FACTORS INFLUENCING PRODUCTIVITY AND SUSTAINABILITY OF SMALL-SCALE BEEF FARMS IN THAILAND

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Abstract

Over the past few decades, Thailand has witnessed a decline in production from small-scale beef cattle farming, accompanied by a reduced interest from younger generations in continuing family farming. The present study aimed to determine the state of these farms based on good agricultural practices (GAP) and explored factors influencing beef herd productivity and the willingness of the next generation to sustain the family business. Data from 1,175 questionnaires from 34 provinces was analyzed using SPSS. Beef herds with higher calving rates (CR $\geq$ 60%) had better herd, reproductive, and health management scores compared with the lower CR (<60%) group. Results from a negative binomial regression showed that factors, i.e., prediction of calving date and routine deworming positively impacted CR, while others like feeding types, mineral supplements, vaccination and hormonal estrus synchronization negatively correlated with CR. Expert opinions (N = 83) highlighted the importance of recording systems, heat detection programs, pregnancy diagnosis, feeding type, sufficient qualified water supply and mineral supplements. The use of Artificial Neural Network (ANN) and GLM analysis also noted that farm potential score, farmer gender, and occupations were pivotal for the sustainability of beef farming. This research aids in strategizing for enhanced sustainable beef production in Thailand.

Keywords: Good Agricultural Practices (GAP), beef farms, reproduction, career sustainability, SDG1, SDG8

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1. INTRODUCTION

In recent decades, Thailand's beef farms have evolved to meet rising global and local meat demands (Thornton & Herrero, 2010). Many of these farms, particularly in rural and border areas, are small-scale and require governmental support, including artificial insemination (AI) services with high genetic merit frozen bull semen. The Thai Department of Livestock Development (DLD) highlighted a significant decline in beef cattle numbers between 2007-2017, with a drop from ~8.9 million to ~4.9 million (44.9%) and a 42.9% reduction in beef farmers from 1.4 million to 0.8 million (Department of Livestock Development, 2017). These trends necessitate prompt policy recommendations to refine Thailand's livestock strategic plans.

The Office of Agricultural Economics (2023a) reported that out of 2,459,576 breeding beef cattle, only 1,373,368 were producing, resulting in a calving rate (CR) of 55.84%. This highlights challenges such as limited management knowledge, fodder shortages, inconsistent breed development, and diseases such as FMD. Beef production also declined due to labor and land limitations. In 2010, falling cattle prices (12,998 baht/animal) led to exports, primarily to Laos and Vietnam, reducing local production and causing younger cattle and breeding females to be slaughtered. However, 2012 saw a turnaround with a 33% beef price increase, peaking in 2015 at 36,677 baht/animal. This price hike, driven by demand for quality beef, revived interest in beef farming. Therefore, refining the breeding system, boosting breeding efficiency, and adopting frozen semen technology can reduce production costs and raise market value.

In 2013, the National Bureau of Agricultural Commodity and Food Standards introduced the "Good Agricultural Practice (GAP) for Beef Cattle Farm" policy, establishing beef cattle farm standards and certifications. However, the adoption of GAP certifications remains limited. Office of Agricultural Economics data (2017-2022) shows that while beef consumption and imports rose by 0.15% and 20.33% annually, domestic production declined by 1.24% (Office of Agricultural Economics, 2023b). This gap can be attributed to small-scale beef farmers shifting to quicker cash crops such as rice, corn, and cassava. Insufficient cattle management knowledge, due to limited farmer education, further affects beef production. Additionally, market dynamics, regulatory constraints, and domestic policies have compounded the decline in beef cattle productivity. (Department of Livestock Development, 2017).

Beef farm productivity is gauged using reproductive indices, notably the conception rate, pregnancy rate, CR, and weaning rate. The CR, diligently recorded by AI service officers in Thailand, serves as an indicator of the efficiency in cattle management, spanning from estrus onset, to breeding, pregnancy, and ultimately calving. It can be calculated by dividing the number of calves born by the number of cows that have been bred (Perry & Smith, 2004). Suboptimal productivity often prompts farmers to exit the profession. The primary objective for beef cattle farmers is optimizing each cow's offspring production. Ideally, 80-85% of the herd should bear offspring annually, targeting an average herd CR of about 95% (Dutil et al., 1999).

Previous studies have identified various external factors which impact the CR in beef cattle, including aspects such as herd and reproductive management, disease and parasite control, feed management, record-keeping, bull genetic merit and climatic conditions (Mokantla et al., 2004). However, comprehensive studies focusing on the reproductive indices in Thai beef cattle especially factors regarding CR, are limited. Similarly, a holistic analysis of factors influencing farm sustainability is lacking. This study, therefore, aims to i) elucidate factors influencing CR in beef cattle farms, ii) examine the relationship between farmers' socioeconomic conditions and their adherence to the GAP guidelines for beef farms and iii) investigate the key factors related to the next generation's intent to pursue careers in beef farming.

2. LITERATURE REVIEW

2.1 Overview Beef Production in Thailand

Global population growth and escalating environmental stress, notably on land resources, necessitate enhancements in the productivity and efficiency of beef production systems. Beef, renowned as a high quality protein source, offers a commendable culinary experience and is ranked third for meat consumption, trailing only behind poultry and pork (Greenwood, 2021). Thailand has sustained agricultural growth by boosting the yield of various crops and livestock products. While the top exports in 2022 included rubber, sugarcane, durian, and rice, livestock production remains a linchpin for both domestic and export markets (Office of Agricultural Economics, 2023b). Despite various challenges from pandemics, economic shifts, and natural calamities causing a decline in cattle numbers, Thai beef farming has witnessed growth (Khunchaikarn et al., 2022). Remarkably, buffalo numbers soared by over 82% from 2021-2022 (Office of Agricultural Economics, 2023a). Changing economic and social status provides opportunities for beef cattle producers to meet increasing consumer beef demand. Consequently, farmers, responding to rising prices resulting from supply shortages, have amplified beef cattle production.

Despite its efforts, Thailand's beef supply remains inadequate to fulfill current demand. Predominantly, Thai beef serves domestic needs, with only 1% served for the premium market, distinguished by marbling scores. A further 40% goes to modern markets focusing on muscling, while the rest serves traditional markets. Thai beef cattle are categorized into three genetic types: native cattle, Brahman and Brahman crossbreeds, and fattening beef cattle. Crossbred cattle targeting the premium market typically undergo intensive rearing. These premium producers typically operate within cooperatives or have substantial business investments. With a spike in urban demand, beef farming is currently promoted as a diversification strategy by the Thai government (Bunmee et al., 2018). Historically, Thailand imported beef until 2008, but rising demands from China and Vietnam shifted this pattern, with the country now exporting and facilitating cattle transit between Myanmar, China, and Vietnam. With the Asian Economic Community (AEC) emerging as a significant beef consumer, especially in Malaysia and Indonesia with growing halal needs, Thai producers are pressed to secure their market position. A holistic beef production strategy for Thailand is thus essential.

2.2 Small-scaled beef farm in Thailand

In line with other nations within the AEC, Thailand's beef production predominantly consists of small indigenous cattle herds that may exhibit lower productivity. To enhance output, these native breeds frequently undergo crossbreeding with superior imported breeds (Greenwood, 2021). This sector's farmers are primarily smallholders. Historically, Thai animal husbandry was centered on backyard farming, mainly using indigenous cattle breeds for domestic consumption and labor. These cattle served dual purposes for farmers: as laborers and as food sources. They also symbolized a tangible form of savings, as they could be sold during festivals and significant life events, like weddings and funerals. However, to upscale cattle quality, the Thai DLD integrated the American Brahman breed, elevating the typical mature weight from the native 250-300 kilograms to a substantial 400-500 kilograms (Limlamthong, 2012).

Over recent decades, Thailand has witnessed marked advancements in beef cattle production and breeding, notably with the emergence of Crossbred Thai breeds like "Kamphaeng Saen beef", "Tak beef" and "Phonyangkham cattle". The expanding AEC market has surged with a demand for live cattle and beef products from neighboring nations, positively bolstering Thailand's beef industry. Yet, unlike other countries, Thailand doesn't predominantly showcase vast commercial farms. The farming landscape remains dominated by smallholder farmers engaged in backyard farming. Although there is a notable rise in cattle numbers, only a minority have transitioned to commercial farming. Unfortunately, the majority of farmers' knowledge and skills regarding animal health care and management practices remain rudimentary (Department of Livestock Development, 2017).

2.3 Agriculture Sustainability

Farmers' intentions in small-scale beef farming sustainability are influenced by economic, environmental, regulatory, and communal factors. Understanding these intricate motivations and challenges is crucial for bolstering sustainable practices among small-scale farmers. Socio-psychological elements play a significant role in their decision-making and adoption behaviors. Encouraging sustainability requires policies that bolster social capital, enhance advisory services, promote media outreach, and provide intensive training for these farmers (Zeweld et al., 2017). Notably, economic benefits often drive these intentions: when sustainable practices are adeptly executed, they can bolster cost-effectiveness, enhance efficiency, and augment profitability. The important factors of modern farming include behavioral intentions and the adaptation of Asian farmers as the involved demographic, the technology acceptance usage indicator, and internal or external factors such as communication technology, financial management and entrepreneurial orientation, as reviewed by Shariff et al. (2022). These listed factors may influence and transform traditional agriculture into modern agricultural practices among the Asian farmer community. Hence, state-initiated policies and strategies are essential to fortify the agricultural sector for the future.

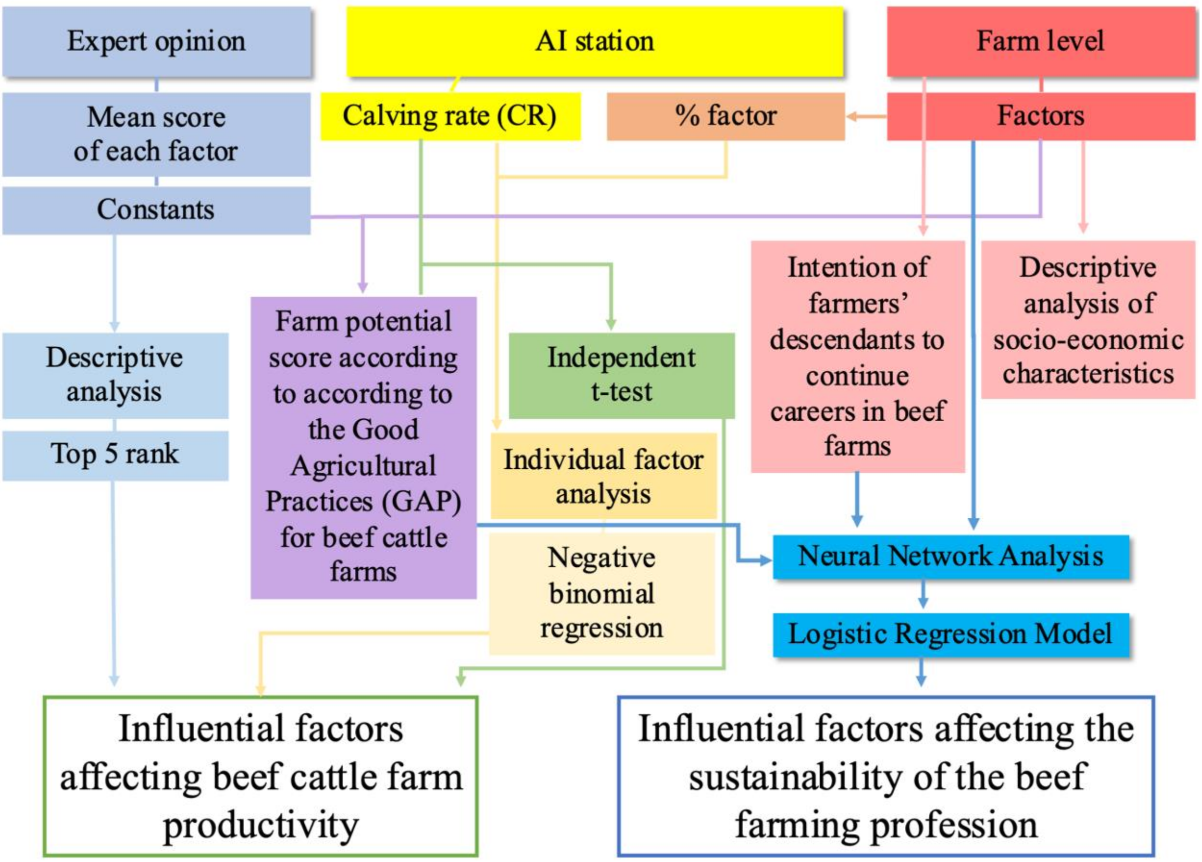

Figure 1 Conceptual Framework and Data Analysis of the Research

3. Conceptual Framework

The conceptual framework of this study integrates variables sourced from expert opinions, the Military Beef Cattle AI station, and the farm level. Utilizing relevant analytical tools, these variables were examined to discern the pivotal factors influencing beef cattle farm productivity and sustainability of the beef farming profession as illustrated in Figure 1.

3. RESEARCH METHODOLOGY

3.1 Data Collection

The data collection system was implemented from December 2014 to February 2018. A questionnaire survey was conducted, encompassing direct interviews with 1,175 farmers. These farmers availed artificial insemination (AI) services from 62 Mobile Development Units (MUD) under the Armed Forces Development Command (AFDC). We gathered data on farmers' socio-economic backgrounds, farm sizes, herd and reproductive management practices, cattle health management, the average CR reported from each AI station between 2012 to 2014, and the intentions of farmers' descendants regarding continuing in the profession. Notably, questions related to herd management, reproductive management, and cattle health were framed as check-list assessments, aligning with the GAP guidelines for beef cattle farms. The collected data were then utilized to compute an overall farm management score and individual category scores.

3.2 Expert Survey toward Factors Related to Beef Herd Production

A survey involving 83 cattle experts was conducted to assess the perspectives of key stakeholders in cattle farming. This survey encompassed representatives from four distinct stakeholder groups: 13 officers from the DLD, primarily directors from provincial biotechnology centers specializing in animal breeding; 7 academic experts, including university professors, experienced in cattle-related teaching or research; 20 commanders from the AFDC military development units and various regional military units; and 43 cattle farmer leaders and AI officers from the research region. The questionnaire consisted of 28 items to gauge the perceived importance of factors influencing beef herd production, utilizing a 5-point Likert scale ranging from "strongly agree" to "strongly disagree". The collected responses were subsequently analyzed to determine the significance score related to the efficiency of beef production (constant value) (see Appendix Table 1). The potential score of the herd, their health and reproductive management were then calculated for each farm. In addition, data were used to calculate the average score for each factor affecting the beef farm productivity and ranked based on their significance, listing the top five in descending order of importance.

3.2 Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 22. Data were tested for a normal distribution. It was necessary to devide factors with non-normal distribution into two groups using the median value. To explore the influencing factors of Thai beef farm productivity, the differences in the average score of beef farm management between farm members of AI stations that achieved CR $\geq 60\%$ or $< 60\%$ using an independent t-test. Individual factors associated with CR were then identified using a negative binomial regression model. Finally, a logistic regression within a general linear model was used to identify associations between farm socioeconomic status (gender, age, education, career and duration of farming) and herd management score, reproductive management score and health management score. Data were presented as sample mean ± SEM. The significance level was set at P value ≤ 0.05.

Regarding factors of small-scale beef farms' sustainability, it was necessary to analyze the farmers' responses to the questionnaire, particularly answers to the question "Will family members/the younger generation continue the occupation of cattle farming?" and to assess the factors that were significant or which influenced this response. The factors included the overall potential score of the beef farm management, the herd farm management score, the reproductive management score, the health management score and the farmers' socio-economic and farm characteristics. For statistical analysis, an Artificial Neural Network (ANN) model was employed to indicate the significance of each factor (variable importance) with a standard gradient descent algorithm (with batch training). Analyses were then performed using a general linear model (GLM, IBM SPSS Statistics version 22). A logistic regression was used to identify associations between the intention to continue career and the profiles of farm management score, farmer socio-economic status and farm size. Data were presented as sample mean ± SEM. Charts were created using GraphPad PRISM software (version 5.00; GraphPad Software Inc., San Diego, CA). Significance levels were set as P value ≤ 0.05.

4. RESULTS

4.1 Socio-economic Characteristics of Farmers and Farm Management Assessments in Accordance with GAP Guidelines for Beef Cattle Farms

Data were collected from beef cattle farmers affiliated with 62 out of the 76 nationwide AI stations of MUD, AFDC across 34 Thai provinces. The demographic profiles of the sample group are shown in Table 1. A total of 1,175 verified questionnaires were utilized, with 77.5% male respondents, 21.2% female respondents, and 1.3% respondents of unidentified gender. The average age of the farmers was 53.4 years with 52.2% aged 46-60. The main occupation was farming, accounting for 92.7%, followed by 2.9% government officials, 2.2% Sub-district Administration Organization (SAO) members and 2.2% other professions. Regarding educational status, 68.1% had completed primary education, 23.7% secondary education, while 8.3% held a vocational certificate or bachelor's degree. The duration of cattle farming ranged from 1 to 79 years with 59.1% having 7-20 years of experience.

The data from each farm included farm management, objectives of cattle rearing, utilization of cattle manure, labor, feeding practices, purchases of agricultural equipment, fixed assets, breeding methods, and the health and welfare of cattle, presented in Table 1.

The socio-economic data of the beef farmers revealed an average age of 53.4 years, with ages spanning from 21 to 85 years. A significant majority, 87.7%, identified agriculture as their main occupation. Notably, when exploring the future sustainability of beef cattle farming, about 32% of the 1,057 participants signaled that their descendants showed interest in pursuing cattle farming as a vocation. This inclination prompts further analysis to understand the underlying determinants affecting the continuity of beef cattle farming.

The results disclosed diverse cattle farming experiences among respondents, spanning from less than a year to 79 years, averaging at 14.24 years. Their farming objectives varied: 62.7% focused on breeding female cattle and selling calves; 17.6% aimed at weight attainment for cattle before selling them for further fattening; 8.4% reared cattle for direct slaughterhouse sales, and a mere 11.1% undertook full-cycle farming from beginning to end. Cattle ownership ranged from 1 to 200 heads per household, averaging 7.4 heads. Investment in female cattle saw purchases from 1 to 10 heads, with prices ranging from 7,000 to 530,000 Baht. Notably, only 23.8% could specify the source of the cattle they purchased for their farms with prompt disease quarantine and requiring health certification before procurement.

Table 1 Demographic Data of Beef Farmer Respondents in the Present Study

Characteristic	Number	Percent
Gender		
Male	911	77.5
Female	249	21.2
Unidentified	15	1.3
Age (Year)		
<= 45	253	22.6
46-60	585	52.2
>=61	283	25.2
Education		
Primary	619	68.1
Secondary	215	23.7
College-University	75	8.3
Occupations		
Farmer	1,031	92.7
Government officials	32	2.9
Subdistrict administration organization member	24	2.2
Others	25	2.2
Duration of farm operation		
<= 6	286	25.5
7-20	663	59.1
>=21	173	15.4
Total	1175	100.0

From the evaluation concerning feeding practices, it was found that 52.4% of farmers could provide both roughage and quality concentrate feeds in quantities that met the nutritional requirements of their animals. Regarding methods of providing roughage, 16.7% of farmers cut and fed grass to their cattle, 21.8% let their cattle graze, and 24.1% combined both methods. Of the 441 respondents to this survey, 33.9% purchased registered animal feed. Moreover, 54.9% of the farmers could provide water troughs or basins made from easily cleanable materials placed at convenient locations for cattle to drink, and 64.6% could ensure adequate water provision for all their cattle.

Regarding breeding practices, only 16.2% of farmers kept records of animal pedigree and breeding events. Natural breeding was favored by 24.6%. For heifer management, only 18.9% verified the age and weight before the first breeding, resulting in an average first calving age of 32.2 months. Managing breeding females revealed that 23.4% had regular estrus detection programs, while only 2% utilized hormones for estrus synchronization; 25.9% had regular pregnancy diagnosis programs and 64.9% actively monitored the calving procedure.

Concerning cattle health and welfare, the study indicated that while 71.7% of farmers prioritized animal welfare (ensuring care, comfort, and appropriate treatment for injured or ill cattle), only 13.4% used identifiable markings on their livestock. Furthermore, a mere 31.1% maintained health records encompassing treatment, disease prevention and vaccinations. Veterinarian oversight was available in only 27.6% of farms, and 34.1% adhered to prescribed animal medication guidelines. Notably, vaccination and deworming were quite prevalent, with 79.6% and 80.2% of farms engaging in such practices, respectively. However, only a scant

14.9% conducted regular testing for tuberculosis and brucellosis. Regarding biosecurity, 13.7% enforced preventive measures for disease control at farm entry and exit points, a minor 6.8% logged farm visitors, 53.1% pledged adherence to disease control laws during outbreaks, and 31.0% managed animal carcasses appropriately. The survey regarding prevalent cattle health issues revealed that lameness was the most frequent concern, affecting 32.3% of respondents. This was followed by digestive disorders at 25.1%, respiratory diseases at 16.8%, underweight and stunted growth at 15.6%, and infertility at 15.1%. Additionally, 5.4% reported pregnancy loss, while 1.7% encountered FMD. Other less common concerns included bloat, parasites, Hemorrhagic Septicemia, leptospirosis, joint inflammation, and skin conditions due to mosquito bites.

The study revealed that the majority of the beef cattle farms surveyed did not fully comply with the GAP guidelines for beef cattle farms. Specifically, the average score for herd management was 21.60, ranging from 3.40 to 41.80. In reproductive management, the average score was 11.85 with scores between 0 and 22.90. The average health management score was 9.74, ranging from 0 to 19.20. Overall, when evaluating the efficiency of beef cattle farming based on these parameters, the composite average score stood at 45.61, spanning from a low of 11.80 to a high of 83.90.

4.2 Influencing Factors of Thai Beef Cattle Farm Productivity

4.2.1 Expert Opinions

Data from the expert opinions of experts involved in Thailand's beef cattle production are shown in Appendix Table 1. The respondent groups emphasized different factors. Farmers, AI officers, and academic experts prioritized cattle feed type and estrus inspection equally. Academic experts additionally underscored the importance of pregnancy diagnosis, aligning with military development unit commanders. DLD officials highlighted the essentiality of water supply. Cumulatively, the top five factors, based on average scores, were: estrus detection, water supply, record-keeping, cattle feed type, and mineral supplementation, as presented in Table 2.

Table 2 The Top Five Most Important Factors Related to Beef Farm Productivity According to the Experts' Opinions

Rank	Farmers and AI officers	DLD officers	AFDC commanders	Academic Professors
1	Sufficient qualified water supply for all cattle.	Sufficient qualified water supply for all cattle.	Regular pregnancy diagnosis	Types of feed that cattle receive
2	Regular estrus detection.	Regular estrus detection.	Regular testing of TB and Brucellosis	Regular pregnancy diagnosis
3	Types of feed that cattle receive	Recording system	Regular estrus detection.	Recording system
4	Mineral supplementation	Types of feed that cattle receive	Regular vaccination	Regular vaccination
5	Area management (sufficient for each cattle to rest and have shade for heat protection)	Mineral supplementation	Mineral supplementation	Regular testing of TB and Brucellosis

4.2.2 Farm Management and Farmers' Socio-Economic Profiles

Farms with an AI station-CR ≥ 60% had significantly higher overall farm management scores compared to those with an AI station-CR < 60%. This pattern was consistent for both reproductive and health management scores (Table 3).

Negative binomial regression analysis (Table 4) found no significant association between CR and farmer socio-economic factors, including gender, age, occupation, educational status, and farm operation duration. Likewise, herd management aspects such as cattle rearing patterns, cattle count, rearing areas, and manure management didn't notably affect the beef farm's CR. However, predicting the calving date and routine deworming showed a positive correlation with CR. In contrast, factors such as feed types, mineral supplementation, estrus synchronization, health recording, and vaccination negatively correlated with CR.

Table 3 Table 3 Score Differences (Mean ± SEM) in Beef Cattle Farm Between AI Station Farms with CR ≥ 60% and < 60%

	Potential scores (CR ≥ 60%)	Potential scores (CR < 60%)	*P* value
Overall management	42.14 ± 0.81	38.00 ± 0.71	0.001
Herd management	20.94 ± 0.41	20.95 ± 0.37	0.986
Reproductive management	11.01 ± 0.32	8.51 ± 0.27	0.001
Health management	10.17 ± 0.24	8.53 ± 0.20	0.001

Table 4 Analysis of the Factors Influencing CR using Negative Binomial Regression Analysis

Parameter	**Beta**	**hypothesis test**	**Exp (B)**	**95% Wald confidence interval for Exp (B)**	
		P-value		Lower	Upper
Gender					
Male	0.306	0.274	1.358	0.785	2.348
Age (Year)					
>=54	0.161	0.618	1.174	0.625	2.208
Occupations					
Farmer	-0.715	0.236	0.723	0.422	1.237
Government officials	0.256	0.505	1.292	0.608	2.745
SAO member	0.026	0.932	1.026	0.567	1.857
Others	0.52	0.179	1.681	0.787	3.589
Education					
Primary	0.199	0.551	1.22	0.634	2.347
Secondary	-0.298	0.394	0.743	0.374	1.473
College	-0.457	0.097	0.633	0.37	1.085
University	0.58	0.115	1.786	0.869	3.67
No qualification	0.066	0.872	1.068	0.476	2.397
Duration of farm operation					
>=10 years	0.005	0.406	1.005	0.994	1.016

Table 4 (Continued)

Parameter	**Beta**	**hypothesis test**	**Exp (B)**	**95% Wald confidence interval for Exp (B)**	
		P-value		Lower	Upper
Rearing patterns					
Group herd	-0.135	0.678	0.874	0.462	1.653
Single herd	0.148	0.649	1.16	0.612	2.197
Rearing areas (Rai)					
>=5	-0.171	0.416	0.843	0.558	1.273
Cows number					
>=5	0.002	0.655	1.002	0.994	1.009
Herd management					
Sufficient qualified water supply	0.253	0.327	1.288	0.776	2.138
Manure and Waste management	-0.139	0.677	0.871	0.454	1.67
Provide only roughage	0.479	0.058	1.615	0.983	2.653
Provide mixed roughage and concentrate*	-0.643	0.005	0.526	0.337	0.819
Mineral supplementation *	-0.536	0.04	0.585	0.351	0.975
Reproductive Management					
Breeding recording*	-0.512	0.024	0.599	0.385	0.934
Estrus examination	-0.177	0.584	0.838	0.445	1.577
Synchronization estrus by hormonal usage*	-1.072	0	0.342	0.194	0.603
Regular Pregnancy diagnosis	0.465	0.072	1.592	0.96	2.64
Estimation of calving date	0.28	0.297	1.323	0.782	2.236
Health Management					
Health recording	-0.8	0.817	0.913	0.469	1.816
Regular FMD vaccination	0.343	0.228	1.409	0.807	2.46
Regular HS vaccination*	-0.1442	0.001	0.237	0.164	0.34
Regular other vaccination	-0.486	0.089	0.615	0.352	1.076
Regular vaccination of FMD+HS	-0.163	0.628	0.849	0.439	1.643
Regular vaccination of FMD+HS+others	-0.274	0.243	0.76	0.48	1.204
Regular deworming*	0.657	0.004	1.929	1.232	3.018
Appropriate treatment of sick cattle	0.36	0.209	1.433	0.817	2.511

*The average score of parameter differs significantly, $P < 0.05$.

4.3 Influencing Factors of Small-Scale Beef Farms' Sustainability in Thailand

Factors influencing family farm sustainability were identified at farmer and farm levels. These include the farm's potential scores for the herd, health, and reproductive management, as well as the farmers' socio-economic status. Comprehensive data demonstrated that all aspects of farm management scores were pivotal for the sustainability of beef cattle farming. Notably, both ANN analysis (Figure 2) and logistic regression (Table 5) pinpointed reproductive management as the foremost determinant of professional sustainability, followed by health and herd management, respectively. A detailed examination (Table 5 and Figure 4) revealed that the young generations of farms with high and medium reproductive management scores were 3-fold and 2-fold more likely to continue the profession of beef farming compared to lower-scoring counterparts. This was similar to those with high and medium health management scores, which were 2.5 times and 1.6 times, respectively, more inclined to continue family farming. Moreover, farms exhibiting high herd management scores saw family members 1.8 times more likely to perpetuate the beef farming business relative to those with a low management score.

Regarding the farmer's socio-economic status, the ANN model (Figure 3) pinpointed occupation as the most important factor. However, logistic regression highlighted both gender and occupation as significant determinants of beef farming's sustainability (Table 5 and Figure 4). Notably, farms with owners serving as local administrative organization officials (SAO members) or as part of a family farm were 7.6 times and 4.7 times more likely, respectively, to continue in beef farming compared to farms with owners in other professions. Female-owned farms exhibited a 1.5-fold higher likelihood of persisting in the profession compared to male-owned farms. However, factors such as age, educational level, cattle farming experience, and the number of cattle raised did not significantly impact the profession's sustainability.

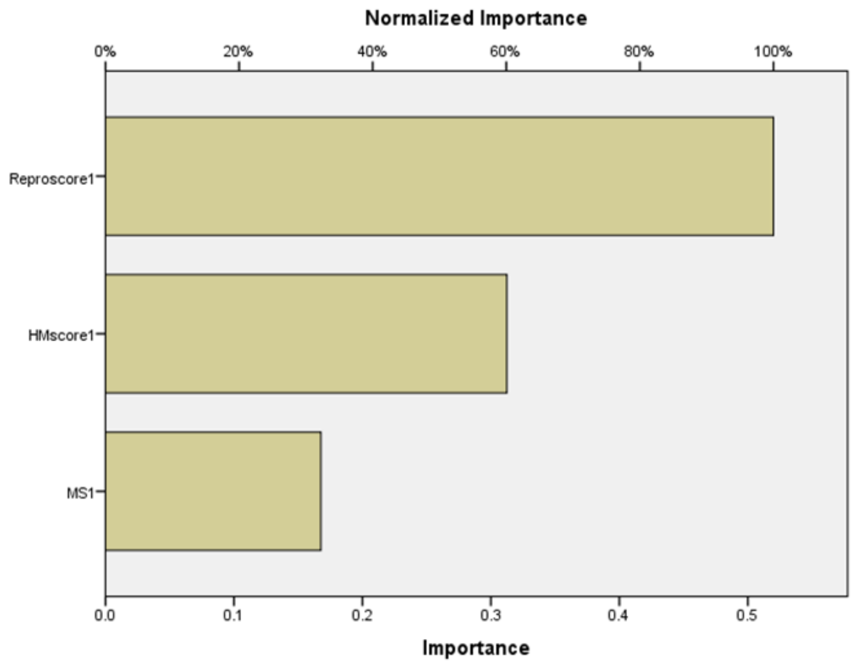

Figure 2 Neural Network Analysis of Important Factors Affecting Beef Farming Sustainability Based on Reproductive (Reproscore1), Health (HMscore1), and Herd Management (MS1) Scores

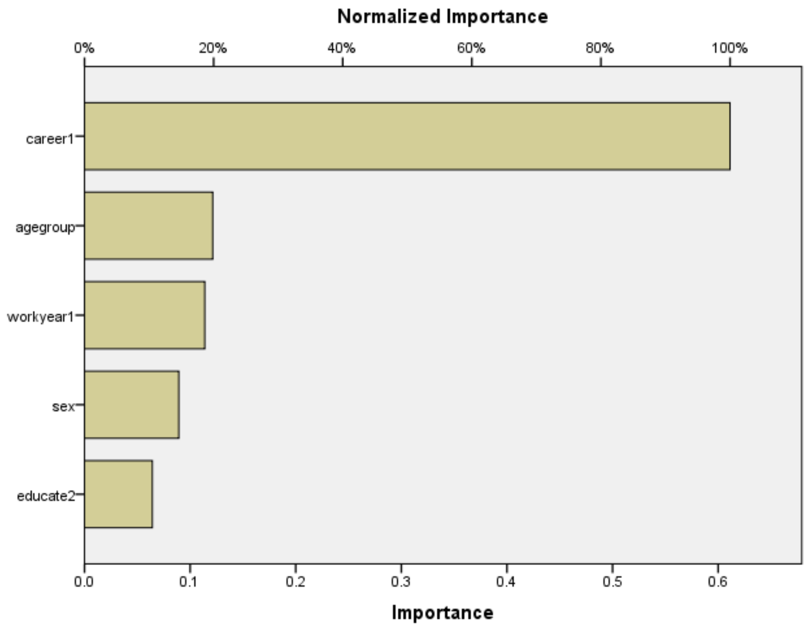

Figure 3 Neural Network Analysis of Important Socio-Economic Factors Affecting Beef Farming Sustainability Based on Occupation (career1), Age (agegroup), Farm Duration (workyear1), Gender (sex), and Education (educate2)

Table 5 Factors Influencing the Intention of Farmers' Descendants to Continue Careers in Small-Scale Beef Farms

Factor	Beta	*P-value*	OR	95% confidence interval Lower-Upper
Farm Potential				
Herd management score				
1 Low	Ref.	-	-	-
2 Medium	1.06	<0.01	2.89	2.07-4.03
3 High	1.74	<0.01	5.68	3.63-8.90
Reproductive management score				
1 Low	Ref.	-	-	-
2 Medium	1.63	<0.01	8.02	3.65-7.07
3 High	2.08	<0.01	5.08	5.08-12.67
Health management score				
1 Low	Ref.	-	-	-
2 Medium	0.38	0.03	1.46	1.05-2.03
3 High	1.63	<0.01	5.09	3.24-7.98
Farmer socio-economic profiles				
Gender				
Male	-0.41	0.02	0.66	0.47-0.98
Female	Ref.	-	-	-
Age (Year)				
<= 45	0.25	NS	1.28	0.86-1.91
46-60	-0.02	NS	0.98	0.71-1.36
>=61	Ref	-	-	-

Table 5 (Continued)

Factor	Beta	P-value	OR	95% confidence interval Lower-Upper
Education (School)				
Primary	-0.24	NS	0.79	0.46-1.36
Secondary	-0.33	NS	0.72	0.39-1.32
College	Ref.	-	-	
Occupations				
1 Farmer	1.76	<0.01	5.84	2.26-15.08
2 Government officials	0.61	0.33	1.83	0.55-6.16
3 SAO member	2.01	0.004	7.47	1.87-29.88
4 Others	Ref.	-	-	-
Duration of farming				
<= 6 ปี	0.13	NS	1.14	0.69-1.88
7-20	0.42	NS	1.52	0.97-2.36
>=21	Ref.	-		

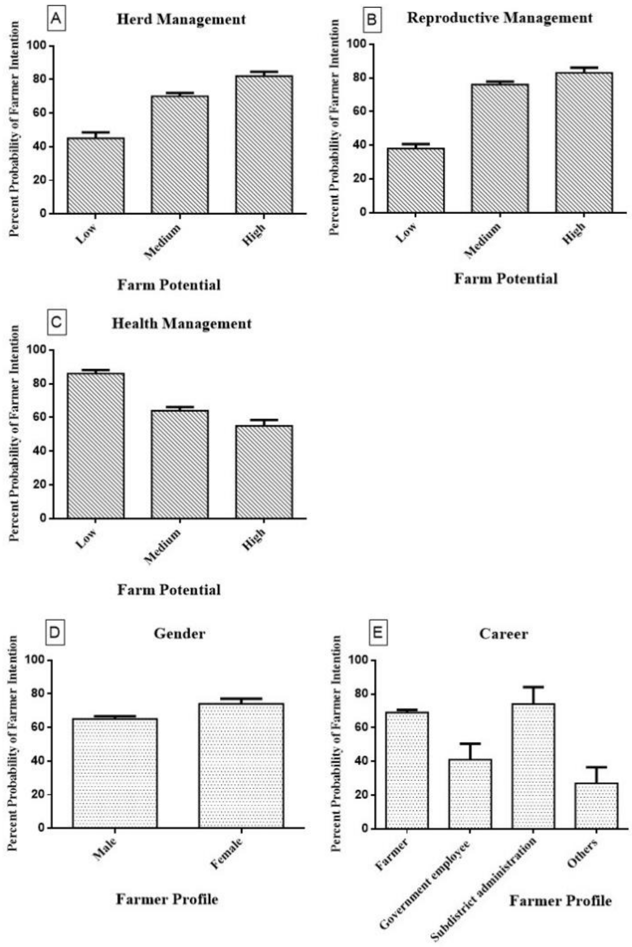

Figure 4 Probability (%) of Farmer Descendants Pursuing Beef Farming, Correlating with Farm Potential Score and Farmer Profile

5. DISCUSSION

Beef farming plays a role in addressing several of the Sustainable Development Goals (SDGs) established by the United Nations, including SDG1 (zero hunger), SDG3 (good health and wellbeing), SDG8 (decent work and economic growth), SDG13 (climate action), and SDG15 (life on land) (Arvidsson Segerkvist et al., 2021). Similar to the perception of smallholder beef farmers in developing nations such as Indonesia, this research emphasizes economic and social sustainability in terms of preserving familial farming traditions. Both Thai and Indonesian smallholder beef farms confront challenges such as inconsistent feed resources, increasing debt, and the younger generation's waning interest in agriculture. However, the findings of this study suggest that the younger generation might remain in beef cattle farming if they inherit knowledge from previous generations and recognize its profitability potential (Gayatri & Vaarst, 2020).

This study examines the sustainability of beef farming by identifying key factors at both the farmer and farm levels. These factors encompass farm potential, emphasizing reproductive, health, and herd management, as well as the farmer's gender and primary occupation. Earlier research indicates that many farmers leave this profession due to challenges in achieving the desired reproductive performance (Rojanasthien, 1995). The findings underscore the reproductive management score as a crucial determinant of beef farming sustainability. Regarding health management, research on Indonesian smallholder beef farms indicated diseases (diarrhea, scabies, flatulence, itching, demodecosis, pink eye, anthrax, infertility and epizootic septicemia) as determinants of farm sustainability (Mashur et al., 2022). However, factors such as farmer age, education, farming duration, and farm size showed no significant correlation in this study. Previous work on feed management suggests that larger farms (> 25 cattle) are more energy-efficient than smaller ones (5-10 cattle), emphasizing the need to adjust feed levels for energy sustainability without sacrificing productivity (Demircan & Koknaroglu, 2007). Furthermore, the future of Asian smallholder farming can be shaped by various catalysts, including innovations that offer immediate benefits, capacity-building strategies, and market-linked approaches (Stur et al., 2013).

This study employed an Artificial Neural Network (ANN) model to assess the key factors impacting the sustainability of small-scale beef farms. While previous research identified significant predictive inputs with acceptable accuracy (Dreiseitl & Ohno-Machado, 2002; Naseri & Elliott, 2010), the specific contributions of individual parameters within ANN models remain largely unexplored (Gevrey et al., 2003; Olden et al., 2004). Therefore, a logistic regression model was also applied in parallel. The results show that ANN generates predictions that are comparable to the logistic regression. Both models identified similar important factors influencing the intentions of farmers' descendants to continue careers in small-scale beef farms, i.e., the farm's reproductive management score, health management score and the respondent's occupation, suggesting that neural network analysis is an alternative method for ranking the remarkable factors related to personal attitudes as the neural network can learn from data and is able to handle noisy, complex and incomplete data in the livestock farm surveys (Wawrzyniak et al., 2022).

The sustainability of beef cattle production requires enhanced farm efficiency and productivity (Capper & Bauman, 2013). As Thailand pushes for sustainable beef farming in alignment with its national strategy, the GAP for beef cattle farming offers a reference for beef farming practices. However, the findings in this research have revealed that the majority of beef farmers are not entirely compliant with these standards, underscoring an imperative for future farm enhancement. Nonetheless, the findings provide valuable insights into determining developmental directions based on the factors affecting beef farm sustainability. Notably, policymakers must prioritize reproductive management, as it is a crucial factor directly influencing the sustainability of beef farming (Caldow et al., 2005; Thundathil et al., 2016). This can lead to enhanced beef farm productivity, particularly in breeding herds. Moreover, investments in animal health and comprehensive farm management are essential to bolster beef farming sustainability. From a socio-economic lens, farmer gender and primary occupation emerged as influential determinants in sustainable beef farming. These aspects profoundly sway the longevity of the beef farming profession. However, this study also highlights that the quantity of cattle may not necessarily dictate beef farming sustainability.

Beef production efficiency is measured by the CR, an indicator grounded in field-collectible data (Ponzoni, 1992). Factors influencing the CR encompassed estrus detection, timing of AI, semen quality, pregnancy care, post-calving care, and the expertise of AI personnel. The optimal AI time for Thai cows is typically 6-8 hours after the onset of standing estrus. Furthermore, maintaining reproductively active cattle free from diseases such as bovine tuberculosis and infectious rhinotracheitis (IBR) is paramount (Veerakul et al., 2005). Additionally, farms affiliated with AI stations boasting a CR of $\geq$ 60% typically have superior farm management scores, suggesting a correlation between reproductive and health management proficiency with higher CRs. While the efficiency of AI officials undeniably influences CR, field observations underscored the advisory role these officials hold, guiding farmers in farm management strategies. Consequently, the relationship between farmers and AI officials could be a pivotal determinant in enhancing farm management, thereby positively impacting the CR.

Socio-economic factors surprisingly did not exert a significant influence on the CR. Notably, cattle farming was often a secondary occupation for many participants in this study, even when their primary profession was still within the agricultural sector, such as rice farming or fruit cultivation. This suggests that these farmers might not prioritize beef cattle rearing, possibly lacking the motivation to acquire the necessary knowledge or practice optimal management techniques. Although one might assume that a prolonged duration in cattle farming, with an average of 14.24 years among participants, would equate to better management due to increased experience, this isn't necessarily the case. Given that most farmers view beef cattle rearing as an ancillary occupation, often not anticipating substantial profits from it, their commitment to best practices and continued learning could be limited, regardless of how long they've been involved in the activity.

Factors related to beef cattle rearing methods, such as group or individual rearing, impact the CR. A retrospective study (Diskin & Sreenan, 2000) links CR with insemination success, influenced by estrus detection rates. Accurate estrus detection relies on observing specific cattle behaviors, more evident in group settings that allow for cattle interaction. While this study found most cattle were backyard-reared, hindering effective estrus detection, herd size also played a role. Smaller herds, especially those with fewer non-pregnant cows, pose challenges in observing estrus behaviors, as these signs are more pronounced with multiple cows in estrus. In this sample, farmers typically had 7-8 cattle, with only 4.9% maintaining herds of 20 or more. Challenges in estrus detection consequently led to decreased insemination and conception success, impacting CR.

Feeding types and mineral supplementation correlated with the CR, echoing expert opinions ranking these factors highly for beef productivity in Thailand. They also emphasize the critical role of sufficient qualified water that is essential for cattle health and reproductive function. Proper water management is vital throughout a cow's life cycle. Nutritional balance, assessed through food component analysis and body condition scores, also influences cattle reproductive systems, as they require a balanced diet of concentrate and roughage (Canal et al., 2020). While some cattle receive minerals from government-distributed blocks, this periodic supplementation may not consistently meet their needs. Gayatri and Vaarst (2020) recommend enhancing sustainability through better beef farm management, including optimized feeding practices. Additionally, Nakamanee et al. (2008) found that increased beef cattle production in Thailand contributes to stabilizing the fresh forage supply-demand balance, since roughage is a primary feed source for cattle.

Reproductive management, particularly data recording of breeding events, was significantly associated with CR, aligning with expert opinions and previous study (Larson & White, 2016). This study identified a negative correlation between synchronization hormone usage and CR, contrasting with previous findings highlighting its benefits (Johnson & Day, 2004; Mialot et al., 2003; Thomas et al., 2016). An estrus synchronization program in Thailand led to increased insemination and a 7% rise in pregnancies (Aiemlamai, 2005). Differences might arise from the limited use of these hormones by small-scale farmers, pointing to inherent conception challenges. Relying solely on natural reproduction limits beef cow productivity and potential profits (Hlavatý et al., 2023), emphasizing the necessity for controlled hormonal interventions. Monitoring calving is positively correlated with CR, consistent with research noting that attentive management can minimize calving complications (Mee et al., 2008). Contrarily, estrus detection showed no correlation with CR, diverging from expert rankings. Although 68.43% of farmers practiced estrus detection, only 0.5% followed best practices, checking at least twice daily for 20-30 minutes (Graves et al., 1997). Many beef cattle exhibit unclear estrus signs, short estrus periods, abnormal estrus cycles, or silent heats and 25% of cows show estrus signs for less than 8 hours (Rojanasthien, 1995). The inconsistency in estrus sign clarity and duration might explain the lack of a significant difference in CR between different estrus detection practices.

Regular deworming shows a statistically significant positive correlation with CR, consistent with previous research (Stromberg et al., 1997). This suggests that parasites can impede nutrient intake, subsequently affecting the reproductive system. Conversely, there’s a notable negative correlation between vaccination and CR. The specific reason, especially regarding FMD and HS vaccinations, leading to reduced CR remains unclear. It’s hypothesized that the stress from restraining animals during vaccination may be a contributing factor. Further investigations are required to validate this assumption.

6. CONCLUSION

The present study primarily aimed to evaluate various management facets of beef cattle farms, encompassing herd, reproductive, and health management. Assessment was based on the GAP guidelines for beef cattle set by the National Bureau of Agricultural Commodity and Food Standards. By weighing the compliance to these standards against expert opinion, a management potential score was derived for each farm. Notably, farms with an AI station-CR ≥ 60% had significantly higher management scores, especially in reproductive and health areas, compared to those with an AI station-CR < 60%.

In conclusion, this study underscores that effective farm management is integral to achieving commendable productivity. The findings offer insights into small-holder beef farming in Thailand, highlighting the factors that influence production. Although the socio-economic factors of farmers do not appear to directly influence calving rates, they significantly affect adherence to the GAP standards for beef cattle farming. Key determinants of farm management quality included the farmer’s experience and primary occupation. Notably, farmers with up to 6 years of experience outperformed those with over 21 years in terms of herd and health management. Additionally, farms with fewer cattle (≤5) had superior reproductive management scores. These insights are invaluable for policymakers aiming to support small-holder beef farmers and enhance Thailand’s beef production. Furthermore, understanding the management practices influencing the next generation’s intent to continue in farming can guide strategies for sustainable beef production enhancement.

6.1 Practical Recommendations

This study highlights that some beef farmers are aware of their challenges and identify potential factors to boost beef productivity. Based on the findings, suggested interventions are given as follows:

6.1.1 Infrastructure Enhancement of Farms: Improved farm infrastructure is essential, emphasizing water sources, waste management, adequate space for cattle rest and shade, and calving pen and fence structures. Such enhancements align with superior farm management practices. Proper infrastructure addresses farm management challenges and prepares farmers for future expansions in line with the bioeconomy (Harrahill et al., 2023). Additionally, a well-organized farm enhances biosecurity, mitigating external disease risks that affect production.

6.1.2 Government Subsidization: The government should initiate projects offering farmers support, including quality beef cattle breeds, shelter, veterinary resources, and proper feed management, as many lack understanding in these areas. Access to AI tools, high genetic value bull semen, and training on beef cattle practices is essential. Given the limited state resources, policymakers should prioritize supporting farmer groups with the potential for sustainable productivity, especially those meeting GAP standards, focusing primarily on beef cattle farming, or with less than 6 years of experience in beef rearing.

6.1.3 Market Access for Farmers: Standard pricing for live beef is crucial for farmers. A market supporting both upstream and downstream cattle purchases at standardized prices, or with proper incentives, is essential (Goddard & Boaitey, 2016). This would counteract middlemen's price reductions and the effect of subpar beef on market rates. Furthermore, strategies should be developed to increase beef exports, particularly to nearby high-demand countries.

6.1.4 Breed Improvement: Improving genetic selection using AI clearly demonstrates an opportunity to improve sustainability (Goddard & Boaitey, 2016; White et al., 2015). Easy access to frozen bull semen is essential for breed upgrading tailored to regional needs or specific farmer preferences. Key breeds for improvement in Thai beef farms include Charolais, Brahman, and Angus.

6.1.5 Augmenting AI Services: Expand AI stations and deploy more AI officials throughout beef cattle regions. Offer farmers guidance on effective breeding practices, including optimal AI timing, heifer puberty preparation, semen handling, and infertility solutions. Addressing insemination challenges is essential for enhancing farm productivity and sustainability.

6.1.6 Establishment of Local Beef Cattle Rearing Promotion Units: Officials should be deployed to provide knowledge and assistance to farmers. For sustainable family farms, a systemic approach with customized solutions is crucial (Colnago et al., 2021). This fosters ongoing development, timely issue resolution, and adoption of innovative practices for improved production efficiency.

6.2 Limitations and Future Research

Cattle farm sustainability can be assessed through various dimensions, including nutrient surplus, land use, greenhouse gas emissions, and animal welfare (Sturaro et al., 2012). While research on livestock sustainability, especially in small-scale beef cattle farms in developing countries, is limited (Bahta et al., 2023; Honjo et al., 1989; Ogino et al., 2016), this case-control study focused on traditional parameters. Future research should integrate modern technologies such as smart farming, precision diets, reproductive biotechnologies, molecular genetics, and animal welfare management (Greenwood, 2021; Lyles & Calvo-Lorenzo, 2014; Pulina et al., 2021; Ventura et al., 2016). Such innovations can elevate the ecological and efficiency aspects of beef cattle farming sustainability.

While CR is a suitable indicator for beef farm productivity, it couldn't be directly sourced from many farms due to inadequate record-keeping. Consequently, this study derived the CR at the AI station level. Data for CR calculations was managed by AI officials who oversee results with farmers and keep systematic records. This allowed for the analysis to discern farm-level factors influencing the area's overall CR.

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