p-ISSN 2615-787X e-ISSN 2615-790X
Accredited by Directorate General of Strengthening for Research and Development No: 30/E/KPT/2018

Tropical Animal Science Journal, June 2022, 45(2):239-246
DOI: https://doi.org/10.5398/tasj.2022.45.2.239
Available online at http://journal.ipb.ac.id/index.php/tasj

Inseparability of Dairy Farming Technologies and Their Impacts on Milk Production Systems in Brazil

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(Received 20-03-2021; Revised 14-05-2021; Accepted 08-06-2021)

ABSTRACT

Several studies have analyzed the impact of one technology on the productive performance of dairy systems. However, analyses that consider the impact of joint technologies are scarce. This study was aimed to analyze the inseparability of a set of technologies and their impacts on dairy farm performance. Questionnaires were applied on-site with 155 dairy farmers in Paraná State, Brazil. We collected 17 technological variables related to milk production and variables related to dairy farms' production. Data analysis was performed in three steps: descriptive analysis, exploratory factor analysis (EFA), and multiple regression. Descriptive analysis was applied to characterize the sample, EFA was applied to generate factors related to the technological variables, and multiple regression was used to compare technological factors with productivity variables – farm performance. Four factors were defined: (i) Forage and farm structure, (ii) management, (iii) genetics, breeding strategies, and concentrate feeding, and (iv) animal health. The four factors significantly explained the differences in milk productivity between dairy farms. Technologies grouped under the factor of genetics were the most important in explaining milk yield per lactating cow, land productivity, and dairy herd reproductive efficiency.

Keywords: dairy farm; factor analysis; farm survey; technology adoption

INTRODUCTION

At the beginning of the 1960s, the Green Revolution introduced the term "technological package" to denote a combination of several inseparable practices related to agricultural mechanization and the use of improved inputs, including seeds, pesticides, and fertilizers (Ameen & Raza, 2018; Evenson & Gollin, 2003). Although technology package components are generally interdependent, some can be adopted individually, providing farmers with many technology choices (Feder *et al.*, 1985). The sequential choice is an important strategy to overcome individual limitations without losing sight of the ultimate goal of improved technical and economic efficiency (Mann, 1977; Simões *et al.*, 2015). Scientific investigation of technology adoption and diffusion as an independent event is simpler than evaluating the adoption of a set of complementary technological packages. However, the independent analysis may provide a distorted view of reality, given that the experience of adopting a technology necessarily influences an individual's perception and ability to adopt another technology (Rogers, 2003). Most studies investigating the impact of technology adoption on agricultural production systems, such as dairy farms, used methodological approaches to isolate the individual effects of technology on system performance. Some examples of previously evaluated technologies include pasture irrigation, compost barns, and sexed semen (Black *et al.*, 2013; Ma *et al.*, 2019; McCullock *et al.*, 2013; Moraes *et al.*, 2015). Other studies applied techniques for grouping variables into factors or indicators to investigate, for instance, nutrition, genetics, and reproduction. However, associations between factors are almost always disregarded (Koerich *et al.*, 2019; Rangel *et al.*, 2020; Rauniyar & Goode, 1992; Rivas *et al.*, 2019), rendering the analysis less adequate to describe a scenario in which technology adoption depends on many factors that are inherent to production systems (Rogers, 2003).

Debate on adopting new technologies and their impacts on agricultural systems has been fundamental for sectoral development and promotion of public policies. Therefore, it becomes relevant to identify and recommend the main technological practices in agricultural production systems that have some degree of interdependence for the increased efficiency gains.

This topic is particularly relevant to dairy production systems in Brazil, as milk production is an essential source of income and employment in virtually all states.

In 2018, Brazil was the third-largest milk producer globally, with 33.8 billion liters produced, behind only the USA and India. However, the country's mean milk yield per cow (2 068 L/year) is still far short of that achieved by other, more-developed countries, such as the USA, members of the European Union, and New Zealand, where cows produce on average 10 400, 6 245, and 4 269 L/year, respectively (FAO, 2018). Therefore, the dairy sector has ample room for growth in Brazil as long as public policies and business strategies promote technology diffusion and consider technological interdependencies (Costa *et al.,* 2013; Janssen & Swinnen, 2017).

In this study, we start from the assumption that it is impossible to dissociate some of the technological dimensions of dairy production systems because certain technologies need to be implemented to promote productivity gains. This study was aimed to analyze the inseparability of a set of technologies and their impacts on dairy farm performance. To the best of our knowledge, no other study has carried out this type of analysis on milk production in Brazil. Within certain limits and considering system particularities, it may be possible to extrapolate the findings to other regional contexts and agricultural products.

METHODS

The study was approved by the Human Research Ethics Standing Committee of the State University of Maringá, Paraná, Brazil (protocol No. 3.961.092). The sample comprised 155 dairy farms located in North Central, Northwest, and Central West mesoregions of Paraná State, southern Brazil, similar to previous studies conducted in the state (Bánkuti *et al.,* 2020; Borges & Lansink, 2015; Gabbi *et al.*, 2013).

Paraná State is the second-largest milk producer in the country. In 2020, 3.4 billion liters of milk were produced, accounting for 14% of the national production (IBGE, 2021). There are 87,048 dairy farms and about 1.7 million lactating cows in Paraná. Milk production fulfills important economic and social functions, contributing to regional development and generating employment for nearly 87,048 families in the state (IBGE, 2018).

Milk production is typically carried out in pasture-based production systems. Paraná dairy farms differ in productivity, technological level, and animal genetics, among other characteristics (Yabe *et al.,* 2015; Bánkuti *et al.,* 2020; Casali *et al.,* 2020). In the regions analyzed in this study, small and medium-scale farms predominate, which produce up to 150 L/day/farm and 3,700 L/cow/year. Herds are generally formed by mixed breeds composed by Holstein, Jersey, and Gir, and cows are almost always milked by manual or mechanical bucket milking (Yabe *et al.*, 2015; Bánkuti *et al.*, 2020).

The first farmers interviewed were randomly selected from the initial list and asked to indicate other farmers to participate. Farmers who could not be located or contacted or were unwilling to participate in the study were excluded from the list.

The questionnaire included items on 17 variables related to dairy farming technologies, selected taking into account the main technological aspects of milk production (Fleming *et al.*, 2018; Rangel *et al.*, 2017; Rivas *et al.,* 2019; Simões *et al.,* 2019), and milk productivity variables, encompassing factors with a high impact on dairy farm profitability, such as land, herd, and workforce characteristics (Ferrazza *et al.,* 2020; Nascimento *et al.,* 2012) (Table 1).

Data analysis was performed in three steps: descriptive analysis, exploratory factor analysis (EFA), and multiple regression analysis. EFA was used to extract correlated variables (factors) representing different aspects of the same dimension (Hair *et al.*, 2018).

The EFA model was applied as follows (Equation 1):

$$\begin{aligned} X_1 &= a_{11} \times F_1 + a_{12} \times F_2 + \ldots + a_{1m} \times F_m + e_1 \\ X_2 &= a_{21} \times F_1 + a_{22} \times F_2 + \ldots + a_{1m} \times F_m + e_2 \\ &\vdots \\ X_p &= a_{p1} \times F_1 + a_{p2} \times F_2 + \ldots + a_{pm} \times F_m + e_p \end{aligned} \quad (1);$$

where X_p represents the p-th score of the standardized variable (p = 1, 2, ... m), F_{m} is the extracted factor, a_{pm} is the factor loading, and e_p is the error.

Factor scores for each case were estimated by multiplying standardized variables by the coefficient of the corresponding factor score (Equation 2):

$$\begin{aligned} F_1 &= d_{11} \times X_1 + d_{12} \times X_2 + \ldots + d_{12} \times X_3 \\ F_2 &= d_{21} \times X_1 + d_{22} \times X_2 + \ldots + d_{23} \times X_3 \\ &\vdots \\ F_j &= d_{j1} \times X_1 + d_{j2} \times X_2 + \ldots + d_{jp} \times X_p \end{aligned} \quad (2);$$

where F_j is the j-th factor extracted, d_{jp} is the factor score coefficient, and p is the number of variables (Hair *et al.*, 2018).

EFA was performed using a correlation matrix, and factors were extracted by principal component analysis with Varimax orthogonal rotation. The latent root criterion was used to determine the number of retained indicators (Hair *et al.*, 2018; Kaiser, 1960). Cross-loadings were used to measure factor validity and Cronbach's alpha as a measure of internal consistency. Sampling adequacy for EFA was assessed by Kaiser–Meyer–Olkin (KMO) and Bartlett's sphericity tests (Hair *et al.*, 2018).

Multiple regression was used to quantify the ability of extracted factors to explain differences in productive efficiency between dairy farms. Factor scores were used as independent regression variables and productivity indicators as dependent variables (Çamdevýren *et al.,* 2005; Koerich *et al.*, 2019). The enter method was applied to select factors for each model using the F-test at a significance level of 5%. Regression coefficients were tested using t-tests. The adjusted coefficient of determination (adjusted R^2) was used as the standard criterion of predictive potential, and the variance inflation factor (<4.0) was applied to determine the presence of multicollinearity among independent variables (Hair *et al.*, 2018). Statistical analyses were performed using Statistical Package for Social Sciences version 18 (IBM-SPSS®).

RESULTS

The farmers included in this study had a mean age of 48.80±13.02 years, 8.60±3.87 years of formal education, and 21.56±14.32 years of experience in dairy farming.

Table 1. Technological variables, response categories, and scores of the questionnaire used to interview dairy farmers, Paraná State, Brazil

Variables	Response category and scores
Bull and/or semen genetics	(1) Mixed breeds, (2) beef breeds, (3) cross breeds selected for milk production, (4) pure breeds
Breeding strategy	(1) Natural breeding, (2) natural breeding + artificial insemination, (3) artificial insemination, (4) artificial insemination + estrus synchronization, (5) embryo transfer
Cow genetics: Genetic composition of dairy cow herd	(1) Mixed breeds, (2) mixed + cross breeds, (3) cross breeds, (4) cross + pure breeds, (5) pure breeds
Ultrasound is used to diagnose pregnancy	(1) No, (2) yes
Main forage base	(1) Perennial grasses, (2) perennial + winter grasses, (3) perennial grasses + conserved forage, (4) conserved forage
Use of forage machinery	(1) No, (2) yes
Conserved forage	(1) Not used, (2) corn silage, (3) corn silage + hay, (4) corn silage + haylage
Amount of concentrate feeding to lactating cows (kg/day/head)	Numerical value
Feed lotting	(1) Not performed, cows are pasture-fed, (2) semi-feedlot, (3) feedlot
Cost control	Rated on a Likert scale[a]
Use of computational tools for cost control	(1) No, (2) yes
Animal health and performance control	Rated on a Likert scale[a]
Use of computational tools for animal health and performance control	(1) No, (2) yes
Vaccination against infectious bovine rhinotracheitis	(1) Not practiced, (2) partially/sometimes, (3) routinely performed
Vaccination against bovine viral diarrhea	(1) Not practiced, (2) partially/sometimes, (3) routinely performed
Vaccination against leptospirosis	(1) Not practiced, (2) partially/sometimes, (3) routinely performed
Vaccination against symptomatic carbuncle	(1) Not practiced, (2) partially/sometimes, (3) routinely performed

Note: [a]Five-point Likert scale, where 1= very poor, 2= poor, 3= moderate, 4= good, and 5= very good.

The mean farm size and milk production area were 28.62±41.03 ha and 18.47±21.50 ha, respectively. Farms produced 426.66±506.56 L/milk/day, with a milk yield per cow of 13.88±5.61 L/day. The mean numbers of lactating and total cows were 27.55±24.07 and 38.32±29.97, respectively, and the total herd size was 59.61±48.18 -included the bulls, heifers, and calves.

EFA revealed four orthogonal factors explaining 81% of the variance in the dataset. All variables had good factor loadings, with no cross-loadings. Cronbach's alpha values were greater than 0.70 for all items, except vaccination for carbuncle, which was excluded from the model because it did not meet the predefined criteria. Variables within a factor were internally correlated, and variables loading on different factors had little or no correlation with each other (Hair *et al.*, 2018). Bartlett's test ($p<0.0001$) and the KMO value (0.855) showed that the correlation matrix was significant and that the dataset was adequate for EFA.

Factors were similar with regard to the amount of variance explained (eigenvalues ≈ 3) and their contributions to explaining the total variance of the data (≈20%). Communalities were higher than the threshold (>0.50), indicating that the sample size was adequate for the factor model. Such communality values also indicate the high capacity of extracted factors to represent dairy farming technologies (Bánkuti *et al.*, 2020; Hair *et al.*, 2018). Based on the significant factor loadings (>0.60), we named factors 1 to 4 as forage and farm structure; management; genetics, breeding strategy, and concentrate feeding; and animal health, respectively (Table 2).

The forage and farm structure factor was composed of the variables forage base, forage machinery, conserved forage production, and feed lotting. The factor explained 22% of the variance in the dataset, and the mean communality of significant variables was 86% (Table 2). Items related to this factor allowed us to infer that production and supply of supplementary forage are correlated with the availability of related machinery and equipment and feed lotting.

The factor of management was composed of variables solely related to management practices. That is, they did not include practices associated with other technologies. Management was composed of cost control, cost control software, animal performance, and animal performance software, explaining 21% of the total variance, with a mean communality of 84%.

The factor of Genetics, breeding strategy, and concentrate feeding explained 19% of the total variance and comprised the following variables: pregnancy diagnosis by ultrasound, cow genetics, bull genetics, amount of concentrate feeding to lactating cows (purchased and/or produced on the farm), and breeding strategy. The mean communality of significant variables was 63% (Table 1).

The factor of animal health was composed of variables solely related to health practices, animal health comprised the variables vaccination against infectious bovine rhinotracheitis, bovine viral diarrhea, and leptospirosis, explaining 19% of the variance, with a mean communality of 99% (Table 2).

Table 2. Factor loadings, communalities, and other statistics for Varimax-rotated factors extracted by exploratory factor analysis

Variables	Factor				Communalities
	F1	F2	F3	F4	
Forage base	0.923	0.101	0.245	−0.002	0.923
Forage machinery	0.89	0.114	0.183	0.069	0.844
Conserved forage production	0.875	0.164	0.245	0.095	0.861
Feed lotting	0.847	0.164	0.271	0.067	0.822
Cost control	0.103	0.888	0.292	0.188	0.92
Cost control software	0.094	0.886	0.141	0.177	0.844
Animal performance control	0.186	0.837	0.294	0.233	0.876
Animal performance control software	0.194	0.781	0.109	0.221	0.708
Pregnancy diagnosis by ultrasound	0.189	0.107	0.754	0.113	0.629
Cow genetics	0.325	0.206	0.709	0.133	0.668
Bull and/or semen genetics	0.181	0.175	0.694	0.251	0.608
Amount of concentrate feeding to lactating cows	0.146	0.224	0.69	0.179	0.58
Breeding strategy	0.335	0.184	0.664	0.252	0.651
Vaccination against infectious bovine Rhinotracheitis	0.065	0.25	0.247	0.932	0.996
Vaccination against bovine viral diarrhea	0.074	0.251	0.239	0.931	0.993
Vaccination against leptospirosis	0.06	0.252	0.247	0.931	0.994
Statistics					
Eigenvalues	3.540	3.319	3.079	2.978	
% of Variance	22.12	20.74	19.24	18.61	
Cumulative %	22.12	42.86	62.1	80.72	
Cronbach's alpha	0.925	0.844	0.743	0.998	

Note: F1= Forage and farm structure; F2= Management; F3= Genetics, breeding strategy, and concentrate feeding; F4= Animal health.

Multiple linear regression allowed identifying the individual contribution of factors to milk performance parameters. The four factors were better at predicting (adjusted R^2) milk yield per lactating cow than land productivity, the ratio of lactating cows to total cows, or labor efficiency. Genetics, breeding strategy, and concentrate feeding had the highest standardized coefficient, indicating that this factor had a greater influence on milk yield per lactating cow, followed by management, animal health, and forage and farm structure (Table 3).

Three technology factors were significant in explaining land productivity (L/ha/year). The variable was most influenced by genetics, breeding strategy, and concentrate feeding, with a standardized coefficient of 0.403. The factors of forage and farm structure and management had lower coefficients, indicating that forage type and feeding system had little influence on land productivity determination. Animal health was not significant in explaining land productivity.

Three of the four factors were significant in predicting the ratio of lactating to total cows. Genetics, breeding strategy and concentrate feeding was the most significant factor, followed by animal health and management. Forage and farm structure was not significant

All coefficients were significant in explaining differences in labor efficiency. The factors of Genetics, breeding strategy, and concentrate feeding and management had similar standardized coefficients. Forage and farm structure and Animal health showed the lowest standardized coefficients (Table 3).

DISCUSSION

The EFA revealed four orthogonal factors: F1 was forage and farm structure; F2 was Management; F3 was genetics, breeding strategy, and concentrate feeding; and F4 was animal health. The four factors made similar contributions to explaining the total variance of the dataset and, consequently, the variability between dairy farms of the studied region. Previous studies have shown that similar technological aspects are important in distinguishing dairy farms in Brazil (Gabbi *et al.*, 2013; Neumann *et al.*, 2016; Simões *et al.*, 2017; Zimpel *et al.*, 2017) and other developing countries (García *et al.*, 2012; Janssen & Swinnen, 2017; Rangel *et al.*, 2020).

Two of the factors comprised technologies with distinct characteristics. Those related to genetic improvement and reproduction were grouped with feeding technologies under the factor of genetics, breeding strategy, and concentrate feeding. Forage production technologies were grouped with machinery and productive structure investments, constituting the factor of forage and farm structure. This confirms our initial assumption that it is impossible to dissociate some dairy production systems' technological aspects.

From a behavioral point of view, the experience of adopting a certain technology can influence an individual's perception about the need to adopt other technologies so that the technologies are deemed inseparable (Rogers, 2003). Our results agree with the interdependence of technologies associated with concentrate feeding productivity gains, such as genetically improved seeds, synthetic fertilizers, agricultural pesti-

Table 3. Parameters of multiple linear regression models describing milk productivity and technological variables of dairy farms in Paraná State, Brazil

Dependent variables	Independent variables	Unstandardized coefficients		Std. B. Coef.	p-value	Adj. R^2
		B	Std. error			
Milk yield per lactating cow (L/cow/day)	Constant	13.8	0.31		<0.01	0.502
	F1	0.9	0.31	0.168	<0.01	
	F2	1.2	0.31	0.220	<0.01	
	F3	3.5	0.31	0.629	<0.01	
	F4	1.1	0.31	0.209	<0.01	
Land productivity (1000L/ha/year)	Constant	10.84	0.73		<0.01	0.275
	F1	3.02	0.73	0.281	<0.01	
	F2	2.02	0.73	0.188	<0.01	
	F3	4.33	0.73	0.403	<0.01	
	F4	1.41	0.73	0.132	>0.05	
Ratio of lactating cows to total cows	Constant	0.7	0.01		<0.01	0.259
	F1	0.02	0.01	0.135	>0.05	
	F2	0.02	0.01	0.155	<0.01	
	F3	0.07	0.01	0.409	<0.01	
	F4	0.04	0.01	0.263	<0.01	
Labor efficiency (L/worker/day)	Constant	196	14.2		<0.01	0.231
	F1	44.9	14.3	0.222	<0.01	
	F2	57.3	14.3	0.283	<0.01	
	F3	57.7	14.3	0.285	<0.01	
	F4	40.8	14.3	0.202	<0.01	

Note: F1= Forage and farm structure; F2= Management; F3= Genetics, breeding strategy, and concentrate feeding; F4= Animal health.

cides, and mechanization, promoted during the Green Revolution. The lack of or inability to provide one of the technical elements necessary for optimal combination of technologies may hinder the achievement of expected gains, as was observed in some African countries where the assumptions of the Green Revolution have not been widely spread (Ameen & Raza, 2018).

The use of artificial insemination, estrus induction and synchronization strategies, and embryo transfer is known to promote genetic gains in dairy herds (Fleming *et al.*, 2018). Animals of high genetic value, in turn, have higher nutritional requirements (Kaniyamattam *et al.*, 2016). The high nutritional requirements of specialized dairy breeds must be met through the supply of foods with high nutritional value that increases dry matter intake, such as high-quality forage (Daniel *et al.*, 2019; Zardin *et al.*, 2017) or grain-based feed (Hills *et al.*, 2015). In our analysis, we considered nutrition technologies based on the production of corn silage as roughage and corn and soybean as concentrate.

Concentrate feeding was not associated with farm structure or specific equipment; however, Bernardes & Rêgo (2014) argued that production and supply of high-quality conserved forage are related to investments in these areas. Our results revealed the interrelation of structural and nutritional aspects. Farmers seeking to produce conserved forage, such as corn silage, require tractors and other agricultural equipment and tend to keep animals in confined structures such as free stalls and compost barns (Becker *et al.*, 2018; Black *et al.*, 2013; Daniel *et al.*, 2019).

The need for financial investments in infrastructure and machinery for roughage production may explain the inseparability of technologies. Feedlot systems require greater investments in infrastructure (Breitenbach, 2018), resulting in higher production costs (Kühl *et al.*, 2020). According to Bernardes & Rêgo (2014), one of the biggest obstacles to producing conserved forage in Brazil is the lack of access to equipment for planting and harvesting crops. Kühl *et al.* (2020) found that low-input dairy production systems from the mountainous regions of Italy must adopt feeding technologies and improve productive structures to achieve economic sustainability.

Intensification of production systems through investments in machinery and infrastructure has been associated with a shortage of skilled workers. According to Breitenbach (2018) and Bánkuti *et al.* (2018), feedlot systems are greatly used because of the lack of labor force, as it allows a high number of cows per worker and, in many cases, better working conditions and income. Similarly, Bernardes & Rêgo (2014) observed that the lack of skilled workers limits the production of conserved forage on Brazilian dairy farms.

Unlike our results, studies conducted in other countries showed that the supply of conserved forage and feedlot farming is associated with concentrate feeding and genetic parameters (Becker *et al.*, 2018; Kühl *et al.*, 2020). Gabbi *et al.* (Gabbi *et al.*, 2013), in investigating production systems in southern Brazil, found a weak association between conserved forage production (silage and haylage) and concentrate feeding.

Balanced ruminant diets contain an optimal proportion of roughage and concentrate (Reid *et al.*, 2015), suggesting interdependence between production technologies. Low forage production capacity, resulting from a lack of specific equipment, may lead to intensive grazing and increased concentrate feeding (Balcão *et al.*, 2017; Novo *et al.*, 2013). Koerich *et al.* (Koerich *et al.*, 2019) found that concentrate feeding is associated with intensified grazing, forage production, crop fertilization, and rotational grazing.

The results indicate that the adoption of health-related technologies is independent of other technologies. Vaccination against infectious bovine rhinotracheitis, bovine viral diarrhea, and leptospirosis is carried out by some but not all dairy farmers in Paraná State, Brazil, regardless of the adoption of other technologies. Because these diseases may decrease the reproductive efficiency of cows (Souza *et al.*, 2019), it was expected that animal health technologies would be dependent on breeding strategies; however, this was not observed in the current study. Vaccination against these diseases is not mandatory in Brazil; thus, adoption of the practice is influenced by the personal characteristics of farm operators. Frössling & Nöremark (2016) observed that gender and level of education influence farmers' opinions and perceptions toward biosecurity improvements. Other studies have shown that sociopsychological factors, such as the influence of social networks and perceived risks, influence dairy farmers' intention to implement disease prevention and control measures (Brennan *et al.*, 2016), as was the case for voluntary vaccination against Bluetongue disease reported by Sok *et al.* (2016) and Sok *et al.* (2018).

Cost and animal performance management allow farmers to make more assertive decisions (Alary *et al.*, 2016; Notte *et al.*, 2020) about adopting new practices. These factors are also correlated with the increased milk yield (Losinger & Heinrichs, 1996; Smith *et al.*, 2014). Our results indicate that adopting management practices does not depend on other technologies and has a lower influence on productivity.

Practices associated with genetic improvement, breeding techniques, and concentrate feeding were the most important to predict productivity indices, including those associated with land, livestock, and labor. In agreement with our findings, Prospero-Bernal *et al.* (2017) highlighted simultaneous adoption of multiple-herd feeding practices as an important strategy to enhance economic performance, especially in small-scale production systems in developing countries.

CONCLUSION

This study demonstrated the inseparability of the main dairy farming technologies and assessed their impacts on production performance. Adoption of forage production technologies, mainly specific machinery, is related to the improved farm structure. Technologies for breeding management, genetic improvement, and concentrate feeding were associated and grouped into a single factor. Computational tools and technologies for controlling costs and animal performance were independently grouped into a single factor, as were vaccination practices. The four factors, composed of key technological indicators, significantly explained the differences in milk productivity between dairy farms. Technologies grouped under the factor of genetics, breeding strategies, and concentrate feeding were the most important in explaining milk yield per lactating cow, land productivity, and dairy herd reproductive efficiency.

CONFLICT OF INTEREST

The authors have no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the manuscript's material.

ACKNOWLEDGEMENT

The authors thank the dairy farmers, processors, and extension agents from the Paraná Institute of Technical Assistance and Rural Extension (EMATER-PR). We also thank the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES) for the scholarship awarded to the first author.

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