Research Article

Sustainable Feed Supply for Bali Cattle Breeding Center in Pulukan, Bali, Indonesia: A System Dynamics Modelling

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Abstract | This study aimed to simulate and determine the dynamics of feed supply under three scenarios at the Bali cattle breeding centre in Pulukan, Bali, Indonesia. The system dynamics approach were employed to develop the model, and Pulukan data from 2019 to 2021 was used to validate the model. The data were analysed using Powersim Academic version 10. The dynamic modelling consisted of three sub-models, i.e., cattle population, forage production, and concentrate supplementation. The model predicted that the level of feed supply would increase as forage production was increased the cattle population was reduced and although concentrate supplementation was decreased. The simulations of three scenarios revealed that a combination of scenarios across the cattle-forage-concentrate nexus appears to be the most efficient in meeting answer to meet the standards for recommended nutrient intake. In conclusion, larger forage production rate and cattle distribution rate scenario returned the higher feedstock, which could supply 100% of the needs for protein and energy, and 96.5% for dry matter by 2029.

Keywords | Bali cattle, Feed supply, Forage production, Sustainability agriculture policy, System dynamics

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INTRODUCTION

Beef is an important source of protein and is the third most consumed protein source after chicken and fish (MLA, 2018). Recently, however demand has been growing (Rusdiana et al., 2018; Greenwood, 2021; Hadi and Chung, 2022). The Indonesian government is pursuing beef cattle development as part of agricultural development initiatives to increase food security systems (Agus and Widi, 2018). The government has established a "golden triangle" that includes management, breeding, and feeding (Amam and Harsita, 2019). Bali cattle are one of Indonesia's four indigenous cattle breeds, along with Madura, Pesisir, and Aceh (Sutarno and Setyawan, 2016; Diwyanto and Priyanti, 2008). According to BPS (2020), there are currently 17 million heads of local beef cattle in Indonesia, split between a variety of breeds, with Bali cattle accounting for the largest population (34.9%). In the context of rusticity, fertility, and low calf mortality, Bali cattle breeding programme have been established (Agung et al., 2019).

Feed is the most significant factor in beef cattle production (Finneran et al., 2010) and accounts for approximately 57% of total production costs (BPS, 2017). Beef cattle are ruminants whose natural diet comprises of all vegetative parts of grasses, legume plants, and other cultivated crops, collectively termed forage (Allen et al., 2011). Concentrate supplementation is required when the forage is poor quality and cannot provide sufficient amounts of nutrients (Romanzin et al., 2018; Mckay et al., 2019). A reliance on forage as the primary feed for beef cattle significantly affects beef production and quality (Razminowicz et al., 2006). It is essential to ensure a forage supply of forage sufficient to maintain beef cattle output (Boval and Dixon, 2012; Berca et al., 2021); thus, sustainability of the forage supply is the primary concern.

However, there are some key challenges to providing forage in Indonesia, i.e., (1) the unpredictability of production owing to the weather (Ardiansyah et al., 2022; Kumalasari et al., 2021), (2) the poor quality of the forage itself (Nasrullah et al., 2003), and (3) the restricted land area in which to plant forage (Bremer et al., 2022). Low productivity and limited land ownership may cause problems in forage supply and increase feed-related expenses. These existing forage supply issues may additionally have a feedback effect on cattle population development (Yuniar et al., 2016). As such, the feeding system has become an indicator used in cattle production (Arthur and Herd, 2008; Santana et al., 2014) to interpret actual conditions. The provision of feed for animals is a major contributor to both land and water use and greenhouse gas emissions (Adli, 2021). There is a lack of information regarding the provision of dynamic systems. Previously, models have only been reported on the basis of the related articles using the meta-analysis method (Adli et al., 2023; Sholikin et al., 2022).

The feeding system depends on various interconnected and dynamic systems. The interrelated nature of cattle and feed means that, a systems approach to balancing cattle production and feed production merits consideration. This research aimed to investigate the sustainability of feed supply for Bali cattle using a dynamic systems approach and model simulation process. This study used the Bali cattle breeding centre in Pulukan, Bali, as a case study.

MATERIALS AND METHODS

This study developed models based on a running system constructed with a dynamic model that displays the time function resulting from input changes for each observed variable using Powersim Academic 10 modelling software.

Quantitative model development

Quantitative agricultural and natural resource management applications have been used for forage production issues (Turner et al., 2013). This study collected quantitative data for model parameterisation and validation through direct interviews using questionnaire sheets. The data included cattle population structure, body weight, cropland and pasture production, concentrate feeding, and nutrient quality. Nutrient requirements were calculated using the daily nutrient requirements for calves (NRC, 2000; Moran, 2012), and young and adult cattle (Kearl, 1982). The variables measured were the supply of dry matter (DM), crude protein (CP), and total digestible nutrients (TDN). The Stock and Flow Diagram (SFD) was set to simulate the period from 2019 to 2029. The simulation end date was set for 2029, corresponding with the completion date for implementation of the National Strategic Plans of Sustainable Livestock Development 2025–2029 Ministry of Agriculture (RENSTRA PKH 2025–2029). It was assumed that increasing the feed supply to the recommended level by this date would contribute to achieving RENSTRA PKH 2025–2029. The model was validated using Mean Absolute Percentage Error (MAPE), a model calibration method (de Myttenaere et al., 2016).

The model was segmented into three sub-models: Cattle Population, Forage Production, and Concentrate Supplementation. Each sub-model was constructed based on fundamental herd processes and iterative consultations with the managers the at Pulukan breeding centre. The Cattle Population sub-model determines the behaviour of feed demand. The Forage Production sub-model determines the behaviour of forage supply as the primary ruminant feed, while Concentrate Supplementation sub-model determines the behaviour of concentrate supply in feed. The existence of policy intervention in a sub-model impacts the other sub-models and affects the output of the model.

RESULTS AND DISCUSSION

Description of the study area

The Pulukan breeding centre is a technical implementation unit of the Directorate General of Livestock and Animal Health Services, Ministry of Agriculture, which is responsible for the breeding, production, rearing, development, and distribution of Bali cattle breeds. Pulukan is located in Jembrana Regency, Bali Province and has 70 hectares of pasture divided into 15 paddocks and 26.5 hectares of cropland. Pulukan has both intensive and extensive farming systems. The feeding system at Pulukan is heavily dependent on forage and purchased concentrates. A system of intensive farming feeding is carried out directly with the provision of cut grass, legume, and concentrates. In contrast, an extensive farming feeding system comprises carried out by grazing on available pastures of competidor grass (*Paspalum notatum cv. competidor*) and obtaining cut grass, legume, and concentrates. The forages supplied is king grass (*Pennisetum purpuphoides*), while the legume is Indigofera (*Indigofera zollingeriana*). Concentrates are provided for calves and adults.

Causal loop diagram (CLD)

The CLD development in this study (Figure 1) reveals several reinforcing and balancing feedback loops. The Cattle Population loop represents the Bali cattle population growth, and reinforcing (R) and balancing (B) feedback loops. Loop R1 shows that a larger population will usually translate into a more significant number of births, leading to an even larger population size over time. Loop B1 indicates that a larger population generally leads to more significant mortality, while a larger mortality will lead to a smaller population. Loop B2 shows that a larger population will lead to a larger cattle distribution (cattle out), and a larger cattle distribution will lead to a smaller population. Loop R2 indicates that a larger population will increase feed demand and supply. With an adequate feed supply, the population size will increase. The Forage Production loops represent the forage crops and pasture production, providing feed for an increasing cattle population. Loop B3 shows that greater demand for feed will lead to a larger supply of feed and forage. In turn, a larger forage supply will lead to lower forage availability. Lower forage availability will lead to lower feed availability and a smaller population. A smaller population will lead to lower feed demand. Forage production is a balancing loop, where an increase in forage production reduces concentrate supplementation. The Concentrate Supplementation loop represents the feeding of concentrate feeding to increase nutrient supply. Loop B4 shows that an increase in forage supply will increase the feed supply and nutrient supply, such as that of DM. Increasing the supply of DM will increase the supply of CP and TDN. An adequate nutrient supply will decrease concentrate supplementation.

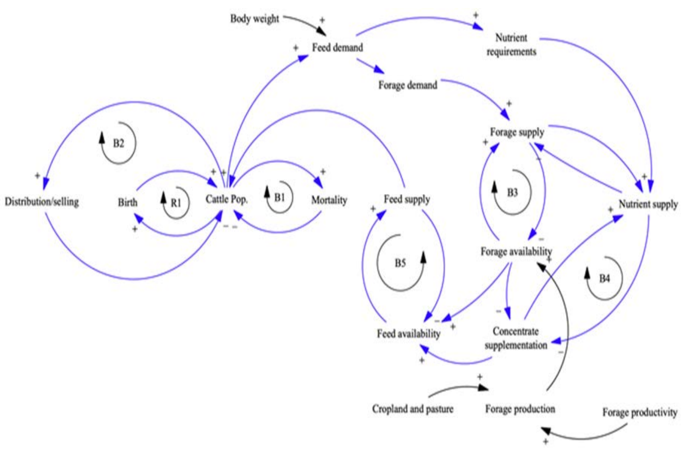

Figure 1: Causal loop diagram of the sustainable feed supply

Stock and flow diagram

The CLD conceptual model was then formulated into a system dynamics model using the SFD. This process changes the transformation from informal conceptual to formal conceptual. The top-level module structure mirrors the overall causal structure hypothesized in the CLD. Figure 2 illustrates the feedback loops among the Cattle Population, Forage Production, and Concentrate Supplementation sub-models. The feedback loop between Cattle Population and Forage Production indicates that cattle population increases, forage availability reduces, and vice versa. A feedback loop between the Forage Production and Concentrate Supplementation sub-models shows that an increase in forage production increases will lead to feed availability increase and concentrate supplementation, and vice versa. The SFD structures used within each sub-model are explained below.

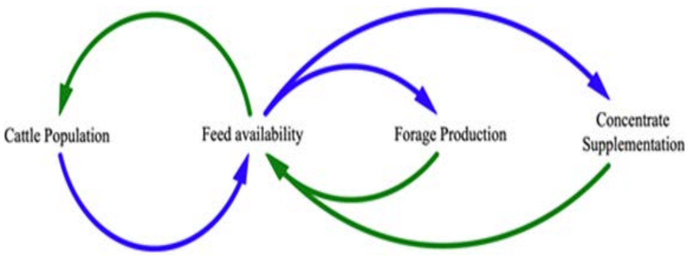

Figure 2: Top-level model structure composing the sustainable feed supply

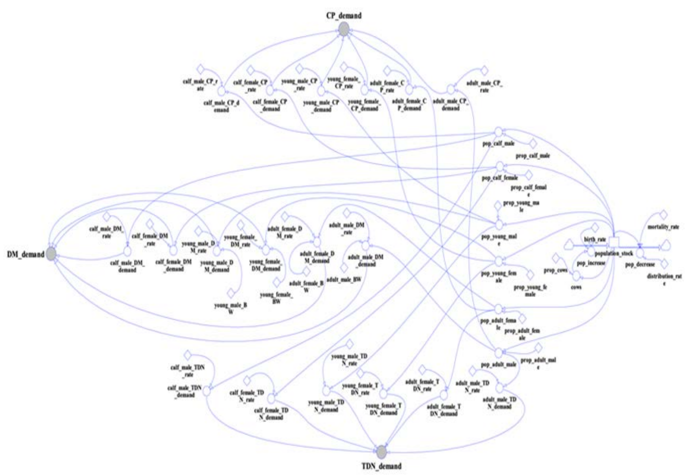

Figure 3: Stock and flow diagram of the cattle population sub-model

Cattle Population sub-model

The sub-model containing the SFD is shown in Figure 3. The Cattle Population sub-model is based on the age of cattle, with calves (<1 year), young (1-2 years), and adults (>2 years). The population structure of Bali cattle in Pulukan is dominated by adult female cattle, which account for an average of 50% per year of the total population. The stock for cattle increases by the increase rate, which is determined by the proportion of cows in the population and the birth rate. The stock for cattle flow decreases by the decline rate, which is determined by mortality and distribution. The cattle population dynamics that occur over a year will affect the feed demand. The development of the Cattle Population sub-model in the forage production simulation aims to predict future feed demand based on the cattle population dynamics since 2019.

Forage Production sub-model

Forage crops and pasture were designated as the primary feed source for the simulation. The forage crops and pasture components are dynamic, thus influencing the availability and quality of forage. As the primary determinants of forage supply, forage crops and pasture production can affect feed supply. The Forage Production sub-model in this study (Figure 4) involved king grass (*Pennisetum purpuphoides*). Other forage crops were a legume, namely Indigofera (*Indigofera zollingeriana*), and pasture, i.e., competidor grass (*Paspalum notatum cv. competidor*). King grass, Indigofera, and competidor grass stocks are needed for forage crops and grazing due to the increasing cattle population and the need to maintain that cattle population. Forage crops and pasture (in hectares) influence the feed (in tonnes) available, which is influenced by the production rate of cropland and pasture.

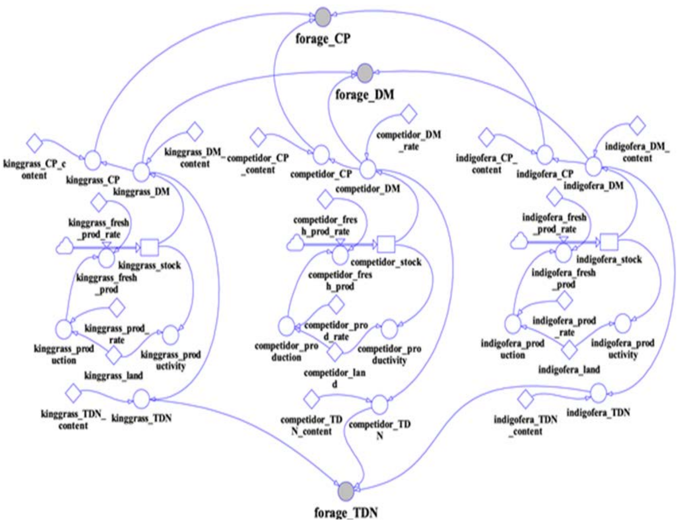

Figure 4: Stock and flow diagram of the forage production sub-model

Concentrate Supplementation sub-model

The aim of providing concentrate is to improve feed quality and reduce the gap between nutrient requirements and nutrient supply from forage. The Concentrate Supplementation sub-model provided concentrate for both calves and mature cows (Figure 5). The provision of concentrate determines the total feed supply, including DM, CP, and TDN. The average DM and CP contents in the concentrate for calves were 89% and 19%, while the concentrate contents for mature cows were 88% and 14%, respectively. The concentrate stocks for calves and mature cows tended to decline by 10.9% per year. A low level of concentrate feeding may be continued to maintain the minimal concentrate input strategy and low production costs (Ramsbottom et al., 2015).

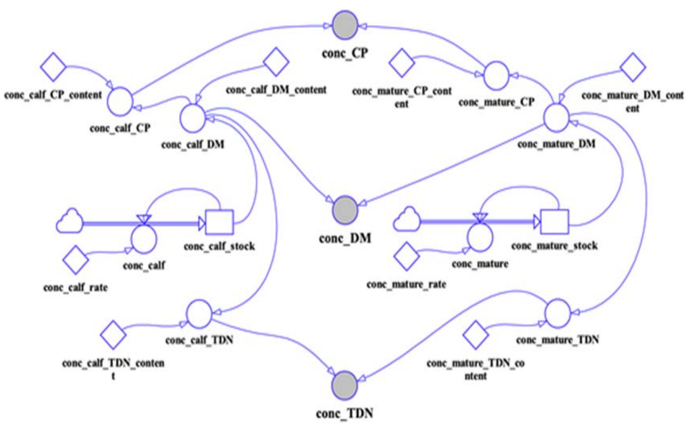

Figure 5: Stock and flow diagram of concentrate supplementation sub-model

Actual data, baseline simulation, and validation

Table 1 shows that the cattle population increased by 5% per year, from 1,084 heads in 2019 to 1,197 heads in 2021. The number of female cattle is greater than the number of male cattle. The ratio of males to females among adults is 1:3. The average body weights of the calves, young, and adults were 92.8 kg, 173.6 kg, and 255.7 kg, respectively. The males' body weight tended to be higher than that of the females. During 2019–2021, variations in cattle population growth caused fluctuations in nutritional requirements. Fresh forage production increased from 2,520 tonnes in 2019 to 3,312 tonnes in 2021, while concentrate supplementation decreased from 775 tons to 616 tonnes. Proximate analysis was employed utilized to evaluate the quality of forage and concentrate. The average DM contents in king grass, competidor grass, and Indigofera were 14.6%, 24.4%, and 32.2.8%, respectively, while the CP and TDN contents were 10.1%, 7.7%, 21.8%, and 59.8%, 61.7%, 64.3%, respectively. The average DM, CP, and TDN contents in concentrate for calves and adults were 89.1%, 19.3%, 73.2%, and 88.3%, 14.6%, and 74.3%, respectively.

The baseline simulation during the period 2019–2029 (see Fig. 6) revealed that the cattle population increased from 1,084 to 1,757 heads by 2029, while the nutrient requirements, such as DM, CP, and TDN, increased from 2,108.4 tonnes, 206.4 tonnes and 1,003.2 tonnes to 3,416.8 tonnes, 334.5 tonnes and 1,627 tonnes, respectively (Fig. 6A). Fresh forage production, including king grass, competidor grass, and Indigofera, increased from 2,520.1 tonnes to 6,278.9 tonnes by 2029 (Fig. 6B). Concentrate supplementation decreased from 775.6 tonnes to 275.6 tonnes by 2029, which decreased by an average of 10.9% per year (Fig. 6C).

Table 1: Actual condition in Pulukan breeding center

Actual Data	2019			2020			2021		
Population	**Heads**	**BW (kg)**		**Heads**	**BW (kg)**		**Heads**	**BW (kg)**	
- Population total	1,084	-		1,148	-		1,197	-	
- Calf male	61	94.5		91	100.0		101	86.0	
- Calf female	71	93.2		80	92.2		107	85.8	
- Young male	82	200.0		121	177.8		142	183.7	
- Young female	68	154.5		126	143.9		116	172.4	
- Adult male	251	297.6		145	262.8		152	318.9	
- Adult female	551	217.6		585	203.7		579	217.4	
Feed Production	Tons	DM, CP, TDN (%)		Tons	DM, CP, TDN (%)		Tons	DM, CP, TDN (%)	
- King grass	2,145.4	13.5; 10.5; 57.2		2,681.3	13.6; 9.8; 60.7		2,896.8	16.6; 10.0; 61.8	
- Competidor grass	232.3	23.2; 10.0; 57.0		258.5	29.4; 6.7; 65.4		274.5	20.6; 6.3; 62.9	
- Indigofera	142.4	31.1; 19.0; 64.3		120.1	32.9; 22.8; 66.7		141.3	32.7; 23.7; 62.1	
- Concentrate adult	707.4	89.6; 14.8; 74.7		613.8	86.9; 14.4; 73.0		549.6	87.3; 14.2; 75.2	
- Concentrate calf	68.2	89.7; 19.4; 72.8		82.8	88.7; 18.7; 74.7		60.2	88.3; 20.2; 72.3	
Nutrient Requirements	DM	CP	TDN	DM	CP	TDN	DM	CP	TDN
- Tons	2,249.7	215.1	1,060	2,094.5	211.4	1,023.8	2,290.6	144.5	1,060.2

BW = average body weight; DM = dry matter content; CP = crude protein content; TDN = total digestible nutrient content.

Table 2: Model validation through MAPE test

Variable	MAPE (%)	Validation*
Cattle Population sub-model:		
Cattle Population	0.4	highly accurate forecast
DM requirement	4.4	highly accurate forecast
CP requirement	2.4	highly accurate forecast
TDN requirement	4.2	highly accurate forecast
Forage Production sub-model:		
Forage production	2.2	highly accurate forecast
King grass production	2.8	highly accurate forecast
Competidor grass production	0.9	highly accurate forecast
Indigofera production	7.5	accurate forecast
Forage DM supply	5.9	accurate forecast
Forage CP supply	5,0	accurate forecast
Forage TDN supply	8.9	accurate forecast
Concentrate supplementation sub-model:		
Concentrate supplementation	0.7	highly accurate forecast
Concentrate DM supply	0.7	highly accurate forecast
Concentrate CP supply	1.1	highly accurate forecast
Concentrate TDN supply	0.7	highly accurate forecast

*Swanson (2015): <5%, highly accurate forecast; 5–10%, accurate forecast; 10–25%, low accurate forecast; >25%, very low accurate forecast (not acceptable)

The total feed supply for DM, both forage and concentrate, increased from 1,101.2 tonnes to 1,230.5 tonnes (Fig. 6D). Supply for TDN increased from 760.2 tonnes to 774.7 tonnes, while supply for CP decreased from 148.6 tons to 141.6 tonnes. Reduced concentrate supplementation implied a lower supply of CP. In the baseline simulation, the feed supply of DM, CP, and TDN would be 36%, 42.3%, and 47.6%, respectively, by 2029.

Scenario tests, analyses, and recommendations

The simulated and validated feed supply model was then transformed into "what if" scenarios to determine the sustainable feed supply (Table 2). In this study, scenario simulation was conducted by comparing the three scenarios and identifying the one policy with the best scenario. The scenario designs were implemented as follows, (1) Scenario 1, improved forage production and reduced concentrate supplementation; (2) Scenario 2, increased forage production, reduced concentrate supplementation, and increased cattle distribution; and (3) Scenario 3, increased forage production, reduced concentrate supplementation, and reduced Bali cattle population. This study assumed that the following sub-model that can affect the behaviour of the other sub-models as follows: (1). Interventions to improve forage production can lead to increasing feed availability in line with the growing demand for feed due to the rising population; (2). Interventions to increase the cattle population will increase feed demand and decrease feed and forage availability. In contrast, an intervention to decrease the cattle population will decrease feed demand and increase feed availability; and (3).

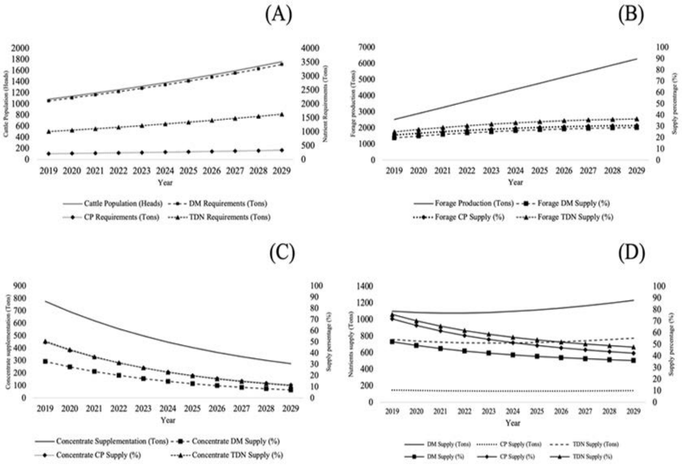

Figure 6: Feed supply model baseline run: (A) cattle population baseline; (B) forage production baseline; (C) concentrate supplementation baseline; (D) feed supply baseline

Interventions to increase forage production can reduce the use of concentrate, thus rendering Bali cattle breeding more efficient from a budgetary perspective. In this section, policy tests and analyses were performed to assess the key drivers of sustainable feed supply in Pulukan. From these analyses, policies are proposed to improve feed production levels. Overall, this study aimed to meet the recommended nutrient requirements by increasing forage production by a minimum of two times its current level; thus, the feasibility of the policy assumptions was relaxed. Below we present the three hypothesised policies, each of which potentially increase feed availability. The presence of testosterone produced by the testes in males means the males grow faster than the female livestock (Kusumawati et al., 2019; Susilawati et al., 2020; Susilawati et al., 2017).

Scenario 1 uses an intervention to improve forage production and reduce concentrate supplementation. Within this scenario, we assume that: (1) the king grass production rate is increased to a potential value of 25.5% per year from its current level of 2,145.4 tonnes through a cropland improvement plan; (2) the competidor grass production rate is increased by 26.2% per year from its current level of 232.3 tonnes through a pasture improvement plan; (3) the Indigofera production rate is increased by 0.9% per year from its current level of 142.4 tonnes; (4) the concentrate supplementation rate is decreased to 10.9% per year from its current level of 775.6 tonnes; and (5) the Bali cattle distribution rate is increased to a potential value of 16.6% per year.

Scenario 2 comprises an intervention to encourage a larger feedstock by increasing forage production, reducing concentrate supplementation, and increasing cattle distribution. The level of feed demand is steady due to the zero growth of the Bali cattle population during 2022–2029. Within this scenario, we assume that the Bali cattle population is held constant by increasing the cattle distribution rate to 21.4% from its current level of 16.6% per year. The forage production improvement and concentrate supplementation reduction were assumed to be similar to those in Scenario 1.

Scenario 3 uses an intervention to increase feed availability by increasing forage production and reducing the Bali cattle population to decrease feed demand. Within this scenario, we assume that the Bali cattle population is reduced by increasing the cattle distribution rate to a possible value of 26.1% from its current level of 16.6% per year. This scenario aims to reduce the existing Bali cattle population, assuming that the number of cattle out would be equivalent to the number of cattle births. In this scenario, the Pulukan manager will increase the distribution of mature or adult male cattle. A decline in the current population in Pulukan can occur due to cattle mortality, where the average mortality stands at reached 4.9% per year. Guimarães et al. (2009) reported that small changes in mortality rates could considerably affect herd dynamics as they relate to production outputs. The forage production improvement and concentrate supplementation reduction were assumed to be similar to those in Scenario 1.

Figures 7–9 present a compilation of graphs showing the baseline and the three policy scenarios tested in the model. For Scenario 1, where forage production is increased and concentrate supplementation is decreased, we observe that feed supply increases gradually with a maximum DM, CP, and TDN supply of 44.9%, 50.9%, and 58.9%, respectively, by 2029—producing a 20% increase on the baseline ("business as usual") run. In this scenario, we assumed that feed demand increases because the cattle population increases. Mortality and the cattle distribution rate are lower than the birth rate.

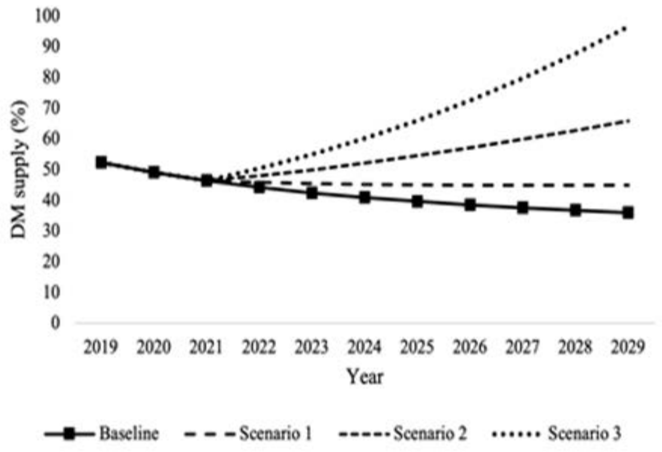

Figure 7: DM supply (in %) under various scenarios

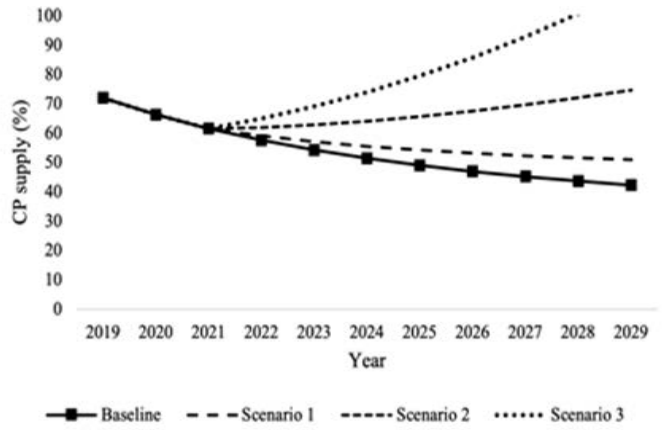

Figure 8: CP supply (in %) under various scenarios

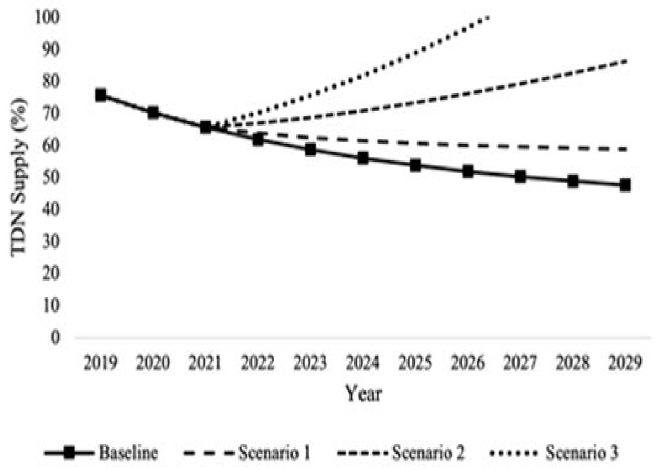

Figure 9: TDN supply (in %) under various scenarios

For Scenario 2, where forage production is increased and feed demand is assumed to be held constant, we observe that feed supply increases gradually with a maximum DM, CP, and TDN supply of 65.8%, 74.6%, and 86.3%, respectively—producing 80% increase on the baseline run. Another importance was utilisation of using fibre in the feed as previously shown on the (Adli et al., 2022). Finally, in Scenario 3, where forage production is increased, and the feed demand is decreased by decreasing cattle population, we observe that Pulukan will be able to produce more than a double increase on the baseline run and meet 100% of the needs for CP and TDN in 2028 and 2027, respectively, and a maximum DM supply of 96.5%. Where forage production is gradually increased to double and feed demand is decreased by 25% from its current level, shows a steady increase in feed availability to double the baseline scenario value in 2029. At the end of this simulation run, a feed supply level of 100% is assumed to be obtained, approximately two times greater than the baseline scenario.

Scenario 1—An increase in the feedstock via a higher forage production rate, obtainable through an improvement in cropland and pasture productivity, can lead to a slightly higher feed supply. In this case, the feed supply of DM, CP, and TDN would be 44.9%, 50.9%, and 58.9%, respectively, by 2029, compared to 36%, 42.3%, and 47.6% in the baseline run, which is far from the desired goal. The model analysis indicates that this sub-optimal outcome results from low feed production and high demand for feed from the population. Scenario 2—Increasing feed availability via an increase in through forage production, with constant feed demand from 2022 to 2029—does result in a higher level of feed supply in 2029 compared to Scenario 1 and the baseline scenario. In this case, the feed supply of DM, CP, and TDN would be 65.8%, 74.6%, and 86.3%, respectively, by 2029. While this intervention simulation has approaches the cattle nutrient needs, an increase in DM, CP, and TDN supply is still required.

Scenario 3— Policy to reduce the number of cattle in Bali, along with a policy to improve forage production, gradually reduce feed demand and increase feed availability, resulting in the highest feed supply. In this scenario, the feed supply would be 96.5% for DM and 100% for CP and TDN. The ability to provide DM, CP, and TDN is optimised, resulting in a gradual decline in the Bali cattle population, while concentrate supplementation is decreased. It is important to note that this policy neglects any negative influence on other variables in the model, as it is assumed that all positive gains in feed supply are obtained from internal efficiencies. This is because such policies would hypothetically be implemented through forage production improvement, concentrate supplementation, and Bali cattle population reduction programmes that are assumed would be properly funded and managed.

CONCLUSION

The forage production improvement policy (Scenario 1) does not achieve the desired feed supply. However, the feed supply will be significantly higher than if the cattle population is constant or even reduced (Scenarios 2 and 3). This study has shown that the scenario of increasing forage production, reducing the cattle population, and reducing concentrate supplementation will produce the highest feed supply by 2029. Within the model, this required strengthening the cattle population and concentrate supplementation balancing loops and strengthening the forage production reinforcing loop.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

NOVELTY STATEMENT

By using system dynamics modelling, the novelty of this research would help to determine variables that influence the dynamics of feed supply and investigate the sustainability of feed supply at the Bali cattle breeding center in Pulukan, Jembrana Regency, Bali Province. As consequences related to the information about this research the related government can be used to improve the quality of feed production policy.

AUTHORS CONTRIBUTION

Roy Malindo, Hosea Abdiel Duto Wicaksono, and Maskur contributed to collecting data, data analysis, system dynamic modelling, and preparing the original manuscript. Osfar Sjofjan and Siti Chuzaemi contributed to the research design, revised the manuscript and supervision. Anuraga Jayanegara supervised and revised the manuscript grammatically. All authors read and approved the final version of the manuscript in the present journal.

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