Abanico Veterinario. January-December 2022; 12:1-21. http://dx.doi.org/10.21929/abavet2022.251
Literature review. Received: 28/02/2022. Accepted:12/09/2022. Published: 07/12/2022. Code: e2022-18.
https://www.youtube.com/watch?v=2pjtZqmxN78

Nutritionals deficiencies that affect to the return of postpartum ovarian activity in dual-purpose cattle

Deficiencias nutricionales que afectan al reinicio de la ciclicidad posparto en bovinos doble propósito

Avilés-Ruiz Ricardo[1ID], Barrón-Bravo Oscar[1ID], Alcalá-Rico Juan[1ID], Salinas-Chavira Jaime[2ID], Flores-Nájera Manuel[3ID], Ruiz-Albarrán Miguel*[2ID]

[1]Campo Experimental Las Huastecas, CIRNE-INIFAP Km 55 carretera Tampico-Mante, Altamira, Tamaulipas, México. C.P. 89610. [2]Facultad de Medicina Veterinaria y Zootecnia, Universidad Autónoma de Tamaulipas Km 5 carretera Cd. Victoria–Mante, Cd. Victoria, Tamaulipas, México. [3]Campo Experimental La Laguna CIRNOC-INIFAP. Matamoros, Coahuila, México. C.P. 27440. *Author for correspondence: Ruiz-Albarrán Miguel. E-mail: aviles.ricardo@inifap.gob.mx, barron.oscar@inifap.gob.mx, alcala.juan@inifap.gob.mx, jsalinasc@hotmail.com.mx, flores.manuel@inifap.gob.mx, miguel.ruiz@docentes.uat.edu.mx

Abstract

Different nutritional factors affect the resumption of postpartum ovarian activity in dual-purpose cattle in the tropical region. First, this review establishes the importance of reducing postpartum anestrus in cows to achieve greater reproductive performance. Next sections describe how each nutritional component has affected reproductive parameters. In most of the studies analyzed, comparisons of reproductive parameters were made between a group receiving the treatment and the control group. Then, a series of strategies to improve reproduction in dual-purpose cattle were described. Finally, conclusions and practical implications were presented.

Keywords: postpartum anestrus, ovarian activity, reproductive efficiency, supplementation, requirements.

Resumen

Son diversos los factores nutricionales que afectan al reinicio de la actividad ovárica posparto en bovinos de doble propósito en la región tropical. En este manuscrito se describe la importancia de reducir el anestro posparto de las hembras con el propósito de lograr una mayor eficiencia reproductiva. Las secciones siguientes describen como cada componente de los alimentos ha afectado los parámetros reproductivos. En la mayoría de los estudios analizados se realizaron comparaciones de los parámetros reproductivos entre un grupo que recibe el tratamiento y el grupo control. Asimismo, se describe una serie de estrategias para mejorar la reproducción en bovinos doble propósito. Finalmente, se presenta las conclusiones e implicaciones prácticas.

Palabras clave: anestro posparto, actividad ovárica, eficiencia reproductiva, suplementación, requerimientos.

INTRODUCTION

In Mexico, dual-purpose cattle production systems are mainly distributed in the humid tropical and dry tropical climate regions, where grazing is the basis of feeding (González-Padilla *et al*., 2019). Crossbreds of *Bos primigenius* species, *Bos primigenius indicus*

(Cebu) and *taurus* (Swiss, Holstein, Jersey, Montbeliard and Simmental subspecies) are used in tropical regions (Ríos-Utrera *et al*., 2020). In addition, dual-purpose cattle present a lower nutritional requirement and a different nutrient partition compared to cattle with dairy merit. However, nutritional deficiencies in forages and lack of supplementation lead to low reproductive efficiency in both systems (Aguilar-Pérez *et al*., 2009).

Prolonged postpartum anestrus directly affects reproductive efficiency in dual-purpose systems (Rojo-Rubio *et al*., 2009; Lassala *et al*., 2020). Postpartum anestrus is the period of time from parturition to the restart of postpartum cyclic activity or first estrus with ovulation (Pohler *et al*., 2020), such that the restart of the postpartum reproductive stage occurs when the bovine female presents an estrous cycle with ovulation that produces a viable oocyte. However, it has been shown that the main factors that determine the duration of postpartum anestrus in dual-purpose cattle are calving season and parity (Hernández-Reyes *et al*., 2000); lactation and nutrition (Montiel & Ahuja, 2005; Rojo-Rubio *et al*., 2009). The latter is closely related to factors such as loss of body condition, negative energy balance and metabolic disorders, as well as uterine pathologies, udder health and foot problems in high milk producing cows (Walsh *et al*., 2011). Therefore, it is necessary that the animal covers its nutritional needs to maintain an adequate body condition during pre- and postpartum (Montiel-Olguín *et al*., 2018). This will allow improving the synthesis of essential hormones in sufficient quantities so that follicular development, oocyte quality, corpus luteum function and subsequent embryo survival are not affected (Robinson *et al*., 2006). For this purpose, it is recommended that the cow achieves conception between 75 and 85 days postpartum. Thus, the sum of the postpartum anestrus time plus the duration of gestation is equivalent to an annual cycle in the cow (Bolaños, 2020). Thus, the reproductive efficiency of dual-purpose cattle is influenced by the ability to restart cyclic activity as soon as possible after calving (Butler, 2003). Therefore, the present review has the objective of studying how and how much forage nutritional deficiencies influence the resumption of postpartum ovarian activity in dual-purpose cattle.

Nutritional needs

Dual purpose cattle with 50 % *Bos taurus* genes represent the optimal genotypes for the humid tropical region (López *et al*., 2010). Although Arce *et al*. (2017) found that genotype had no significant effect on calving interval. In contrast, the Holstein x Zebu cross is considered the most appropriate for milk production (Vite-Cristóbal *et al*., 2007). In addition, this cross has lower nutritional requirements and different nutrient partitioning compared to cows with high milk merit. Thus, it would be expected that both the magnitude and duration of the negative energy balance (NEB) would be different in these cattle due to their lower milk production potential. Also, these genotypes show a greater response to additional energy supplementation in early lactation, improving or eliminating NEB and

increasing their productive and reproductive performance (Aguilar-Pérez *et al.*, 2009). In this regard, Garmendia (2005) recommends supplementation when: 1) The forage supply is low, from 3 to 6 tons of dry matter/year, 2) There are energy limitations during the prepartum and postpartum periods, since feed restriction before calving affects the animal's body condition, and in the postpartum period it influences the secretion of essential hormones for the restart of the reproductive cyclic activity, 3) There is a low protein intake in the diet, 4) There are animals that have not finished their growth and in pregnant animals to guarantee the viability of the calf and the restart of the postpartum reproductive cycles, 5) There are lactating cows that rapidly lose body condition and are in a critical period of forage limitation (dry season), and 6) In the diet the phosphorus content is less than 0. 20 %, since it affects voluntary consumption and ruminal fermentation of dry matter, causing imbalances in the production of ruminal gases and microbial protein, affecting reproduction.

Table 1. Nutritional requirements of dual purpose cows with 10 kg milk/day

Live weight kg	Consumption					
	DM kg/day	MP g/day	CP g/day	ME Mcal/day	Ca g/day	P g/day
400	9.2	778	1788	19.2	37	24
450	10.1	814	1870	20.3	39	26
500	11.0	848	1949	21.3	41	28
550	11.9	882	2027	22.4	42	30
600	12.7	915	2103	23.4	23	32

DM: dry matter; MP: metabolizable protein; CP: crude protein; ME: metabolizable energy; Ca: calcium; P: phosphorus (Adapted from Anrique, 2014)

Restart of postpartum cyclic activity in cattle

The anestrus period in beef cattle can vary depending on the effects of lactation, mother-calf relationship, nutrition and calving problems (Pohler *et al.*, 2020), as well as uterine infection, protein deficiency, early mating, parasitism and environmental stress (Bolaños, 2020); even calving season and parity (Hernández-Reyes *et al*., 2000); the day of the week when calving occurs and herd size affect reproductive performance (Montiel-Olguín *et al*., 2020). However, in dual-purpose cattle, suckling and nutrition are the main factors that can modify female ovarian cyclicity (Montiel & Ahuja, 2005; Rojo-Rubio *et al*., 2009). However, it has also been found that body condition and energy balance (dry matter intake) are the factors that contribute most to the frequency of Luteinizing Hormone (LH) pulses to achieve the first ovulation. In addition, these factors have been observed to indirectly affect postpartum uterine health in beef and dairy cattle (Crowe *et al*., 2014).

With less research, in dual-purpose cattle, mastitis has been reported to be a negative factor on cow reproductive efficiency (Bacha & Regassa, 2010; Nava-Trujillo *et al*., 2010). Other factors to consider are semen management at the time of service, among many other factors, sperm deposition in the ideal reproductive tract site at the appropriate estrous cycle time and heat stress (López-Gatius, 2012). Thus, postpartum anestrus or puerperium is defined as the time elapsed from the time of parturition until reproductive functions are restored so that effective service and consequently gestation can occur. Simultaneous to this regeneration, there is a progressive increase in the frequency of circulating LH pulses, which is essential for the establishment of normal estrous cycles after parturition (Pohler *et al*., 2020). In this regard, Diskin *et al.* (2003) in their literature review mentioned that the nutritional status of cattle is an important factor affecting follicular growth, maturation and ovulatory capacity and that the resumption of ovarian activity is related to a reduced frequency of LH pulses, which is controlled by the release of GnRH from the hypothalamus. Therefore, a delay from calving to first estrus with ovulation is caused by a lack of LH pulses, which is a result of calf suckling inhibition in beef breeds (30-130 days) and high production in dairy breeds (25-45 days; Crowe, 2008). When the above occurs, the cow cannot reach conception (Lucy *et al*., 1992; Robinson *et al*., 2006).

In high milk producing cows, it has been shown that the main factors that determine the duration of postpartum anestrus are closely related to situations such as loss of body condition and NEB, metabolic disorders and uterine pathologies, udder health and lameness (Walsh *et al.*, 2011).

Walsh *et al*. (2011) consider that, the points to be addressed to reduce the problem of low fertility in cattle are: firstly, minimize pre- and postpartum NEB; ensure estrous expression and detection in the cow followed by artificial insemination; achieve ovulation and fertilization of a high quality oocyte; followed by this, to provoke a rapid increase in corpus luteum progesterone synthesis, simultaneously, to ensure that the uterine endometrium rapidly produces an appropriate environment to stimulate embryo development and finally, to get the embryo to produce adequate amounts of interferon-τ, which is an antiluteolytic factor that prevents lysis of the corpus luteum in ruminants and in a coordinated and local way between embryo-uterus-ovary maintains pregnancy. Interferon-τ acts on uterine cells to inhibit the transcription of certain genes and to abrogate the development of the endometrial luteolytic mechanism. The molecular mechanisms involved in the silencing of the expression of such genes by interferon-τ are probably due to the fact that interferon-τ induces the expression of another factor, which is a potent repressor of uterine enzyme transcription (Thatcher, 2017). However, all of the above may be limited due to nutritional deficiencies caused by poor forage quality or reduced postpartum dry matter intake. For example, blood progesterone concentration is a factor that becomes more relevant in high-producing dairy cows, because their corpora

lutea produce less progesterone and this hormone is eliminated faster from the blood, due to elevated hepatic metabolism (Hernández, 2016).

Nutritional factors affecting the resumption of postpartum cyclic activity

Dual-purpose cattle production systems are mainly found in humid tropical and dry tropical climate regions, grazing is the basis of feeding (González-Padilla *et al*., 2019) on pasture and rangeland available in the region (Garay-Martínez *et al*., 2020). In addition, dual-purpose cattle in the tropics present a lower nutritional requirement and a different nutrient partition compared to cattle with dairy merit, nutritional deficiency of forages causes low reproductive efficiency in both systems (Aguilar-Pérez *et al*., 2009). Feed supplementation is most frequently used during climatic times with low pasture availability, mainly in drought (Granados-Rivera *et al*., 2018), being the most common with commercial concentrates (Lassala *et al*., 2020). However, offering feed supplementation in strategic physiological stages of dual-purpose cattle correlates with an increase in milk production (Bautista-Martínez *et al*., 2017) and with better reproductive efficiency, so feed supplementation should be a permanent management practice and independent of the climatic season (Granados-Rivera *et al*., 2018). The impact of nutrient deficiency on reproductive parameters in cattle, focusing mainly on dual-purpose systems, is presented below.

Energy deficiency

In ruminants, reproductive activity is associated with energy availability. Deficient glucose availability caused by lower dry matter intake and high demand for milk synthesis, commit the animal to enter a NEB (Chandra *et al*., 2011). In addition, increased ketogenesis is one of the requirements for good hepatic adaptation to increase energy demand in the period immediately after calving, thus ketone bodies are a very important alternative energy resource for the tissue when glucose is being redirected to the mammary gland (Herdt, 2000). However, it can be harmful to the animal causing ketosis.

Energy supplementation prevents or decreases NEB. Thus, cows that are not supplemented before and after calving show a deep postpartum NEB, whose lowest point is called "nadir", taking longer to reach a positive energy balance (Aguilar-Pérez *et al*., 2009). In a study conducted in beef cows of varying age, supplementation during the last third of gestation consisting of whole soybean grain (1.36 kg/day) compared to a soybean meal/hull based supplement (1.56 kg/day), cows fed the first supplement at adulthood represented higher ovarian activity at the beginning and end of the reproductive season compared to those fed a soybean meal/hull-based supplement (Banta *et al*., 2008).

Similarly, Aguilar-Pérez *et al*. (2009) found that supplementation with cereal-based concentrates improved reproductive parameters in cattle. In this study, supplementation consisted of sorghum (69 %), soybean (14 %), wheat bran (15 %) and minerals (2 %). These cereals together contained 878 g/kg dry matter, 168 g crude protein/kg dry matter and 11.8 MJ metabolizable energy/kg dry matter (2.82 Mcal ME/kg DM), providing 0.9 % of the live weight. For the control group only wheat bran and minerals were offered (15 % and 2 %, respectively). It is worth mentioning that the cattle used for this study were dual purpose (Holstein x Zebu) grazing in early lactation in the tropical regions of Mexico. The supplemented cows presented a higher ovulation percentage compared to the control group (58 and 30 %, respectively) and higher gestation rate at day 90 postpartum (47 and 22 %, respectively) and shorter interval from calving to first estrus (62.8±6.9 days and 68.2±3.8 days, respectively), so this supplementation tends to improve reproductive parameters.

In *Cynodon nlemfuensis* grazing cattle (Swiss x Zebu), the addition of an energy supplement in the diet (ground sorghum at 0.4 % of live weight) helped to improve postpartum cyclic activity, shortening the interval from calving to the appearance of the first corpus luteum (ultrasonography, twice a week during the study) in supplemented cows. Likewise, the higher gestation rate of supplemented dual-purpose cows (40±10 vs. 51±10 days) could not be explained by nutritional status, suggesting additional effects of supplementation energy mediated by metabolic hormones, which originate higher progesterone synthesis in luteal cells that are associated with an increase in conception rate in supplemented cows (42 % vs. 0 %; Tinoco-Magaña *et al*., 2012).

Recently, in a study by De Souza *et al*. (2019) in Holstein dairy cows they found that, when supplemented with palmitic acid during the first three weeks after calving, fresh period, they observed that palmitic acid increases plasma beta-hydroxybutyrate concentration during the first week after calving compared to the control group. The significance lies in the fact that ketogenesis, the process by which fatty acids are transformed into beta-hydroxybutyrate, takes place in the mitochondria of liver cells and may occur in response to a lack of blood glucose availability (Robinson y Williamson, 1980). The production of beta-hydroxybutyrate is initiated to make energy available primarily from fatty acids. Therefore, elevated plasma beta-hydroxybutyrate concentrations as markers of excessive NEB reveal a decrease in reproductive performance (Chapinal *et al*., 2012). Plasma beta-hydroxybutyrate concentrations of 10 to 14 mg/dL tend to increase the risk of a metabolic disorder (abomasal displacement, metritis, clinical ketosis) and 15 % less likely to become pregnant after a voluntary 70-day waiting period. Although in this study, palmitic acid increased plasma beta-hydroxybutyrate concentration in the first week of the fresh period, a pronounced decrease occurred immediately thereafter that does not represent a risk. Therefore, the researchers concluded that plasma beta-hydroxybutyrate concentrations from palmitic

acid supplementation are probably associated with increased nutrient partitioning to the mammary gland rather than as an indicator of metabolic dysfunction. This feeding strategy reduces NEB and prevents loss of body condition of the postpartum cow.

Protein deficiency

Bolaños (2020) suggests avoiding protein underfeeding of the cow in the diet during peripartum, since the immune system through the formation of antibodies (protein compounds) are responsible for capturing and digesting the bacteria that enter the reproductive system during parturition causing uterine infections. Inflammation in response to the presence of bacteria in the reproductive tract has negative effects on reproductive efficiency; in this sense, the researcher considers that the lack of an adequate protein level in the diet is a cause of metritis. On the other hand, Garmendia (2005) commented that once the protein reserves in the body are depleted, the lack of protein limits milk production in the first instance and the synthesis of immunoglobulins, so that immune competence is compromised. The result is a greater predisposition to the appearance of pathologies during and after parturition, such as the retention of fetal membranes.

The low protein quality of unimproved pastures, where ruminants are grazed, does not cover the nutritional requirements. Protein produces a greater response on dry matter intake. As crude protein content of forages increases, the magnitude of production responses due to additional protein supplementation may not be related to changes in forage intake, but to changes in forage digestibility or metabolic efficiency of nutrient utilization, including the effects of degradable and non-degradable protein. Due to the high degradable protein content of grasses, supplementation of non-degradable protein (overage) can improve grazing performance (Kawas, 2007).

Lara *et al.* (2015) conducted a study, the objective of which was to evaluate progesterone and LH concentrations during postpartum in response to different doses of surplus or protected methionine (0, 8, 16 and 24 g/day). The study was conducted on an experimental ranch in Mexico with Holstein dairy cows for 96 days in the early postpartum period. Although the results showed that there was a higher concentration of progesterone in the first three cycles in those cows that were fed the protected or overage amino acid, the concentrations of LH, which produce the preovulatory peak, were not statistically different. Therefore, they concluded that supplementation with protected methionine to cows during postpartum appears to improve corpus luteum function, without achieving a higher LH peak compared to cows that are not supplemented. In the literature review by Alvarez-Cardona *et al*. (2019) mention that the action of neurostimulatory amino acids stimulate the secretion of adenohypophysial gonadotropins and, therefore, regulates the control of gonadal physiological events.

Vitamin deficiency

Vitamins play an indispensable role in reproductive processes. The nutritional requirements for vitamin A, D and E are 2123-3685, 579-1004 and 16-27 IU/kg dry matter, respectively for cows from 400 to 600 kg (Anrique, 2014). For example, deficiencies of these vitamins cause a high percentage (80 %) of cases of retained fetal membranes, due to failure of feto-maternal junction separation (Ndiweni y Finch, 1996). Although the mechanisms associated with fetal-maternal tissue separation are poorly understood, there have been suggestions of insufficient leukocyte activity immediately after delivery, resulting in inadequate collagen breakdown of tissue and, therefore, failure of tissue separation (Kimura *et al*., 2002). Furthermore, for the chorionic villi to become dislodged from the crypts on the maternal side of the placenta, strong vasoconstriction of the villus arteries must be achieved. Vasoconstriction reduces the pressure of the arteries and thus allows the villi to be released from the crypts (Senger, 2003). In this regard, Montiel-Olguín *et al*. (2018) found that dairy cows from family farms in Mexico that arrive at calving in low body condition are more likely to have retained fetal membranes. This may be attributed to vitamin deficiency. Supplementation with vitamin E (α-tocopherol) has been shown to increase various aspects of the immune system including increased migration and chemotaxis of polymorphonuclear cells (Ndiweni y Finch, 1996) and an increase in the chemotaxis response by blood neutrophils (Politis *et al*., 1996). Thus, it has been suggested that vitamin E supplementation may reduce the prevalence of fetal membrane retention due to an increase in the immune system and thus ensure the separation of fetal and maternal tissue (Bourne *et al*., 2007). Regarding postpartum reproductive infectious processes, Kaewlamun *et al*. (2011) found that a higher concentration of β-carotene, a precursor of vitamin A, in blood has a positive effect on the percentage of polymorphonuclear leukocytes in both the uterus and cervix in supplemented cows compared to the control. From such a study, it is proposed that supplementation with β-carotene prior to calving may have a consequent beneficial effect on reproduction. On the other hand, Gagnon *et al.* (2015) suggest that intramuscular administration of vitamin B12 (cyanocobalamin) in combination with folic acid in dairy cows during postpartum has an effect on gene expression, which may be the result of an increase in LH secretion and consequently promoting cell differentiation and an arrest of cell division in granulosa cells. Therefore, we can say that vitamins are indispensable micronutrients for the proper functioning of the organism and the maintenance of cellular homeostasis; in reproductive matters, their use is focused on preventing disease problems that can occur frequently in the animal production unit. In their literature review, De Rensis *et al*. (2017) mentioned that the administration vitamin E, A and selenium (antioxidants) can protect the oocyte in follicular dynamics in the ovary during heat stress. It is worth mentioning that vitamin A does not exist as such, it has to undergo changes and processes to transform into retinol. It has been shown that these vitamins supplemented prior to calving in cattle have positive

impacts on the immune and reproductive system, by reducing oxidative stress rates, helping to prevent some common diseases in production units such as fetal membrane retention, metritis and abnormal puerperium, caused by immunodeficiency and that have negative impacts on reproductive parameters (Hernández, 2016). Furthermore, in this regard Montiel-Olguín *et al*. (2018) found that retained fetal membranes, dystocic parturition and body condition ≤ 2.5 are the main risk factors associated with reduced reproductive performance of cows (1263 lactations) from small-scale dairy herds (96) in the tropical and subtropical region of Mexico.

In their literature review, González-Maldonado *et al.* (2019) emphasize that vitamin C (ascorbic acid), being an antioxidant and indispensable cofactor in enzymatic processes, collagen degradation in preovulatory follicles, in follicular development and growth, plays a very important role in the production of viable oocytes. In conjunction with vitamin E, the results have not shown a better size of the follicle or corpus luteum. However, when integrated into fixed-time artificial insemination protocols, it has been shown to increase the number of pregnant cows, possibly due to the fact that, when cows are injected with these vitamins, they produce better quality oocytes and therefore viable embryos compared to cows that are not injected.

Regarding the retention of fetal membranes, a medical condition associated with prolonged postpartum anestrus, there are three theories behind the etiology of this condition, which are failures in the separation of the feto-maternal union, mechanical obstruction and myometrial contractions. The first failure is probably due to enzyme dysfunction, caused by the lack of organic molecules called coenzymes, mainly vitamins, which help the enzyme in the biochemical transformations for the separation of the cotyledons from the caruncles. However, no studies have shown that vitamin E deficiency alone has an effect on the retention of fetal membranes, but that its mechanism of action may be mediated by selenium (Bourne *et al.*, 2007).

Mineral deficiency

Infertility in dairy cattle is a very complex and multifactorial problem, which should be evaluated considering other diseases or disorders that occur in the animal. It is pertinent to mention that hypocalcemia, mastitis, laminitis, retained placenta have a negative impact on the cow's subsequent fertility. Minerals, trace elements and vitamins play an important role in the prevention of these diseases (Wilde, 2006).

Mineral requirements during lactation are: calcium, phosphorus, magnesium, sulfur, sodium and chlorine (0.60-0.80, 0.40-0.45, 0.22-0.28, 0.23, 0.20 and 0.25 % dry matter, respectively; Anrique, 2014). However, most forages do not provide the adequate amount of minerals required by the animal (Rojo-Rubio *et al*., 2009). Limited supplementation aggravates the body condition and consequently its sexual cycle, which means longer postpartum anestrus time and longer time for the cow to become pregnant again (Bolaños,

2020). It has been demonstrated that the supplementation of macro and micro minerals in premixes, offered to free access, has been the most efficient way to improve the reproductive response in cattle (Rojo-Rubio *et al*., 2009).

Macrominerals are involved in acid-base balance and calcium metabolism in dairy and dual purpose cows. The use of anionic salts in combination with supplementation of adequate concentrations of calcium and magnesium can help improve dry matter intake and reduce the negative energy balance in the postpartum period, as well as prevent hypocalcemia, which is associated with uterine prolapse (Bolaños, 2020), cystic ovaries, placental retention and formation of small corpora lutea (Román *et al.*, 2009). In this regard, Bolaños (2020) considers that the availability of calcium can be responsible for slow parturition and cause the calf to die before being expelled, due to the fact that at the moment of parturition the uterine muscle cells demand an energy expenditure and calcium ions that are responsible for the activation of the contractile system.

On the other hand, zinc and vitamin E are effective in the prevention of mastitis, which occurs mainly in the first weeks of lactation, by increasing the antioxidant functions and keratinization of the mammary nipple duct. Likewise in lameness, a result of laminitis in dairy cattle that occurs mainly during lactation, although most of the original aggressions to the hoof can occur before calving. However, zinc and biotin are also involved in improving hoof keratinization and in the prevention of this disease (Wilde, 2006).

In addition, it is important to mention that the percentage of cows that retain placenta can be reduced by preventing hypocalcemia and administering adequate concentrations of selenium (Wilde, 2006). In a study by Vedovatto *et al*. (2019) demonstrated that the administration of a single dose of trace minerals (60, 10, 5 and 15 mg/mL of Zn, Mn, Se and Cu, respectively) 30 days before artificial insemination has no positive effect on ovarian structures in Nelore cows under grazing conditions in the region of Mato Grosso, Brazil. However, this same group of researchers found that administration of trace minerals mentioned above does increase plasma concentrations of antioxidant enzymes in all cows applied to them, regardless of body condition and cows with body condition <5 points tended to improve pregnancy rate, but not in those whose body condition was ≥5 (scale of 1-9). There are probably other minerals that are related to reproduction and their performance is still unknown.

A compendium of recent studies on the effect of nutrient deficiency on the restart of postpartum cyclic activity in cattle was made (Table 2), showing the supplement and

production system studied, as well as the parameters that influenced the increase in postpartum anestrus time reported by the authors.

As shown in Table 2, with respect to the present literature review, a small number of studies conducted in dual-purpose systems were obtained. In this regard, it has been found that dual-purpose systems the low adoption of reproductive technologies is one of the main problems (Espinosa-García *et al*., 2018; Bautista-Martínez *et al*., 2019; Lassala *et al*., 2020; Villarroel-Molina *et al*., 2021), they have a very small number of heads, considered subsistence because much of the production is for self-consumption, there is variability in production that depends on the environment. Similarly, González-Padilla *et al*. (2019) considered that the main limitations for the growth and profitability of the production units were the lack of access to credit, followed by the low market value of their products and insufficient infrastructure. The above leads to the fact that in this guild of producers is not taken into account to carry out basic and transcendental science.

Table 2. Effect of supplementation on the resumption of postpartum cyclic activity in dairy and dual-purpose cattle

Nutritional component	Supplement	Production system	Reproductive parameters	Research
Energy	Concentrates (grains)	Dual purpose	↑ estrus 74% vs 39% ↑ ovulation 59% vs 30% ↑ gestation rate 47% vs 22%	Aguilar-Pérez *et al*., 2009
	Sorghum	Dual purpose	↑ presence of CL to 70 days 50% vs 33% ↑ gestation rate 42% vs 0%	Tinoco-Magaña *et al*., 2012
Protein	Methionine (24g/d)	Dairy	Improves the CL function	Lara *et al*., 2015
Vitamins	E	Dual purpose	↓ calving interval-1st estrus 28.3±2.4 vs 41.4±1.3 ↑ gestation rate 86.7% vs 36.84%	Khatti *et al*., 2017
Minerals	Zn, Mn, Se and Cu (30 days before AI)	Meat	↑ gestation rate when BC < 5 (scale 1-9) 58.4% vs 46.8%	Vedovatto *et al*., 2019

CL: corpus luteum; BC: body condition; AI: artificial insemination; ↑: increase; ↓: decrease

Feeding management strategies to improve reproduction in dual-purpose cattle

The negative effects exerted by suckling and grazing, without being supplemented, inhibit the reestablishment of postpartum ovarian activity, lengthening the interval between calving, which can exceed 500 days, an extensive period of postpartum anestrus in dual purpose cattle (Rojo-Rubio *et al.*, 2009), which is no longer economically profitable for a production unit to keep a cow empty for a year or more (Martínez *et al*., 2021).

Use of improved pastures

Samadi *et al.* (2013)demonstrated that pasture-based nutritional control before and after calving can be used to induce marked differences in weight, body condition, and metabolic hormonal status in postpartum beef cows. These researchers concluded that cows receiving improved pasture had higher plasma concentrations of glucose, insulin, insulin-like growth factor-I and leptin compared to cows receiving less digestible pasture. These differences in glucose and metabolic hormone profiles were associated with earlier resumption of ovulation for cows on improved pasture. The reduction in the postpartum anestrus period in beef cows grazing improved subtropical pastures may result in improved metabolic homeostasis. The earlier resumption of cyclic ovarian function of cows on improved pasture probably resulted from the general positive actions of glucose and metabolic hormones on somatic tissues and more specifically on the hypothalamus and ovaries. The potential actions on different tissues within the reproductive axis probably reflect the nature of the interrelationships between nutrition, metabolic regulators and reproductive function, with information available that allows for an integration of the effects of leptin and insulin-like growth factor-I, on GnRH secretion, which appears to involve an indirect action through kisspeptin and leptin neurons; and a more direct action on GnRH (insulin-like growth factor-I) neurons. Since in the experiment the restart of postpartum ovarian cyclicity (ovulation) at 12 and 15 weeks was 100 % for cows kept on improved pasture compared to those kept on less digestible pasture, where only 14 % showed ovulation at 15 weeks.

Technification of production units and manipulation of nutritional components in the diet

Velázquez *et al.* (2020) evaluated an induction protocol to restart ovarian activity in *Bos tauros* x *Bos indicus* crossbred cows in the tropical region of Mexico. The hormonal treatment consisted of the placement of CIDR with and without estradiol in dual-purpose production units with three technification statuses described as: High technification level, where grazing is done on pastures with improved pastures, they perform productive and reproductive records and nutritional supplementation during milking of the animals; medium technification level, the same conditions as the previous one; however, they do not perform productive and reproductive performance recording; low technification level, where grazing is on available natural forage and without productive and reproductive

records or nutritional supplementation of the animals. In this research, this group of researchers concluded that cows respond to the induction of ovarian activity of the combination of progesterone and estradiol in a high proportion in all levels of technification. These results confirm the benefits of production units with medium and low technification status, since fixed-time artificial insemination programs, for example, can be carried out. However, economic issues should be evaluated. Bautista-Martínez *et al*. (2019) in their economic-productive characterization of the dual-purpose cattle system in three tropical regions of Mexico found that practices related to reproductive management are the least frequently performed in production units, the promotion in the application and adoption of technologies related to this area, could be an alternative to improve productive and reproductive variables in the long term.

On the other hand, in the same Mexican region described above, Zárate-Martínez *et al*. (2022) studied the reproductive behavior of dual-purpose systems with two levels of neutral detergent fiber, inducing ovulation with a hormonal protocol of fixed-time artificial insemination. The experiment consisted of: treatment 1 fed 4.5 kg of concentrate cow/day and treatment 2 fed 3 kg of concentrate cow/day. Forage was offered *ad libitum* in both treatments. The results obtained were that cows in treatment 2 consumed more neutral detergent fiber than cows in treatment 1, 38 and 44 % of the total diet, respectively. This group of researchers commented that the increase in forage intake to where the neutral detergent fiber allowed compensating the energy and metabolizable protein intake, being similar for both treatments during the first 15 days before calving. Cows in treatment 2 (6.25 dry matter/day) tried to compensate for nutrient deficits by consuming more forage than those in treatment 1 (7.37 kg dry matter/day). In addition, they comment that metabolizable protein was always deficient during lactation for both treatments. In treatment 2 cows, the poor metabolizable protein resulted in lower milk nitrogen content. Finally, they found that cows in treatment 1 lost less body condition by 75.2 %, this was reflected in a higher gestation rate at first service in the treatment compared to treatment 2 with 42.8 %, although they did not produce more milk. They concluded that the decrease of neutral detergent fiber in the diet from 44 to 38 % and the application of the hormonal protocol of fixed-time artificial insemination decreased the open period to 105 days in lactating cows in the tropics of Mexico.

CONCLUSIONS

The importance of nutritional deficiencies affecting postpartum resumption of cyclicity and dietary management strategies to improve reproduction in dual-purpose cattle were described. In addition, while conducting this review, the authors became aware of the lack of scientific information on the effects of feed and forage deficiencies on postpartum ovarian resumption, specifically in dual-purpose cattle [*Bos taurus* (Holstein, Jersy) x *Bos indicus* (Gir, Nelore, Braman)]. Research on this topic should be developed to establish specific practical recommendations for these crosses, and thus avoid the improper use of information generated in other production chains (beef and dairy cattle) and regions (arid and temperate) in Mexico.

CITED LITERATURE

AGUILAR-PÉREZ C, Ku-Vera J, Centurión-Castro F, Garnsworthy PC. 2009. Energy balance, milk production and reproduction in grazing crossbred cows in the tropics with and without cereal supplementation. *Livestock Science*. 122:227-233. ISSN: 1871-1413. https://doi.org/10.1016/j.livsci.2008.09.004

ALVAREZ-CARDONA F, Maki-Díaz G, Franco-Robles E, Cadena-Villegas S, Hernández-Marín A. 2019. L-Arginina, Aspartato y Glutamato, y su relación con la reproducción de ovejas Review. *Abanico Veterinario.* 9:1-13. ISSN: 2448-6132.

http://dx.doi.org/10.21929/abavet2019.929

ANRIQUE R. 2014. Composición de alimentos para el ganado bovino. 4ta. Edición. Universidad austral de Chile. ISBN 978-956-8765-04-0.
https://www.academia.edu/9785035/Composicion_de_alimentos_para_ganado_bovino

ARCE C, Aranda EM, Osorio MM, González R, Díaz P, Hinojosa JA. 2017. Evaluación de parámetros productivos y reproductivos en un hato de doble propósito en Tabasco, México. *Revista Mexicana de Ciencias Pecuarias*. 8:83-91. ISSN: 2448-6698.
https://doi.org/10.22319/rmcp.v8i1.4347

BACHA B, Regassa FG. 2010. Subclinical endometritis in Zebu x Friesian crossbred dairy cows: its risk factors, association with subclinical mastitis and effect on reproductive performance. *Tropical Animal Health and Production*. 42:397-403. ISSN: 1573-7438.
https://doi.org/10.1007/s11250-009-9433-5

BANTA JP, Lalman D, Wettemann R. 2008. Whole soy bean supplementation and cow age class: effects on intake, digestion, performance and reproduction of beef cows. *Journal of Animal Science*. 86: 1864-1878. ISSN: 1740-0929.

https://doi.org/10.2527/jas.2007-0383

BAUTISTA-MARTÍNEZ Y, Herrera-Haro JG, Espinosa-García JA, Martínez-Castañeda FE, Vaquera-Huerta H, Bárcena-Gamma JR, Morales A. 2017. Relación entre las prácticas tecnológicas de manejo, la producción y su asociación con las épocas del año en el sistema de doble propósito del trópico mexicano. *Nova Scientia*. 9:154-170. ISSN: 2007-0705. https://doi.org/10.21640/ns.v12i25.2117

BAUTISTA-MARTÍNEZ Y, Herrera-Haro JG, Espinosa-García JA, Martínez-Castañeda FE, Vaquera-Huerta H, Morales A, Aguirre-Guzmán, G. 2019. Caracterización económico-productiva del sistema bovino doble propósito en tres regiones tropicales de México. *ITEA, Información Técnica Económica Agraria: revista de la Asociación Interprofesional para el Desarrollo Agrario* (AIDA). 115(2): 134-148. ISSN: 1699-6887. https://www.aida-itea.org/index.php/revista/contenidos?idArt=618&lang=esp

BOLAÑOS ED. 2020. Producción de becerros bajo el sistema vaca-cría en el trópico. Libro Técnico Núm. 40. INIFAP.CIRGOC. Huimanguillo, México. Pp. 105. ISBN: 978-607-37-1262-0. https://vun.inifap.gob.mx/BibliotecaWeb/_Content

BOURNE N, Laven R, Wathes DC, Martinez T, McGowan M. 2007. A meta-analysis of the effects of vitamin E supplementation on the incidence of retained foetal membranes in dairy cows. *Theriogenology*. 67: 494-501. ISSN: 0093-691X. https://doi.org/10.1016/j.theriogenology.2006.08.015

BUTLER WR. 2003. Energy balance relationships with follicular development, ovulation and fertility in postpartum dairy cows. *Livestock Production Science*. 83: 211-218. ISSN: 0301-6226. https://doi.org/10.1016/S0301-6226(03)00112-X

CHANDRA G, Aggarwal A, Singh AK, Kumar M, Aggarwal A, Singh AK, Kumar M., Kushwaha R, Singh A, Singh YK. 2011. Negative energy balance and reproduction. *Agriculture Reviews*. 32: 246-254. ISSN: 0976-0741. https://arccjournals.com/journal/agricultural-reviews/ARCC910

CHAPINAL N, Carson ME, LeBlanc SJ, Leslie KE, Godden S, Capel M, Santos JEP, Overton MW, Duffield TF. 2012. The association of serum metabolites in the transition period with milk production and early-lactation reproductive performance. *Journal of Dairy Science*. 95:1301-1309. ISSN: 1525-3198. https://doi.org/10.3168/jds.2011-4724

CROWE MA, Diskin MG, Williams EJ. 2014. Parturition to resumption of ovarian cyclicity: comparative aspects of beef and dairy cows. *Animal*. 8:40-53. ISSN: 1751-732X. https://doi.org/10.1017/S1751731114000251

CROWE MA. 2008. Resumption of ovarian cyclicity in post-partum beef and dairy cows. *Reproduction in Domestic Animal*. 43:20–28. ISSN: 1439-0531.

https://doi.org/10.1111/j.1439-0531.2008.01210.x

DE RENSIS F, Lopez-Gatius F, García-Ispierto I, Morini G, Scaramuzzi RJ. 2017. Causes of declining fertility in dairy cows during the warm season. *Theriogenology*. 91:145-153. ISSN: 0093-691X. https://doi.org/10.1016/j.theriogenology.2016.12.024

DE SOUZA J, Strieder-Barboza C, Contreras GA, Lock AL. 2019. Effects of timing of palmitic acid supplementation during early lactation on nutrient digestibility, energy balance, and metabolism of dairy cows. *Journal of Dairy Sciences*. 102:270-287. ISSN: 1525-3198. https://doi.org/10.3168/jds.2018-14977

DISKIN MG, Mackey DR, Roche JF, Sreenan JM. 2003. Effects of nutrition and metabolic status on circulating hormones and ovarian follicle development in cattle. *Animal Reproduction Science* 78:345–370. ISSN: 0378-4320. https://doi.org/10.1016/S0378-4320(03)00099-X

ESPINOSA-GARCÍA JA, Vélez-Izquierdo A., Góngora-González SF, Cuevas-Reyes V, Vázquez-Gómez R, Rivera-Maldonado JA. 2018. Evaluación del impacto en la productividad y rentabilidad de la tecnología transferida al sistema de bovinos de doble propósito del trópico mexicano. *Tropical and Subtropical Agroecosystems.* 21:261-272. ISSN: 1870-0462. https://www.revista.ccba.uady.mx/ojs/index.php/TSA/article/view/2411

GAGNON A, Khan DR, Sirard MA, Girard CL, Laforest JP, Richard FJ. 2015. Effects of intramuscular administration of folic acid and vitamin B12 on granulosa cells gene expression in postpartum dairy cows. *Journal of Dairy Science*. 98:7797–7809. ISSN: 1525-3198. https://doi.org/10.3168/jds.2015-9623

GARAY-MARTÍNEZ JR, Barrón-Bravo OG, Maciel-Torres SP, Avilés-Ruiz R, Joaquín-Cancino S, Bautista-Martínez Y, Granados-Rivera LD. 2020. Caracterización de las unidades de producción de bovinos en El Mante, Tamaulipas. *Ciencia e Innovación*. 3: 113-124. ISSN: 2594-150X.

http://cienciaeinnovacion.com.mx/2020/06/22/caracterizacion-de-las-unidades-de-produccion-de-bovinos-en-el-mante-tamaulipas/

GARMENDIA J. 2005. Suplementación estratégica de vacas de doble propósito alrededor del parto. IX Seminario de pastos y forrajes.
http://avpa.ula.ve/eventos/ix_seminario_pastosyforraje/Conferencias/C8-JulioGarmendia.pdf

GONZÁLEZ-MALDONADO J, Rangel-Santos R, Rodríguez-de Lara R, Ramírez-Valverde G, Ramírez-Bribiesca JE, Monreal-Díaz JC. 2019. Suplementación con ácido ascórbico para mejorar la fertilidad del ganado lechero. *Revista Mexicana de Ciencias Pecuarias*. 10: 1000-1012. ISSN: 2448-6698. https://doi.org/10.22319/rmcp.v10i4.4703

GONZÁLEZ-PADILLA E, Lassala A, Pedernera M, Gutiérrez CG. 2019. Cow-calf management practices in Mexico: Farm organization and infrastructure. *Veterinaria México OA*. 6: 1-17. ISSN: 2448-6760.

https://doi.org/10.22201/fmvz.24486760e.2019.3.677

GRANADOS-RIVERA LD, Quiroz-Valiente J, Maldonado-Jáquez JA, Granados-Zurita L, Díaz-Rivera P, Oliva-Hernández J. 2018. Caracterización y tipificación del sistema doble propósito en la ganadería bovina del Distrito de Desarrollo Rural 151, Tabasco, México. *Acta Universitaria*, 28:47-57. ISSN: 2007-9621. https://doi.org/10.15174/au.2018.1916

HERDT TH. 2000. Ruminant adaptation to negative energy balance. *Veterinary Clinics of North America: Food Animal Practice*. 16: 215–230. ISSN: 1558-4240. https://doi.org/10.1016/S0749-0720(15)30102-X

HERNÁNDEZ J. 2016. Fisiología clínica de la reproducción de los bovinos lecheros. Primera edición. Universidad Autónoma de México. Coyoacán, México. Pp. 172. ISBN: 978-607-02-8690-2.
https://fmvz.unam.mx/fmvz/publicaciones/archivos/Fisiologia_Clinica.pdf

HERNÁNDEZ-REYES E, Segura-Correa VM, Segura-Correa JC, Osorio-Arce MM. 2000. Intervalo entre partos, duración de la lactancia y producción de leche en un hato de doble propósito en Yucatán, México. *Agrociencia*. 34:699-705. ISSN: 1405-3195.

http://www.redalyc.org/articulo.oa?id=30234604

KAEWLAMUN W, Okouyi M, Humblot P, Techakumphu M, Ponter AA. 2011. Does supplementing dairy cows with carotene during the dry period affect postpartum ovarian activity, progesterone, and cervical and uterine involution? *Theriogenology*. 75: 1029-1038. ISSN: 0093-691X. https://doi.org/10.1016/j.theriogenology.2010.11.010

KAWAS JR. 2007. Producción y utilización de bloques multinutrientes como complemento de forrajes de baja calidad para caprinos y ovinos: la experiencia en regiones semiáridas. *Tecnologia e Ciência Agropecuaria*. 2: 63-69.
https://www.researchgate.net/publication/237756032_Produccion_y_Utilizacion_de_Bloques_Multinutrientes_como_Complemento_de_Forrajes_de_Baja_Calidad_para_Caprinos_y_Ovinos_La_Experiencia_en_Regiones_Semiaridas

KHATTI A, Mehrotra S, Patel PK, Singh G, Maurya VP, Mahla AS, Chaudhari RK, Narayanan K, Das GK, Singh M, Sarkar M, Gupta HK. 2017. Supplementation of vitamin E, selenium and increased energy allowance mitigates transition stress and improves postpartum reproductive performance in crossbred cow. *Theriogenology.* 104: 142-148. ISSN: 0093-691X. https://doi.org/10.1016/j.theriogenology.2017.08.014

KIMURA K, Goff JP, Kehrli ME, Reinhatdt TA. 2002. Decreased neutrophil function as a cause of retained placenta in dairy cattle. *Journal of Dairy Science*. 85:544–50. ISSN: 0022-0302. https://doi.org/10.3168/jds.S0022-0302(02)74107-6

LARA A, Mendoza GD, Sánchez-Torres T, Hernández PA, Martínez JA. 2015. Response of LH and progesterone in postpartum cows added with different levels of protected methionine. *Life Science Journal*. 12: 104-112. ISSN: 1097-8135. http://www.lifesciencesite.com/lsj/life1202s15/

LASSALA A, Hernández-Cerón J, Pedernera M, González-Padilla E, Gutiérrez CG. 2020. Cow-calf management practices in Mexico: Reproduction and breeding. *Veterinaria México OA*. 7: 1-15. ISSN: 2448-6760. http://dx.doi.org/10.22201/fmvz.24486760e.2019.3.677

LÓPEZ R, Díaz M, García JG, Núñez R, López R, Martínez PA. 2010. Eventos reproductivos de vacas con diferente porcentaje de genes *Bos taurus* en el trópico mexicano. *Revista Mexicana de Ciencias Pecuarias*. 1(4):325-336. ISSN: 2448-6698. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-11242010000400002

LÓPEZ-GATIUS F. 2012. Factors of a noninfectious nature affecting fertility after artificial insemination in lactating dairy cows. A review. *Theriogenology*. ISSN: 0093-691X. 77:1029-1041. https://doi.org/10.1016/j.theriogenology.2011.10.014

LUCY MC, Savio JD, Badinga L, De La Sota RL, Thatchers WW. 1992. Factors that affect ovarian follicular dynamics in Cattle. *Journal of Animal Science*. 70:3615-3626. ISSN: 1740-0929. https://doi.org/10.2527/1992.70113615x

MARTÍNEZ JF, Galina CS, Rubio I, Balam WL, Corro MD. 2021. Evaluación reproductiva y costos en programas de empadre estacional con *Bos indicus* en trópico mexicano. *Revista MVZ Córdoba*. 26:e2130. ISSNL: 0122-0268. https://doi.org/10.21897/rmvz.2130

MONTIEL F, Ahuja C. 2005. Body condition and suckling as factors influencing the duration of postpartum anestrus in cattle: a review. *Animal Reproduction Science*. 85: 1-26. ISSN: 0378-4320. https://doi.org/10.1016/j.anireprosci.2003.11.001

MONTIEL-OLGUÍN L, Espinosa-Martínez M, Ruiz-López F, Estrada-Cortés E, Durán-Aguilar M, Vera-Avila H. 2020. El día de parto y tamaño del hato impactan indicadores reproductivos en establos familiares. *Abanico veterinario.* ISSN: 2448-6132. http://dx.doi.org/10.21929/abavet2020.23

MONTIEL-OLGUÍN LJ, Estrada-Cortés E, Espinosa-Martínez MA, Mellado M. 2018. Risk factors associated with reproductive performance in small-scale dairy farms in Mexico. *Tropical Animal Health and Production*. 51: 229–236. ISSN: 1573-7438. https://doi.org/10.1007/s11250-018-1681-9

NAVA-TRUJILLO H, Soto-Belloso E. Hoet AE. 2010. Effects of clinical mastitis from calving to first service on reproductive performance in dual-purpose cows. *Animal Reproduction Science.* 21:12–16. ISSN: 0378-4320.

https://doi.org/10.1016/j.anireprosci.2010.05.014

NDIWENI N, Finch JM. 1996. Effects of in vitro supplementation with α-tocopherol and selenium on bovine neutrophil functions: implications for resistance to mastitis. V*eterinary Immunology and Immunopathology*. 51:67-78. ISSN 0165-2427.

https://doi.org/10.1016/0165-2427(95)05515-0

POHLER Ky G, Franco G A, Reese S T, Smith M F. 2020. Physiology and pregnancy of beef cattle. *Animal Agriculture*. 37-55. ISBN: 978-0-12-817052-6.
https://doi.org/10.1016/B978-0-12-817052-6.00003-3

POLITIS I, Hidiroglou N, White JH, Gilmore JA, Williams SN, Scherf H, Frigg M. 1996. Effects of vitamin E on mammary and blood leukocyte function, with emphasis on chemotaxis, in periparturient dairy cows. *American Journal of Veterinary Research*. 57:468-471. ISBN: 0002-9645. https://europepmc.org/article/med/8712508

RÍOS-UTRERA Á, Villagómez-Amezcua E, Zárate-Martínez J P, Calderón-Robles R C, Vega-Murillo V E. 2020. Análisis reproductivo de vacas Suizo Pardo x Cebú y Simmental x Cebú en condiciones tropicales. *Revista MVZ Córdoba*. 25:e1637. ISSN: 0122-0268. https://doi.org/10.21897/rmvz.1637

ROBINSON JJ, Ashworth CJ, Rooke JA, Mitchell LM, McEvoy TG. 2006. Nutrition and fertility in ruminant livestock. *Animal Feed Science and Technology*. 126:259–276. ISSN: 0377-8401. https://doi.org/10.1016/j.anifeedsci.2005.08.006

ROBINSON AM, Williamson DH. 1980. Physiological roles of ketone bodies as substrates and signals in mammalian tissues. *Physiological Reviews*. 60:143–187. ISSN: 1522-1210. https://doi.org/10.1152/physrev.1980.60.1.143

ROJO-RUBIO R, Vázquez-Armijo JF, Pérez-Hernández P, Mendoza-Martínez GD, Salem AZM, Albarrán-Portillo B, González-Reyna A, Hernández-Martínez J, Rebollar-Rebollar S, Cardoso-Jiménez D, Dorantes-Coronado EJ, Gutierrez-Cedillo JG 2009. Dual purpose cattle production in Mexico. *Tropical Animal Health and Production*. 41: 715-721. ISSN: 1573-7438. https://doi.org/10.1007/s11250-008-9249-8

ROMÁN H, Ortega L, Hernández L, Díaz E, Espinoza JA, Nuñez G,Vera HR, Medina M, Ruiz FJ. 2009. Producción de leche de bovinos en el sistema doble propósito. Libro Técnico Núm. 22. INIFAP.CIRGOC. Veracruz, México. 335p.ISBN: 978-607-425-171-5.Disponible en: https://www.uv.mx/veracruz/cienciaanimal/files/2013/11/Produccion-de-leche-de-bovinos-en-el-sistema-doble-proposito.pdf

SAMADI F, Phillips NJ, Blache D, Martin GB, D'Occhio MJ. 2013. Interrelationships of nutrition, metabolic hormones and resumption of ovulation in multiparous suckled beef cows on subtropical pastures. *Animal Reproduction Science*. 137: 137-144. ISSN: 0378-4320. https://doi.org/10.1016/j.anireprosci.2012.12.012

SENGER PL. 2003. Pathways to pregnancy and parturition. Segunda edición. Editorial Current Conceptions, Inc. Washington State University. Pullman, E.U.A. 323p. ISBN: 0-9657648-2-6. www.currentconceptions.com

THATCHER W. 2017. A 100-Year Review: Historical development of female reproductive physiology in dairy cattle. *Journal of Dairy Science*. 100: 10272–10291. ISSN: 1525-3198. https://doi.org/10.3168/jds.2017-13399

TINOCO-MAGAÑA JC, Aguilar-Pérez CF, Delgado-León R, Magaña-Monforte JG, Ku-Vera JC, Herrera-Camacho J. 2012. Effects of energy supplementation on productivity of dual-purpose cows grazing in a silvopastoral system in the tropics. *Tropical Animal Health and Production*. 44: 1073-1078. ISSN: 1573-7438. https://doi.org/10.1007/s11250-011-0042-8

VEDOVATTO M, Moriela P, Fernandes R, Sampaio D, Carvalho FJ, Cortada IM, da Silva C, Luiz De Lucca A, Garcia R, Aparecida S, Loriano G. 2019. Effects of a single trace mineral injection on body parameters, ovarian structures, pregnancy rate and components of the innate immune system of grazing Nellore cows synchronized to a fixed-time AI protocol. *Livestock Science*. 225: 123-128. ISSN: 1871-1413.

https://doi.org/10.1016/j.livsci.2019.05.011

VELÁZQUEZ H, Galindo L, Barrientos M, Galina CS, Maquivar MG, Montiel F. 2020. Effect of the technological status of small cow-calf farm producers on the induction to resumption of ovarian activity of dual-purpose cattle raised under tropical conditions. *Open Journal of Veterinary Medicine*. 10: 195-205. ISSN: 2165-3364.
https://doi.org/10.4236/ojvm.2020.1011017

VILLARROEL-MOLINA O, De-Pablos-Heredero C, Barba C, Rangel J, García A. 2021. The Importance of Network Position in the Diffusion of Agricultural Innovations in Smallholders of Dual-Purpose Cattle in Mexico. *Land*. 10:401. ISSN: 2073-445X.
https://doi.org/10.3390/land10040401

VITE-CRISTÓBAL C, López-Ordaz, García-Muñiz J G, Ramírez-Valverde R, Ruiz-Flores A, López-Ordaz R. 2007. Producción de leche y comportamiento reproductivo de vacas de doble propósito que consumen forrajes tropicales y concentrados. *Veterinaria México*. 38:63-79. ISSN: 0301-5092. https://www.redalyc.org/pdf/423/42338107.pdf

WALSH SW, Williams EJ, Evans ACO. 2011. A review of the causes of poor fertility in high milk producing dairy cows. *Animal Reproduction Science*. 123: 127-138. ISSN: 0378-4320. https://doi.org/10.1016/j.anireprosci.2010.12.001

WILDE D. 2006. Influence of macro and micro minerals in the peri-parturient period on fertility in dairy cattle. *Animal Reproduction Science*. 96: 240-249. ISSN: 0378-4320. https://doi.org/10.1016/j.anireprosci.2006.08.004

ZÁRATE-MARTÍNEZ JP, Juárez-Lagunes FI, Ríos-Utrera Á, Montero-Lagunes M, Fragoso-Islas A. 2022. Consumo de FDN y su efecto sobre la respuesta a la IATF en vacas del trópico de México. *Revista MVZ Córdoba*. 27: e2121. ISSN: 0122-0268. https://doi.org/10.21897/rmvz.2121

Errata Erratum

https://abanicoacademico.mx/revistasabanico-version-nueva/index.php/abanico-veterinario/errata