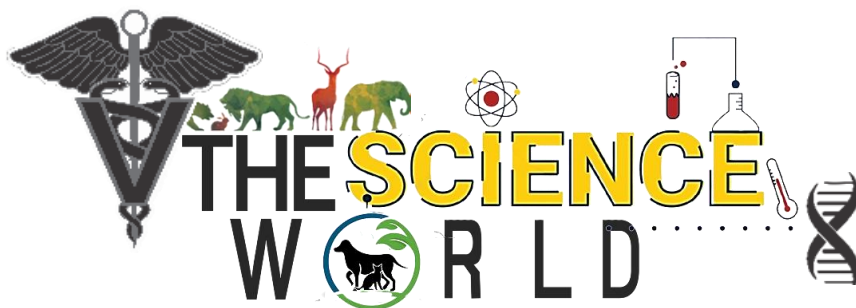




A Monthly e Magazine
ISSN:2583-2212

Popular Article

Sept, 2026 Vol.6(9), 2742-2747

Dietary Minerals and Bovine Reproductive Efficiency

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doi.org/10.5281/ScienceWorld.22971064

Abstract

Minerals are essential nutrients required in relatively small quantities but play critical roles in maintaining health, productivity, and reproductive efficiency in livestock. They are broadly classified into macro minerals and trace minerals, with calcium, phosphorus, magnesium, sodium, potassium, and sulfur being required in larger amounts, while copper, zinc, manganese, selenium, iodine, cobalt, iron, and chromium are required in trace amounts. The bioavailability of minerals is influenced by their chemical form, with organic and chelated minerals generally having greater bioavailability than conventional inorganic sources. Recent advances have also introduced nano-mineral supplements as an alternative source of mineral nutrition. Mineral balance is particularly important for reproductive functions, as deficiencies or excesses may adversely affect hormone synthesis, ovarian activity, fertility, sperm quality, conception, uterine health, and embryonic development. Calcium and phosphorus are associated with parturition, uterine function, fertility, and semen quality, while sodium, potassium, magnesium, and sulfur contribute to physiological and reproductive processes. Among trace minerals, copper, cobalt, selenium, manganese, zinc, iodine, chromium, and iron have important roles in antioxidant defense, hormone regulation, spermatogenesis, ovarian activity, and reproductive health. Therefore, maintaining an appropriate balance and bioavailable supply of dietary minerals is essential for optimizing reproductive performance, productivity, and overall health in livestock.

Keywords: Mineral nutrition; Livestock; Reproductive efficiency; Macro minerals; Trace minerals; Mineral bioavailability; Fertility; Selenium; Zinc; Copper; Dairy cattle; Reproductive performance

Introduction

Minerals (ash) constitute only a very small amount of the body, about 3–5%. However, despite their small proportion, they are very important for maintaining health and ensuring efficient production. Minerals are generally classified into macro- and trace-elements based on the quantities required. Macro minerals such as calcium, phosphorus, magnesium, sodium,



potassium, and sulfur are required in larger amounts, whereas copper, zinc, manganese, selenium, iodine, cobalt, iron, and chromium are trace or micro minerals. Minerals, though required in small amounts, are essential for normal growth and body functions in livestock. They provide strength to bones and teeth and are also part of many body tissues and structural components. Minerals help maintain important physiological processes, such as fluid balance, acid–base equilibrium, nerve function, and the proper functioning of the heart and muscles. They are involved in several metabolic activities by acting as cofactors for enzymes and supporting energy production and nutrient utilization. In addition, certain trace minerals play key roles in blood formation, oxygen transport, hormone synthesis, and gene regulation. Therefore, a proper balance of minerals in the diet is necessary to maintain health, productivity, and reproductive performance in animals.

Forms of Minerals and Their Bioavailability:

Bioavailability of different forms of minerals used in livestock and poultry varies considerably. The conventionally used forms are inorganic ones which are present typically in oxide, sulfide and carbonate forms. They are released and ionized in the stomach's low pH and react with other products of digestion resulting in formation of insoluble, unavailable substances especially in the small intestine. Organic trace minerals remain intact in the upper gastro-intestinal tract and are less likely to form insoluble and indigestible compounds like inorganic trace minerals. Organic form undergo less dissociation in the reticulo-rumen, omasum, and abomasum than their inorganic counterparts. In the organic form the metals are present as chelates by forming complex with amino acids, proteins, polysaccharides. The primary chelated minerals used in animal feed are the trace elements iron, manganese, cobalt, copper, and zinc. Chelates increase the bioavailability of minerals to animals, supporting metabolic functions. Another form of organic mineral is mineral-enriched yeast, among which selenium-enriched yeast is the most widely used, where selenium is primarily present in the form of selenomethionine. In addition, chromium-enriched yeast has gained attention due to its beneficial effects on animal performance and productivity. Furthermore, recent advances have introduced nanotechnology-based mineral supplements. Nano-sized minerals are emerging as an alternate source of minerals. Nanoparticles of Cu, Se, Ag, Zn, Ca, and Se have been studied in livestock and poultry. Due to small size (<100 nm) nano minerals exhibit increased absorption from the GIT, making them more effective than bulk minerals even at lower doses.

Role of Minerals in Reproductive Efficiency

In this context, the role of minerals in reproduction becomes particularly significant. Reproductive efficiency is considered essential for profitable livestock farming, as it ensures



regular calving, higher milk production, and overall herd productivity. Although emphasis is often placed on the quantity of feed, the importance of minerals is frequently overlooked. Minerals are required for hormone synthesis, ovarian activity, and fertility, and their deficiency has been shown to adversely affect both steroidal and thyroid hormone production (Boland, 2003). Low productivity and poor reproductive performance in livestock have largely been attributed to inadequate nutrition and mineral deficiencies.

Role of Macro Minerals in Reproduction

Among macro minerals, calcium is considered vital for parturition, muscle contraction, maintenance of uterine tone, and uterine involution. When calcium levels are reduced, delayed involution, retained placenta, dystocia, and uterine prolapse have been observed. Retained placenta may be caused by reduced secretion of oxytocin and prostaglandins (PGF₂α), low serum calcium levels, dystocia, and delayed uterine involution (Akar and Yildiz, 2005). Calcium present in seminal plasma has also been reported to influence sperm motility and viability, although variable effects have been observed across species (Machal et al., 2002; Eghbali et al., 2010; Asadpour, 2012). It has further been reported that excessive calcium levels may reduce conception rates by interfering with the absorption of other essential minerals such as phosphorus, magnesium, zinc, and copper (Dias Betini et al., 2025).

Phosphorus has been recognized as equally important for reproductive performance, and its deficiency has been associated with decreased fertility, reduced feed intake, delayed sexual maturity, and low conception rates (Talukdar et al., 2016). Its role in sperm motility has also been reported and a positive correlation between phosphorus concentration in seminal plasma and semen quality has been observed (Machal et al., 2002). The reproductive performance of lactating dairy cows has been reported to differ markedly with variations in dietary phosphorus levels. Cows fed diet deficient in phosphorus have been observed to exhibit delayed onset of estrus, reduced ovarian activity, lower conception rates, increased services per conception, and prolonged calving intervals, indicating compromised fertility. However, excessively high levels may not provide additional reproductive benefits (Lopez et al., 2004), emphasizing the importance of maintaining optimal dietary phosphorus levels. Salt (NaCl) has been widely used as a supplement, and its deficiency has been linked to digestive disturbances, indirectly affecting reproductive health. Sodium and potassium act as major cations in body fluids and help regulate plasma volume, acid–base balance, nerve activity, and muscle function through Na⁺/K⁺-ATPase mechanisms (Huang et al., 2024). These minerals also play a key role in reproduction by maintaining osmotic balance and supporting sperm activity, sperm movement and the acrosome reaction (Newton et al., 2010). Very high levels of potassium may



negatively affect reproduction by delaying puberty and ovulation, impairing corpus luteum development, and increasing the chances of anestrus in heifers. Lower fertility has also been observed in cows fed high-potassium diets or when the potassium-to-sodium ratio becomes too wide (Bindari et al., 2013). Therefore, maintaining a proper balance of sodium and potassium in the diet is essential for good reproductive performance. Magnesium has been found to support enzyme activity and the nervous system, and its imbalance may influence reproductive functions. Sulphur has been reported to play a role in protein synthesis and sperm function, and its imbalance has been associated with impaired reproductive performance (Zhang et al., 2006; Tumenbaevish et al., 2012).

Role of Trace Minerals in Reproduction

Trace minerals, although required in small amounts, have been found to exert significant effects on reproduction. Copper has been identified as an essential cofactor in enzymatic reactions and hormone regulation. Deficiency of copper has been associated with early embryonic death, fetal resorption, retained placenta, delayed estrus, and infertility. Interactions of copper with other minerals such as iron, zinc, and molybdenum have also been reported to influence its bioavailability and reproductive functions (Galbat, 2020). Cobalt has been recognized for its role in vitamin B₁₂ synthesis, and its deficiency has been linked to irregular estrous cycles, prolonged uterine involution, and reduced conception rates (Sethy et al., 2017).

Selenium has been widely reported to function as an antioxidant in association with vitamin E, protecting reproductive tissues from oxidative damage. Its supplementation has been shown to reduce retained placenta, mastitis, and uterine infections, whereas deficiency has been associated with abortion and weak offspring (Majors et al., 2025). Manganese has been identified as essential for the synthesis of steroid hormones such as estrogen and progesterone, and its deficiency has been linked to infertility, reduced fetal growth, increased embryonic mortality, and smaller litter size and higher piglet mortality (Studer et al., 2022). Zinc has been reported to play a role in hormone function, uterine repair, and spermatogenesis, and its deficiency has been associated with reduced fertility, abnormal estrus, and impaired sperm quality (Cai et al., 2025). Iodine has been recognized for its role in thyroid hormone production, which regulates reproductive processes. Its deficiency has been associated with abortion, retained placenta, and weak offspring, while excess iodine has also been reported to adversely affect reproductive health (Kumar et al., 2011; Hess et al., 2008). Chromium has been found to influence carbohydrate metabolism, enhance insulin-mediated glucose uptake, thereby improving reproductive performance. Chromium may improve reproductive



performance during heat stress by alleviating insulin-mediated damage to the follicle (Negrón-Pérez et al., 2019). Iron has been identified important for ovarian activity and sperm health, and both deficiency and excess have been reported to negatively affect reproduction. When iron levels are low, animals may show irregular heat cycles, delayed ovarian activity, and reduced fertility due to impaired hormone synthesis and increased oxidative stress (Regmi and Dhakal, 2020). On the other hand, excess iron can be harmful, as it interferes with other minerals like copper, damages reproductive tissues, and increases the risk of early embryonic loss and follicular degeneration (Wang et al., 2026).

Conclusion

Mineral deficiencies have been commonly observed due to poor-quality feed and lack of supplementation, resulting in reduced reproductive efficiency and economic losses. Although required in small quantities, their impact on reproductive performance is substantial. Both deficiency and excess of minerals have been shown to adversely affect fertility. Therefore, balanced mineral nutrition is considered essential for improving fertility and productivity in livestock.

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