95.3	26.8	668.7	99.6 \pm 73	8.2	450.0	134.7 \pm 104.1	16.2	416.0
Total Cows, N	262.7 \pm 176.4	47.3	1,152.8	197.2 \pm 131.7	21.3	816.1	272.1 \pm 194.3	37.8	795.8
Area, ha	85.1 \pm 68.9	10.3	373.3	82.4 \pm 69.8	6.0	615.0	95.8 \pm 116.9	7.5	748.4
Labor, N	5.4 \pm 3.4	0.0	15.7	3.4 \pm 2.3	0.6	25.8	6.1 \pm 3.7	0.4	19.0
MY L/yr	978,261.9 \pm 699508.9	100,166.0	3,839,385.0	511,727.5 \pm 398131.4	55,946.0	2,833,605.0	1,045,200.2 \pm 833488.2	119,951.0	3,543,063.0
Annual milk revenue ¹ , \$	372699.77 \pm 265551.59	35,079.87	1381817.54	192356.40 \pm 157955.07	16,487.95	1204583.51	403968.84 \pm 336932.21	43162.87	1549655.06
Annual Beef revenue ¹ , \$	26,290.85 \pm 39318.43	0.00	243039.54	16,413.83 \pm 16728.56	0.00	122,068.93	25,197.70 \pm 30910.76	0.00	161016.91
Milk Price ¹ , \$	0.37 \pm 0.03	0.31	0.47	0.36 \pm 0.03	0.26	0.47	0.37 \pm 0.03	0.30	0.46
Roughage ¹ , \$	44,003.72 \pm 35753.31	734.79	232873.27	26,991.67 \pm 22994.01	32.42	182,133.95	47,588.33 \pm 38947.17	586.94	180893.71
Concentrate ¹ , \$	132,182.34 \pm 98566.52	10,717.43	599430.56	70,608.84 \pm 60589.24	3,718.21	548,570.12	137773.47 \pm 109367.84	15,218.71	462,177.84
Medicine ¹ , \$	12,636.29 \pm 11631.27	513.97	80123.37	7,675.82 \pm 8486.27	288.87	87,332.74	13,945.52 \pm 13744.19	1052.64	77,681.44
Sundry ¹ , \$	93,438.20 \pm 80396.39	11,231.46	469286.84	44,569.12 \pm 37815.25	4,480.36	324,829.88	99,149.94 \pm 81530.84	9,407.65	371,725.08
Hired labor ¹ , \$	39,599.22 \pm 34024.81	94.72	138982.12	21,152.04 \pm 24521.94	22.95	254,435.05	50,118.71 \pm 42539.64	1,520.84	193,163.61
Depreciation ¹ , \$	18,725.39 \pm 14285.16	1,110.92	75744.01	11,212.31 \pm 8169.97	96.28	62,669.66	21,780.44 \pm 12500.1	3,602.83	63,442.38
Family labor ¹ , \$	10,847.76 \pm 7660.48	2,983.89	43937.15	8,877.69 \pm 6437.51	2,501.44	49,294.12	6,904.10 \pm 5992.75	2,501.44	37,211.71
TOC ¹ , \$	321859.81 \pm 248192.93	31,117.54	1403124.53	170997.52 \pm 145073.29	13,346.49	1397301.77	348575.99 \pm 271394.53	46,360.11	1177928.06
AOC ¹ , \$	351432.96 \pm 269358.82	1,502,820.94	1502820.94	191087.54 \pm 140548.01	21,763.00	1469071.38	377260.54 \pm 251629.81	53279.83	1227852.91
Net margin ¹ , \$	77130.82 \pm 68893.89	-82,120.90	320285.26	37772.72 \pm 51604.62	-299216.18	319,788.90	80590.55 \pm 110521.41	-84273.18	616,179.91
Profit ¹ , \$	47557.67 \pm 61913.44	-153,526.82	241457.68	17682.70 \pm 47253.09	-337094.03	275,803.82	51906.00 \pm 85832.53	-132405.12	372,825.47
Assets ² , \$	450244.09 \pm 348911.26	45,544.74	2226423.98	264271.46 \pm 188203.91	35,045.49	1555877.88	515149.95 \pm 350198.28	77108.70	1439875.98

MYeq= milk yield equivalent; MY= annual milk yield;¹ per year; ² indicates assets without land; SD=standard deviation.

Table 2. Regression equations to estimate farm characteristics based on milk yield equivalent from compost bedded pack, free stall and drylot dairy production systems

Farm Characteristics	System	Equation	AIC	R ²	RMSE
Total cows, N	CB	$28.04 + 0.041 \times \text{MY}_{\text{eq}} - 0.00000051 \times \text{MY}_{\text{eq}}^2$	7308.9	0.99	7.00
	FS	$28.04 + 0.045 \times \text{MY}_{\text{eq}} - 0.0000014 \times \text{MY}_{\text{eq}}^2$			
	DL	$28.04 + 0.048 \times \text{MY}_{\text{eq}} - 0.00000036 \times \text{MY}_{\text{eq}}^2$			
Milking cows, N	CB	$15.61 + 0.038 \times \text{MY}_{\text{eq}} - 0.00000077 \times \text{MY}_{\text{eq}}^2$	6731.6	0.99	5.39
	FS	$15.61 + 0.039 \times \text{MY}_{\text{eq}} - 0.00000118 \times \text{MY}_{\text{eq}}^2$			
	DL	$15.61 + 0.042 \times \text{MY}_{\text{eq}} - 0.00000032 \times \text{MY}_{\text{eq}}^2$			
Heifers, N	All systems	$44.70 + 0.031 \times \text{MY}_{\text{eq}}$	8209.7	0.96	12.53
Labor, N	CB and DL	$1.53 + 0.002 \times \text{MY}_{\text{eq}} - 0.00000005 \times \text{MY}_{\text{eq}}^2$	1880.4	0.96	0.39
	DL	$1.53 + 0.001 \times \text{MY}_{\text{eq}} - 0.00000005 \times \text{MY}_{\text{eq}}^2$			
Area, ha	CB	$51.95 + 0.014 \times \text{MY}_{\text{eq}} - 0.00000076 \times \text{MY}_{\text{eq}}^2$	7539	0.97	7.79
	FS	$51.95 + 0.015 \times \text{MY}_{\text{eq}} - 0.00000076 \times \text{MY}_{\text{eq}}^2$			
	DL	$51.95 + 0.018 \times \text{MY}_{\text{eq}} - 0.00000076 \times \text{MY}_{\text{eq}}^2$			
Assets ¹ , \$	CB	$145665 + 116.22 \times \text{MY}_{\text{eq}} - 0.00187 \times \text{MY}_{\text{eq}}^2$	22156	0.98	23208
	FS	$266065 + 87.46 \times \text{MY}_{\text{eq}} - 0.00187 \times \text{MY}_{\text{eq}}^2$			
	DL	$122053 + 111.31 \times \text{MY}_{\text{eq}} - 0.00187 \times \text{MY}_{\text{eq}}^2$			

MYeq=milking yield equivalent; AIC= Akaike information criterion; R²=coefficient of determination; RMSE=root mean square error.¹Assets without land.

Table 3. Regression equations to estimate production costs for milking cows based on milk yield equivalent from compost bedded pack, free stall and drylot farms dairy production systems

Costs (\$/farm/yr)	PS	Equation	AIC	R ²	RMSE	TOC*	AOC*
Concentrate	CB	$-218.27 + 42.26 \times MY_{eq}$	19822	0.98	1412.2	x	x
	FS	$2977.75 + 40.52 \times MY_{eq}$					
	DL	$-5480.69 + 44.24 \times MY_{eq}$					
Roughage	CB	$435.83 + 14.84 \times MY_{eq} - 0.00028 \times MY_{eq}^2$	18990	0.91	6148	x	x
	FS	$435.83 + 15.92 \times MY_{eq} - 0.00028 \times MY_{eq}^2$					
	DL	$435.83 + 16.50 \times MY_{eq} - 0.00028 \times MY_{eq}^2$					
Medicine	FS	$640.74 + 3.13 \times MY_{eq} + 0.000073 \times MY_{eq}^2$	16669	0.93	1494.9	x	x
	CB and DL	$640.74 + 3.13 \times MY_{eq} + 0.000053 \times MY_{eq}^2$					
Hired Labor	CB	$7319.83 + 6.41 \times MY_{eq} + 0.000526 \times MY_{eq}^2$	16680	0.98	2890.5	x	x
	FS	$7319.83 + 9.21 \times MY_{eq} + 0.000511 \times MY_{eq}^2$					
	DL	$7319.83 + 2.27 \times MY_{eq} + 0.00149 \times MY_{eq}^2$					
Sundry	CB	$156.77 + 27.38 \times MY_{eq} + 0.000387 \times MY_{eq}^2$	18987	0.98	5459.2	x	x
	FS	$156.77 + 31.22 \times MY_{eq} - 0.00015 \times MY_{eq}^2$					
	DL	$156.77 + 22.64 \times MY_{eq} + 0.000936 \times MY_{eq}^2$					
Family Labor	CB	$4333.28 + 1.26 \times MY_{eq}$	15663	0.89	1412.2		x
	FS	$4333.28 + 0.58 \times MY_{eq}$					
	DL	$4333.28 + 1.59 \times MY_{eq}$					
Depreciation	CB	$7147.41 + 2.41 \times MY_{eq} + 0.000253 \times MY_{eq}^2$	16466	0.97	1235.5		x
	FS	$7147.41 + 3.36 \times MY_{eq} + 0.000253 \times MY_{eq}^2$					
	DL	$7147.41 + 1.33 \times MY_{eq} + 0.000253 \times MY_{eq}^2$					

PS=production system; CB=compost bedded pack; FS= free stall; DL=drylot; MYeq=milking yield equivalent; AIC= Akaike information criterion; R²=coefficient of determination; RMSE=root mean square error; *x indicates if that item is included in the calculus of TOC (total operational costs) or AOC (accrual operational costs).

Table 4. Regression equations to estimate production costs for non-milking animals based on milk yield equivalent from compost bedded pack, free stall and drylot farms dairy production systems

Costs (\$/farm/yr)	PS	Equation	AIC	R ²	RMSE	TOC*	AOC*
Concentrate	CB	$774.79 + 2.52 \times MY_{eq}$	16119	0.81	1696	x	x
	FS	$774.79 + 2.39 \times MY_{eq}$					
	DL	$774.79 + 3.18 \times MY_{eq}$					
Roughage	CB	$493.36 + 0.80 \times MY_{eq}$	15156	0.65	905.91	x	x
	FS	$493.36 + 0.76 \times MY_{eq}$					
	DL	$493.36 + 1.02 \times MY_{eq}$					
Medicine	CB	$110.94 + 0.26 \times MY_{eq} - 0.00001 \times MY_{eq}^2$	12616	0.80	194.82	x	x
	FS	$110.94 + 0.18 \times MY_{eq} + 0.000012 \times MY_{eq}^2$					
	DL	$110.94 + 0.27 \times MY_{eq} + 0.000015 \times MY_{eq}^2$					
Hired Labor	CB	$400.92 + 0.71 \times MY_{eq}$	13998	0.85	654.93	x	x
	FS	$400.92 + 0.95 \times MY_{eq}$					
	DL	$400.92 + 0.86 \times MY_{eq}$					
Sundry	All systems	$884.52 + 1.85 \times MY_{eq}$	16226	0.82	1252.3	x	x
Family Labor	CB	$502.03 - 0.006 \times MY_{eq} + 0.000018 \times MY_{eq}^2$	12250	0.66	242.84		x
	FS	$502.03 - 0.061 \times MY_{eq} + 0.000012 \times MY_{eq}^2$					
	DL	$502.03 + 0.099 \times MY_{eq} - 0.00000084 \times MY_{eq}^2$					
Depreciation	CB	$558.72 + 0.24 \times MY_{eq}$	13423	0.69	333.47		x
	FS	$558.72 + 0.34 \times MY_{eq}$					
	DL	$558.72 + 0.27 \times MY_{eq}$					

PS=production system; CB=compost bedded pack; FS= free stall; DL=drylot; MYeq=milking yield equivalent; AIC= Akaike information criterion; R²=coefficient of determination; RMSE=root mean square error; *x indicates if that item is included in the calculus of TOC (total operational costs) or AOC (accrual operational costs).

List of figures

Figure 1 – Farms characteristics according to increasing equivalent milk yield (kg/d) levels in compost bedded pack (★), free stall (●) and drylot farms (Δ). Orange lines represent grouped data for free stall and compost bedded pack. Letters indicate total cows, # (A); milking cows, # (B); heifers, # (C); full time equivalent labor, # (D); area, ha (E); and assets without land, \$ (F).

Figure 2 – Graphic of production costs data related to increasing farm equivalent milk yield (kg/d) levels for milking cows and non-milking animals in compost bedded pack (★), free stall (●) and drylot farms (Δ). Letters indicate: concentrate expenses for milking cows, \$/yr (A), roughage expenses for milking cows, \$/yr (B), medicine expenses for milking cows, \$/yr (C), hired labor expenses for milking cows, \$/yr (D), sundry expenses for milking cows, \$/yr (E), family labor expenses for milking cows, \$/yr (F), depreciation expenses for milking cows, \$/yr (G), concentrate expenses for dry cows and heifers, \$/yr (H), roughage expenses for dry cows and heifers, \$/yr (I), medicine expenses for dry cows and heifers, \$/yr (J), hired labor expenses for dry cows and heifers, \$/yr (K), sundry expenses for dry cows and heifers, \$/yr (L), family labor expenses for dry cows and heifers, \$/yr (M), depreciation expenses for dry cows and heifers, \$/yr (N).

Figure 3 – Simulation of number of milking cows (A); milk yield/cow, L/d (B); milk yield/area, L/ha/yr (C); and full time equivalent labor (D) according to increasing equivalent milk yield (kg/d) levels in compost bedded pack, free stall and drylot.

Figure 4 – Simulation of assets/L (A), assets turnover ratio (B), return on assets (C) and operational profit (D) according to increasing equivalent milk yield (kg/d) levels in compost bedded pack, free stall and drylot.

Figure 5 – Simulation of profit per farm, \$/L (A), where is the real profit obtained from farm, considering the price of milk paid; profit per cow, \$/yr (B); risk, % (C); and

expected profit, \$/L (**D**) which considers (instead of the real price) the milk expected price estimated based on the Monte Carlo's analysis. according to increasing equivalent milk yield (kg/d) levels in compost bedded pack, free stall and drylot.

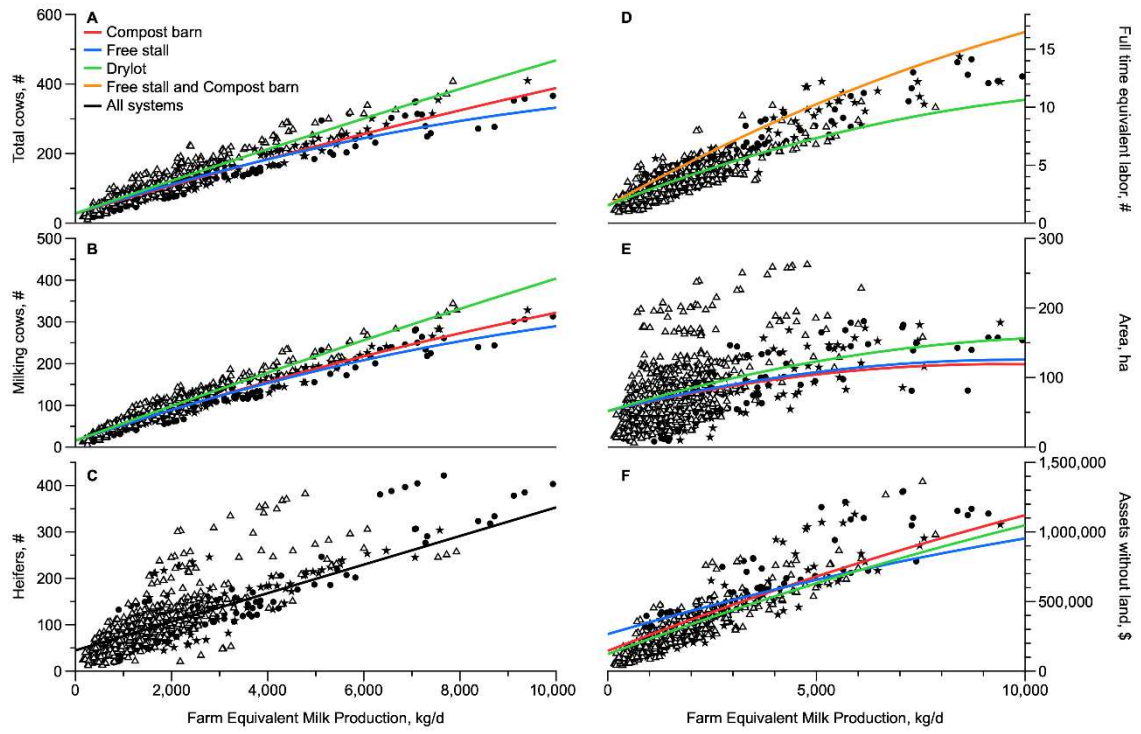


Figure 1. *Pinheiro et al.*

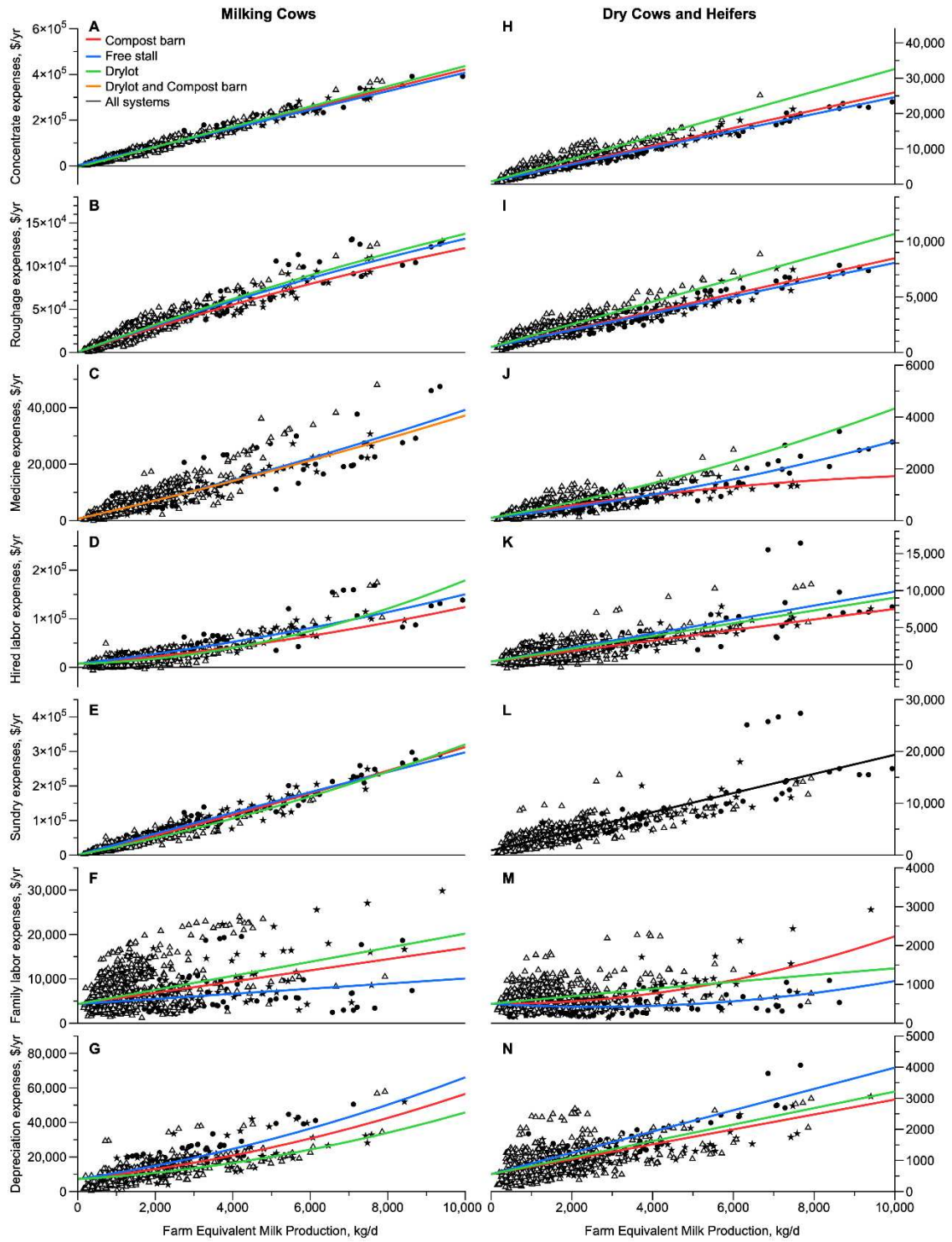


Figure 2. *Pinheiro et al.*

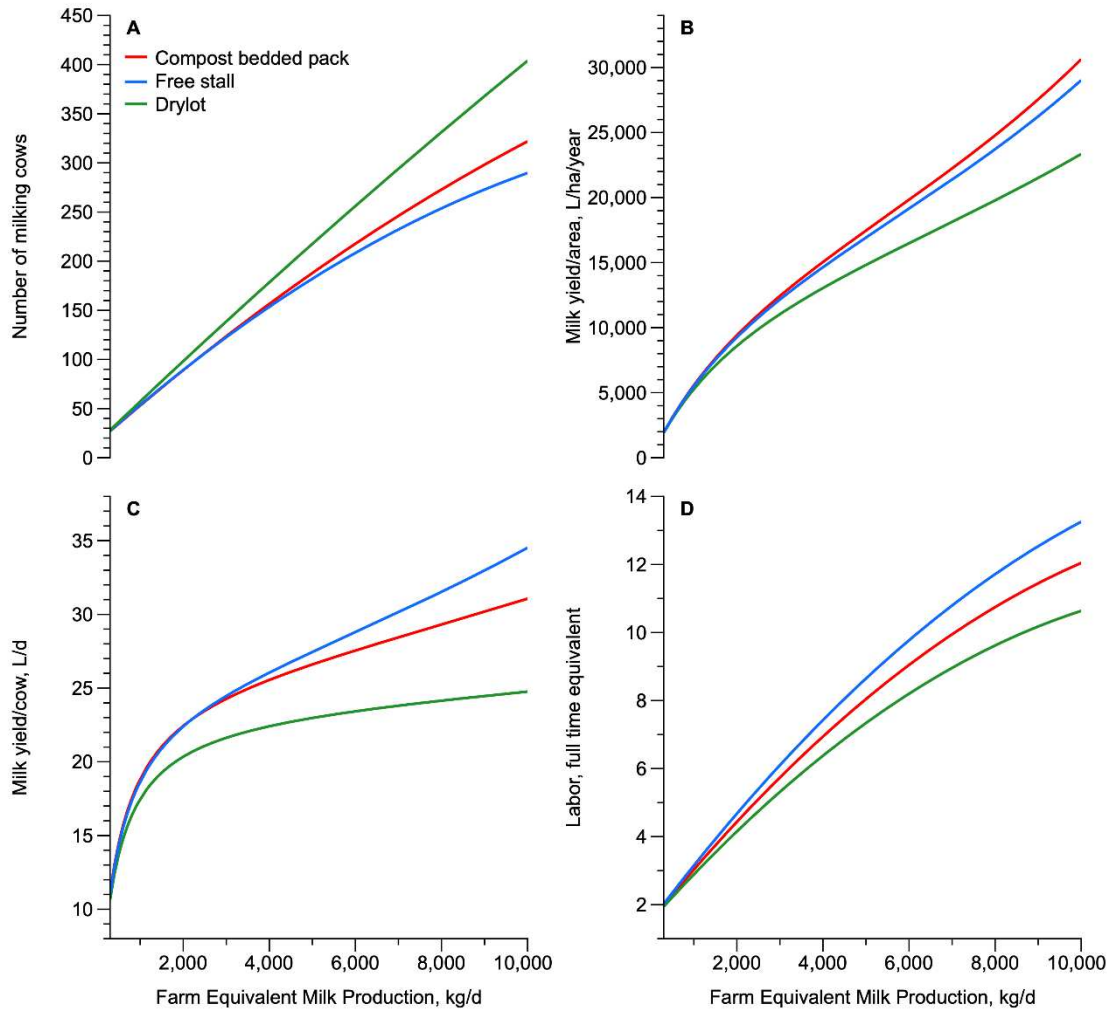


Figure 3. *Pinheiro et al.*

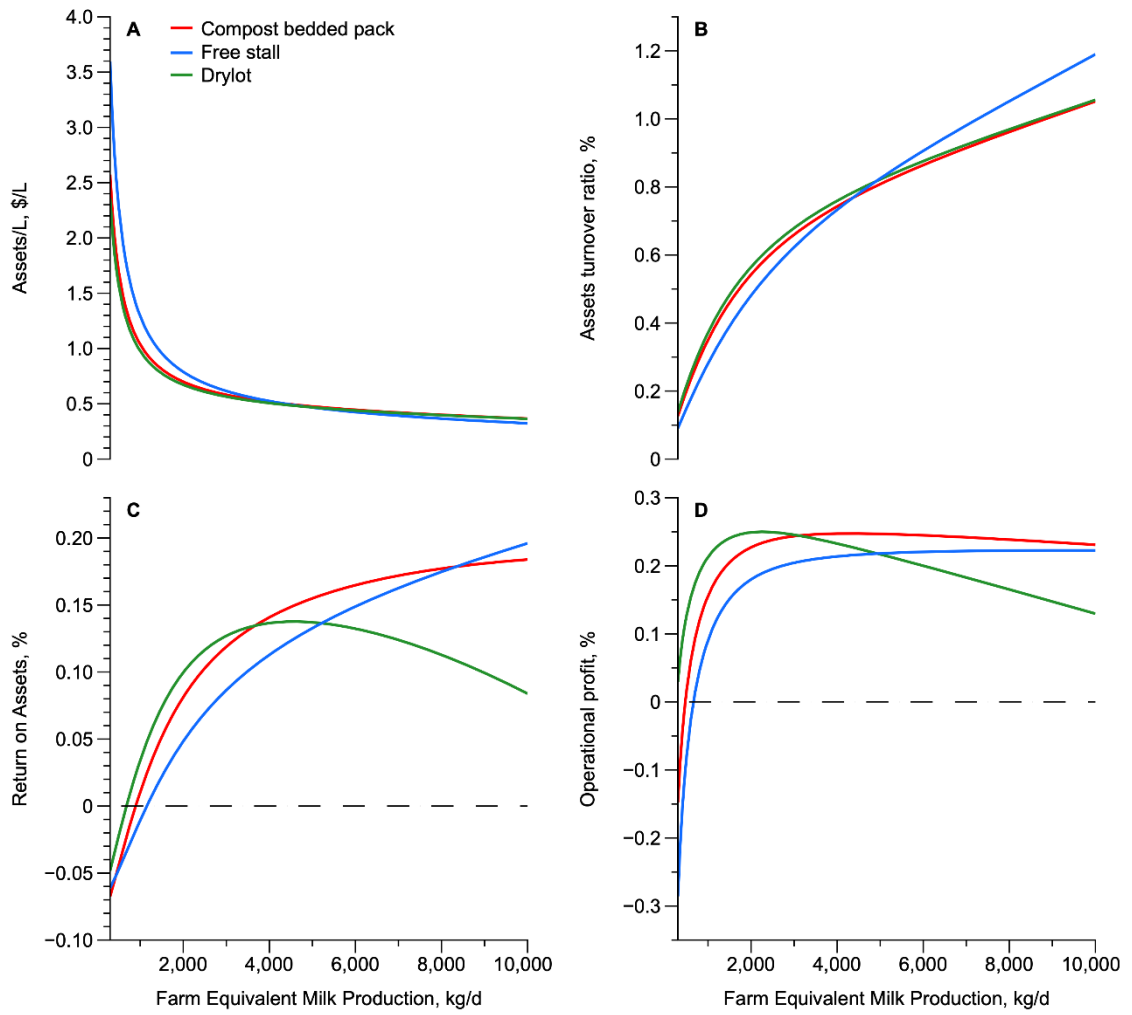


Figure 4. *Pinheiro et al.*

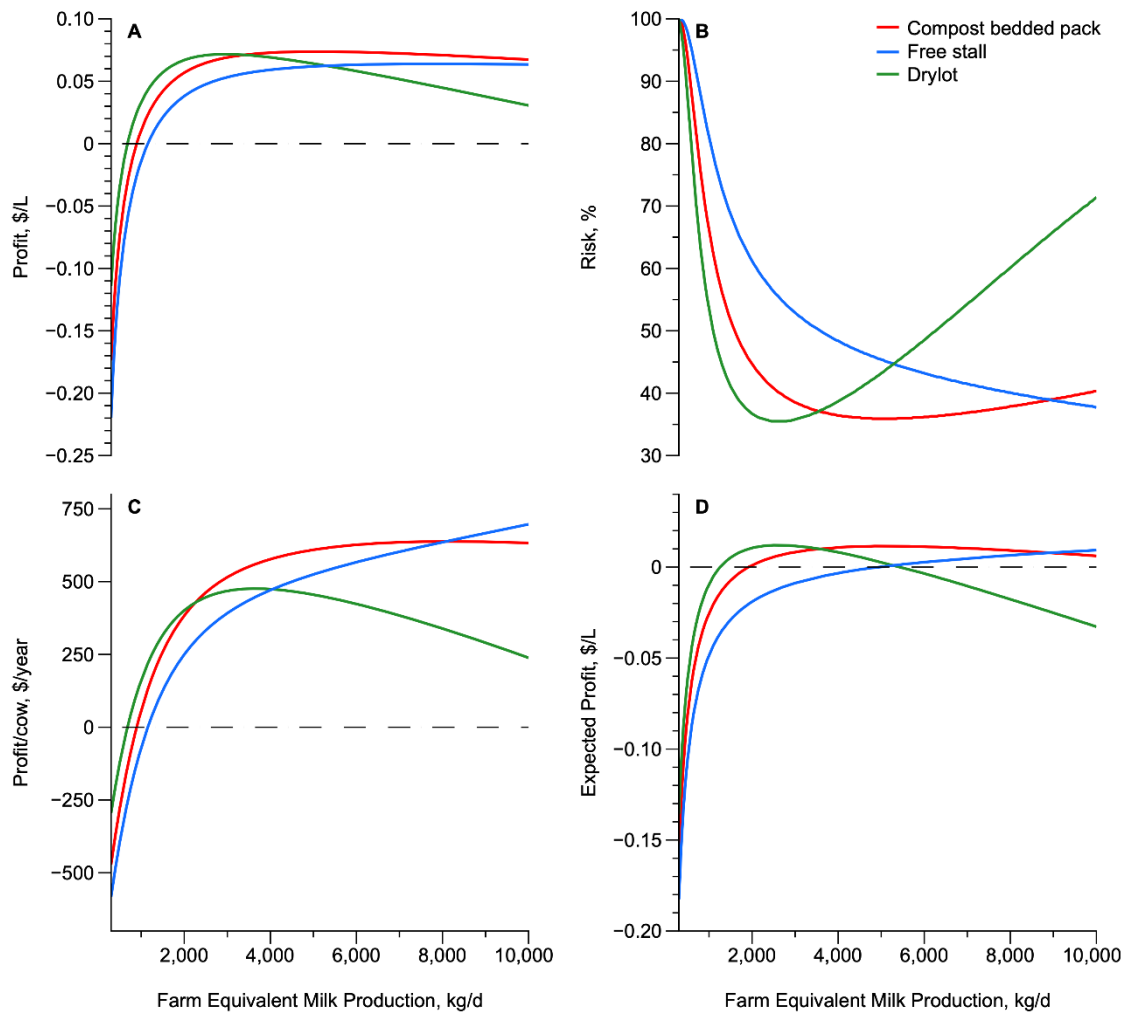
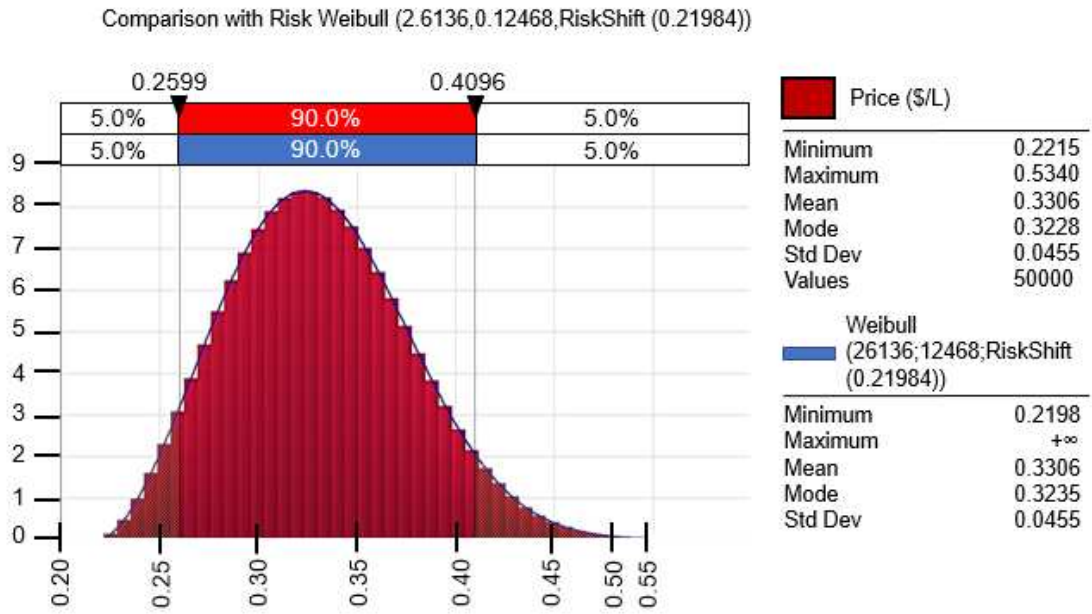


Figure 5. *Pinheiro et al.*

List of Supplementary Figures

Supplementary Figure 1 – Frequency distribution of milk prices (\$/L) obtained from 169 months (January 2005 to January 2019) from Brazilian farms.



Supplementary Figure 1. *Pinheiro et al.*