FARMING SYSTEM DESIGN FOR SUSTAINABLE AGRIFOOD SYSTEMS: THEORIES AND PRACTICES

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Marion CASAGRANDE, Marie-Hélène JEUFFROY, Gentiane MAILLET

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Functional classification and technical performance of cow-calf systems on campos grasslands

PAPARAMBORDA I.[1,2], DOGLIOTTI S.[1], SOCA P.[1], ROSSING W.A.H.[2]

[1] Universidad de la República, Facultad de Agronomía, Uruguay, [2] Wageningen University and Research, Wageningen, the Netherlands

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Introduction

Cow-calf systems on native grasslands dominate South America's Pampas and Campos region.Their sustainability, however, is questionable because of their low productive and economic results and their negative environmental impacts (Modernel et al., 2018). Ecological intensification (Doré et al., 2011) aims to increase meat production per unit area without increasing costs while preserving and improving ecosystem services such as biodiversity, soil and water quality, and soil carbon stocks by promoting intelligent and intensive use of the ecosystem's natural support and regulation functions through managing biodiversity, solar energy capture, and biogeochemical cycles. Paparamborda et al., (2023) developed a conceptual model to support the ecological intensification of cow-calf systems, identifying key strategic, tactical, and decision-supporting techniques, concluding that their application by Uruguayan farmers is low. In this study, we used archetype analysis to construct functional farm typologies (Necula et al., 2024; Tittonell et al., 2020) aiming to classify Uruguayan cow-calf farm systems based on distinct combinations of strategic, tactical, and decision-supporting techniques and exploring their relationship with resource endowment and farm results indicators.

Materials and methods

We used two datasets combined with archetype and discriminant analyses. The first, more general dataset contained results from a representative survey of Uruguayan livestock farms. The second, highly detailed dataset included information on 28 family farm participants in the "Climate-smart livestock production and land restoration in the Uruguayan rangelands" co-innovation project (GyC dataset). The first dataset was used to elucidate archetypes. Archetypes were created by iteratively applying the algorithm of Eugster & Leisch (2009) to the 109 farms x 9 techniques data matrix, increasing the number of archetypes starting from one. The number of archetypes most supported by the data was chosen based on the smallest relative residual sum of squares (RSS). The 28 farms of the GyC dataset were assigned to the archetypes using discriminant analysis. The archetypes were then compared in terms of structural and functional variables. Differences between the archetypes for these variables were tested with a Kruskal-Wallis test. Data analyses were performed using R 3.6.3 using the following R-packages: "archetypes" (Eugster and Leisch, 2009).

Results

Four archetypes (A1 to A4) of cow-calf systems emerged. A1 and A4 exhibited strongly contrasting levels of techniques implementation, while A2 and A3 were intermediate (Table 1). Our data showed that the archetype with the highest level of technique application (A1) achieved the best performance in meat production, weaning percentage, and weight of calves at weaning and in trophic (TEf) and conversion efficiency (CEf) but not in above-ground net primary productivity (ANPP) (Table 2). The difference in productive performance between the archetypes represents a gap that can be closed by increasing the application of ecological intensification techniques.

Category	Technique	Score	Archetypes			
			A1	A2	A3	A4
Strategic	Selecting stocking rate	1 = until 0.6 AU ha^{-1} 2 = 0.6 - 0.8 AU ha^{-1} 3 = 0.8 – 1 AU ha^{-1}	2.59	3.00	1	3.00
	Determining mating season starts and length	1 = Continuous 2 = Double 3 = Seasonal	3.00	2.98	2.88	1
	Weaning timing	1 Delayed 2 Others 3 March	3.00	2.98	2.74	1
Tactical	Applying temporary weaning, possibly combined with flushing	1 No 2 Temporary weaning 3 Temporary weaning + Flushing	2.00	1.62	1.34	1
Decision-making supporting	Monitoring Body Condition Score (BCS).	1 No 2 Yes	1.60	2.00	1	1
	Testing bulls' fertility before the mating season	1 No 2 Yes, by the farmer 3 Yes, by a vet	3.00	1.00	1.38	1.22
	Diagnosis of ovarian activity.	1 No 2 Yes	2.00	1	1	1
	Pregnancy diagnosis.	1 No 2 Yes	2.00	2.00	1.30	1
Other	Share of improved pastures in the total grazing area of the farm (%)	1 0% 2 1-5 % 3 5-10% 4 10-15 % 5 15-25 % 6 25-40 % 7 > 40%	5.21	4.64	2.96	1

Table 1. Scores of the strategic, tactical, and decision-supporting techniques for each of the four cow-calf farm archetypes based on a representative sample of 109 farms from the Cuesta Basáltica and Sierras del Este regions in Uruguay.

All farms from the GyC dataset could be assigned to the four archetypes by discriminant analysis. There were no significant differences (Table 2) in farm size (ha), percentage of land owned (%), total stocking rate (AU), and cattle and sheep stocking rates (AU) among the archetypes based on the GyC farm data. A1 and A2 had larger percentages of improved pasture areas than A3 and A4 ($p = 0.019$). A1 farms had the greatest weaning rate value, reaching 0.82 ± 0.08 ($p = 0.012$), while A1 and A3 farms tended to achieve higher calf weight at weaning than A2 and A4 ($p = 0.08$). Beef production was lower on A4 farms than in the other three groups ($p = 0.029$), mutton production and wool production were not different, and meat equivalent was the highest in A1 farms (108 ± 28.6 kg ha^{-1}; $p = 0.027$). There were no statistical differences in ANPP among the four groups, while TEf and CEf of A1 farms were the highest ($p = 0.017$). The ANPP differed between years ($p < 0.001$) and regions ($p = 0.0219$). There was a significant interaction between the archetype and month ($p < 0.001$). In November, the ANPP of A1 farms exceeded that of A3 and A4 farms.

Conclusions

There is a diversity of cow-calf production systems in Uruguay that we were able to capture from the construction of archetypes. These archetypes show diversity in implementing techniques and the productive results they obtain. The archetype with the greatest implementation of techniques is the most productive and energy efficient. In contrast, the archetype with the least implementation of techniques is the least productive and least energy efficient, with values below the averages reported for Uruguay. In addition, this last archetype is the most prevalent in Uruguay involving 40 or 50% of farms. Our findings reveal a significant potential for productivity improvement in Campos grasslands without reliance on additional external inputs. Knowledge and application of ecologically intensive management, rather than farm resource endowment, is the primary factor enabling productivity and trophic efficiency increases.

			GyC dataset				
Dimension	Variables	Unit	Archetype 1 (7 Farms)	Archetype 2 (4 Farms)	Archetype 3 (7 Farms)	Archetype 4 (10 Farms)	p-value
Farm Structure	Farm size	Hectares (ha)	585 ± 651	699 ± 223	545 ± 499	592 ± 442	0.59
	Land owned	%	68.7 ± 37.1	91.5 ± 17.0	94.1 ± 15.5	79.4 ± 35.6	0.38
	Total stocking rate	AU[1]	0.84 ± 0.11	0.82 ± 0.07	0.68 ± 0.09	0.74 ± 0.13	0.061
	Cattle stocking rate	AU[1]	0.70 ± 0.20	0.68 ± 0.06	0.53 ± 0.19	0.55 ± 0.21	0.3
	Sheep stocking rate	AU[1]	0.08 ± 0.07	0.08 ± 0.01	0.10 ± 0.09	0.15 ± 0.1	0.61
	Percentage of the grazing area with improved pastures	%	17 ± 13 a	19 ± 8 a	9 ± 10 ab	3 ± 3 b	**0.019**
Farm results	Weaning rate	%	82 ± 8 a	69 ± 7 ab	72 ± 13 ab	60 ± 10 b	**0.012**
	Calf weight at weaning	Kg animal^{-1}	162 ± 23	138 ± 21	159 ± 24	140 ± 15	0.087
	Beef production	Kg ha^{-1}	89.9 ± 36.9 a	73.0 ± 17.5 a	71.8 ± 24.9 a	48.5 ± 14.1 b	**0.029**
	Sheep meat production	Kg ha^{-1}	11.1 ±9.1	6.2 ± 0.6	9.9 ± 10.0	12.5 ± 9.5	0.78
	Wool production	Kg ha^{-1}	2.4 ±1.8	1.4 ± 1.0	1.9 ± 2.0	3.9 ± 3.1	0.36
	Equivalent meat production (EMP)	Kg ha^{-1}	108.0 ± 28.6 a	83.2 ± 16.2 ab	86.7 ± 16.9 ab	71.0 ± 17.4 b	**0.027**
	ANPP	Kg DM ha^{-1}	5114 ± 451	5231 ± 1079	5064 ± 420	5211 ± 383	0.71
	Trophic efficiency (TEf)	MJ meat MJ^{-1} forage	0.012 ± 0.002 a	0.009 ± 0.001 ab	0.010 ± 0.002 ab	0.008 ± 0.002 b	**0.017**
	Forage to meat conversion efficiency (CEf)	kg meat Mg^{-1} forage DM	21.1 ± 4.5 a	16.0 ± 1.4 ab	17.1 ± 2.9 ab	13.7 ± 3.5 b	**0.018**

Table 2. Main farm structure and farm results (avg±sd) for the 28 farms from the GyC dataset, per archetype. Different letters indicate significant differences among archetypes

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