



## Negative Energy Balance and Reproductive Hormones in Postpartum Beef Cows Under Intensive Systems

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### ABSTRACT

Digital transformation in land systems in postcolonial countries challenges the legitimacy and effectiveness of customary justice in land dispute resolution. This qualitative juridical-sociological case study involved 15 key informants indigenous leaders, land officials, and residents in three Indonesian indigenous communities. Data were collected through in-depth interviews, field observations, and analysis of legal documents and digital maps, then examined using thematic analysis and source triangulation. Customary justice remains central in dispute resolution but faces normative and technological tensions due to misalignment with national land digitalization. Some socially recognized decisions lack legal force in the digital registration system, creating legitimacy dualism. Contextual integration between customary law and formal digital systems is essential to prevent exclusion of indigenous rights in the digital era.

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## INTRODUCTION

Beef production globally is facing high pressure due to increasing demand for animal protein and the need for livestock reproductive efficiency in intensive farming systems. Intensive systems are characterized by full swing, structured feed control, and aggressive reproductive performance improvement strategies (Roche et al., 2021). In Indonesia, increasing the beef cattle population is one of the national strategic targets in supporting food security, but the main obstacle still lies in the low efficiency of postpartum reproduction, especially in female cows (Ministry of Agriculture of the Republic of Indonesia, 2023). The physiological condition of beef cattle after calving is greatly influenced by their metabolic status and energy balance. One of the most common conditions is an energy imbalance or negative energy balance condition, which causes the cow's body to lack energy due to high metabolic needs that are not balanced with feed intake (De Souza et al., 2022). This phenomenon contributes greatly to the inhibition of hormonal activity and the delay of the subsequent reproductive cycle.

Negative energy balance after childbirth has been identified as one of the key factors that interfere with physiological homeostasis and affect the endocrine system in ruminants, especially female beef cattle. When a cow experiences a prolonged energy deficit, its body prioritizes vital functions such as organ maintenance and milk production, while reproductive function is suspended (Van Hoeck et al., 2020). This leads to a decrease in levels of important hormones such as progesterone, estrogen, luteinizing hormone, and follicle-stimulating hormones, which regulate ovarian activity and ovulation (Butler et al., 2021). In the context of intensive farming systems that do not provide flexibility for natural adaptation, these conditions become increasingly severe (Moraes et al., 2020). Globally, research shows that negative energy balance conditions are also correlated with delayed return time to first lust, abnormal ovulation, and decreased pregnancy success rates (Carter et al., 2022).

Although various studies have addressed the effect of energy balance on reproduction, most of the focus is still on dairy cows in dairy production systems, rather than beef cows in intensive systems. Studies by (Khan et al., 2020) show that negative energy balance plays a role in suppressing progesterone hormone levels in dairy cows, but not much is known about how this condition works specifically in beef cattle farming systems that have different metabolic and feed management patterns (Abeni & Petrera, 2023). In addition, local research in Indonesia highlighting the relationship between energy imbalance and reproductive hormone dynamics of beef cattle in an intensive context is still very limited. This shows that there is a significant knowledge gap, both conceptually and empirically, in understanding the physiological mechanisms that inhibit the reproductive efficiency of beef cattle after calving.

Previous research by (Ani et al., 2023) in South Sulawesi showed that most postpartum beef cattle in intensive farms showed a delay in re-calving by more than 60 days, which significantly reduced the pregnancy interval and annual productivity. However, the study has not explained in detail the relationship between energy metabolic status and reproductive hormone levels, and has

focused only on external estrus behavior. Therefore, this study aims to fill the research gap by examining the relationship between negative energy balance and key reproductive hormone profiles physiologically and laboratory in the intensive farming system of beef cattle in Indonesia.

This study explicitly aims to analyze the relationship between negative energy balance and levels of progesterone, estrogen, luteinizing hormone, and follicle-stimulating hormone in postpartum female beef cattle in intensive farming systems. The main focus is directed at how the body's energy status after childbirth affects hormonal dynamics that play an important role in the recovery of ovarian function and subsequent reproductive readiness. Using a quantitative approach and a longitudinal observational design, the study also observed gradual hormonal changes during the eight weeks postpartum (Hess et al., 2021).

Theoretically, this study is expected to contribute to enriching the literature on ruminant reproductive physiology, especially in understanding the role of metabolic status on postpartum endocrine regulation in beef cattle. In addition, this research can be an empirical reference to support the development of a theory of reproductive management based on physiological and nutritional conditions in modern livestock systems (Moraes et al., 2020). Knowledge of the direct relationship between energy balance and reproductive hormones may also open up opportunities for nutrition-based or management interventions to improve the efficiency of the reproductive cycle in the critical phase of the postpartum.

From a practical perspective, the results of this study have direct implications for feed management and metabolic improvement strategies in female beef cattle after giving birth. Information about the dynamics of hormone levels in conditions of negative energy balance can be the basis for farmers and veterinarians in developing prevention and improvement programs for reproductive disorders in the field (López-Gatius et al., 2022). Thus, this research contributes not only in the scientific framework, but also in the development of livestock policies that are science-based and responsive to reproductive challenges in the field, particularly in intensive livestock systems in developing countries.

## **THEORETICAL REVIEW**

### ***Negative Energy Balance in Postpartum Beef Cattle***

Negative energy balance is a common physiological condition in postpartum heifers, especially in intensive farming systems that demand high productivity but are often not balanced by optimal nutrient management. This condition occurs when the body's energy needs are greater than the energy intake from feed, causing the mobilization of the body's energy reserves which ultimately impacts the health and reproductive function of the cow (De Souza et al., 2022). In the early postpartum phase, cows experience increased energy requirements for uterine involution, milk production, and reproductive tissue recovery, which if not met will trigger prolonged metabolic stress (Moraes et al., 2020).

Research by (Van Hoeck et al., 2020) shows that in beef cattle, prolonged energy deficits after childbirth not only lower body condition scores, but also lead to impaired ovarian function and lower conception success rates. In Indonesia, a study (Ani et al., 2023) found that more than 60% of slaughtered cattle in intensive systems showed a delay in returning to the farm due to the unattainability of energy needs during the transition period. Therefore, the negative energy balance is a central issue in modern livestock reproduction, especially in the context of livestock intensification with little room for physiological adaptation.

### ***Dynamics of Postpartum Reproductive Hormones***

Reproductive hormones such as progesterone, estrogen, luteinizing hormone, and follicle-stimulating hormones play a key role in regulating the activity of the estrus cycle and postpartum ovulation. The production and secretion of these hormones is highly sensitive to the metabolic status of the body, especially to the presence of energy and body fat (Butler et al., 2021). In conditions of negative energy balance, there is a disturbance in the hypothalamic-pituitary-ovarian axis which leads to a decrease in the frequency of luteinizing hormone release as well as impaired follicle maturation (Roche et al., 2021). As a result, ovulation is delayed and the chances of pregnancy decrease significantly.

(Hess et al., 2021) identified that progesterone hormone levels tended to be low in beef cattle that experienced energy deficits during the initial postpartum phase, even up to the 6th week, which had implications for estrus cycle irregularities. This is reinforced by research by Carter et al. (2022) which shows that hormonal disorders due to energy deficits lead to subclinical anestrus, which is a condition without signs of bias even though the reproductive organs appear morphologically normal. These findings indicate that energy balance not only affects the condition of the body, but also regulates the course of the reproductive cycle through endocrine mechanisms.

### ***Intensive Farming Systems and Their Challenges to Energy Balance and Fertility***

Intensive farming systems provide advantages in the form of environmental control and improved space efficiency, but pose serious challenges to the energy balance and reproductive health of cattle. In this system, cows are fully caged and feed is given in a limited and standardized manner, so the possibility of energy deficiency is higher if feed management is not adjusted to the metabolic needs of postpartum cows (Abeni & Petrera, 2023). Limited movement and high energy competition between milk production and reproductive system recovery make cows susceptible to hormonal disorders.

(López-Gatius et al., 2022) states that without individual needs-based nutritional interventions, intensive systems can worsen postpartum physiological conditions and lower reproductive performance. This is in line with findings (Khan et al., 2020) which report that timely high-energy feed interventions can accelerate the return of estrus and significantly increase levels of the hormone progesterone. Therefore, energy balance-based management is crucial in intensive farming systems to ensure the sustainability of production and the reproductive efficiency of beef cattle.

## **METHODOLOGY**

### ***Types and Approaches to Research***

This study used a quantitative approach with a longitudinal observational design, to monitor the dynamics of energy balance status and reproductive hormone levels of postpartum beef cows. This design was chosen because it is able to depict periodic physiological changes during the eight-week period after birth, which is a critical phase of metabolic and endocrine recovery. A quantitative approach is considered appropriate because it emphasizes objective measurement and statistical analysis of the relationship between metabolic and hormonal variables (Hess et al., 2021; Carter et al., 2022).

### ***Population and Sampling Techniques***

The population in this study is all postpartum female beef cattle reared in an intensive system in the Bobonaro region, Timor-Leste. Samples were taken by probability method through purposive random sampling, with the inclusion criteria of cows that had given birth a maximum of 7 days before the observation began. A total of 30 cows were randomly selected to represent physiological and management variations in the field. Observations were made on each cow for eight consecutive weeks postpartum to capture physiological dynamics in the reproductive transition period.

### ***Data Collection Techniques and Instruments***

Data collection is carried out through laboratory measurements and field recording. Energy balance is calculated from data on daily feed consumption, weight change, and estimated energy needs based on National Research Council standards. Hormone levels were measured through weekly blood sampling for eight weeks, from the jugular vein. The samples were then analyzed using the Enzyme-Linked Immunosorbent Assay (ELISA) method at a partner laboratory in Kupang, Indonesia. The validity of the test tool is guaranteed by laboratory certification, while reliability is measured through test repeats and coefficients of variation between measurements (López-Gatius et al., 2022).

### ***Research Implementation Procedure***

The implementation of the research is divided into four stages. The first stage is postpartum cow selection (maximum age of 7 days), initial recording of body weight and body condition scores. The second stage is the collection of daily feed consumption and weekly weight data. The third stage is a weekly blood draw for eight weeks, followed by sample storage and shipment to a laboratory for hormone analysis. The last stage is data processing and analysis using a statistical approach.

### ***Data Analysis Techniques***

Data analysis was performed using multiple linear regression methods to evaluate the effect of energy balance on reproductive hormone levels throughout the eight-week period. Previously, the data was tested on statistical assumptions including normality, linearity, and heteroscedasticity. The analysis was

conducted using IBM SPSS Statistics version 26 with a significance level of 0.05. Results are presented in the form of weekly averages and hormonal trend graphs to provide an overview of biological patterns over observation time (Moraes et al., 2020).

## RESEARCH RESULTS

The results of the study have been systematically compiled based on observations of 30 female beef cows after giving birth for 8 weeks in the intensive farming system.

### *Tren Kadar Progesteron*

Progesterone hormone levels showed a clear pattern of decline from the first week to the fifth week of observation. In the first week after giving birth, the average progesterone level of beef cattle was 3.2 ng/mL. This value continued to decline progressively until it reached its lowest point in the fifth week, which was 2.0 ng/mL. After the fifth week, there is a gradual increase in the levels of this hormone until it reaches 3.0 ng/mL by the eighth week.

A decrease in progesterone levels during the early postpartum phase indicates an inhibition of the activity of the corpus luteum which functions as the main producer of this hormone. In accordance with the eight-week longitudinal observational research design used, the downward trend in the early phase reflects the most critical period of negative energy balance. This condition physiologically occurs because the metabolic energy needs of cows after calving increase sharply, while nutrient intake is often insufficient. The effect is a disruption in the synthesis of progesterone and a delay in the reactivation of ovarian function.

The trend of recovery in progesterone levels that occurred after the fifth week showed that most cows were beginning to enter a more stable metabolic phase. This recovery indicates a reactivation of the corpus luteum that allows the return of the cow to the estrus cycle. These data confirm that the restoration of energy balance is closely related to the normalization of the production of reproductive hormones, specifically progesterone, as measured weekly in this study.

As an illustration of the dynamics of the hormone progesterone observed during the eight weeks of the postpartum period, the following graph presents the change in weekly progesterone levels that reflect the phase of initial decline to final recovery:

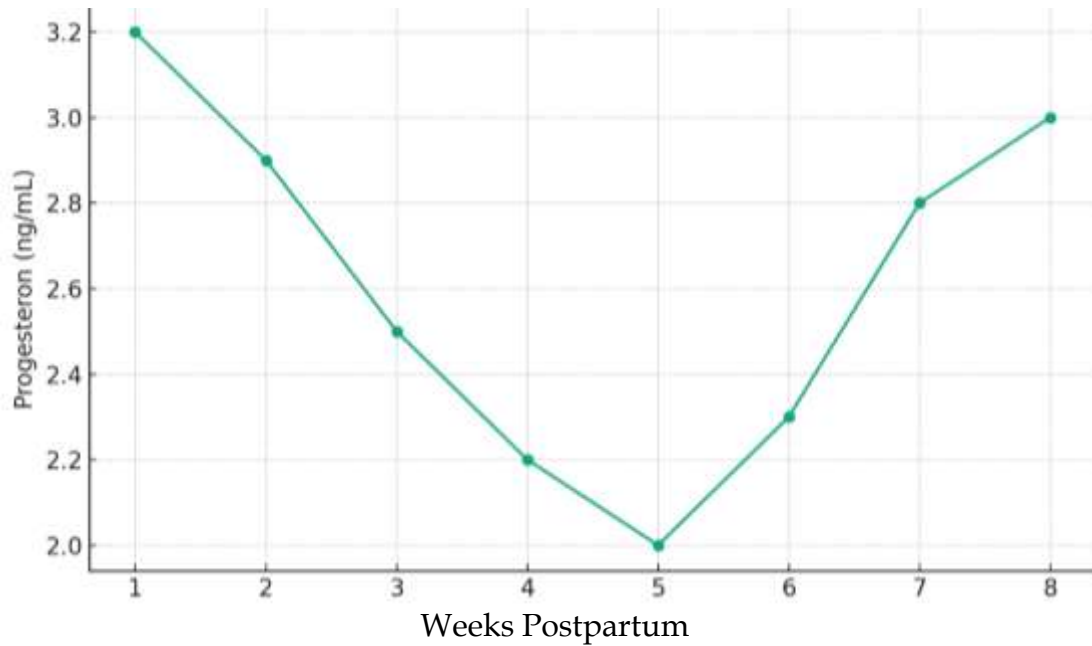


Figure 1. Progesterone Trend Chart During 8 Weeks Postpartum

This graph reinforces the quantitative finding that the decrease in progesterone occurs most significantly in the first five weeks postpartum before gradually increasing again.

#### ***Estrogen Decrease in the Early Phase***

The hormone estrogen, which has a major role in facilitating estrus and the development of the dominant follicle, experienced a progressive decline in the first five weeks of observation. Estrogen levels, which were initially at 12.5 pg/mL in the first week, continued to decline until they reached 9.7 pg/mL in the fifth week. This decrease indicates an emphasis on follicular activity in the ovaries, which is the impact of the negative energy balance that occurs after childbirth.

Estrogen is synthesized by granulosa cells in the ovarian follicle, and its production depends largely on the presence of a cholesterol substrate and the metabolic status of the cow. In the context of the intensive system that is the background of this study, the limited variety of feed and the high postpartum energy requirement result in metabolic priorities shifting from reproductive functions to vital functions, thereby reducing the synthesis of the hormone estrogen. Weekly measurement of hormone levels through the Enzyme-Linked Immunosorbent Assay (ELISA) in this study allowed careful observation of the pattern of decline.

Starting from the sixth week, estrogen levels show a gradual increase and reach 11.2 pg/mL by the eighth week. This suggests that the cows in the study are beginning to experience a restoration of follicular function and are preparing to return to the estrus cycle. Recovery in estrogen levels also serves as an indicator that the dominant follicle has developed physiologically close to the ovulation phase.

The following graph illustrates the trend in the estrogen hormone levels of beef cows during the eight weeks postpartum:

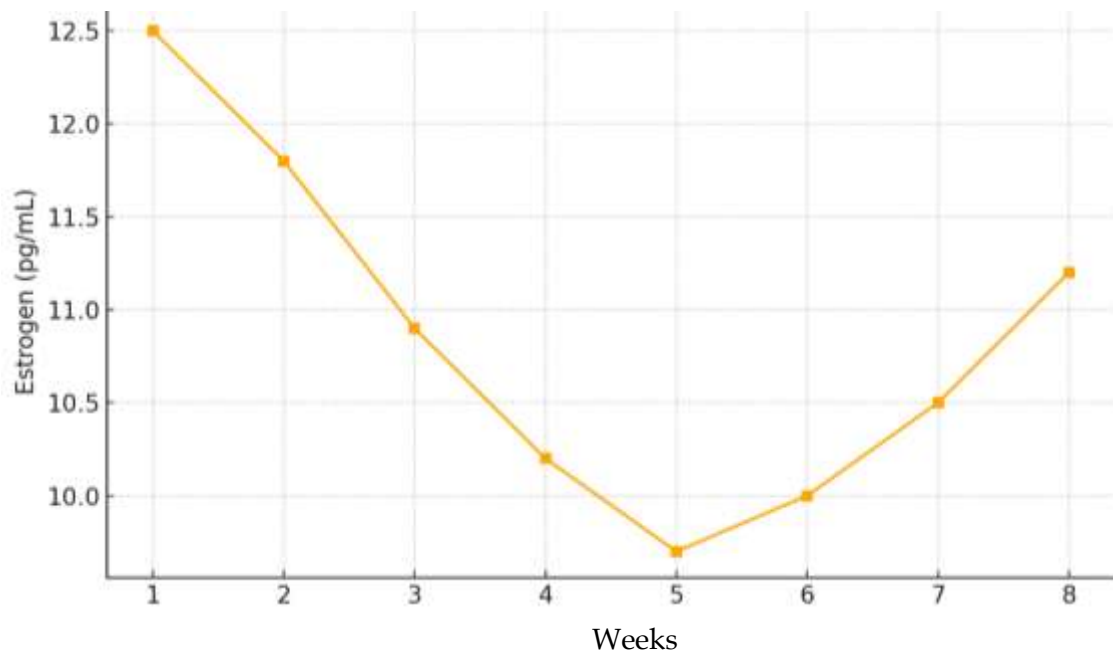


Figure 2. Trend Chart of Estrogen Levels During 8 Weeks Postpartum

This visualization shows a consistent pattern of decline during the first five weeks and a gradual increase thereafter, reflecting follicular inhibition related to negative energy balance and gradual recovery in the reproductive system.

### ***Luteinizing Hormone Fluctuations***

Luteinizing hormone is a gonadotropin hormone that is released from the anterior pituitary gland and plays an important role in the late maturation of follicles and the triggering of ovulation. In postpartum female beef cattle in this study, luteinizing hormone levels decreased from 6.1 mIU/mL in the first week to 4.2 mIU/mL in the fifth week. This pattern of decline is consistent with the effect of negative energy balance on the hypothalamic-pituitary-ovarian axis, which inhibits the release of gonadotropin-releasing hormone (GnRH), thereby reducing stimulation of luteinizing hormone.

A decrease in luteinizing hormone during the first five weeks can lead to impaired maturation of the dominant follicle and delayed ovulation. In intensive farming systems where feed control and range of motion are limited, metabolic stress conditions tend to be stronger, and this is reflected in disrupted hormonal patterns as shown in the data of this study. The weekly measurements made allow for the quantitative identification of critical phases of endocrine disorders.

In the sixth week onwards, luteinizing hormone levels began to show an increase again, reaching 5.4 mIU/mL by the eighth week. This increase suggests that the cow is beginning to restore the neuroendocrine ability to respond to ovulation stimulation. In practical terms, this data suggests that proper nutrition

management support can help accelerate luteinizing hormone recovery and improve postpartum reproductive performance.

To clarify the pattern of luteinizing hormone fluctuations, the graph below shows a sharp decrease from the first week to the fifth week, followed by an increase that signals the start of the restoration of ovulation function:

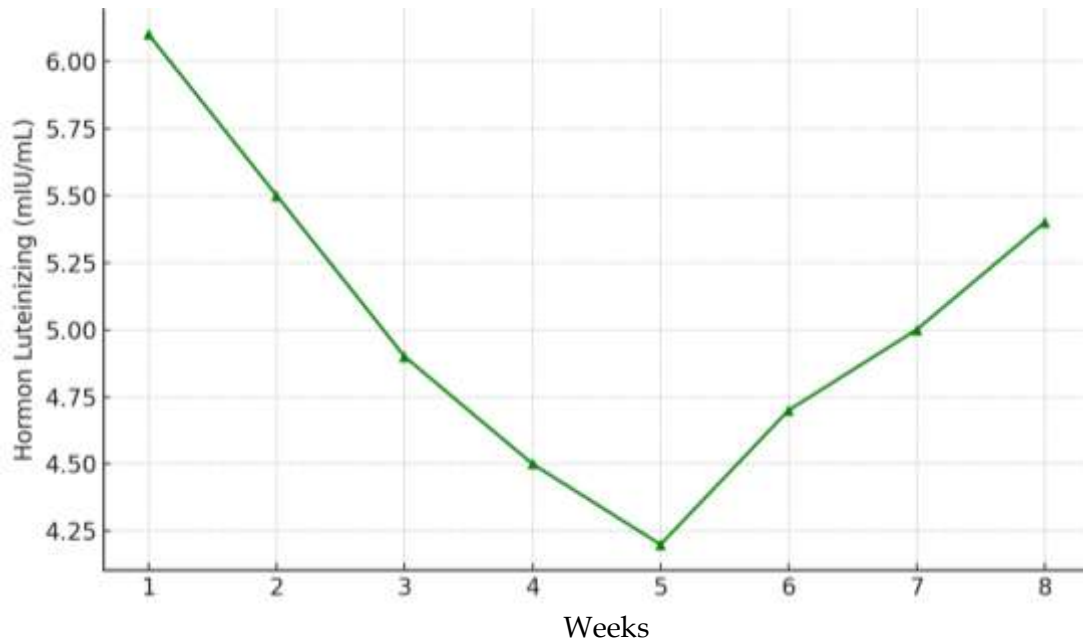


Figure 3. Luteinizing Hormone Trend Chart During 8 Weeks Postpartum

This visual representation supports numerical data on the association between decreased luteinizing hormone and hypothalamic-pituitary stimulation inhibition in slaughtered cattle in intensive systems.

### *Follicle-stimulating hormone levels are steadily decreasing*

Follicle stimulating hormone (FSH) plays an important role in stimulating the early growth of follicles and the formation of dominant follicles. During eight weeks of observation, this hormone showed a more stable pattern of decline than other hormones. In the first week, hormone levels were at 7.0 mIU/mL and gradually decreased until they reached 5.5 mIU/mL in the fifth week. This decline is not very sharp, but consistent, suggesting that the follicle's early growth phase is also affected by postpartum energy deficits.

Follicle-stimulating hormone levels began to increase again by the sixth week, reaching 6.7 mIU/mL by the eighth week. This indicates that the initial follicular activity has begun to recover, and the cow is entering a phase of restoration of stable reproductive function. Compared to luteinizing hormones that are volatile and sensitive to hypothalamus signals, follicle-stimulating hormones are more stable and have a medium-term response to changes in metabolic status.

Decreased FSH levels during the early postpartum phase in an intensive system may be attributed to the body's metabolic priority to maintain other vital functions, so reproductive hormones become a secondary priority. Nevertheless,

an increase in levels of this hormone in the final weeks suggests that the body's metabolic recovery has a direct impact on the stimulation of follicle growth and preparation for the next estrus cycle.

The following visualization of trends in follicle-stimulating hormone levels shows a more moderate but stable decline compared to other hormones, with a gradual recovery after the fifth week:

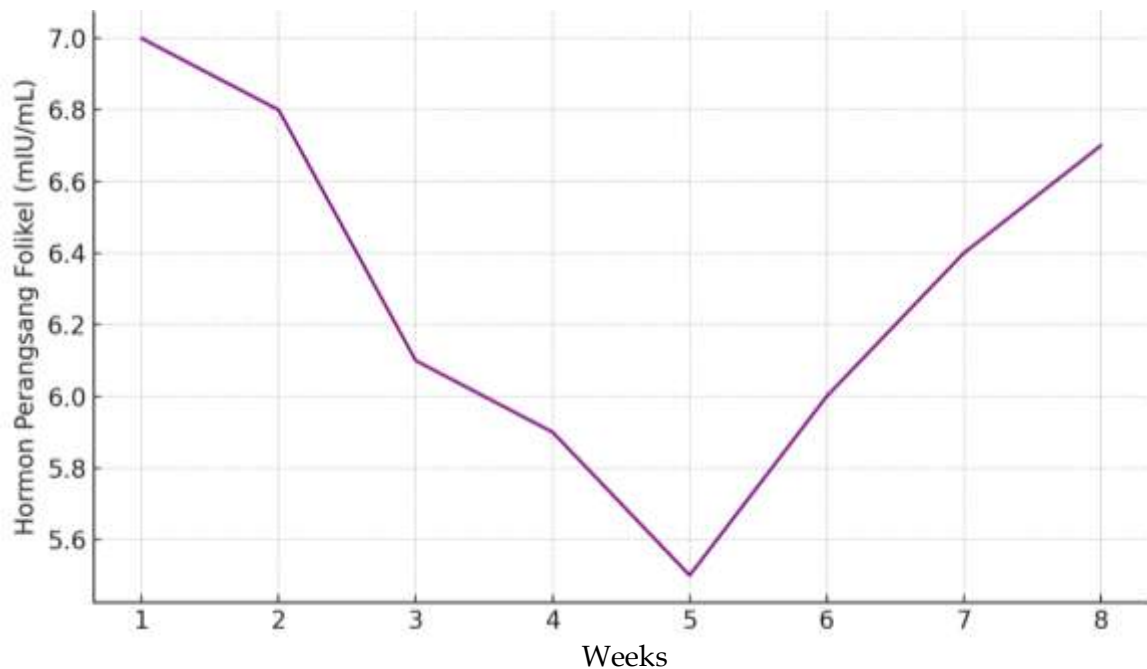


Figure 4. Follicle-stimulating hormone levels graph for 8 weeks postpartum

This graph supports the conclusion that follicle growth inhibition in the early postpartum phase is relatively milder but still significant, and recovers progressively as the cow's metabolic status improves.

## DISCUSSION

This study shows that negative energy imbalances have a significant impact on reproductive hormone dynamics in female beef cattle in intensive farming systems. These findings are in line with the theory of reproductive physiology which states that the reproductive system is one of the body's functions that is first compromised in postpartum metabolic stress conditions (Butler et al., 2021; Van Hoeck et al., 2020). The four main hormones progesterone, estrogen, luteinizing hormone, and follicle-stimulating hormone experience a marked decrease in levels during the first five weeks of the postpartum period, when the cow's body energy status is at its lowest.

The observed decrease in progesterone up to the fifth week indicates an inhibition of the activity of the corpus luteum, which is the main producer of progesterone. These findings are consistent with studies (Hess et al., 2021) that stated that metabolic disorders during the postpartum transition period inhibit luteal function and result in subclinical anesthetics. This decrease also has implications for delayed reactivation of the estrus cycle, extending the calving-to-conception interval which has a direct impact on production efficiency. The

trend of recovery in progesterone levels after the fifth week supports the hypothesis that the body's improved energy balance is able to restore luteal function physiologically.

Similarly, a decrease in estrogen levels until the fifth week reflects stagnation of the growth of the dominant follicle due to a lack of metabolic substrate. Estrogen is highly dependent on the activity of granulosa cells that are sensitive to energy status. This is in accordance with the reports of Roche et al. (2021) and Carter et al. (2022), which found that energy deficits cause disruption of estrogenic hormone secretion and have an impact on delayed estrus. An increase in estrogen after the sixth week indicates that the cow is beginning to undergo follicular recovery, an important phase before ovulation.

Findings regarding luteinizing hormone fluctuations show that the hypothalamic-pituitary-ovarian axis is acutely disturbed in the early postpartum phase. The decrease in luteinizing hormone until the fifth week reflects a decrease in the release of gonadotropin-releasing hormone (GnRH), which occurs due to the body's response to negative energy balance (Van Hoeck et al., 2020; López-Gatius et al., 2022). The recovery of luteinizing levels in the final weeks reinforces the understanding that the neuroendocrine system is highly dependent on the body's metabolic status.

Follicle-stimulating hormones undergo a more stable, but still significant decline. This suggests that energy disruptions affect not only ovulation, but also the early stages of follicle development. A mild but consistent decline indicates that follicular cell activity has begun to be affected from the initial growth phase. This trend is in line with the findings (Khan et al., 2020), which state that although follicle-stimulating hormones tend to be more stable than luteinizing hormones, there is still a decrease in conditions of severe metabolic stress. An increase in levels of this hormone in the seventh and eighth weeks is an indicator that metabolic recovery supports the gradual revival of ovarian function.

The difference in results with several studies on dairy cows, for example by (Moraes et al., 2020), which reported that hormonal recovery occurred faster (3rd week), showed a difference in metabolic response between the type of livestock and the rearing system. Beef cattle in intensive systems tend to recover more slowly because the main focus of metabolism remains on tissue maintenance and recovery, rather than milk production as in dairy cows.

One of the limitations of this study is that the energy balance calculation still uses estimates of energy consumption and demand based on the general standards of the National Research Council, without actual clean energy measurements from the local feed consumed by cows. In addition, the influence of genetic factors or cattle breeds was not analyzed in depth, although it is known to affect hormone profiles. For further research, it is recommended to conduct metabolomics analysis and involve other biochemical parameters such as beta-hydroxybutyrate (BHBA) and non-esterified fatty acid (NEFA) to obtain a more comprehensive metabolic picture.

Theoretically, this study reinforces the notion that the reproductive system is a sensitive indicator of the metabolic status of postpartum cows. Practically, these findings recommend the importance of actual energy

requirement-based feed formulation for the postpartum transition period, especially in intensive farming systems. Nutrient interventions based on hormone levels data can be a more adaptive management strategy, to prevent long-term fertility disorders.

## CONCLUSION AND RECOMMENDATION

This study concluded that the negative energy balance in postpartum female beef cattle in intensive farming systems had a significant impact on the decrease in the levels of key reproductive hormones, particularly progesterone, estrogen, luteinizing hormone, and follicle-stimulating hormones. A decrease in levels of these hormones mainly occurs during the first five weeks postpartum, which is the period with the highest metabolic stress. This imbalance contributes to a delayed recovery of ovarian function and prolongs the time to return to the normal estrus cycle.

These findings strengthen the theory that the reproductive system is a sensitive indicator of the body's metabolic status after childbirth. The gradual recovery of hormone levels after the fifth week reflects the physiological adaptation that follows the improvement of the body's energy status, suggesting that proper nutritional support is crucial in accelerating the fertility recovery of beef cattle.

Theoretically, this study expands the understanding of reproductive endocrine mechanisms in the context of metabolic stress in intensive systems. In practical terms, these results provide strategic recommendations for livestock management, particularly in designing nutritional interventions based on hormonal physiology to improve postpartum reproductive efficiency. Further research that integrates other metabolic indicators is needed to produce a more holistic approach to managing beef cattle reproduction sustainably.

## FURTHER STUDY

Future research should integrate additional metabolic indicators such as insulin, glucose, non-esterified fatty acids, and beta hydroxybutyrate to better understand the complex relationship between energy balance and reproductive hormone regulation in postpartum beef cattle. Longitudinal studies across varying nutritional regimes and management systems could reveal optimal strategies for minimizing metabolic stress and accelerating fertility recovery. Moreover, exploring the role of micronutrients, feed supplementation timing, and precision feeding technologies may provide actionable insights for sustainable reproductive management in intensive farming systems. Such research would contribute to a more comprehensive, physiology-based approach to improving reproductive efficiency and animal welfare.

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