Review Article

Role of Trace Minerals in Animal Production and Reproduction

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Abstract

Productive and reproductive efficiency of animal is the most important factor for success of dairy farm. Minerals play very precious role in maintaining productive and reproductive health of a dairy herd. Trace elements, though required in little quantities (less than 100 mg/kg dry matter) have critical roles in key interrelated systems of immune function, oxidative metabolism and energy metabolism in ruminants which are directly or indirectly involved in growth, production and reproduction. Deficiencies in trace minerals can lead to deficits in any of these processes, as well as reductions in growth performance. Most animal diets are supplemented with inorganic and/or organic forms of trace minerals. Inorganic trace minerals (ITM) form bulk of trace mineral supplementation, but these forms of minerals are well known to be prone to dietary antagonisms. Feeding high-quality chelated trace minerals or other classes of organic trace minerals can provide animal with more bioavailable forms of minerals.

Key words: Trace Minerals, Production, Reproductive Disorders, Bioavailability

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Introduction

The minerals are usually classified into macro elements (Ca, P, K, NaCl, and Mg) and trace elements (Cu, Co, Se, Mn, I, Zn, Fe Mo and Cr) depending upon the quantities (NRC, 2001). The "trace elements" are those elements existing in natural and perturbed environments in small amounts, with excess bioavailability having a toxic effect on the living organism (Wada, 2004). Trace elements are essential dietary components for life and necessary for numerous metal-dependent enzyme and protein activities (Kramer *et al.*, 2007).Trace mineral requirements are affected by a number of factors like age, stage (lactating vs non-lactating) and level of production, breed, and bioavailability of the mineral from the diet. Iron (1.0-2.0 ppm) is most abundantly found in serum followed by zinc (0.8-1.2 ppm) (Radostits *et al*., 2007; Andrieu, 2008) and copper (0.57-1.0). Along with these cobalt (1-3 µg/dl), iodine (2.4-14 µg/100ml), manganese (18-19 µg/dl) and selenium (50-220 ng/L) are required in least amounts (Radostits *et al*., 2007; Andrieu, 2008).Trace minerals are required by cattle because of their roles inthe production of hormones, enzyme activity, synthesis of tissues, energy production andcollagen formation (Paterson and Engle, 2005). Even short periods of insufficient alimentary supply can promote significant physiological changes (Brugger *et al*., 2014). Its improper level may affect embryonic development, post-partum recovery activities and over all fertility of animal may be impaired along with reduction in quality and quantity of milk production. In male animals it may change spermatogenesis and reduce libido. So, in order to maintain adequate trace mineral status in dairy animals, balanced intake and absorption are necessary.

Chemical Structure of Trace Mineral Supplements

Conventionally, Mn, Cu and Zn supplements have been fed as inorganic salts, for example magnesium sulfate, cupric sulfate and zinc sulfate. Trace mineral in these salts is associated with sulfate in a dry form but dissociates from the sulfate when hydrated in the rumen. A current trend is to feed "organic" forms of Zn, Cu, and/or Mn in place of inorganic salts. In organic Zn, Cu and Mn the mineral is bound to an organic (i.e. carbon-containing) molecule, typically an amino acid or protein and further these supplements are classified as complexes, chelates or proteinates based upon their chemical structure. The minerals and organic molecules are associated in complexes, but not necessarily by covalent bonds (Spears, 1996). Covalent bonds exist between the minerals and organic molecules for both chelates and proteinates (Spears, 1996). For Zn, an example of a complex, chelate, and proteinate is Zn-methionine (ZN-met), Zn-methionine hydroxy-analogue (Zn-MHA), and Zn-proteinate, respectively. Selenites and selenates provide inorganic Se in the form of sodium salts while organic Se is provided by Se-yeast, a product made from growing yeast in media supplemented with Se (Weiss, 2005). Yeast incorporates Se into a variety of compounds, with the predominant compound being selenomethionine (Schrauzer, 2000). In Se-met, Se is covalently bound to the amino acid and takes the place of Sulfur in the molecular structure.

Bioavailability of Trace Mineral in Ruminants

Bioavailability determines efficacy of trace minerals. Several factors directly or indirectly affect the concentrations of minerals in plants and hence the amounts available for animals that depend on plants for feeds. Soil condition has been reported to influence the mineral compositions of feed ingredients (Kavanek and Janicek, 1969). In animals, supplemental trace minerals are supplied through inorganic sources. Although some new organic sources have been introduced in recent years, like sulphates and oxides, are still most widely used in animal feeds. For Se, most studies indicate that the bioavailability of selenium from selenite and selenate is similar in ruminants (Podoll*et al.*, 1992; Ortman and Pehrson, 1999). Organic

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selenium in selenized yeast results in much larger increases in blood and milk selenium concentrations than selenite (Podoll *et al.*, 1992; Knowles *et al.*, 1999). Absorption of selenium is much lower in ruminants than in non-ruminants. Absorption of orally administered ^{75}Se was only 34% in sheep compared with 85% in swine (Wright and Bell, 1966). The relative bioavailability of copper from tribasic cupric chloride (Cu_2OH_3Cl) was 121% (based on plasma copper) to 196% (based on liver copper) that of cupric sulfate when supplemented to cattle diets high in molybdenum and sulfur (Spears *et al.*, 1997). Tribasic copper chloride and cupric sulfate were similar in bioavailability when evaluated in copper-deficient steers fed diets that were low in molybdenum (Spears *et al.*, 1997). Copper absorption in ruminants is low (<1.0–10.0%) relative to values reported in non-ruminants (Underwood and Suttle, 1999). Manganese is poorly absorbed (1% or less) from ruminant diets (Hidiroglow, 1979; Van bruwaene *et al.*, 1984). Manganese from two feed-grade manganese oxide sources tested in lambs was 70% and 53% as bioavailable as manganese from reagent-grade manganese sulfate (Henry *et al.*, 1992). Relative bioavailability of manganese from manganese methionine was 120% of that present in the sulfate form (Henry *et al.*, 1992). The percentage of dietary zinc that is absorbed decreases as dietary zinc increases in ruminants (Miller, 1970). Zinc requirements of ruminants appear to be affected by dietary factors based on the variable animal responses that were observed after zinc supplementation (Underwood, 1977). Studies indicate that addition of 250–1,200 mg of iron (from ferrous carbonate)/kg of diet greatly reduces copper status in cattle (Bremner *et al.*, 1987; Phillippo *et al.*, 1987) and sheep (Prabowo *et al.*, 1988). High dietary iron did not affect copper status in young pre-ruminant calves, which suggests that a functional rumen is needed for iron to interfere with copper metabolism (Bremner *et al.*, 1987).

Functions of Trace Minerals

Trace mineral functions are categorized into four broad categories (Underwood and Suttle, 1999).

Structural Function

Structural function refers to minerals forming structural components of body organs and tissue, for example, the contribution of zinc to molecular and membrane stability.

Physiological Function

Physiological function occurs when minerals in body fluids and tissues act as electrolytes to maintain osmotic pressure, acid base balance and membrane permeability.

Catalytic Function

Catalytic function is probably the largest category for trace minerals as it refers to catalytic role of metalloenzymes in enzyme and hormone systems. Trace elements serve as structural components of

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metalloenzymes. Upon removal of the trace element or lack of adequate trace mineral levels the enzyme activity is lost. There are numerous metalloenzymes that are required for a wide range of metabolic activities such as energy production, protein digestion, cell replication, antioxidant activity and wound healing.

Regulatory Function

Regulatory function is exemplified by the role of zinc to influence transcription and iodine serving as a constituent of thyroxine, a hormone associated with thyroid function and energy metabolism.

Effect of Trace Minerals on Productive Performance of Animals

The role of trace minerals in animal production is an area of strong interest for farmers, producers, feed manufactures, veterinarians and scientists. Micro minerals are very essential part of animal's ration which is required only in little amount and excess feeding of some of these may show toxicity symptoms. Deficiency of trace minerals in the diet alone can reduce animal production by 20-30%. Therefore, supplementation of trace elements in animal diets has long been practiced in order to ensure their rapid growth, boost reproductive performance and improve immune response (Overton and Yasui, 2014).

Table 1: Trace minerals requirement for maintenance of dairy cattle

Mineral	Requirement
Copper	10 mg/kg DMI
Cobalt	0.11 mg/kg DMI
Selenium	0.25 mg/kg DMI
Manganese	15 mg/kg DMI
Zinc	40 mg/kg DMI and 80 mg/kg DMI during summer and transitional animals, respectively
Iron	50 mg/kg DMI
Iodine	0.25 mg/kg DMI (in extreme summers, reduce the content to 0.15 mg/kg DMI

Source: ICAR (2013)

Table 2: Trace minerals requirement during gestation period of dairy cattle

Mineral	Requirement (after 190 days (6 months) of pregnancy)
Copper	1.5-2.0mg/day
Manganese	0.3mg/day
Zinc	12mg/day
Iron	18mg/day

Source: ICAR (2013)

Recent data indicate that micronutrient management will enhance the production of good quality milk. The keratin lining of the teat canal has been described as a physical and chemical barrier for protection of the mammary gland. Keratin lining may physically trap bacteria and prevent migration into the mammary

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gland. Because the mammary gland is a skin gland, it is highly likely that zinc will have a positive role in its protection.

Table 3: Trace minerals requirement for per kg milk production of dairy cattle

Mineral	Requirement
Copper	3.75mg/kg
Cobalt	0.006mg/kg
Manganese	3.0 mg/kg
Zinc	26.67 mg/kg
Iron	2.25 mg/kg
Iodine	5 to 50 mg/kg

Source: ICAR (2013)

Zinc deficiency in ruminants has been postulated to weaken skin and other stratified epithelia as well as reducing the magnitude of basal metabolic rate following infectious challenge (Harmon, 1998). Skin integrity of the teat has been shown to be especially linked with mastitis prevention. Kellogg (1990) reported that chelated zinc decreased somatic cell counts (SCC) by 22-50% in eight trials, depending on the dose of zinc used and increased milk production. Selenium supplementation increased SCC resistance to intra-mammary infusion of *Escherichia coli*. Erskine *et al*. (1987) demonstrated lower blood selenium concentrations in cows with high SCC compared with cows with low SCC.

Effect of Trace Mineral on Animal Reproduction

According to Smith and Chase (2010), the interaction between mineral and reproduction in farm animals have been documented. These reports generally suggest that adequate mineral intake improves production efficiency and reproduction performance parameters in farm animals (Almeida *et al*., 2007; Griffiths *et al*., 2007). Excess mineral intake results in loss of body weight and condition, and may delay puberty, reduce ovulation, lower conception rates, interferes with normal ovarian cyclicity by decreasing gonadotropin secretion and increases infertility (Boland *et al*., 2001; Wright, 2012).

Copper

Copper is one of the important mineral for reproduction point of view as such its deficiency is reported to be responsible for early embryonic death and resorption of the embryo (Miller *et al*., 1988), increased chances of retained placenta and necrosis of placenta (O'Dell, 1990) and low fertility associated with delayed or depressed estrus (Howell and Hall, 1970). In addition to this, proper copper supplementation is must for quality semen production (Puls, 1994). Copper treatment is reported to improve conception rate as the copper treated cow require 1 service and the untreated cow require 1.15 services per conception (Hunter, 1977).

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Cobalt (Co)

Cobalt plays important role in the synthesis Vitamin B12 (Miller and Tillapaugh, 1967). Levels of Vitamin B12 are high in milk and colostrum which is required for the conversion of propionate into glucose and folic acid metabolism. Cobalt deficiency leads to reduce fertility and poor conditioning of the developing fetus. In dairy animal deficiency leads to prolonged uterine involution, irregular estrous cycle, lower conception rates and early calf mortality (Puls, 1994; Kumar, 2003). Deficiency of cobalt will in turn lead to Vitamin B12 deficiency. Manganese, zinc and iodine may reduce cobalt deficiency (Patterson *et al*., 2003).

Selenium

In pregnant animal marginal deficiency of selenium leads to abortion, birth of weak calves that are unable to stand. Research indicates that selenium supplementation reduces the incidence of retained placentas, cystic ovaries, mastitis and metritis (Patterson *et al*., 2003). Being having direct link to the uterine involution selenium is important dietary mineral (Arthington, 2005). Among dairy animals, where subclinical selenium deficiency is there, reproductive performance may get retarded with delayed ovulation, increased services per conception and high incidence of mastitis (Goff, 2005). Selenium helps in enhancing the reproductive efficiency by increasing the activity of glutathione peroxidase in blood and tissues. Selenium easily crosses placenta whether fed as inorganic or organic food. It has been reported that selenium supplementation leads to improved conception rate at first service (McClure *et al*., 1986). Selenium injections prior to parturition helps in reducing the incidence of retained placenta in deficient animals.

Manganese (Mn)

Manganese is important in cholesterol synthesis (Keen and Zidenberg-Cheer, 1990) which in turn is necessary for the synthesis of steroids like progesterone, estrogen and testosterone. Decrease concentration of these steroids in circulation following manganese deficiency may lead to related reproductive abnormality. Deficiency cause poor fertility problem in male and female. It is responsible for silent estrus and anoestrus (Corrah, 1996) or irregular estrus (Brown and Casillas, 1986) and decrease conception rate, birth of deformed claves and abortions in females and absences of libido and improper or failure of spermatogenesis in males (Sathish Kumar, 2003). Postpartum anestrus in dairy cows has proven to be reduced following manganese supplementation (Krolak, 1968) so thus the number of services required per conception increased (Rojas, 1965).

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Zinc

Zinc act as cofactor and coenzyme of many enzymes and various reproductive hormones. Zinc plays an essential role in the maintenance and repair of uterine lining after calving, helps in early involution. Abnormal levels of zinc is associated with decreased conception rate, abnormal estrous and abortion. Zinc as coenzyme, is involved in the formation of prostaglandins form arachidonic acid suggesting its profound effect on reproductive cycles and maintenance of pregnancy (Kumar *et al*., 2011). Zinc also increases the plasma beta carotene level that has been directly correlated to higher conception rate and embryonic development (Staats *et al*., 1988). Delayed puberty and low conception rates, failure of implantation and reduction of the litter size are also found in association with the zinc deficiency in feed. The recommended dietary requirement of zinc for dairy cattle lies between 18-73 ppm (Patterson *et al*., 2003) depending upon the stage of the lifecycle and dry matter intake, whereas according to the feeding standards the requirement is 40 ppm (NRC, 2001).

Iron

Iron is essential for the synthesis of hemoglobin and myoglobin and various other enzymes that help in formation of ATP through electron transport chain. It helps in transport of oxygen to tissues, maintenance of various oxidative enzyme systems (Khillare *et al*., 2007). Deficiency is rare in adult animals due to its abundance in feed stuffs. But in cases where deficiencies are there, reproductive health is deteriorated due anemia, reduced appetite and poor body condition. Chances are there that deficient animal will become a repeat breeder and will require increased number of services per conception and may abort occasionally (Kumar *et al*., 2011).

Iodine

Iodine due to its action on thyroid gland affects the reproduction. Iodine is regarded as essential for the developing fetus and maintaining the basal metabolic rate. Iodine through its effect on thyroid gland helps in secretion of gonadotropin by stimulating the anterior pituitary gland, thereby affects the estrous cycle (Khillare *et al*., 2007). Deficiency of iodine affects the fertility and increases the abortion rate (Hetzel, 1990), the incidence of retained placenta and post-partum uterine infections, respectively (Hemken, 1960). Conception rate and ovarian activity is reduced with the impaired thyroid functions. Thus, iodine affects the reproduction in many ways and a recommended dose of 15-20 mg of iodine each day is necessary for a cow to have good reproduction status. Excess of iodine also have deleterious effect on reproductive health by inducing premature births of weak calves, abortions and lowers the immunity status of animal (Kumar *et al*., 2011). Subclinical iodine deficiency is characterized by increased stillbirths, suppressed estrous, increased chances of retained placentas and prolonged gestation periods (Hess *et al*., 2008). Normal plasma level of inorganic iodine in cows should be maintained between 100-300 ng/ml.

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Chromium

Chromium is essential for carbohydrate metabolism (Tuormaa, 2000). It is present in nuclear protein in higher amount thus has a role in gametogenesis and for healthy fetal growth. It is also an integral part of the pregnancy specific protein that is secreted by uterine endometrium which helps in preventing the early embryonic mortality (Kumar *et al*., 2011). It is having a crucial role in maturation of follicle thus maintaining the estrous cycle and also in LH release which triggers the ovulation. Deficiency of chromium will lead to irregular estrous cycle, delayed ovulation, early embryonic mortality and retarded fetal growth (Tuormaa, 2000). In lactating animals, it may predispose the animal to ketosis and decreased milk production.

Molybdenum

Molybdenum deficiency in animals delays the onset of puberty, decreases conception rate and causes anestrus (Kumar, 2003). Molybdenum and copper are interlinked with each other as deficiency of one occurs in the presence of toxic levels of other. Therefore, a proper balance in feeding the copper and molybdenum must be followed to avoid the reproductive problems (Randhawa and Randhawa, 1994).

Deficiency of Trace Minerals

Trace mineral deficiencies in livestock are often divided into two distinct categories:

1. Primary: A deficiency resulting from the consumption of an essential trace mineral at levels inadequate to support the physiological functions associated with that element.
2. Secondary: A deficiency resulting from the consumption of an element which antagonizes the pre- or post-absorption of an essential trace mineral rendering the element incapable of supporting the physiological functions associated with that element.

Reproductive performance of cattle may be compromised if zinc, copper, or manganese status is in the marginal to deficient range. Common copper deficiency symptoms in cattle include delayed or suppressed estrus, decreased conception, infertility and embryo death (Phillippo *et al*., 1987; Corah and Ives, 1991). Inadequate zinc levels have been associated with decreased fertility, abnormal estrus, abortion, and altered myometrial contractibility with prolonged labor (Maas, 1987; Duffy *et al*., 1977). Manganese deficiency in cows results in suppression of conception rates, delayed estrus in post-partum females and young prepuberal heifers, infertility, abortion, immature ovaries and dystocia (Brown and Casillas, 1986; Maas, 1987; Corah and Ives, 1991). Dairy producers can benefit from year-round complexed trace mineral supplementation due to additional effects such as enhanced milk production and reduced somatic cell counts. Improving reproductive performance of dairy cows by achieving confirmed conception rates early in the breeding period could have economic returns to the producer. Subclinical or marginal deficiencies may be a larger problem than acute mineral deficiency, because specific clinical symptoms are not evident

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to allow the producer to recognize the deficiency; however, animals continue to grow and reproduce but at a reduced rate. As animal trace mineral status declines immunity and enzyme functions are compromised first, followed by a reduction in maximum growth and fertility, and finally normal growth and fertility decrease prior to evidence of clinical deficiency.

Environmental Issues and Ration Formulation Strategy

Currently producers are faced with many challenging issues related to sustainable agriculture. These environmental issues make deleterious impact on livestock production practices. In the near future, regulations may possibly limit the level of trace minerals fed in order to reduce the amount found in animal wastes. When producers are confronted with these types of restriction, form of trace minerals fed may become more critical in relation to bioavailability to the animal. The question then becomes, can lower levels of more bioavailable organic minerals give the same response as higher levels of inorganic minerals? In the swine industry it is a common practice to include copper sulfate at elevated levels (200-250 ppm) to enhance growth in the nursery. In a trial evaluating levels of copper sulfate and copper lysine, pigs fed 100 ppm copper lysine gained more weight and consumed more feed than those fed 250 ppm copper sulfate (Coffey *et al*., 1994). Feeding lower levels will also reduce the total amount of mineral excreted in the feces. In a study evaluating copper metabolism in growing calves, retention was improved when copper complex was the sole source of supplemental copper or blended with sulfate source and compared to copper sulfate alone.

Conclusion

A well-coordinated nutrition, health care, and management program is required to maximize efficiency and productivity. Trace elements are required for numerous metabolic functions in livestock, and optimal production and performance require adequate intake of balanced trace minerals. As trace mineral status of the animal declines from adequate to marginal, immunity and enzyme function are compromised followed by the loss of performance and reproduction. In order to avoid the chances of reproductive failure and other reproductive disorders we have to supplement adequate quantities of mineral required by the animal but Still trace mineral nutrition continues to be an area of interest for research and production applications.

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