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# Development and application of a sustainability assessment model for dairy production systems

# Desenvolvimento e aplicação de modelo para avaliação de sustentabilidade em sistemas produtivos leiteiros

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## Abstract

In the present study, we aimed to develop and apply a model to evaluate the social, economic, and environmental sustainability of dairy production systems (DPS). In addition, we sought to analyze structural and production characteristics of DPS of different sustainability levels. Semi-structured questionnaires were used to collect structural and production data as well as information on sustainability actions taken by rural producers in 152 DPS located in Paraná, Brazil. The proposed model was applied to analyze the data. Each DPS received a score to represent its level of social, environmental, and economic sustainability, and DPS with similar sustainability levels were grouped according to these indicators using hierarchical cluster analysis. Three groups were formed: G1, comprising the largest proportion of DPS (63.8%); G2 comprising 20.4% of DPS; and G3, comprising 15.8% of DPS. The mean values of the sustainability indicators of each group were compared to those of other groups using analysis of variance (ANOVA) and Tukey's test. Subsequently, groups were analyzed in terms of structural and production characteristics. G2 was characterized by the highest levels of environmental, social, and economic sustainability. G1 had intermediate sustainability levels, and G3 achieved the worst results in the three sustainability indicators. The best sustainability performance of the three DPS groups was in the environmental dimension, followed by the economic dimension and lastly the social dimension. DPS with large-scale production and high productivity showed the highest sustainability indicators. The sustainability assessment model was suitable for DPS, having the advantages of being easy to apply, easy to interpret, and low cost.

**Key words**: Model. Evaluation. Sustainability. Multivariate analysis. Milk production. Paraná.

## Resumo

Buscou-se o desenvolvimento e aplicação de modelo para avaliação de sustentabilidade social, econômica e ambiental de sistemas produtivos leiteiros (SPL). Além disso, buscou-se analisar características estruturais e produtivas de sistemas leiteiros com diferentes níveis de sustentabilidade. Foram aplicados formulários semiestruturados para coleta de variáveis estruturais, produtivas e sobre as ações de sustentabilidade tomadas por produtores rurais de 152 sistemas leiteiros localizados no

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Estado do Paraná. As variáveis coletadas foram aplicadas ao modelo de sustentabilidade proposto. Como resultado do modelo, cada SPL recebeu um valor, indicativo do grau de sustentabilidade social, ambiental e econômica. A partir destes indicadores, foi aplicada técnica de formação de *clusters* hierárquicos, agrupando SPL com semelhantes graus de sustentabilidade. Os valores médios dos indicadores de sustentabilidade de cada grupo foram comparados entre si, a partir de Análise de Variância (ANOVA) e teste *Tukey*. Em seguida os grupos de SPL, já classificados quanto aos indicadores de sustentabilidade foram analisados frente a características estruturais e produtivas. Três grupos foram definidos, G1 concentrou a maior parcela, 63,8% dos sistemas leiteiros, seguido por G2, com 20,4% dos SPL e por G3, com 15,8% dos casos analisados. G2 foi definido por sistemas leiteiros com os melhores resultados de sustentabilidade ambiental, social e econômico. G1 apresentou resultados intermediários para os indicadores de sustentabilidade e G3 apresentou os piores resultados para os três indicadores de sustentabilidade. Para os três grupos de SPL analisados, a melhor adequação de sustentabilidade foi para o indicador ambiental, seguido pelo indicador econômico e pelo social. Pôde-se constatar que SPL com maior escala de produção e produtividade apresentaram os melhores indicadores de sustentabilidade. O modelo de avaliação de sustentabilidade de sistemas produtivos leiteiros mostrou-se adequado, sendo de fácil aplicação, interpretação e de baixo custo.

**Palavras-chave**: Modelo. Avaliação. Sustentabilidade. Análise multivariada. Produção de leite. Paraná.

## Introduction

Human activities are exerting increasing impacts on all ecological components and have been the cause of several socio-environmental problems (MENDONÇA, 2011; FEO; MACHADO, 2013; CARVALHO, 2015). Considering this issue, regulating bodies and the society as a whole have increased the pressure for sustainable means of food production (GRUNERT et al., 2014; SPECHT et al., 2014; BERRY et al., 2015).

The Brazilian food production sector stands out internationally as one of the largest producers and exporters of animal products, including milk, beef, pork, and chicken (TUBIELLO et al., 2014). Therefore, it follows that food production in Brazil can cause great environmental, economic, and social impacts.

Livestock production can have negative impacts on land and water resources as well as on biodiversity, contributing substantially to climate change and land pollution (STEINFELD et al., 2007). Emission of greenhouse gases from agriculture, forestry, and other land use activities has increased in recent years and is currently affecting ecosystems (TUBIELLO et al., 2014). Agricultural production is also associated with child labor and slave labor in several regions of the world (STROPASOLAS, 2012). These factors compromise the sustainability of agricultural systems in the medium and long term (BRASIL, 2010).

Brazil has become the fifth largest milk producer in the world (FAO, 2013). In 2015, more than 35 billion liters of milk were produced in the country (CNA, 2016). Dairy farms also have an important social role, employing 3.6 million people in about 1.8 million rural properties, 80% of which are family based (ALTAFIN et al., 2011).

Among other Brazilian states, Paraná excels in milk production. In 2015, 4.6 billion liters of milk were produced in Paraná (IBGE, 2015), where it is estimated that approximately 114.5 thousand rural producers have this activity as their main source of income (IPARDES, 2009). Dairy production systems in Paraná are highly heterogeneous. Small- and large-scale producers with different technological and productive capacities coexist in the sector (BRITO et al., 2015; YABE et al., 2015; NEUMANN et al., 2016; ZIMPEL et al., 2017). Half of the producers gain more than 50% of their income from milk production. Another important characteristic of many milk producers in Paraná is their advanced age and low schooling level (IPARDES, 2009).

Dairy farming involves the interaction of different activities, which affects the cost of milk production and demands financial resources (ALMEIDA et al., 2011). In Paraná, the economic and social importance of livestock production, in addition to the environmental, economic, and social implications of the activity, emphasizes the urgency for socio-environmental sustainability in these systems (IRIAS et al., 2004).

Several sustainability assessment models and indicators have been developed: ISO (International Organization for Standardization) standards (URSINI; SEKIGUCHI, 2005), the Rainforest Alliance Sustainable Agriculture Standard (BINI et al., 2015), organic certifications (SILVA; OLIVEIRA, 2014; ANACLETO; PALADINI, 2015), the Guide to Good Dairy Farming Practice (FAO/ IDF, 2013), among others (URSINI; SEKIGUCHI, 2005; FAO/ IDF, 2013; SILVA; OLIVEIRA, 2014; ANACLETO; PALADINI, 2015; BINI et al., 2015). However, because of their complexity and high implementation and control costs, most of these assessment models and indicators are not appropriate to the reality of dairy farms in Paraná.

We aimed to develop and apply a model to evaluate the social, economic, and environmental sustainability of dairy production systems in Paraná. In addition, we sought to analyze structural and production characteristics of systems with different sustainability levels.

## Materials and Methods

Semi-structured questionnaires were applied in 152 dairy production systems (DPS) located in the three main regions of Paraná (West, Southwest, and Central North). These regions were chosen because of their representativeness of the total milk production of the state (IBGE, 2015) and because of their easier access to the research team. Dairy production systems were randomly chosen from a list provided by production cooperatives and public technical assistance agencies (BRITO et al., 2015; YABE et al., 2015).

Information on structural variables (total farm area, milk production, number of cows, and number of lactating cows) and production variables (milk productivity per cow and milk productivity per area) was collected. These metric data were analyzed using descriptive statistics (mean, maximum, and minimum values) for general characterization of the sample and for comparison between DPS of different sustainability levels. In addition, a set of questions were aimed at investigating the actions taken by rural producers regarding environmental, economic, and social sustainability aspects. The producer was asked to assign a score (PS, producer score) from 0.0 to 10.0 on a continuous Likert scale (LIKERT, 1932) for each sustainability question. A score of 0.0 indicates that no action was taken by the producer toward sustainability, and a score of 10.0 indicates that the best possible action was taken.

A multidisciplinary team of five researchers assigned an importance weight (IW) from 0.0 to 10.0 for each sustainability variable (SILVA; BATALHA, 1999). Important variables were considered those required by law and were assigned an IW of 10. The other variables were rated according to their environmental, economic, and social impacts, based on the researchers' judgments. For operationalization of indicators, the most important variables within each sustainability dimension should be identified and should be assigned different weights (TAYRA; RIBEIRO, 2006).

The variables that composed each indicator (environmental, economic, and social indicators) were weighed in order to balance their relative contribution (ELKINGTON, 1997). Then, the IW of each variable was multiplied by the score attributed by the producer (PS), resulting in environmental, economic, and social sustainability indicators (Tables 1, 2, and 3).

The mean values of environmental, economic, and social sustainability indicators (SI) of each DPS were calculated. These values were classified using agglomerative hierarchical cluster analysis. The aim was to aggregate DPS with similar characteristics in the three dimensions of sustainability. Cluster analysis is an interdependence technique used to group variables according to their similarities. The result is the formation of groups composed of similar internal elements that differ greatly from those of other groups (HAIR JÚNIOR et al., 2009).

**Table 1.** Environmental variables.

<table>
<tr><th>Environmental variable</th><th>PS</th><th>IW</th><th>ESI</th></tr>
<tr><td>Conformity with permanent preservation area laws</td><td rowspan="22">0 to 10</td><td rowspan="22">0 to 10</td><td rowspan="22">ESI = PS × IW</td></tr>
<tr><td>Conformity of riparian forests</td></tr>
<tr><td>Conformity of springs with the new Forest Code</td></tr>
<tr><td>Conformity with legal reserve area laws</td></tr>
<tr><td>Legal and registered property</td></tr>
<tr><td>Disposal of pesticide containers</td></tr>
<tr><td>Disposal of animal waste</td></tr>
<tr><td>Disposal of animal carcass and production waste</td></tr>
<tr><td>Water allocation</td></tr>
<tr><td>Frequency of pasture and vegetation burning</td></tr>
<tr><td>Importance of environmental preservation for dairy production</td></tr>
<tr><td>Registered in the Rural Environmental Registry</td></tr>
<tr><td>Disposal of drug packaging</td></tr>
<tr><td>Knowledge of the new Forest Code</td></tr>
<tr><td>Water resource conservation</td></tr>
<tr><td>Fertilization with organic waste</td></tr>
<tr><td>Visual appearance of pastures</td></tr>
<tr><td>Visual appearance of soils</td></tr>
<tr><td>Preservation of native flora and fauna</td></tr>
<tr><td>Disposal of common waste</td></tr>
<tr><td>Feed management</td></tr>
<tr><td>Chemical fertilization</td></tr>
</table>

PS: Score attributed by the rural producer to the actions taken toward sustainability; IW: importance weight; ESI: environmental sustainability indicator.

**Table 2.** Economic variables.

| Economic variable | PS | IW | ESI |
|---|---|---|---|
| Milk composition<br>Compulsory vaccination<br>Knowledge of Normative Instruction no. 62<br>Financial management<br>Individual files for animals<br>Management of individual milk production<br>Average calving interval<br>Genetic merit for milk production<br>Calf mortality rate<br>Amount of milk returned by the dairy industry<br>Access to technical assistance<br>Frequently participates in training/courses on milk production<br>Adoption of good milking practices<br>Participation in cooperatives that help improve milk production | 0 to 10 | 0 to 10 | ESI = PS × IW |

PS: Score attributed by the rural producer to the actions taken toward sustainability; IW: importance weight; ESI: economic sustainability indicator.

After clustering, the mean SI values of each group were compared using analysis of variance (ANOVA). Significant differences between means were determined using Tukey's test. Thus, groups were analyzed in terms of their SI.

Finally, ANOVA and Tukey's test were applied to compare structural and production characteristics between groups. With this procedure, it was possible to infer possible relationships between SI and characteristics of the analyzed DPS.

**Table 3.** Social variables.

| Social variable | PS | IW | SSI |
|---|---|---|---|
| Conformity with work regulations<br>Provides workers with one day off per week<br>Annual paid leave of 30 days<br>Non-use of child labor<br>Individual protection equipment<br>Planning of future activities<br>Daily hours of work<br>Satisfaction with the milk activity<br>Planning for family succession in the activity<br>Risks of work accidents<br>Facilities for animal welfare<br>Facilities for employee welfare<br>Incentives for reading, studying, and participating in courses<br>Frequency of participation in meetings associated with milk production<br>Access to information on milk production<br>Type of milking system<br>Ergonomic aspects of facilities and equipment<br>Level of schooling of employees | 0 to 10 | 0 to 10 | SSI = PS × IW |

PS: Score attributed by the rural producer to the actions taken toward sustainability; IW: importance weight; SSI: social sustainability indicator.

## Results and Discussion

Dairy production systems had an average of 48 hectares, 42.2 dairy cows, and produced an average of 322.15 liters of milk per day (Table 4). The heterogeneity observed in these DPS is consistent with the findings of other studies carried out in Paraná (IPARDES, 2009; BRITO et al., 2015; YABE et al., 2015; NEUMANN et al., 2016; ZIMPEL et al., 2017).

**Table 4.** General characteristics of the dairy production systems.

| Variable | N | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|---|
| Total area (ha) | 152 | 0.60 | 1,331.00 | 47.95 | 163.43 |
| Milk production (L $day^{-1}$) | 152 | 20.00 | 2,000.00 | 322.15 | 317.36 |
| Number of cows (n) | 152 | 5.00 | 180.00 | 42.26 | 29.85 |
| Number of lactating cows (n) | 152 | 3.00 | 72.00 | 22.07 | 14.37 |
| Milk productivity per cow (L $cow^{-1}$ $day^{-1}$) | 152 | 2.00 | 30.00 | 13.52 | 6.27 |
| Milk productivity per area (L $ha^{-1}$ $day^{-1}$) | 152 | 0.86 | 134.00 | 28.98 | 27.17 |

The majority (78.9%) of milk producers relied on a second source of income. This indicates that producers had the need for extra income, which is a typical situation in small-scale farms, as has been discussed in other studies (IPARDES, 2009; BRITO et al., 2015; YABE et al., 2015; LANGE et al., 2016; ZIMPEL et al., 2017).

Mechanical milking was performed in 84.9% of the DPS, a similar percentage to the reported in other studies carried out in Paraná (IPARDES, 2009; ZIMPEL et al., 2017). The high proportion of DPS that used mechanical milking equipment indicates that investments in production technologies were common, even among small-scale farmers. Mechanization increases process speed and improves product safety and quality, which can result in higher financial profitability (VIANA; RINALDI, 2010; SCHMITZ; SANTOS, 2013). Milk producers who adopt more technological approaches tend to produce milk of higher quality and at a lower cost and can be paid more for the liter of milk by the industry (OLIVEIRA et al., 2013; PINTO et al., 2014; PEIXOTO et al., 2016).

*Sustainability assessment model*

The method comprised three major steps. The first step was the application of the semi-structured questionnaire, in which producers assigned a score for each action taken toward sustainability. We elaborated the questions having in mind the reality of DPS in Paraná. During the interviews, no questions considered "not applicable" or difficult to answer were made, for example, precise measurements or equipment and technologies that are not used by milk producers in Paraná. In addition, the Likert scale with scores ranging from 0.0 to 10.0 (LIKERT, 1932; SCHLECHT; SPILLER, 2012; POPPENBORG; KOELLNER, 2013; VEIGA NETO et al., 2014; WAYMAN et al., 2017) was easily comprehended by producers.

The second step involved the attribution of IW for each sustainability variable by a team of researchers. This step yielded satisfactory results. The maximum weight (10) was attributed to variables associated with legal requirements, and relative weights were attributed to the other variables. This action resulted in consistent values and rendered easy consensus among researchers (SILVA; BATALHA, 1999; SCALETSKY, 2010; SANTOS, 2015). The variables legal and registered property, water allocation, milk composition, compulsory vaccination, conformity with work regulations, and non-use of child labor received IW of 10.0 because these are legal requirements. On the other hand, the variables disposal of drug packaging, financial management, and daily work hours are not compulsory but are of great importance; thus, they received IW of 9.0. The variables feed management, adoption of good milking practices, and level of schooling of employees, received a lower IW, 5.0, 7.0, and 7.0, respectively, as they have a lower impact on sustainability (Tables 5, 6, and 7). It is important to note that no variable received an IW lower than 5.0 because all variables were selected for their importance in the assessment of sustainability.

The third and final stage of the model, development of SI, was also deemed adequate, easy to apply, and easy to interpret.

**Table 5.** Importance weight of environmental variables.

| Environmental variable | Importance weight |
|---|---|
| Conformity with permanent preservation area laws | 10.0 |
| Conformity of riparian forests | 10.0 |
| Conformity of springs with the new Forest Code | 10.0 |
| Conformity with legal reserve area laws | 10.0 |
| Legal and registered property | 10.0 |
| Disposal of pesticide containers | 10.0 |
| Disposal of animal waste | 10.0 |
| Disposal of animal carcass and production waste | 10.0 |
| Water allocation | 10.0 |
| Frequency of pasture and vegetation burning | 10.0 |
| Importance of environmental preservation for milk production | 9.0 |
| Registered in the Rural Environmental Registry | 9.0 |
| Disposal of drug packaging | 9.0 |
| Knowledge of the new Forest Code | 8.0 |
| Water resource conservation | 8.0 |
| Fertilization with organic waste | 8.0 |
| Visual appearance of pastures | 8.0 |
| Visual appearance of soils | 8.0 |
| Preservation of native flora and fauna | 7.0 |
| Disposal of common waste | 7.0 |
| Feed management | 5.0 |
| Chemical fertilization | 5.0 |

**Table 6.** Importance weight of economic variables.

| Economic variable | Importance weight |
|---|---|
| Milk composition | 10.0 |
| Compulsory vaccination | 10.0 |
| Knowledge of Normative Instruction no. 62 | 9.0 |
| Financial management | 9.0 |
| Individual files for animals | 9.0 |
| Management of individual milk production | 8.0 |
| Average calving interval | 8.0 |
| Genetic merit for milk production | 8.0 |
| Calf mortality rate | 8.0 |
| Amount of milk returned by the dairy industry | 8.0 |
| Access to technical assistance | 8.0 |
| Frequently participates in training/courses on milk production | 8.0 |
| Adoption of good milking practices | 7.0 |
| Participation in cooperatives that help improve milk production | 7.0 |

**Table 7.** Importance weight of social variables.

| Social variable | Importance weight |
|---|---|
| Conformity with work regulations | 10.0 |
| Provides workers with one day off per week | 10.0 |
| Annual paid leave of 30 days | 10.0 |
| Non-use of child labor | 10.0 |
| Individual protection equipment | 10.0 |
| Planning of future activities | 9.0 |
| Daily hours of work | 9.0 |
| Satisfaction with the milk activity | 9.0 |
| Planning for family succession in the activity | 9.0 |
| Risks of work accidents | 9.0 |
| Facilities for animal welfare | 8.0 |
| Facilities for employee welfare | 8.0 |
| Incentives for reading, studying, and participating in courses | 8.0 |
| Frequency of participation in meetings associated with milk production | 8.0 |
| Access to information on milk production | 8.0 |
| Type of milking system | 8.0 |
| Ergonomic aspects of facilities and equipment | 8.0 |
| Level of schooling of employees | 7.0 |

*Application of the sustainability assessment model*

The sustainability assessment model was applied to the data collected from the 152 DPS located in the West, Southwest, and North Central regions of Paraná.

Environmental, economic, and social SI were used as input variables for hierarchical clustering, which resulted in three DPS groups.

Group 1 contained the largest number of DPS, 97 (63.8%), followed by Group 2, with 31 DPS (20.4%), and Group 3, with 24 DPS (15.8%). Graphically (Figures 1 and 2), it is clear that the groups were completely segregated.

**Figure 1.** Milk production systems: environmental and economic sustainability indicators.

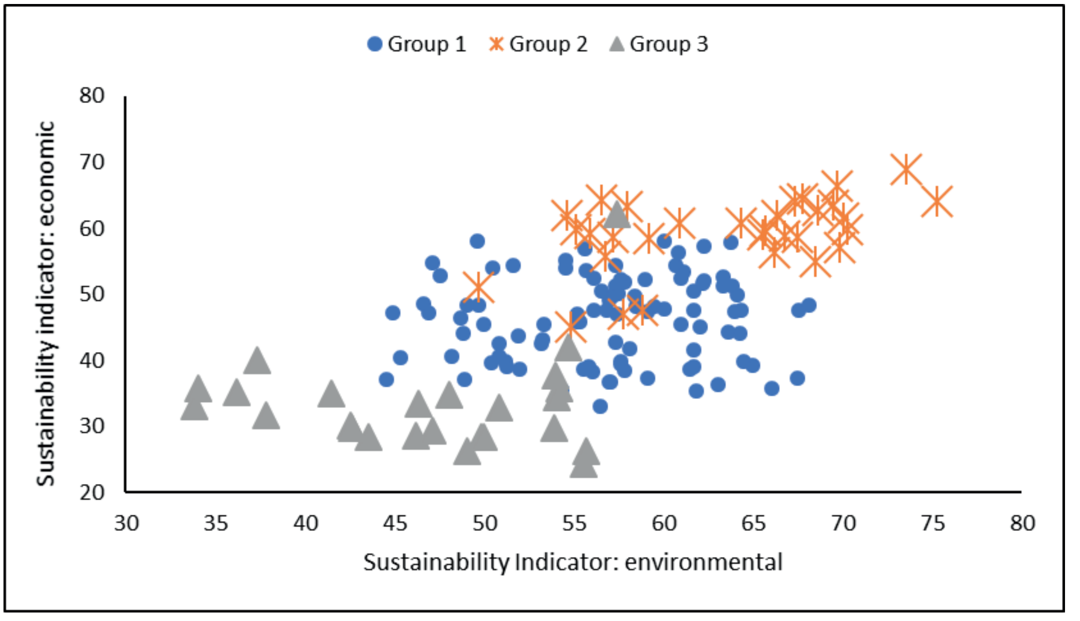
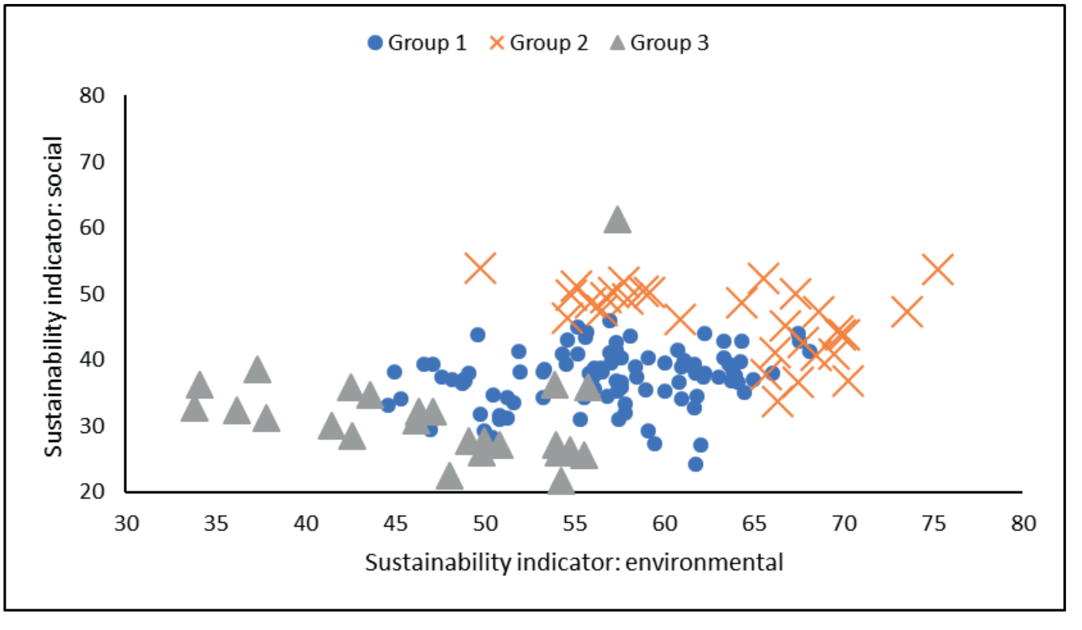



**Figure 2.** Milk production systems: environmental and social sustainability indicators.




Mean SI values differed significantly among groups ($p < 0.05$) (Table 8). This result confirms the good suitability of the method for defining groups according to SI.

**Table 8.** Mean sustainability indicator values of each group.

| Sustainability indicator | Group | N (%) | Mean | Standard deviation |
|---|---|---|---|---|
| Environmental | 1 | 97 (63.8%) | 56.92b | 5.66 |
| | 2 | 31 (20.4%) | 63.48a | 6.55 |
| | 3 | 24 (15.8%) | 46.63c | 7.09 |
| Economic | 1 | 97 (63.8%) | 46.20b | 6.39 |
| | 2 | 31 (20.4%) | 59.20a | 5.51 |
| | 3 | 24 (15.8%) | 32.12c | 4.45 |
| Social | 1 | 97 (63.8%) | 37.26b | 4.35 |
| | 2 | 31 (20.4%) | 46.17a | 5.29 |
| | 3 | 24 (15.8%) | 30.21c | 4.59 |

[a,b,c] Means followed by different letters within the same sustainability dimension differ significantly by Tukey's test ($p < 0.05$).

Group 1 (G1) had intermediate environmental (56.92), economic (46.20), and social (37.26) SI compared to the other groups. Group 2 (G2) had the best mean SI results: environmental SI of 63.48, economic SI of 59.20, and social SI of 46.17. Group 3 (G3) was formed by DPS with the worst environmental (46.63), economic (32.12) and social (30.21) SI.

Social SI had the lowest values in all groups, followed by economic SI and environmental SI (Table 2). In recent years, the concept of sustainability has been widely disseminated, which explains why the environmental suitability of DPS stood out from the other dimensions of sustainability. Producers have sought conformity with institutional regulations. Furthermore, consumers are increasingly demanding products with a proven history of sustainable production (REMPEL et al., 2012). The environmental sustainability of an DPS is an important factor, especially for small-scale production systems (REMPEL et al., 2012; MARTINS et al., 2014, 2015).

On the basis of these results, we consider that the proposed model is adequate for assessing sustainability in DPS.

Regarding production and structural characteristics, groups differed ($p < 0.05$) in terms of the number of lactating cows, milk productivity per cow, and milk productivity per area. Groups also differed ($p < 0.10$) in milk production and number of cows (Table 9).

G2, which was the most sustainable of the three groups (Table 8), was characterized by higher milk production, larger number of cows ($P < 0.10$) and lactating cows, higher milk productivity per cow, and higher milk productivity per area ($P < 0.05$) (Table 9). These results indicate that there is a relationship between production scale, productivity, and socio-environmental sustainability in DPS, as demonstrated in other studies (CROSSON et al., 2011; BELFLOWER et al., 2012; PENATI et al., 2013; BATTINI et al., 2016).

Despite some controversies (BAVA et al., 2014; SALOU et al., 2017), the results of G2 demonstrate that rural production associated with increased animal performance causes lower environmental impact. This result was also reported by other researchers (CROSSON et al., 2011; BELFLOWER et al., 2012; PENATI et al., 2013; BATTINI et al., 2016; HESSLE et al., 2017). The better management of resources made by G2 resulted in more environmentally sustainable production, in agreement with the findings of Urdiales et al. (2016).

**Table 9.** Structural and production characteristics of milk production systems.

| Variable | Group | N | Mean | Standard deviation | Min. | Max. |
|---|---|---|---|---|---|---|
| Total area (ha) | 1 | 97 | 35.06a | 135.30 | 0.60 | 1.331.00 |
| | 2 | 31 | 80.11a | 212.59 | 3.63 | 1.162.00 |
| | 3 | 24 | 58.49a | 194.37 | 2.42 | 968.00 |
| Milk production (L $day^{-1}$) | 1 | 97 | 275.46b | 238.73 | 40.00 | 1.430.00 |
| | 2 | 31 | 648.06a | 398.35 | 100.00 | 2.000.00 |
| | 3 | 24 | 89.91c* | 88.13 | 20.00 | 350.00 |
| Number of cows (n) | 1 | 97 | 40.12b | 24.19 | 5.00 | 120.00 |
| | 2 | 31 | 64.77a | 40.07 | 18.00 | 180.00 |
| | 3 | 24 | 21.87c* | 13.38 | 7.00 | 70.00 |
| Number of lactating cows (n) | 1 | 97 | 21.09b | 12.55 | 4.00 | 72.00 |
| | 2 | 31 | 34.35a | 15.50 | 13.00 | 70.00 |
| | 3 | 24 | 10.16c | 5.46 | 3.00 | 24.00 |
| Milk productivity per cow (L $cow^{-1}$ $day^{-1}$) | 1 | 97 | 13.02b | 5.92 | 3.00 | 29.00 |
| | 2 | 31 | 18.56a | 5.07 | 8.00 | 30.00 |
| | 3 | 24 | 9.04c | 4.65 | 2.00 | 17.00 |
| Milk productivity per area (L $ha^{-1}$ $day^{-1}$) | 1 | 97 | 27.58b | 25.64 | 1.48 | 134.00 |
| | 2 | 31 | 46.47a | 30.21 | 6.90 | 125.00 |
| | 3 | 24 | 12.05c | 13.90 | 0.86 | 41.00 |

[a,b,c] Means of the same variable followed by different letters differ by Tukey's test at $p < 0.05$. * Means of the same variable followed by an asterisk differ by Tukey's test at $p < 0.10$.

Regarding the economic indicator, the better performance of G2 is directly associated with larger scale of production and higher productivity. These factors can lower production costs per liter of milk, giving rural producers better profit margins, which may also lead to better sale prices (OLIVEIRA et al., 2013; PINTO et al., 2014; PEIXOTO et al., 2016). Better economic performance can mean financial investments in technical assistance, training, access to information, and production technologies, increasing not only the possibility of higher income but also the quality of life of rural producers and the shifting toward sustainability (CASTANHEIRA et al., 2010; BORGES et al., 2011; LAMARCA et al., 2015; TARGANSKI et al., 2017).

The larger scale of production and higher productivity of G2 might be a consequence of their greater professionalization and higher percentage of hired workers compared to family workers, as observed by Redin (2015). Rural producers who hire workers must comply with the legal requirements of Brazilian work regulations (SOUZA et al., 2013; MARTINS et al., 2015), such as the non-use of child labor and providing workers with a weekly day-off and annual leave (BÁNKUTI et al., 2018).

G1, which comprised the highest percentage (63.8%) of DPS, had an intermediate performance in sustainability (Table 8) and structural and production variables (Table 9). That is, the majority of the analyzed DPS had average production and productivity as well as average environmental, economic, and social sustainability. G1 rural producers must commit to improving the sustainability of their farms. Efficient use of resources is a pre-requisite to achieving sustainability (BATALHA et al., 2005).

Dairy production systems sustainability can be improved with investments in technical training and in aspects associated with environmental and social sustainability. Participation in associations and production cooperatives as well as greater integration with other agents of the production system, such as the dairy industry, are important strategies to improve environmental, economic, and social SI (BATALHA et al., 2005; BÁNKUTI et al., 2014).

G3, composed of DPS with the worst sustainability results (Table 8), was characterized by low milk production, few cows ($P < 0.10$) and lactating cows, low milk productivity per animal, and low milk productivity per area ($P < 0.05$) in comparison with the other groups (Table 9). These results indicate that G3 have low chances of survival in the medium and long term, as they are not aligned with institutional and market demands and have low economic capacity. The survival of DPS in the activity will depend on managerial and technological innovations (MARTINS et al., 2014). Transition toward more sustainable technological alternatives is inevitable and should comprise the intelligent use of environmental resources, the search for economic results, and compliance with social obligations (MARTINS et al., 2015). We suggest that G3 producers undertake actions that will lead to changes in sustainability. SI should be reinforced by research, extension, and technical assistance agents and implemented through programs of good management practices and use of environmentally friendly technologies (MARION; SEGATTI, 2006; MARTINS et al., 2015). Sustainability is an important part of the producer's strategy to remain competitive in the long term, promoting quality of life for both milk producers and consumers (MARTINS et al., 2015, HESSLE et al., 2017).

## Conclusions

The development of a sustainability assessment model and SI for evaluating DPS was achieved successfully. The model proved to be useful, easy to apply, and easy to interpret. We suggest that more variables be added for future work, thereby making the model more complete and adapted to possible changes in institutional and market demands of sustainability for DPS.

The analyzed DPS had better performance in the environmental dimension of sustainability, followed by economic and social dimensions. Dairy production systems with larger production scale and higher productivity showed the best SI. We suggest, as public and private strategies, the definition of actions aimed at increasing production scale and productivity in DPS as well as actions that promote greater access to information and training so that rural producers can make low-risk decisions to achieve social, economic, and environmental sustainability.

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