Herd-level associations between somatic cell counts and economic performance indicators in Brazilian dairy herds

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INTERPRETATIVE SUMMARY

Herd-level associations between somatic cell counts and economic performance indicators in Brazilian dairy herds. Gonçalves *et al.*, 2020. The aims of this study were to provide a portrait of the techno-economic status of dairy herds in Minas Gerais, Brazil, and in particular to examine the herd-level association of bulk-tank SCC and various economic efficiency indicators (EEI). We observed that the lower the bulk-tank SCC, the greater the revenue, gross and net margins, and profit of herds. The reduction of milk yield was associated with higher bulk-tank SCC.

BULK TANK SOMATIC CELL COUNT AND ECONOMIC PERFORMANCE INDICATORS

Herd-level associations between somatic cell counts and economic performance indicators in Brazilian dairy herds

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ABSTRACT

The aims of the present study were to provide a portrait of the techno-economic status of dairy herds in Minas Gerais, Brazil, particularly with respect to bulk tank somatic cell count **(BTSCC)** data, and to examine the herd-level associations of BTSCC with various economic efficiency indicators (EEI). Data from 543 herds, 1,052 herd-year records in total, spread over three years (2015-17), from the South and Southwest mesoregions of Minas Gerais State were provided by the Brazilian Support Agency to Micro and Small Companies Division Minas Gerais **(SEBRAE)**. Herds had an average of 82 lactating cows/herd, milk yield of 17 L/cow per day and availability of financial information via routine monthly economic surveys. The EEI data (revenue, gross margin, **GM**; net margin, **NM**; profit; break-even point and operational profitability) of each herd was measured monthly by SEBRAE personnel and herd-year averages of all variables were computed. Bulk tank data (SCC, TBC, the content of crude protein and fat) taken by producers or dairy processors were recorded by SEBRAE personal; and corresponding herd-year averages were calculated and included in the SEBRAE database. There were 209 selected herds which passed all edit checks, and which had data for all three years. The EEI (all expressed on a per-cow basis, US$/cow per year) were analyzed including the effects of region, year, Ln BTSCC, production level and herd size together with the random effect of herd nested within region. A high proportion of herds (94.6%) presented data records (herd-years) with an average BTSCC > 200×10^3 cells/mL: 37.8% of herd-year records had BTSCC between >200 and ≤ 400, 14.5% with BTSCC between >400 and ≤ 500, 25% with BTSCC between >500 and ≤ 750 and, 17.3% with BTSCC > 750. For each unit increase in Ln BTSCC, revenue declined by US$ 228.5 cow/year, GM by US$155.6 cow/year and profit by $138.6 cow/year. Herds with cows of lower production (< 14 kg/d) presented lower GM (US$ 286.8 cow/year) when compared with herds containing cows producing ≥ 14 kg/d (≥ 14 and < 19 kg/d = US$ 446.5 and, ≥ 19 kg/d = US$ 601.9). The small-scale milk producers (< 39 lactating cows) presented lower revenue (US$ 1,914.9 cow/year) and GM (US$ 274.5 cow/year) and consequently a negative profit (US$ -224.1 cow/year) when compared with other herd size categories (≥ 39 lactating cows). The reduction in milk yield was 641 liters per cow/lactation for each unit increase in Ln BTSCC; this represented 9.4% of the milk yield/lactation, assuming an average milk production of 6,843.3 liters per cow/lactation of cows from herds which had BTSCC ≤ 200×10^3 cells/mL. Consequently, we found a negative association of BTSCC with profit; profit declining from US$ 227.0 to -53.1 cow/year when the BTSCC increased from 100 to 750×10^3 cell/mL. In short, the lower the BTSCC, the greater the revenue, GM and NM, profit and operational profitability of the herds. The reduction of milk yield was the main factor associated with higher BTSCC.

Keywords: Bulk tank cell count. Mastitis. Subclinical. Economic indicator. Profitability.

INTRODUCTION

Brazil is the third largest milk producer, representing 4.8% (about 35 billion liters) of global milk yield in 2017, behind only the United States and India (FAO, 2019, IBGE, 2019). Given the current scenario of milk production in Brazil, it is expected to increase at an annual rate of 1.9%; one possible way to achieve the target of producing 41.3 billion liters of milk in 2023 will be to include strict sanitary measures to reduce disease-related milk production losses (IBGE, 2019). Many Brazilian dairy herds' decisions have been made with a focus on achieving higher productivity, as also described in previous reviews (van der Voort et al., 2017, Hogeveen et al., 2019). However, the demand for higher productivity, might not always be aligned with a greater economic efficiency (Hogeveen et al., 2011, Hogeveen et al., 2019). Unfortunately, due to the increasing demand for increased milk production, dairy farmers may make management decisions that negatively affect the health of cows exactly when the necessary strategies for improving milk quality are not adopted. For example, in a recent study, despite that Brazilian dairy herds had high incidences and prevalences of subclinical mastitis **(SM)**, there was no SCC reduction over the period of the study, from 2011 to 2015 (Busanello et al., 2017).

Milk quality is an important aspect of dairy production that affects milk processing and its technological properties (Botaro et al., 2013). Considering the subclinical form of mastitis for which symptoms are not visually evident, diagnosis can be done at the cow and herd level through the evaluation of somatic cell count **(SCC)**. High SCC milk represents an undesirable feature for dairy processors as it reduces cheese yield and shelf-life of dairy products (Santos et al., 2003), in addition to the impact that it has at the farm-level, i.e reducing milk yield, increasing health and veterinary costs (Hogeveen et al., 2019), and increasing the likelihood of culling. Therefore, economic losses caused by bovine mastitis are recognized worldwide as a major factor affecting profitability of dairy farms (Halasa et al., 2007, Hogeveen et al., 2011).

The costs of SM are highly dependent on the specific context in which they have been estimated considering the differences between countries and regions regarding prevalence, management practices, and price levels of inputs and outputs (Nielsen et al., 2010). For these reasons, Aghamohammadi et al. (2018) described that SM costs estimation should be conducted based on source populations restricted to a single geographical region, such as a country or even a state. Moreover, economic consequences of disease change over time, a broader perspective would be to look at studies across regions, but taking account of region differences. Altogether, economic calculations change over time, owing to changes in milk quality regulations and market circumstances (Bennett, 2003). To complicate matters further, differences among studies have led to differences in the estimation losses, i.e. not completely comparable results (Halasa et al., 2007). These discrepancies are due not only to the disparity in methodologies and differences between regions, but also to variability among dairy cows from different places used for analysis (Petrovski et al., 2006). For these reasons, studies in various regions and over time are necessary, to estimate the economic impacts of this disease on the dairy industry.

The economics of mastitis management can be assessed at the quarter, cow or farm level. There are few studies using both production information and accounting (economic) data at the herd level (Geary et al., 2012, Geary et al., 2013, Dillon et al., 2015), indeed we are not aware of any such data appropriate to Brazil. Although most referred studies have used model-based simulation (Dekkers et al., 1996, Geary et al., 2012, Geary et al., 2013), sometimes performed with no empirical data, a deterministic model using real accountancy data can help producers to perceive the negative association of mastitis and the economic indicators, at the herd level. Another point is that an interesting result from a recent study highlighted the need to establish large-scale milk quality programs in Brazil (Busanello et al., 2017), but for that to occur we believe farmers have to be aware of the negative impacts of elevated BTSCC on milk yield and EEI. Therefore, the aims of the present study were to provide a portrait of the techno-economic status of dairy herds in Minas Gerais, Brazil, particularly with respect to bulk-tank SCC data, and to examine the herd-level associations of bulk-tank SCC and various economic efficiency indicators (EEI).

MATERIAL AND METHODS

Dairy records

Data from 2015 to 2017, used to estimate EEI at a herd level, were retrieved from records of farms enrolled in the Educampo Project, led by the non-profit association SEBRAE - the Brazilian Support Agency to Micro and Small Companies Division Minas Gerais. Briefly, the project is a collaborative teamwork aimed at providing dairy farmers with technical assistance and business management advice for the improvement of the efficiency of dairy farms. There was a total of 543 herds, located in the South and Southwest areas of Minas Gerais State. At the time of the study, herds had, on average, 82 lactating cows/herd (min 7 and max 703). Herds were mainly composed of the Girolando breed (Gir × Holstein crossbred). The average daily milk yield was 17 L/cow.day (min 4 and max 34). The average area used for dairying was 95 ha (min 9 and max 975). Herds had an average total number of head of cattle of 102.4 (min 8 and max 829), and a proportion of 80% lactating cows/total cows (min 36.8 and max 95.9). On-farm surveys of financial statements were performed by the Educampo personnel (Supplementary material Table S1).

Somatic cell count and milk composition

Bulk tank SCC data taken by producers or dairy processors were recorded by SEBRAE personal and were included in the SEBRAE database. Briefly, SCC, protein and fat contents of milk samples were determined according to the International Organization for

Standardization & the International Dairy Federation (ISO 13366-2:2006; IDF 148-2:2006) on a Fossomatic ™ FC (FOSS North America, Eden Prairie, MN, USA).

Monthly data of BTSCC and milk volume were used by SEBRAE personnel to estimate the weighted mean annual BTSCC ($\times 10^3$ cells/mL) prior to the initial data extraction. For descriptive purposes the herds were grouped according to the levels of these weighted annual means (a. ≤ 200, *n* = 57; b. >200 and ≤ 400, *n* = 398; c. >400 and ≤ 500, *n* = 152; e. >500 and ≤ 750, *n* = 263, and f. > 750, *n* = 182). Descriptive data of selected herds are presented in Table 1. Only herds which had complete data information for all three years were kept for statistical analyses (n = 209), in addition 3 regions were removed because they had only a handful of herds each (see Table 2).

Methodology of economic evaluation

The EEI data (revenue; gross margin, GM; net margin, NM; profit; break-even point; and, operational profitability) of each herd were measured monthly by SEBRAE personnel and herd-year averages of all variables were computed. Revenue was defined as the milk production per herd/month multiplied by the market price of milk. GM was defined as the revenue minus the fixed and variable costs (e.g. labor, feed, sanitation costs). NM was defined as the revenue minus all costs (fixed, variable and familiar labor cost) plus depreciation. The profit was defined as the revenue minus the total costs (TC), which included the opportunity cost of the invested capital (assumed to be 6% of the invested capital per year). The break-even point of the dairy farm (L/day) was defined as the total milk production (L/day) that should be produced in order for its value to be equal to the TC. Operational profitability was defined as the profit in percentage after accounting for all costs.

All the above-described annual data (region, year, coded herd number, herd size, milk yield, EEI, etc) were provided by SEBRAE, with the exception of the inflation adjustments, which we carried out. Because of the high inflation rates in Brazil that also affects the prices in dairy farming, the Annual Extended National Consumer Price Index (IBGE, 2018) was taken into consideration to correct all monetary figures from the study period used for analyses to a 2017-basis. The index represents the yearly inflation rate (December vs. December) accounted in Brazil for 2015 (10.67%), 2016 (6.29%) and 2017 (2.95%). Thus, 2015 financial records were multiplied by 1.1067*1.0629, while 2016 financial records were multiplied by 1.0629.

Statistical analysis

Data used to estimate EEI were analyzed using SAS PROC MIXED (SAS Inst. Inc., Cary NC), and the statistical model included the fixed effects of region, year, production level (omitted for the analysis of milk yield), herd size and the linear regression effect of log bulk tank somatic cell count (Ln BTSCC), and the random effect of herd nested within region. A larger model with all two-way interactions was initially fitted and interactions which were not statistically significant ($P<0.05$) were sequentially pruned out.

Model:

$$Y_{ijkmp} = \mu + \text{region}_i + \text{year}_j + \text{region*year}_{ij} + \text{prodLevel}_k + \text{HerdSize}_m + \text{herd}_{ip} +$$

$$b_1 * \text{lnBTSCC}_{ijkmp} + e_{ijkmp}$$

Y corresponds to the dependent variable: EEI (revenue, GM, NM, profit, break-even point and operational profitability); TC and the main four costs (concentrate, forage, medicine and labor); milk yield and components (Kg Fat and Kg Protein). Herds (for which there were 3 records each) were considered as a random effect, nested within region; all other effects were considered as fixed effects.

There were 8 regions of Minas Gerais State included in the initial data collection (see Table 2 with the number of herds in each region-year). Due to the small numbers of herds in regions 2, 4 and 8, they were omitted from the analyses. Table 2 shows the numbers of herds in each of the region-years retained in the data for analyses. Initially there was a total of 543 different herds over 3 years. Not all herds participated in the economic recording for all 3 years. We limited the data records to those herds which had participated in the recording for all 3 years; some herd-years were excluded due to missing values for economic costs of concentrates fed, forage, treatments and labor; therefore 209 herds across 5 regions were used in the statistical analyses. SAS PROC MIXED was used for the analyses and to compute the least squares means for the various classification effects. For the effect of Ln BTSCC one can calculate the estimated EEI for any given Ln BTSCC value, using the PROC MIXED ESTIMATE statement in a manner analogous to computing lsmeans (ie. marginal estimated means). This involves averaging over the solutions for each of the levels of each factor in the model, for example, since there were 5 regions used, then 1/5 of each of the 5 region solutions are accumulated, together with 1/3rd of each of the year solutions (since there were 3 years of data used), etc. Estimated EEI values were calculated corresponding to BTSCC levels of 100, 200, 400, 500 and 750 thousand SCC (Table 3).

All the statistical analyses assume normality; to examine whether this assumption is tenable, the residuals from each analysis (dependent variable/trait) were plotted as a histogram and a normal distribution kernel superimposed to assess normality and to check for outliers. For each of the analyses we assessed that the residuals were normally distributed, except that, for some of the traits, there were one or two residuals which were outliers. These observations were left in the analyses as we judged that removing such observations might well be exactly the ‘outlier’ economic indicators that we wished to observe as particularly performing or under-performing herds. In addition, with only 1 or 2 such outliers we judged that there would be little impact on the overall analyses.

RESULTS

Descriptive results from data records of herds and milk quality

A total of 543 herds and 1,052 herd-year records were collected during three years (2015-17). Descriptive statistics grouped by BTSCC levels are presented in Table 1. The majority of herds (94.6%) had average BTSCC > 200×10^3 cells/mL, 37.8% of herd-year records were grouped as having BTSCC >200 and ≤ 400, 14.5% with BTSCC >400 and ≤ 500, 25% with BTSCC >500 and ≤ 750 and, 17.3% with BTSCC > 750. Descriptive results showed that the land area used for livestock varied from 88.7 to 114.1 ha, lactating cows between 73.5 to 96.5 head/month, milk production/lactating cows between 15.1 to 20.5 kg/d, average milk fat content between 3.7 to 3.8% and average milk protein content between 3.2 to 3.3%. Table 2 shows the number of herds in each year region, and the number (209 herds) retained for the statistical analyses.

Effects of regions, period, herd size and production level on economic indicators

We observed differences among the LSMEANS of revenue, GM, profit, milk yield and feed costs by production level and herd size (Table 3). The higher the milk production level per cow, the higher the revenue and the GM. Herds with cows of milk production < 14 kg/cow/d had a GM that was 17.4% of the revenue (GM US$ 286.8 / revenue 1,652.2 cow/year = 17.4%; Table 3); herds with cows of milk production ≥14 and <19 kg/cow/d had a GM that was 21.8% of the revenue (US$ 446.5 cow/year); and herds with cows of milk production ≥ 19 kg/cow/d had a GM that was 23.3% of the revenue (US$ 601.9 cow/year). Herds with cows of lower milk production (< 14 kg/d) presented lower profit (US$ -106.9 cow/year) than herds with cows ≥ 14 and < 19 kg/cow/d (US$ 20.8), and ≥ 19 kg/cow/d (US$ 144.5). The higher the number of lactating cows/herd the higher the revenue, GM, profit and milk yield. For example, herds with < 39 lactating cows had a GM that was 14.3% of the revenue (US$ 274.5 cow/year), which is lower than the 22.4 to 24.4% found in other herd size categories (GM ranging from US$ 462.1 to 556.5 cow/year) (Table 3). Herds with > 100 lactating cows had higher profit (US$ 196.2 cow/year) and milk yield (6,279.0 Kg/cow.year) than the other categories of herd size. In other words, the small-scale milk producers (< 39 lactating cows) had lower revenue (US$ 1,914.9 cow/year) and GM (US$ 274.5 cow/year) which consequently resulted in negative profit (US$ -224.1 cow/year). In summary, herds with low production cows (< 14 kg/d) had a lower GM as a proportion of revenue in comparison to herds with high milk production cows (≥ 14 kg/d) over three years.

Regression coefficients (effect of Ln BTSCC)

For each unit increase in Ln BTSCC, revenue declined by US$ 228.5 cow/year, GM by US$155.6 cow/year, NM by US$138.4 cow/year and, profit by $138.6 cow/year (Table 4). For example, BTSCC = 100 is equivalent to Ln BTSCC of 4.6; 5.6 = 270; and 6.6 = 750 ($\times 10^3$) = 750,000 cells/mL. In other words, herds which increased BTSCC by 170,000 cells/mL (100,000 to 270,000) would have had a revenue reduction of US$ 228.0 cow/year and the double of this reduction if the BTSCC were modified from 100,000 to 750,000 (US$ - 457 cow/year). Similarly, the costs for each unit increase of Ln BTSCC were: TC declined by US$ 71.4 and the main costs of concentrate and forage declined by US$ 47.3 and 25.1 cow/year, respectively. We observed no significant associations between Ln BTSCC and labor and medicine costs (Table 4). The reduction in lactation milk yield was 641 liters per cow/lactation for each unit increase in Ln BTSCC. Assuming an average milk production of 6,843.3 liters per cow/lactation, this reduction of 641 L represented 9.4% of the milk yield of cows from herds which had BTSCC ≤ 200×10^3 cells/mL. Consequently, the higher the BTSCC the lower the profit, declining from US$ 227.0 to -53.1 cow/year when the BTSCC increased from 100 to 750×10^3 cell/mL (Table 4).

Costs of milk production according to the levels of BTSCC. Herds with low BTSCC (100×10^3 cells/mL) had a lower proportion of their revenue being spent on feed costs ((Concentrates US$ 819.9 + Forage US$ 317.3)/Revenue US$ 2,437.4 = 46.7%) when compared with the herds with high BTSCC (750×10^3 cells/mL; 50.2%). The proportion of medicine and labor costs in relation to the revenue were similar among herds with different levels of SCC (Table 4).

Indicators of milk production/herd grouped by levels of BTSCC. The GM proportion in relation to the revenue decreased with the increase of BTSCC (Figure 1). Briefly, GM represented 27.4% of the revenue for herds with BTSCC of 100×10^3 cells/mL (GM US$ 667.9 /Revenue US$ 2,437.4; see Table 4), 25% for herds with BTSCC of 200×10^3 cells/mL, 21.8% for herds with BTSCC of 400×10^3 cells/mL, 20.7% for herds with BTSCC of 500×10^3 cells/mL and, 18.4% for herds with BTSCC of 750×10^3 cells/mL (Figure 1).

DISCUSSION

We wondered whether an increased BTSCC could be associated with lower economic efficiency on Brazilian dairy farms. For this reason, a portrait of the techno-economic status of dairy herds in Minas Gerais, Brazil, with respect to BTSCC data was evaluated. With an interesting point of view, Guimarães et al. (2017), and Huijps and Hogeveen (2007) comment on the need to show what the impacts of BTSCC are, and that the reduction in milk production is often under-recognized as compared to direct expenses (veterinary treatment, drugs, discarded milk). A total of 42.3% of the herds in this study had BTSCC of > 500×10^3 cells/mL, and the average BTSCC was 515×10^3 cells/mL. The Brazilian regulations state that once the 3-month geometric mean BTSCC reaches 500×10^3 cells/mL the processor must issue a warning to the supplier who then has 3 months to reduce this, as described in the governmental normative instruction nº76 and 77/2018 (BRAZIL, 2018). However, despite the normative instruction, farmers have to have the awareness that reducing SCC results in higher milk yield (Gonçalves et al., 2018). In the current study, we found a negative association of BTSCC and milk yield. Thus, high BTSCC levels were indicative of reduced profitability which corroborate what was found in previous studies (Geary et al., 2012, Geary et al., 2013, Dillon et al., 2015, Aghamohammadi et al., 2018).

In line with our results, Dillon et al. (2015) observed that the net margin decreased 42% (€ -217.00) as BTSCC increased from < 200 to the level of 301-400×10^3 cells/mL; 47% observed in the current study (US$ -192.3) under similar conditions. For example, if an average of 500×10^3 cells/mL BTSCC could be reduced to 300×10^3 cells/mL, it would correspond to an approximate 0.5 reduction in Ln BTSCC, which would be worth (0.5×

228.5= US$ 114.3 cow/year) extra revenue, and (0.5× 155.6 = US$ 77.8 cow/year) extra gross margin. On a herd basis, for an average of 82 cows, this reduction of 0.5 Ln BTSCC would translate into an extra revenue of US$ 9,372.3 and an extra gross margin of US$ 6,379.6 per year. Furthermore, herd solutions were used to compute correlations amongst the various traits. Across herds, gross margin is highly correlated with profit ($r > 0.91$), as might well be expected (data not shown). However, the correlation of gross margin and production per cow ($r=0.04$) indicates that, across herds, there is no correlation between production per cow and gross margin, nor between production per cow and profit ($r = -0.05$); i.e. simply increasing production will not necessarily lead to a higher gross margin nor more profit. Likewise, revenue has only a low correlation with gross margin ($r = 0.10$).

There are only a few studies that employed methods from the field of economics and production, such as data envelopment analysis approach or stochastic frontier analysis, whereas our study is less dependent on such assumptions (such as for fixed costs) (Alvarez et al., 2008, van der Voort et al., 2017), and is more empirical and descriptive. For example, the study of Aghamohammadi et al. (2018) used a questionnaire and the study of Geary et al. (2012) was based on simulation modelling. One consideration is that although the present study might be considered basic for being an association study (BTSCC and efficiency), our results strongly suggest that better management measures should be adopted to reduce BTSCC, particularly in developing countries such as Brazil. We recognize the fact that the usage of panel modeling would have allowed for the control of the effects of unobserved farm level heterogeneity. Moreover, in reviewing the literature with the attempt of justifying adoption of management practices, Dono et al. (2013) conclude that management is a major factor, rather than structural factors *per se*, and that there are major differences amongst farms for productivity. Similarly, Dillon et al. (2015) looking at Irish dairy herds concluded that farmer behavior is as important as physical/structural factors (again, in line with our results), and both of these authors suggest that training and advise to producers is needed to improve productivity via technical skills.

Given the potential for improved profitability arising from BTSCC reduction, we observed that a small milk producer (herds < 39 lactating cows < 14 kg/d, subsistence farming) is mainly the group of farmers that requires careful attention because in all evaluated situations they presented negative profits which means no longer being in production in a short period of time. In this context, the high level of intensification or specialization of a farm has been positively associated with better management practices, in terms of displaying lower herd-level SCC (Alvarez et al., 2008, Dillon et al., 2015). The study of Dillon et al (2015) looked at management interventions, which were not recorded in this retrospective on-farm study. However, the between-herd variance as a proportion of the total phenotypic variance (data not shown), resulted in a high repeatability (60% to 70%) for all the traits. This means that there are large differences amongst herds, even after adjusting for the various fixed effects (region, herd size, etc); which differences one could reasonable presume to be due to differences in management (ie. 'interventions', all be it unknown what exactly they are). Overall, elevated BTSCC is associated with a large amount of milk losses without a perception of losing, demanding the same fixed costs to keep a cow producing milk (Hogeveen et al., 2019). Nonetheless, farmers have more difficulties in understanding that the direct losses represented by milk disposal, cow culling and antibiotics are less important than the reduction in potential of milk production, which has a large weight on the economic impact of mastitis (Guimarães et al., 2017).

As better farmers might have both a higher milk production as well as a lower level of diseases, the higher milk production might have only partly been explained by the disease. In other words, we can not be sure in some specific cases whether the association between BTSCC and gross margin might be due to the udder health problems or due to some kind of confounding effect; this has to be considered as a limitation. Therefore, we strongly advice further studies which might employ difference-in-difference methods or other panel-data methods. However, if we look at the Brazilian study (Gonçalves et al., 2018) (all be it with higher producing cows, from the State of Paraná – Brazil), this cow level test-day study reported effects of log SCC which are broadly in line with the present herd level study. The test-day study from Gonçalves et al. (2018) reported milk losses of 2-3 kg/day per unit Log SCC. When we translate 641L per lactation losses per unit of Ln BTSCC found in this study, to a daily basis (641L / 305 days lactation = 2.1 L/day) we see daily losses approximately of 2.1 L/day. We therefore conclude that these herd-level results reported here are indeed realistic.

Preventive measures are very difficult to separate between clinical and subclinical mastitis forms, since many of these measures (e.g. pre- and post-milking teat disinfection, use of gloves for milking, dry cow therapy, and mastitis vaccination) are targeting both forms of the disease (Aghamohammadi et al., 2018). However, BTSCC represents more than only subclinical mastitis. It is definitely not a one-on-one correlation, but higher BTSCC is often associated with more clinical mastitis (dependent on the type of clinical mastitis). The lack of information about herds' clinical mastitis should be considered a limitation of this study. An interesting result was that medicine costs (inferred to be 80-90% directed to clinical mastitis treatment) was considered one of the four main evaluated costs; although there was no difference for various levels of BTSCC. Our results showed that when BTSCC increased, total costs decreased, in contrast to results observed by Geary et al. (2012); based on these results of total costs (given that medicine costs did not vary across BTSCC levels), we might infer that herds with better udder health status (BTSCC = 100×10^3 cells/mL) invested proportionally more in concentrate and forage costs than herds with elevated BTSCC.

The economic impact of disease on livestock animals should take into account not only the economic aspect, but also the social and environmental aspects related to production and increased costs in disease control (Rushton and Bruce, 2017). Although in the present study no evaluation of social and environmental aspects related to EEI was performed, we venture the possibility that a great majority of Brazilian farmers have a strong cultural aspect influencing their decision making and they would possibly adopt mastitis control measures if perhaps economically convinced. Therefore, similar to what was found by Dillon et al. (2015), the present results suggest the potential productivity and profitability gains associated with reducing BTSCC across herds, which in turn would improve the efficiency and the sustainability of dairy farms (Alvarez et al., 2008).

CONCLUSION

The lower the BTSCC, the greater the revenue, gross and net margins, and profit of the dairy herds. The reduction of milk yield was the main factor associated with higher BTSCC.

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Table 1. Descriptive means of data records of herd-years ($n = 543$ unique herds), for various economic characteristics and milk quality traits, grouped by bulk tank somatic cell count (BTSCC) levels

SCC ($\times 10^3$ cells/mL) groups	≤ 200		> 200 and ≤ 400		> 400 and ≤ 500		> 500 and ≤ 750		> 750	
Number of herds	57		398		152		263		182	
Data records of herds										
Area used for livestock (ha)	89.7	(149.7)[1]	88.7	(90.6)	114.1	(128.9)	98.3	(95.4)	89.2	(73.3)
Lactating cows (heads/month)	73.5	(58.2)	80.2	(70.6)	96.5	(100.5)	81.1	(64.0)	77.3	(53.0)
Total cows (heads/month)	89.7	(71.7)	99.2	(88.6)	119.1	(120.1)	102.8	(80.2)	98.7	(66.4)
Lactating cows/total cows (%)	82.1	(6.6)	81.0	(6.8)	80.2	(7.0)	79.1	(7.1)	78.4	(7.9)
Production/lactating cows (L/d)	20.5	(6.2)	18.0	(4.5)	17.4	(4.0)	15.8	(3.3)	15.1	(3.3)
Production/farm (L/d)	1,577.7	(1,502.1)	1,553.5	(1,618.9)	1,762.8	(1,966.4)	1,324.9	(1,159.7)	1,211.4	(977.4)
Annual milk yield/farm (L/year)	575,848.3	(548,248.5)	567,010.6	(590,885.1)	643,418.9	(717,725.6)	483,598.8	(423,291.7)	442,155.6	(356,741.5)
Data records of milk quality										
Average SCC ($\times 10^3$ cells/mL)	163.0	(26.6)	300.2	(53.6)	446.7	(27.9)	600.5	(69.1)	1087.9	(319.9)
Average TBC[2] ($\times 10^3$ CFU/mL)	17.6	(22.5)	36.1	(56.5)	69.3	(227.4)	95.0	(202.8)	203.0	(332.2)
Average fat content (%)	3.7	(0.3)	3.7	(0.2)	3.7	(0.2)	3.8	(0.2)	3.8	(0.2)
Average protein content (%)	3.2	(0.1)	3.2	(0.1)	3.2	(0.1)	3.3	(0.1)	3.3	(0.1)

[1] Values in parentheses represent the standard deviation.

[2] Total bacteria count

Table 2. Numbers of herds in each region-year from Minas Gerais State, Brazil (total number of unique herds was 543)

Regions	Years		
	2015	2016	2017
1 – Centro	63 (52)[1]	79 (52)	94 (52)
2 – Jequitinhonha e Mucuri	4	4	4
3 – Noroeste	18 (13)	26 (13)	29 (13)
4 – Norte	0	1	1
5 – Rio Doce	12 (7)	13 (7)	16 (7)
6 – Sul	92 (78)	110 (78)	148 (78)
7 – Triângulo	84 (59)	113 (59)	139 (59)
8 – Zona da Mata	0	1	1
Total	273	347	432

[1] Numbers in brackets represents a sub-set of the data from those herds which had all 3 years of data collection and no missing values for the cost variables (e.g. medicine, forage, concentrate and labor).

Table 3. Least squares means of various costs, economic efficiency and production indicators

Item	Number of herds	Revenue (US$/cow.year)			Gross margin (US$/cow.year)			Profit (US$/cow.year)			Milk yield (Kg/cow.year)			Feed cost[1] (US$/cow.year)		
Increase per unit of LnBTSCC[2]	-	-228.5		26.8	-155.6		31.8	-138.6		33.3	-640.9		91.5	-73.2		20.4
Production level (L/cow.d)																
< 14	65	1,652.2	C	37.7	286.8	C	40.8	-106.9	C	42.9	-[3]		-	827.2	C	26.6
≥ 14 and <19	151	2,049.1	B	32.9	446.5	B	33.5	20.8	B	35.3	-		-	1,008.3	B	22.2
≥ 19	74	2,584.6	A	41.1	601.9	A	45.0	144.5	A	47.3	-		-	1,253.9	A	29.3
Herd size (n° lactating cows)																
< 39	50	1,914.9	C	44.9	274.5	B	47.2	-224.1	C	49.6	5,560.1	C	171.8	1,012.8	B,C	31.1
≥ 39 and ≤ 64	68	2,066.3	B	38.6	462.1	A	41.1	20.1	B	43.2	5,866.4	B	149.0	976.8	C	26.9
> 64 and < 100	76	2,119.2	B	38.9	487.2	A	41.5	85.7	B	43.6	5,830.4	B,C	149.5	1,045.1	A,B	27.2
> 100	69	2,281.1	A	41.5	556.5	A	43.0	196.2	A	45.3	6,279.0	A	160.3	1,084.5	A	28.4

[1] Forage and concentrate costs

[2] Ln BTSCC = natural logarithm of BTSCC [e.g., BTSCC = 100 is equivalent to Ln BTSCC of 4.6 = 100 (×1,000) = 100,000 cells/mL].

[3] Data used to estimate EEI were analyzed using SAS PROC MIXED (SAS Inst. Inc., Cary NC), and the statistical model included the fixed effects of region, year, production level (omitted for the analysis of milk yield), herd size and the linear regression effect of Ln BTSCC, and the random effect of herd nested within region.

Table 4. Estimated costs and economic efficiency indicators (EEI) of herds, for various levels of bulk tank somatic cell count

Costs and economic indicators [1]	Levels of SCC ($\times 10^3$) cells/mL					Regression coefficient	SE	*P*
	100	200	400	500	750			
	4.6 [2]	5.3	6.0	6.2	6.6			
Variables in US$/cow.year								
Revenue	2,437.4	2,277.4	2,119.8	2,069.5	1,975.8	-228.5	26.8	<.0001
Dairy farm gross margin	677.9	569.0	461.7	427.5	363.7	-155.6	31.8	<.0001
Dairy farm net margin	410.0	313.2	217.7	187.3	130.5	-138.4	31.9	<.0001
Total profit	227.0	129.9	34.3	3.8	-53.1	-138.6	33.3	<.0001
Total cost of the dairy farm	2,184.9	2,134.9	2,085.7	2,070.0	2,040.7	-71.4	40.1	0.0758
Concentrate	819.9	786.8	754.2	743.8	724.4	-47.3	15.5	0.0024
Forage	317.3	299.8	282.5	277.0	266.7	-25.1	11.3	0.0273
Medicine	82.8	79.8	76.9	76.0	74.2	-4.2	3.7	0.2582
Labor	243.9	244.8	245.7	246.0	246.6	1.3	8.9	0.8816
Variables in liter/cow/lactation								
Milk yield	6,843.3	6,394.7	5,952.5	5,811.5	5,548.7	-640.9	91.5	<.0001
Variables in liter/day								
Break-even point	1,355.8	1,339.4	1,323.1	1,318.0	1,308.3	-23.5	48.6	0.6288
Variables in percent (%)								
Operational Profitability	14.3	10.9	7.4	6.4	4.3	-5.0	1.4	0.0003

[1] is a linear combination of solutions from the proc mixed model, providing L'β estimates.

[2] Ln BTSCC = natural logarithm of BTSCC [e.g., BTSCC = 100 is equivalent to Ln BTSCC of 4.6 = 100 (×1,000) = 100,000 cells/mL].

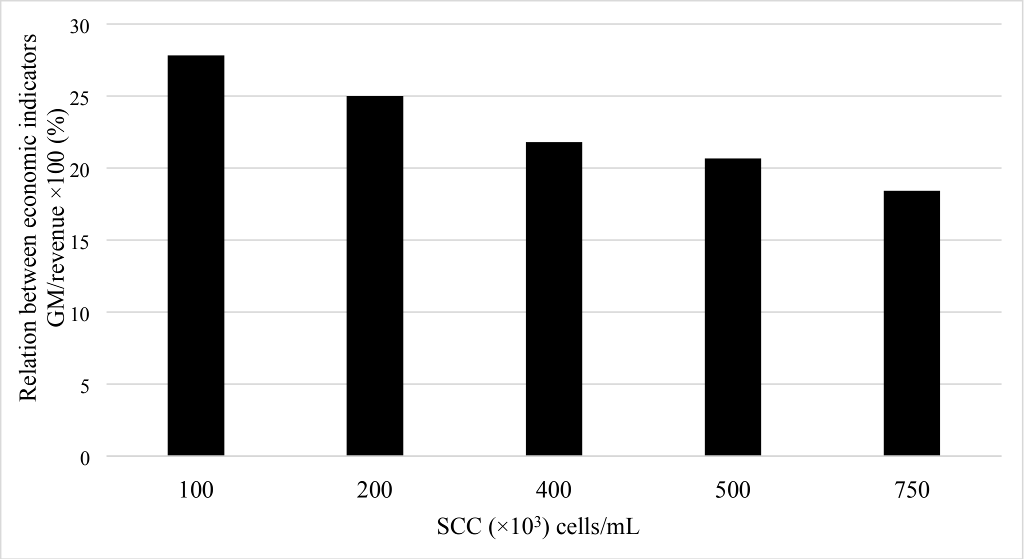

Figure 1. Relation between economic indicators distributed by levels of SCC (×10^3) cells/mL. GM is the gross margin [lsmeans GM/ lsmeans revenue ×100, in %; e.g. GM represented 27.4% of the revenue in herds with BTSCC of 100,000 cells/mL (GM US$ 667.9 / Revenue US$ 2,437.4; see Table 4)].

Supplementary material

Table S1. Specific items considered in the calculation of the effective operational costs and total operational cost (SEBRAE, person communication, 2015)

Items (description):
Effective Operational Cost – EOC
Herd management labor
Concentrates
Forage
Calf milk replacer
Minerals
Medication
Vaccines
Laboratory exams
Reproduction (insemination, oestrus synchronization)
Milk quality
Milking (material and maintenance)
Milk transport and deductions
Technical assistance expenses
Administrative expenses
Taxes and fees
General accessories and expenses
Machinery repair and improvements
Leasing/rent
Electricity and fuel
Total Operational Cost – TOC
EOC
Family labor
Depreciation - Improvements
Depreciation - Machinery and equipment
Depreciation - Service animals
Depreciation - Non-annual Fodder
Total Cost – TC
Remuneration of fixed capital (6% year) based on Improvements, Machinery and equipment, Animals and Non-annual Fodder