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Sustainable Transformation of Dairy Farmers in Latin America: A Perspective from Agribusiness

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Abstract

This study reports on an intervention conducted in a Cuban dairy farm with structural and technological conditions representative of national production systems, aiming to identify and address key constraints limiting sustainable productivity. The initial diagnosis revealed deficiencies in replacement heifer quality, degraded grazing pastures, and low reproductive efficiency. In response, a four-year strategic transformation plan was implemented, focusing on enhancing productive efficiency and business profitability. The herd comprised predominantly crossbred Holstein cows, with some purebred Holsteins selected for their high milk yield potential. Results demonstrated a marked improvement in performance, with milk yield per hectare increasing from 2,720 to 5,353 liters and reproductive success rising from 70% to 85%. These gains were accompanied by a significant reduction in production costs, achieved through optimized pasture use and reduced dependence on external feed supplements. The intervention transformed the farm into an efficient agribusiness model, characterized by rational input use, sustainable pasture intensification, and genetic and reproductive improvements. Overall, the case study underscores the feasibility of achieving high milk yields under low-input tropical systems by integrating sustainability, productivity, and profitability, offering a replicable model for strengthening the dairy sector in similar environments.

Keywords: Sustainable Livestock; Tropical Pastures; Reproductive Efficiency; Milk Productivity; Agribusiness

INTRODUCTION

The shortage of milk in numerous Latin American countries represents a persistent problem that directly affects the food and nutritional security of vulnerable sectors. Milk is an essential food that provides critical nutrients such as proteins, calcium, phosphorus and vitamin B12, so its limited availability implies socio -economic and public health consequences. The shortage is correlated with low productivity per hectare and an inefficient use of agricultural resources, generating sustained increases in consumer prices and affecting millions of families in poverty (FAO, 2023).

From an agribusiness perspective, this problem becomes an opportunity to redesign the productive model, strengthening competitive dairy chains, resilient and sustainable. In most Latin American countries, the average production of milk per hectare does not exceed 1,000 liters/year, a situation that compromises the economic viability of productive units and limits the growth of the sector (Méndez et al., 2022). Overcoming this barrier requires a structural transformation based on adaptive technologies, organizational innovation and reproductive efficiency.

Latin American dairy farms face multiple structural challenges: low technification, scarce access to financing, dependence on extensive systems, soil degradation and low reproduction rates in herds. This situation implies low profitability, which discourages investment and causes stagnation in productivity (Rodríguez & Vivas, 2021). As Rivas et al. (2023), the cost of production per liter of milk in little technified systems can exceed up to 40% of efficient farms, generating competitive disadvantages at national and international level.

In addition, population growth and increased purchasing power in urban sectors are promoting a growing demand for fresh milk and dairy products, which further presses the productive capacity of the sector. Extensive milk livestock cannot satisfy this demand without significantly increasing the environmental footprint and the use of agricultural land, which is unsustainable in the medium term (Salinas & Ramírez, 2024).

The agribusiness approach allows to address milk production as part of an integrated network of actors, processes and technologies ranging from primary production to the final consumer. Under this logic, the increase in milk productivity per hectare becomes a strategic objective to guarantee the competitiveness of the sector. This implies optimizing fodder conversion, improving livestock genetics, strengthening reproduction management systems and adopting technologies such as intensive rotational grazing, animal monitoring sensors and reproductive biotechnology (Jiménez et al., 2022).

Several studies emphasize that an efficient strategy in terms of fresh milk production per hectare should consider an integral management of the soil-strength-aimal system. For example, the implementation of silvopastoral systems and high density grazing with short occupation times has demonstrated increases greater than 300% in production per hectare, compared to traditional systems (López-Hernández et al., 2021).

In addition, the improvement of reproductive efficiency is key to sustaining productive growth. High fertility indices, low intervals in deliveries and proper zeal synchronization allow increasing the replacement rate and improving total milk production per animal and by surface. The adoption of reproductive protocols adapted to the tropics, combined with the use of artificial insemination with sexed semen, can radically transform production rates into dairy herds (Torres & Cordero, 2021).

Productivity and sustainability are not exclusive goals. In fact, regenerative and milk -lively livestock systems in grasslands have shown that it is possible to reach high levels of production per hectare while the quality of the soil is improved, carbon is captured and the water footprint is reduced (Carrillo Espinal et al., 2022). These systems, based on careful management of forage resource and rotational management with high animal density, allow maximizing grass photosynthesis, improving soil biodiversity and increasing resilience against droughts and climatic variations.

From the point of view of agribusiness, demonstrating productive growth under conditions of sustainability generates important competitive advantages. Traceability, certification of sustainable products, access to differentiated markets and the possibility of capturing green financing are aspects that strengthen the position of the producer in value chains (Rangel et al., 2024). In addition, the implementation of sustainability and productivity indicators allows production units to make informed decisions and align their strategies with the Sustainable Development Goals (SDGs).

The reconversion of dairy farmer also implies a transformation into the business model. The new schemes must contemplate the associativity, cooperative financing, vertical integration, commercial innovation and process digitalization. For example, the use of digital platforms for direct sale to the consumer or for the smart management of the herd has allowed small producers to increase their gain margins and reduce intermediation costs (González & Rivera, 2023).

The consolidation of dairy clusters, where universities, innovation centers, supplies, agribusiness and local governments converge, is another strategy that has given positive results in countries such as Colombia, Mexico and Brazil. These clusters promote continuous training, access to technologies, processes standardization and articulation with global markets (Escobar & Maldonado, 2023).

The role of public policy is also fundamental. Foment programs that support innovation in the sector, green subsidies, accessible credit lines, and rural extension systems focused on business management, animal welfare and productive sustainability are required. Agricultural policy must stop subsidizing inefficiency and betting on competitive, fair and inclusive models (FAO, 2023).

MATERIALS AND METHODS

The present research was developed with the objective of evaluating the impact of a set of technical-productive actions aimed at transforming the efficiency of a Vaquería with Holstein genetic predominance, which showed progressive deterioration in its productive indicators during the three years prior to the intervention. The study was carried out under criteria for technical, economic and organizational sustainability, adopting an integral agribusiness approach that considers profitability, efficient use of resources and productive resilience as a key axes of transformation.

Location and characteristics of the productive unit.

The intervened unit corresponds to a cowboy located in a humid tropical climate zone, with an annual average rainfall of 1,200 mm and average temperature of 26 ° C. The farm presented structural characteristics similar to those commonly found in dairy farms of Cuba: semi-intense stables, food based on degraded natural pastures and occasional supplementation with concentrates. The useful area for livestock was 38 hectares.

The flock was predominantly composed of mestizo cows with a high percentage of Holstein blood and a small number of pure holstein specimens, with an average breastfeeding less than 2,800 liters/year at the initial moment of the study. The production system presented significant deficiencies in the food base, the quality of dairy replacement and reproductive indicators, compromising the technical and economic viability of the dairy agribusiness.

Intervention strategy.

The general strategy consisted of a progressive redesign of the productive system for a period of four years, with emphasis on three fundamental components: improvement of the food base, recovery of the dairy replacement and strengthening of reproductive efficiency. From the agribusiness approach, each intervention was evaluated not only for its technical impact, but also for its contribution to system profitability, cost reduction per liter produced and the improvement of economic sustainability indicators.

Milk replacement improvement.

Since the initial diagnosis revealed a critical situation in the quality of the female replacement, a small genetic and nutritional recovery center for this category was established. This center included intensively reset facilities, specialized health management and food control with balanced diets. As García López (2010) points out, in the current global context, the demands on the quality and performance of the replacement are decisive to guarantee the future productivity of the system.

It should be noted that this strategic measure, although key in the medium term, limited the entry of new females to the productive system during the first two years of the study, temporarily affecting the growth of the herd and forcing to optimize the management of animals in active production.

Actions to improve the food base.

One of the pillars of the transformation of agribusiness was the substantial improvement of the Food Base of the Flock. The main actions included:

Establishment of high performance grasses: 0.15 hectares of the CT-115 hybrid were sown (improved variety of Pennisetum Purpureum cloned by fabric cultivation, commonly known as King Grass), with the aim of providing high quality fodder for food in critical times.

Natural grasses rehabilitation: 0.10 hectares of degraded pastures were recovered by selective remedy, weed control and intensive grazing management, managing to increase the useful biomass available per hectare.

Strategic nitrogen fertilization: 150 kg of nitrogen per hectare per year were applied in 38 hectares, distributed in three annual applications, in order to stimulate the regrowth of grasses and improve the protein concentration of the available fodder.

These actions allowed to significantly reduce the dependence on external supplements, which represented a direct economic advantage by decreasing variable feeding costs, one of the most relevant components in the cost structure of dairy livestock.

Statistical evaluation.

To evaluate the impact of the actions implemented on the productive and economic indicators, a statistical design based on variance analysis (ANOVA) was used according to a multiplicative model, as established by Menchaca (1978). The means were transformed by natural logarithms to comply with the assumptions of normality and homogeneity of variances.

In cases where significant differences were detected ($p < 0.05$), Duncan docima for multiple comparison of means was applied. The variables evaluated included: production of milk per hectare, birth rate, percentage of cows in production, cost per liter and net economic performance of the system.

Analysis criteria from agribusiness.

In addition to the technical analysis, indicators of profitability and economic efficiency were integrated that allowed to assess the sustainability of the system from a business perspective. Among them were considered: net income per hectare, return on investment (ROI), gross margin per liter of milk and productive equilibrium point.

This approach allowed to evaluate the system not only as a zootechnical unit, but as a comprehensive dairy agribusiness, capable of responding to market demands, reducing vulnerability to the shortage of inputs and projecting as a replicable model for other tropical regions.

RESULTS AND DISCUSSION

The grass production before and after the work done is reflected in Figure 1. While the bromatological quality in rain and dry is seen in the .1 table.

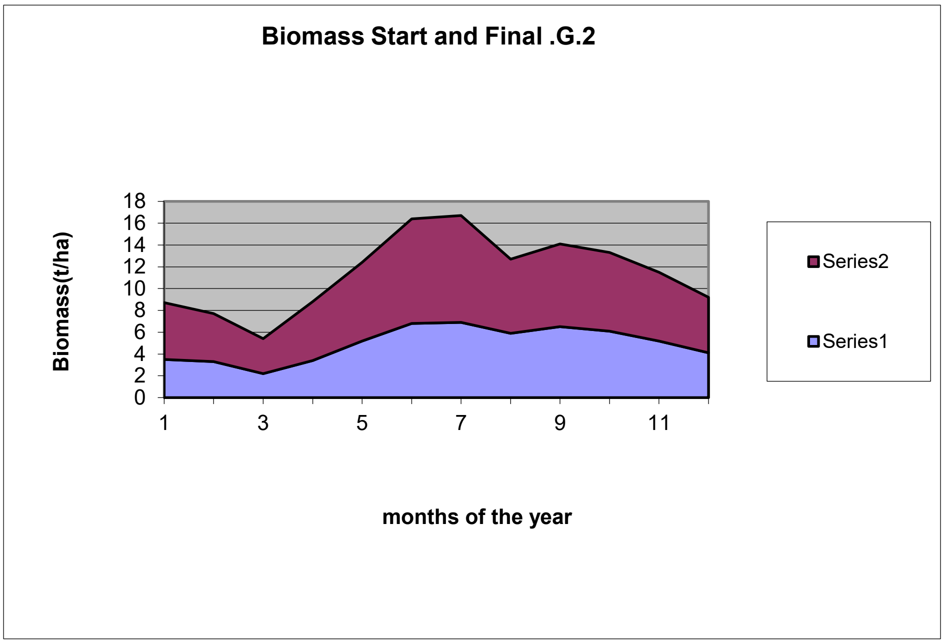

Figure1. Initial and final biomass.

Series 1: Initial biomass/month. SERIES 2: Final Biomass/Month.

It is shown that biomass production is almost doubled in every month (year 4) to what is obtained (year 1) the process of transformation of said unit.

The handling system used suffered changes, within them, the 2 -day grazing system changed to the grazing system according to cell designs as a predominant way and consisted of offering strips protected by electricity for ½ day of occupation with the view to optimizing the quality of the grass consumed. It was necessary to admit that the entire production group grazed together, for two basic reasons, for how small that group was and for the safety measures of the flock, although it could to some extent conspire to achieve the best selection of the most producer group, however, this situation was tried to correct with an adequate group formation to supply the supplementary food. Peyraud and Gonzalez-Rodriquez.2000

Table 1. Bromatological quality of the main pastures used.

Star grass. Dry					**C.T .115. Dry**				
Ashes	P.B	Ca	P	FND	ashes	P.B	Ca	P	FND
5,9	8,3	0,43	0,30	78,3	10,3	9,5	0,45	0,29	69,8
Star grass. Rain					C.T .115. Rain				
6,7	7,4	0,51	0,33	75,9	11,20	9,3	0,45	0,29	70,1

On the other hand, the botanical composition of the grass shows the state of initial deterioration and the way in which I evolve, applying the indicated corrections, which is perfectly reflected in Table 2.

Table. 2. Evolution of the botanical composition of the pasture (start and end).

Start %	**End %**	**Species**
43,65	10,6	Sacasebo.(Paspalum notatum)
37,86	45,36	Pasto estrella(Cynodum nlemfluencis)
5,6	4,5	Espartillo .(Sporobolus Indicus)
4,45	4,4	Bermuda(Cynodum SP.)
0	27	CT-115 (Pennisetum Purpureum)
1,5	5,2	Aroma
6,41	2,94	Others

Table 3. Sanitation and completion of the dairy dough within the transformation.

Transformation time	**Total cows for years**
Base Year	78
Año 1	66
Año 2	64
Año 3	76
Año 4	108

Table 3 shows the total cows that were achieved in the cowboy in each year of work and although in the fourth year, the figures of total females were achieved and all could not exercise the technological impact and although the productive jump is evident, if the follow -up of the project has continued, the productive balance would have been even greater.

The increase in cows in the unit was determined, according to the biomass available in the pastures and according to these results the actions of increasing the mass were taken, it is very noticeable that the fourth year, the unit is in a position to favor a notable growth of the cows to be sustained without increments of the initial areas.

The production results obtained are appreciated in Table 4

Table 4. Indicators of the initial and final production of the grass -based unit.

	Production total Milk	**Liters /ha**	**Total Cows**	**Cow in milking**	**Bith (%)**
Initial	119673	2720	72	39	70
End	203427	5353	108	73	85

The results indicated that the project leads to a gradual recovery of milk production, this cowboy allowed an important productive leap (51 %) in relative time and improve birth in 15 percentage units placing at the expected levels of any advanced livestock in the tropics (Mella, 2003),

The analysis of milk production for years of work indicated that, in individual production, there are no relevant results in the first three years and it is only the fourth year, where a productivity leap per cow can be observed, indicative of a progressive improvement of cows in the flock (Table 5).

Table 5. Results in milk production for years.

Years				
1	2	3	4	Sig.
0,86 (8,3)	0,89 (8,30)	0,86 (7,9)	0,94 (9,2)	p≤0,01
0,0074[a]	0,0075[a]	0,0075[a]	0,0065[b]	

( ) Unconsremplined data

The behavior in breastfeeding productivity (Table 6), was manifested logically, with an adequate differential between the first and the rest of the lactation, without appreciating significant differences between the second and the rest of the lactation, which could be given, by effects, still maintained in part of the flock.

Table 6. Influence of breastfeeding in productive behavior.

Lactation			
1	2	3	following
0,85 (7,4)[a]	0,91 (8,7)[b]	0,92 (9,07)[b]	p≤0,001
0,0042	0,0040	0,0050	

The living weight (Table 7), was evolving after the first two years and seems to settle in lower averages (460 kg) to those desired for the race (Morillo, 2001), due to nutritional deficiencies linked to all its development and from its parentals.

Table 7. Live weight behavior for years.

Years				
1	2	3	4	following
433.4[a]	442.3[a]	462.2[b]	462.2[b]	p≤0.001
1.93	2.56	1.76	2.22	

The milk components improved as the years passed (Table 8) which indicates that feeding practices improved positively, as indicated in some blood components (Table 9). Evidencing that no disturbances were created in the animal system according to the different practices that were executed.

Table 8. Variation in milk component /years.

	Year I	Year II	Year III	following
Fat. %	0,56(3,67) +- 0,0061	0,61(4,12) 0,0131	0,6(4,15) 0,0168	p≤0,001
Total solids	1,06(11,61) +-0,0023	1,09(12,28) 0,0050	1,08(12,06) 0,0064	p≤0,001

Table 9. Hematochemical changes in the dairy herd supplemented according to program.

	Before	After	following
Hb	8,22	9,29	0,1402 $p \leq 0{,}001$
Hto	25,4	30,9	0,4301 $p \leq 0{,}001$

One of the most serious problems confronted in this work was that during the experimental period it was not posible achieving the number of cows needed in the unit, it was considered convenient to perform a weighting exercise in the total number of animals (cows) at a level of 100, and maintain the rest of the real indicators that occurred and that way would give us a more real image of what is truly taking place.

Table 10. Vaquería with grass and cows with Holstein blood weighted data on the basis of 100 total cows, maintaining the rest of the real indicators.

Indicador	Base	1st year	2nd year	3rd year	4th year
Milk/ha	4526	5560	5045	6085	6051
Liters/cow	8,0	8,5	7,6	8,8	9,0
Total cows	100	100	100	100	100
Cows in milking	64	68	72	65	70

A similar analysis was executed with the heifers who participated in the improvement program Table 11. Raising what could have happened if the entire flock could have recovered with this type of animal.

Table 11. Productive responses of brothers incorporated after the year 1. Base 300 days of breastfeeding.

Indicadores	Year 2	Year 3	Year 4
Production/breastfeeding	2380	2718,6	3456
Liters/cow	7,9	9,1	10,8
Total cows	100	100	100
cows/milking	72	65	70
Milk/ha	5463	5681	7261

Within the Estimated Economic Analysis in USD per year throughout the vaqueria, Table 12. The cost of the liter of milk was reduced, as the years advanced, motivated by a greater increase in production and relatively little increase in the level of supplementation

Table 12. USD CTVS costs of the liter of milk per year according to fundamental supplies.

Previous year	Base year	1st year	2nd year	3rd year	4th year
21,7	18,0	17,7	19,6	16,1	15,0

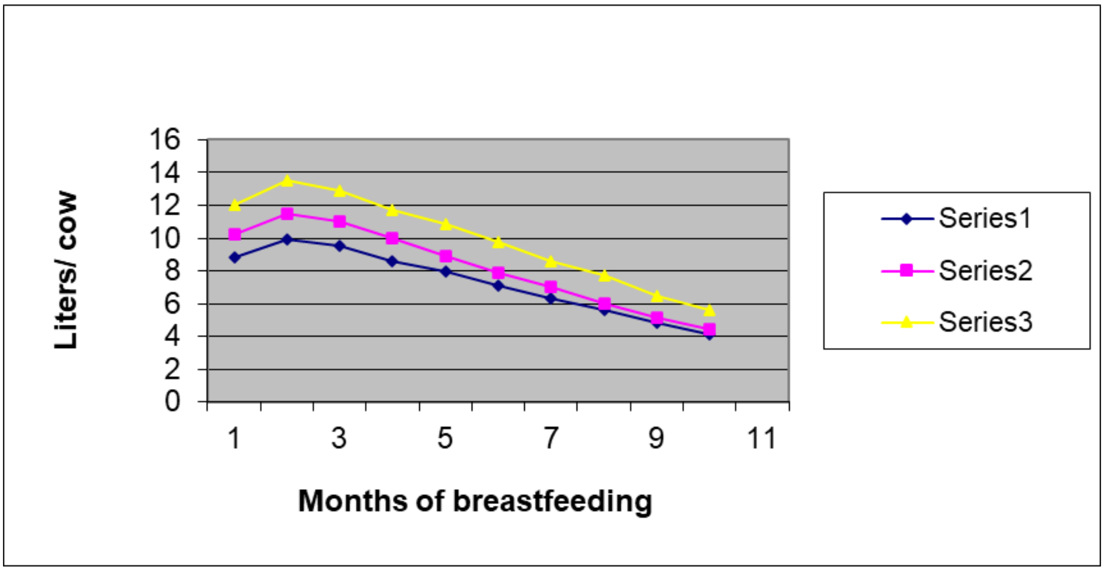

Figure 2. Potential curves according to breastfeeding.

1 series: year 1; 2 Series: Year 2; Series 3: Year3 Applied Technology.

The lactation curves can be seen in Figure 2 are manifested increasingly according to the breastfeeding number, indicating a behavior of lactation physiology more accommodated to the normal behavior of any dairy herd properly fed and justifies the necessary renewal of the dairy herd and better attention to the produced biomass that allows to sustain in an adequate food regime to the entire flock, with a view to obtaining the best results.

CONCLUSION

From an agribusiness perspective, the implementation of a set of technical-productive practices in a dairy unit with a predominance of Holstein genetics, located in a tropical environment, allowed to significantly transform its indicators of efficiency, productivity and sustainability. The integral approach adopted - which covered the genetic improvement of replacement, the rehabilitation of the fodder base and the reengineering of the grazing system - evidenced that, with strategic investments, it is possible to recover the profitability of tropical dairy systems without depending exclusively on expensive external supplies.

The results show that in a period of four years the production of milk per hectare (from 2,720 to 5,353 liters/ha), increase the birth rate of the herd (from 70% to 85%) and reduce the cost per liter produced (from 21.7 to 15 USD cents), key indicators that place this unit as a replicable model of competitive and sustainable agribusiness. In addition, an improvement in the bromatological quality of fodder and the nutritional composition of milk was evidenced, reflecting a favorable physiological response of the flock to food changes.

In economic terms, the return on investment was strengthened with a progressive reduction in variable costs per liter of milk, thanks to the greater prominence of improved forage resources and a more efficient management of the flock in production. The adoption of rotational grazing systems with cell design and the strategic use of nitrogen fertilization contributed decisively to the increase in the available biomass and the rational use of the livestock area.

Likewise, the sanitation practices and the implementation of a genetic and nutritional replacement center allowed to initiate a structural renewal process of the herd, which, although limited in its immediate effects, laid the foundations for productive and reproductive sustainability in the medium term. The statistical analysis confirmed the significance of the observed changes ($P \leq 0.05$), and the simulation models with weighted data per 100 cows project even greater benefits if the total consolidation of the new productive model is reached.

Therefore, experience demonstrates that tropical dairy systems, frequently lagging behind structural and technological limitations, can become profitable, resilient and sustainable agribusiness through planned interventions that integrate the improvement of technical efficiency with business criteria. This case reaffirms that productivity and profitability are not exclusive, and that a systemic transformation focused on innovation, efficient use of resources and data -based management can successfully reactivate the competitiveness of the dairy sector in regions with similar structural challenges.

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