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Review Article

Trace minerals and their responses in dairy cattle: A review

Abreham Zuma[1*]

[1]Department of Animal Science, College of Dryland Agriculture, Kebri Dehar University, Somali, Ethiopia

Abstract

The current dairy revolution demands more effective production in every aspect for which nutrition plays a great role in production and reproduction sustainability. For maintaining a good dairy enterprise and have steady income, it is essential to have the animals with good reproductive status with balanced nutrients in their diet. Most dairy research tends to focus on protein and energy needs, and trace minerals are often overlooked. Though, different forms of organic minerals differ in their solubility, availability and effect on animal performance and benefits appear to be more promising in the non-ruminants than in the ruminants, there is almost a consensus that organic trace minerals have higher bioavailability resulting in better animal performance, health, production immune response and stress alleviation than their inorganic salts. High yielding dairy cow requires quality feed with organic minerals and hence the bioavailability of these minerals form an essential component in the production system. Organic trace minerals consist of the same trace minerals being chelated, complexed or covalently bonded to amino acids, analogues, proteins or organic acids in a way that allows for increased absorption in the animal. In this context, organic (chelated) trace minerals can be a better solution compared to other feeding inventions.It is concluded that minerals from organic sources have higher bioavailability than inorganic sources. In dairy animals, majority of factors like nutrient intake, physiological status, manage mental and climatic conditions affect fertility of the animal. The main factor affecting the reproductive potential in different developing regions including Ethiopia is nutritional status of cows that too trace minerals. So further research with organic trace minerals is needed to: 1) better define conditions where performance or health responses may be expected, 2) define the optimal level of organic trace mineral(s) that should be added to the diet, 3) determine if responses observed are of a magnitude necessary to justify the cost, and 4) determine the mode of action whereby to improve the reproductive efficiency dairy cows.

Keywords: Dairy cows; Dietary requirements; Milk production; Organic trace mineral

*Corresponding author: abrishzuma@gmail.com

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1. Introduction

Novel nutritional management and reproductive health qualifiers are major contributors to economic returns in modern dairy industry and small-scale enterprises. The modern dairy cow in such different levels needs a diet that supplies the sufficient nutrients needed to produce high quality and quantity of milk (Griffiths et al., 2007; Siciliano-Jones et al., 2008; Hackbart et al., 2010). Most dairy research tends to focus on protein and energy needs, and trace minerals are often overlooked. When trace minerals are formulated in whole diet basis, they function as structural, physiological, catalytic and regulatory (McDowell & Arthington, 2005; Suttle, 2010). Yet when we fail to consider the role of trace minerals, problems like, interferences or interactions with minerals in feed and water may arise (Overton & Yasui, 2014).

Trace minerals are also nutrients of variable forms in soils (Fletcher & Doyle, 1978; Williams, 1977; Mcdonald et al., 2010), in feedstuffs and animals in various levels and proportions in particular regions and agro-ecologies. Two broad categories of sources are available to supplement trace elements: inorganic and organic sources. After long term use of sulfates and oxides, organic trace minerals (second generation trace minerals (e.g. chelates, glycinates); it entered the market successfully as a high bioavailable and economically beneficial trace mineral source.

When referring to trace mineral source, the term “organic” is generic and encompasses numerous examples of trace elements (predominantly divalent Cu, Zn, and Mn) covalently bound to an organic ligand. The increased number of binding points results in greater stability for the molecule compared to unidentate molecules, and is known as the chelation effect (Vella, 1993). Though chelates can form four, five, six, or seven membered rings, five membered rings have been shown to have the greatest stability (Murphy, 2009). Though, different forms of organic minerals differ in their solubility, availability and effect on animal performance and benefits appear to be more promising in animals, they have higher bioavailability resulting in better animal performance, health, immune response and stress alleviation than their inorganic salts. This efficiency of its nutritional values has provoked the use of such mineral supplements better able to meet the animal's growing needs.

Mineral chelates are organic trace minerals designed to enhance gut absorption and improve bioavailability in dairy cows to have quality product. More recently, organic trace minerals are also being utilized to maximize animal productivity by elevating the cow’s genetic potential. There are several studies in different animal species with different sources of different mineral elements, which have revealed notable differences in the bioavailability of organic and inorganic minerals. Common organically bound trace minerals used in animal nutrition are iron, copper, zinc, manganese, chromium and selenium. Most of the organic minerals marketed are classified as complexes, chelates or proteinates.

Supplementation of organic mineral complexes is reported to improve dairy animal production to the recent dairy industry, especially in developed countries and least in developed countries like Ethiopia due to lack of sources (accessibility). There studies suggest that binding Cu, Zn, Fe and Mn with amino acids and peptides can enhance the bioavailability of these trace minerals, thereby leading to improved milk production, growth, reproduction and general health status in livestock. Many studies (Griffiths et al., 2007; Siciliano-jones et al., 2008; Hackbart et al., 2010) have shown a positive effect on milk yield by supplementing cows with organic trace minerals in place of inorganic minerals.

2. Trace Minerals in Dairy Cattle

2.1. Trace mineral contents of dairy cow feedstuffs

Trace minerals are present in forages and other feeds used in dairy cattle diets and with the exception of cobalt, meet the trace mineral requirements of rumen microbes (Table 1).

Table 1. Average trace mineral contents of feedstuffs (NRC, 2001; Chahal et al., 2008; Chiba 2009; Punz, 2010)

Feed stuffs	Trace mineral content mg/Kg DM of feed						
	Co	Cu	I	Fe	Mn	Se	Zn
Alfalfa fresh	0.35	12.44	-	315.43	92.68	-	36.08
Alfalfa hay	0.39	17.67	-	224.60	28.00	-	30.86
Barley grain	0.08	6.4	0.25	48	15	0.19	22
Barley straw	0.06	5.39	-	200.76	16.56	-	7.44
Bermuda grass hay	0.12	26.64	0.11	289.96	109.02	-	58.14
Brewers grain (dried)	-	14.9	-	195	57		104
Corn grain	0.14	4.17	0.30	35.20	6.22	0.13	21.63
Corn silage	0.08	7.0	0.06	196	42		32
Cotton seed cake	0.28	19.0	0.30	190	21	0.14	80
Dried skim milk	0.07	0.7	0.03	9	2.2		45
Fish meal	0.15	10.34	1.09	544.58	37.02	2.14	144.32
Grass silage, 1st cut	0.10	7.9	-	696	90		50
Rape seed extracted	-	7.1		190	76.2	-	78.9
Soya beans	0.10	17.0	0.20	125	31	0.48	58
Sunflower seed	-	28.5	-	177	33.5	2.29	79.1
Wheat grain	0.08	6.2	0.07	50	30	0.04	26
Wheat bran	0.80	11.0	0.09	90	119	0.08	95
Wheat straw	0.03	3.4	0.30	120	32	-	67

Therefore, supplementation of trace elements in animal diets of dairy cattle has long been practiced in order to ensure their rapid growth, boost reproductive performance and improve immune response (Overton & Yasui, 2014). Assessment of trace element status in the feedstuffs of animals identifies whether current mineral supplementation of livestock is adequate and whether improved productivity is likely to occur with changes in supplementation.

2.2. Trace mineral requirement in dairy cattle

Excellent nutritional management of dairy cows, particularly during the transition period from late pregnancy to early lactation, is critically important to meeting overall demands for milk yield while maintaining health and reproductive capacity (Roche et al., 2013). The pasture cattle eat, on the other hand, is frequently lacking in trace mineral concentrations. As a result, trace minerals must be added to the feed on a regular basis (Table 2).

Nutritional strategies also ensure that along with the proper energy, protein and amino acid requirements, the optimal amounts of trace minerals (TM) are supplied to the animals in tropics in order to improving body functions of production (Ward & Spears, 1997; Engle & Spears, 2000), reproduction, and immunity (Spears, 2000; Spears & Weiss, 2008).

Table 2. Requirements of trace minerals on lactating dairy cattle on dry matter basis (NRC, 2001)

Mineral	Unit	Recommended	Maximum
Cobalt	mg/ kg	0.11	10
Copper	mg/ kg	12-16	100
Iodine	mg/ kg	0.45-0.6	50
Iron	mg/ kg	50	1000
Manganese	mg/ kg	45-55	1000
Selenium	mg/ kg	0.3-0.5	2
Zinc	mg/ kg	45-60	500

Trace minerals have significant roles in physiological, biochemical, and immune, processes throughout the animal’s body (Lei & Yang, 2005). Recent data indicate that micronutrient management will enhance the production of good quality milk (Table 3).

Table 3. Trace minerals requirement for per kg milk production of dairy cattle (ICAR, 2013)

Mineral	Unit	Requirem
Cobalt	mg/ kg	0.006
Copper	mg/ kg	3.75
Iodine	mg/ kg	5-50
Iron	mg/ kg	2.25
Manganese	mg/ kg	3.0
Zinc	mg/ kg	26.67

The keratin lining of the teat canal has been described as a physical and chemical barrier for protection of the mammary gland from bacterial attack and prevent entry. Because the mammary gland is a skin gland, it is highly likely that zinc will have a positive role in its protection.

Concentrations of TM in soils vary widely across the world, with some areas being high in Fe, Mo, or S, while others are deficient in Se and Zn (Suttle, 2010). Trace mineral status changes depending on several factors, including lactation, health, growth, feed quality, gestation progression, and pregnancy status (Table 4).

Deficiencies of TM (Figure 1) occur either as primary deficiency (inadequate intake or amount in the diet), or more commonly as secondary deficiency because of antagonistic interactions with other TM (Smart et al., 1981; Graham, 1991; Suttle, 2010).

Table 4. Summarization of trace minerals in Dairy rations (De Ondarza & Mary Beth, 1996; Linn et al., 1996; Kumar, 2003; Chaudhary & Singh, 2004)

Trace mineral	Function	Feed sources for dairy cattle
Cobalt	Part of vitamin B12, needed for growth of rumen microorganisms	Trace mineralized salt and commercial supplements
Copper	Needed for manufacture of haemoglobin, coenzyme	Trace mineralized salt and commercial supplements
Iodine	Synthesis of thyroxin	Iodized salt, trace mineralized salt and commercial supplements
Iron	Part of haemoglobin, part of many enzyme systems	Forages, grains, trace mineralized salt, ethylene diamine dihydroiodine
Manganese	Growth, bone formation, enzyme activator	Trace mineralized salt and commercial supplements
Molybdenum	Part of the enzyme xanthine oxidase	Widely distributed in feeds, deficiency rarely problem
Selenium	Functions with certain enzymes, , associated with vitamin E, immune system	Oil meals, alfalfa, wheat, oats, corn, commercial supplements
Zinc	Enzyme activator, wound healing	Forages, trace mineralized salt, zinc methionine

Antagonistic interactions between TM can result from the formation of insoluble complexes that limit its absorption in the gut, competition for binding sites, carrier proteins, or similar metabolic pathways, and induction of non-specific metal-binding proteins (Suttle, 2010).

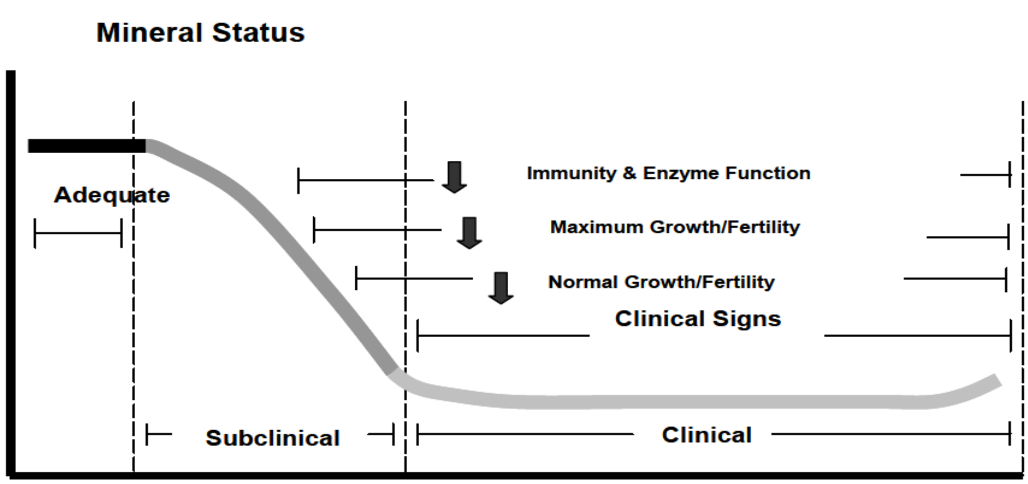

Figure 1. Declining trace mineral status on animal performance (Fraker, 1983; Wikse, 1992)

2.3. Trace mineral sources

Forages and feedstuffs commonly used in dairy rations that were from TM depleted soil are often deficient in zinc, manganese, copper and cobalt which in turn are responsible for low productivity problems among growing cattle in the tropics. Trace minerals such as Cu, Mn, and Zn have important roles (Miller et al., 1988), and have been typically offered to cattle either in inorganic or organic forms. Most research conducted using these various forms has focused on either partial or full replacement of either sulfates or oxides with one of the other forms with potentially greater bioavailability (Spears & Weiss, 2008).

2.3.1. Inorganic supplements

Micro-minerals that are not bound to carbon (C) but arranged with oxygen, chloride or other non-carbon-based compounds are inorganic trace minerals (carbonates, chlorides, sulfates, oxides, etc.) (Taylor & Field, 1998). Inorganic has been the primary option for feed grade TM supplementation for decades due to their affordability (cost) and high rumen solubility (Cunningham et al., 1953; Ammerman & Goodrich, 1983; Greene, 2000). Although inorganic trace minerals are often used in ruminant supplements, these mineral sources often have lesser biological availability and stability when compared to other organic mineral sources.

Inorganic TM dissociates in the reticulo-rumen, omasum, and abomasum, and can form compounds with plant polyphenols (McDonald et al., 1996) or with other TM that may have precipitated out of the digesta (Spears & Weiss, 2008). These complexes are insoluble and cannot be absorbed in the small intestine, which decreases the availability of the inorganic form to the host (Wright et al., 2008).

2.3.2. Organic supplements

The American Association of Feed Control Officials (Gayathri & Panda, 2018) define organic trace minerals as seven different complexes (a soluble metal salt and at least one amino acid); including metal (specific amino acid) complexes, metal amino acid complexes, metal amino acid chelates, metal proteinates, metal polysaccharide complexes, metal propionates, and yeast derivative complexes. Organic is considered to be chelated or complexed as a result of the metal ion (mineral) bound to a ligand via two or more donor atoms to form a heterocyclic ring(s) that contain the metal atom (Power & Horgan, 2000; Andrieu, 2008).

According to Miles & Henry (1999), the perceived benefits of organic trace minerals are: 1) protects the mineral from unwanted chemical reactions in the gastrointestinal tract by the ring structure; 2) chelates can pass easily intact through the intestinal wall into the blood stream; 3) reducing interactions between the mineral and other nutrients because of increased passive absorption; 4) the mineral is delivered in a form similar to that found in the body; 5) chelates are absorbed by different routes than inorganic minerals; 6) each mineral in the chelate facilitates the absorption of other minerals in the chelate; 7) chelates carry a negative charge so they are absorbed and metabolized more efficiently; 8) chelation increases solubility and movement through cell membranes; 9) chelation increases passive absorption by increasing water and lipid solubility of the mineral; 10) chelation increases stability at low pH; and 11) chelates can be absorbed by the amino acid transport system.

2.3.3. Hydroxy chloride trace minerals

Hydroxy trace minerals are relatively insoluble in water but become soluble under acidic conditions typical of those found in the abomasum of ruminants. These mineral sources have low water solubility (Spears & Weiss, 2008; Caldera et al., 2019) and in forage-fed ruminants, hydroxy chloride sources of Cu and Zn are less soluble in the rumen and bind less tightly with solid digestion than sulfate sources of the same metals (Jalali et al., 2020). The low solubility in water results in hydroxy trace minerals being non hygroscopic and less reactive in feeds and premixes than sulfates, resulting in improved vitamin stability (Lu et al., 2010) and less oxidation of lipids (Miles & Henry, 1999). These ruminal characteristics may explain, at least partially, the alleged increase in Cu bioavailability of hydroxy chloride vs. sulfate sources (Caldera et al., 2019) and by-pass the rumen, thus minimizing interactions that normally occur in the rumen.

2.4. Types of organic trace minerals supplements

Organic trace mineral supplements vary in regard to the type of ligand or ligands used to form the metal complex or chelate. In order for an organic mineral to be effective, four criteria should be met: higher water solubility, remain stable throughout the digestion process, enhance absorption and produce an economically beneficial response in the animal of trial.

Different types of organic trace elements are available on the market. For some of them, short-chain peptides and amino acids derived from hydrolysed soy proteins are used as ligands, and others use pure amino acids. Studies have shown that animals absorb, digest and use organic mineral sources better than inorganic ones, resulting in a greater bioavailability. According to the Association of American Feed Control Officials (AAFCO, 1998), various types of organic mineral products are shown in the Table 5. Deficiencies of TM (Figure 1) occur either as primary deficiency (inadequate intake or amount in the diet), or more commonly as secondary deficiency because of antagonistic interactions with other TM (Smart et al., 1981; Graham, 1991; Suttle, 2010).

Table 5. Classification of organic minerals as defined by American Feed Control Officials

Ligand type	Description
Metal (specific AA) complexes	These are the products resulting from complexing a soluble metal salt with a specific amino acid. E.g, zinc methionine is produced by combining zinc sulfate and amino acid (AA) methionine or copper lysine and manganese methionine.
Metal amino acid complexes	These are characterized by a metal atom (zinc for instance) complexed with several single amino acids. Each individual molecule is still one metal ion and one amino acid but has a variety of amino acids in the blend. For instance for a zinc complex in this category, the blend would include zinc methionine, zinc lysine, zinc leucine, zinc cystine, etc.
Metal amino acid chelates	These are formed from the reaction of a metal ion from a soluble metal salt with amino acids having a mole ratio of one mole of metal to one to three (preferably two) moles of amino acids to form coordinate-covalent bonds. The average weight of the hydrolyzed amino acids must be approximately 150 Da, and the final molecular weight of the chelate must not exceed 800 Da. Metal amino acid chelates are available for Co, Cu, Fe, Mn, and Zn.
Metal proteinates	These result from chelation of soluble mineral salt with AA and/or hydrolyzed protein. Final product may contain single amino acids, dipeptides, tripeptides or other protein derivatives.
Metal polysaccharide complexes	These are generally prepared by coating the metal with polysaccharide molecules. These are larger molecules based on chains of simple sugars that are highly soluble in digestive tract.
Metal propionates	These result on combining soluble metals and soluble organic acids such as propionic acid. The resultant products are highly soluble and generally disassociate in solution.
Yeast derivative Complexes	Other sources of organic trace elements that show promise are mineral enriched yeast. Presently the most common is selenium yeast with selenium complexed with a methionine molecule (selenomethionine). Chromium enriched yeast also has gained popularity for improving animal production (Rao et al., 2012).

2.5. Products of organic trace minerals and their effects

In tropical areas, poor grasslands remain the primary bottleneck for optimal cattle production (McDowell & Arthington, 2005) and several environmental characteristics (e.g. parent material, heavy rainfall) increase the risk for trace element imbalances in dairy cattle (Dudal, 1980). In recent years, there has been considerable interest in the use of organic trace minerals (OTM) in ruminant diets in many parts of tropical areas in order to support the overall health, performance and reproduction.

Researches investigating the impacts of organic trace minerals on grazing production systems have been highly variable. This happens due to the impacts that the rumen microbial population and fiber fractions in forage-based diets (Marques et al., 2016) exert on mineral x mineral interactions (e.g., formation of mineral complexes). However, recently organic mineral sources have begun to gain popularity because of a number of perceived benefits to their use (Miles & Henry, 1999).

Studies have confirmed that feeding amino acid complexes of Zn, Mn, and Cu, (Miller et al., 1988) and cobalt glucoheptonate improves performance of dairy cattle. The benefits include preventing mastitis, improving fertility, and reducing the incidence of foot lesions (Nocek et al., 2000; Uchida et al., 2001; Ballantine et al., 2002; Kellogg et al., 2004). According to the work of Krebs (1998), feeding organic sources of Zn, Cu and Selenium to dairy cows reduced the number of subclinical mastitis cases, but did not alter the concentrations of serum super oxide dismutase (SOD), glutathione peroxidase and ceruloplasmin. Through performance increases in milk yield and reproduction, decreased SCC and improved hoof health, the predicted results include a return on investment that tops 2 to 1.

The study of Nocek et al. (2006) was influential with selected organic trace minerals on milk production in that milk production increased (Kinal et al., 2005) due to their inclusion with basal diet in whole diet basis. Availa-4 and 4-Plex (Zinpro Corp., Eden Prairie, MN) are 2 products containing combination of organic Zn, Cu, Mn, and Co. The Zn, Cu, and Mn found in these products are complexed with single AA ligands, whereas the Co is complexed with glucoheptonate. Organic trace minerals significantly increased milk production by 0.93 kg/day, milk fat yield by 0.04 kg/d, and milk protein yield by 0.03 kg/d (Rabiee et al., 2010).

Table 6. Effect of complexed trace minerals on cow performance

Organic mineral	Observations	Refernces
Cu, Zn, Mn	Similar milk yield and composition Similar body weight No effect on uterine health Similar plasma variables	Yasui et al., 2014
Zn-amino acid complex	Decreased postpartum DMI Increased (20%) colostrum IgG concentration Feed efficiency increased Decreased service preconception Decreased milk fat concentration	Nayeri et al., 2014
Cu, Zn, Mn-polysaccahride complex	Reduced no. of days in open Increased conception rate No change in milk yield and composition	Chester-Jones et al., 2013
Cu, Zn, Mn	Increased colostrum immunoglobulins Increased milk fat No change in milk yield, protein and SCC Lower calf mortality Increased service perconception	Formigoni et al., 2011

Benefits of organic trace minerals include improvements in growth, milk production, reproduction, and somatic cell score (Andrieu, 2008; Spears and Weiss, 2008). Improvements in animal production despite measured differences in bioavailability suggest that current measures of bioavailability are either not sensitive enough to detect differences or do not reflect actual pools of minerals available to support animal physiology.

Bioavailability of Organic Trace Mineral

The proposed benefit to feeding organic trace minerals is that they should undergo less dissociation in the reticulo-rumen, omasum, and abomasum than their inorganic counterparts. Bioavailability of trace minerals can be defined as the proportion of an ingested mineral that is absorbed, transported to its site of action, and converted to the physiologically active species (O'Dell, 1983). Bioavailability can be affected by a number of factors such as animal species (breed and genetic variations of TM absorption and metabolism/physiological state), pH of the rumen and abomasum, antagonistic interactions with other TM, previous nutrition of the animal, interactions with dietary nutrients and ingredients, choice of response criteria, choice of standard source, and chemical form and solubility of the mineral element (Ashmead, 1993; Suttle, 2010).

The TM source, as either inorganic or organic is theorized to affect their bioavailability to the animal; with organic TM proposed to be more bioavailable (Gallaher et al., 1999) than their inorganic counter parts (Spears, 2000). Use of a standard source allows expression of bioavailability in terms of relative biological availability (Miller, 1983). Previous researches investigating the effects of metal complexes of methionine and lysine have shown that both mineral sources have greater bioavailability compared to inorganic salts (Wedekind et al., 1992; Nockels et al., 1993).

Amino acid complexes of trace minerals are more bioavailable (Wedekind et al., 1992; Paripatananont & Lovell, 1995) and are better retained by the body (Nockels et al., 1993) than inorganic sources of trace minerals. However, association of minerals with fiber fractions in feedstuffs (Whitehead, 1985) and/ or binding of minerals to undigested fiber constituents in the gastrointestinal tract may alter bioavailability of some trace minerals in ruminants (Kabaija & Smith, 1988). In general, most commonly reported positive responses to feeding in more bioavailable (OTM) forms to dairy cattle include increased milk yield, improved reproductive performance, decreased SCC, decreased lameness and improved foot health, and decreased disease incidence.

2.6. Organic trace mineral on nutrient utilization

Mineral intake is influenced by a variety of parameters, including animal needs, soil features, forage type and availability, water quality, protein and energy supplements, mineral supplement palatability, mineral freshness, mineral access and mineral supplement source and physical form (Tait & Fisher, 1996). The predominant forms of trace minerals available for supplementation typically are categorized as either inorganic or organic, with primary reference to their chemical structure. Metals are chelated, complexed, or covalently linked to AA, AA analogues, proteins, or organic acids, among other organic compounds, in various forms of organic trace minerals.

The majority of research involving these various forms has focused on replacing sulfates or oxides with one of the other forms with potentially improved bioavailability (Spears, 2000). Although some research has been done using these various forms as single sources (as described previously in the discussion for individual trace minerals), a significant amount of research has been done, including several recent studies, in which supplementation of blends of Zn, Cu, and Mn was evaluated in dairy cows during the transition period and(or) early lactation.

Dietary Mo and Cu consumption is influenced by Zn, Fe, and Mo intakes (McDowell & Arthington, 2005) can inhibit cu absorption and utilization. Organic trace minerals consist of the same trace minerals being chelated, complexed or covalently bonded to amino acids, analogues, proteins or organic acids in a way that allows for increased absorption in the animal (Figure 1) and to “do more with less” through lower inclusion levels. Research demonstrates that providing a more stable and predictable source of trace minerals, like hydroxychloride trace minerals; improves the precision of diets while supporting cow growth, digestive health, and milk production.

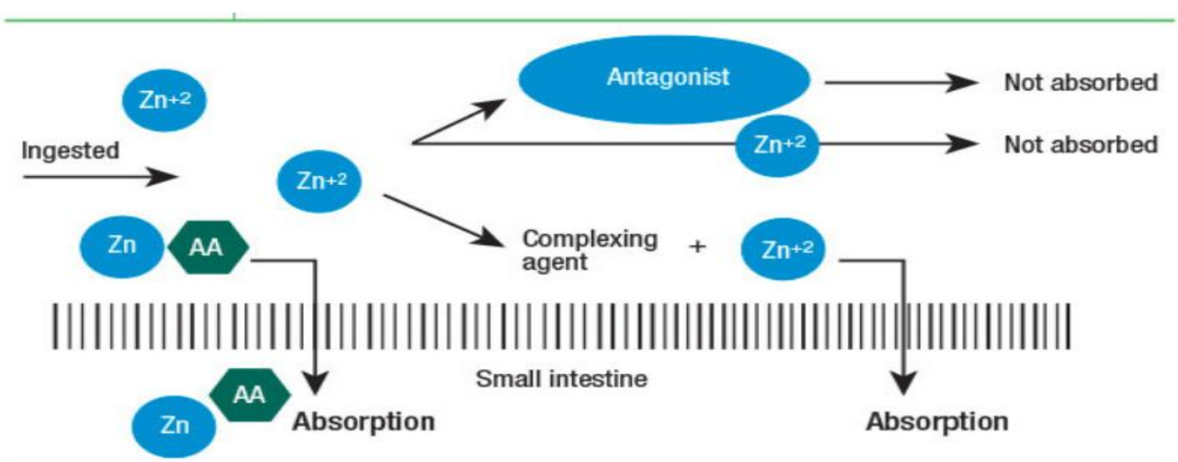

Figure 2. Mineral absorption in the gut

2.7. Organic trace mineral on lactation and reproductive performance

Functions of lactation and reproductive performance of dairy cattle are critical to the profitability of dairy operations (Table 7). From the perspective of trace mineral nutrition, among organic parts play very precious role in maintaining production, reproductive function and health of a dairy herd. As level of milk production has progressively increased, there has been considerable interest in the use of organic trace minerals in rations for ruminants. Organic forms of Cu, Mn, and Zn including metal amino acid chelates, metal complexes, metal methionine hydroxy-analog chelates, metal proteinates, and metal propionates have been shown to increase intestinal absorption and mineral bioavailability (Predieri et al., 2005; Wright et al., 2008).

Rabiee *et al*. (2010) performed a meta-analysis of production and reproductive results from 24 studies in which cows were supplemented with AA-complexes of Zn, Cu, and Mn, as well as Co-glucoheptonate from the same business. Although findings were significantly diverse, supplementing with these kinds of trace minerals enhanced milk output by a weighted mean difference of 0.93 kg/d. Kellogg et al. (2004) reviewed 12 studies that looked at the effects of feeding Zn-methionine complex on lactation performance and udder health, and found that supplementing with Zn-methionine complex decreased somatic cell count (SCC), and increase milk output.

Table 7. Effect of complexed Zn, Mn, Cu and Co on milk yield and milk components, milk composition and cases of mastitis of intensively grazed, lactating dairy cows (Cope et al., 2009)

	Treatment		S.E.[a]	P
	Control	CTM		
Milk production (kg/day)	16.6	17.5	0.31	0.04
Milk energy output (MJ/day) (kg/day)	55.3	58.6	0.93	0.01
Fat yield (kg/day)	0.73	0.78	0.014	0.02
Crude protein yield (kg/day)	0.58	0.62	0.010	0.01
Solids yield (kg/day)	1.31	1.39	0.023	0.01
Fat (g/kg)	44.4	44.9	0.67	0.11
Crude protein (g/kg)	35.1	35.5	0.31	0.37
Solids (g/kg)	79.4	80.3	0.93	0.50
Mastitis (cases/100 cows)	29.9	23.8	–[b]	0.08
Somatic cell count ($\times 10^3$ mL^{-1})	126	110	9.5	0.22

2.8. Effect of organic trace mineral nutrition on the environment

Factors that complicate trace mineral nutrition at the farm level include the existence of a large number of antagonisms affecting bioavailability of individual trace minerals and uncertainty in terms of requirements under all physiological and management conditions; thus, determining the optimum level and source of trace minerals under each specific situation continues to be a challenge. Soil type, elevation and plant group appeared to be the major determining factors for trace element supply.

Environment and certain grazing strategies were intimately related, and might provide both explanation and solution for hampered trace element supply. Targeted use of trace minerals also may limit the release of non-absorbed minerals in waste, supporting environmental sustainability efforts. Organic minerals were designed to reduce antagonistic relationships within the gastrointestinal tract and thus increase the bioavailability of trace elements. The organic part of trace minerals has tremendous quality over inorganic counterpart in that, the former increased bioavailability, reduction in their excretion and thereby reduction in the environmental pollution in different dairy cow enterprises.

2.9. Supplementation strategies of trace minerals

Cattle producers have a variety of methods for providing supplementary trace minerals to their animals in organic or inorganic form based on their chemical structure. Each method's applicability is determined by the animal's demands, the mineral concentrations in the feedstuffs consumed by the cattle, and the ability to offer trace mineral supplementation.

2.9.1. Free-Choice, salt-based supplements

The most common method for providing supplemental trace minerals to grazing cattle involves the formulation and blending of supplemental trace minerals with common salt, offered free choice. The success of the free choice, salt-based supplementation system is based on the concept that cattle are naturally seeking salt; therefore, it is essential that supplemental trace minerals be mixed directly in the salt carrier, not separate. In study, Manzano *et al*. (2021) reported a range in variation in free-choice mineral intake (reported as CV) of 77.5 to 108.4% among individual steers grazing cool season forages.

These researchers also observed differences in the pattern of mineral feeder visits throughout the day, whereas in the autumn period steers concentrated their visits during the mid-day hours compared to a uniform pattern of visits throughout the day in the spring period. The authors suggest that the steers targeted their visits to the mineral feeder during the daylight hours, fewer of which were available in the autumn period. When attempting to determine the optimal salt inclusion level of a free-choice, trace mineral-fortified supplement, the average intake of the herd over a 1- to 2-week period should be the target.

The level of increased salt inclusion will reduce visits to the mineral feeder and overall supplement intake (Braghieri et al., 2011). Mineral blocks (i.e., salt blocks) offer management conveniences related to labor because they often require less frequent replacement due to reduced intake by cattle. Block intake can be as much as 10% less than the consumption of supplements in loose form, potentially creating a gap between mineral consumption and cattle requirements (McDowell & Arthington, 2005).

2.9.2. Fortification of energy/protein supplements

The best method of insuring intake of supplemental trace minerals is through the fortification of energy and protein supplements. Although variation in voluntary intake among cattle that are provided with energy and protein supplements is expected, it is less than the variation observed with loose, mineral mix supplements (Bowman et al., 1997). Careful examination of the nutrient profile, matched to targeted intake, can determine if additional trace mineral supplementation is needed. If properly formulated, free-choice, salt-based supplementation could be replaced by energy and protein supplements during specific seasons of the year. Attention to animal dominance, adequate bunk space, feeding methods, and targeted intakes are essential (Bohman *et al*,. 1984). When properly managed, this supplementation strategy can significantly affect the overall economics of nutrient supplementation of the grazing cowherd.

2.9.3. Trace mineral injections

More recently, injectable multielement trace mineral products containing a combination of EDTA-bound Cu, Zn, and Mn with Na selenite have become more commonly used in grazing cattle. Injectable trace minerals have also been shown to improve reproductive performance among grazing beef cattle. In the example of Cu, they have not been favorably adopted due to the propensity to create injection site reactions (Boila et al., 1984) which were sometimes severe depending on the preparation (Pogge et al., 2012). Indeed, it is not surprising to conclude that trace mineral status of the cow or heifer at the time of injectable trace mineral administration would impact subsequent performance responses, such as reproduction. Additionally, injectable trace minerals may serve as a complement to traditional oral supplementation strategies, particularly in production systems having trouble managing routine delivery and/or intake of free-choice supplements.

2.9.4. Biofortification

Biofortification of forages is a noteworthy advancement in field of trace mineral supplementation of grazing cattle, particularly for Se. This methodology is based on the application of trace minerals as fertilizers to plants or amendments to soil. In the case of Se, biofortification of agronomic crops in Finland has been responsible for improving the Se status of the livestock and human population (Ranches et al., 2017).

Research with forage crops has shown substantial increases in forage Se concentrations in Se-biofortified warm season grasses (Valle et al., 1993; Filley et al., 2007), cool-season grasses (Hall et al., 2013) and legume forages (Hall et al., 2011). Selenium from Se-biofortified forage appears to be more available than inorganic Se at similar levels of intake when consumption is limited (<3 mg/d) (Valle et al., 1993). Additionally, short-term access to Se-biofortified forages improves Se stores that may support cattle through subsequent periods of Se inadequacy (Wallace et al., 2017).

2.9.5. Boluses and drenches

Boluses and drenches are considered direct methods of supplementing trace minerals. Long-acting trace mineral boluses (including Cu, Se, and Co) that can last up to six months are beneficial for cattle on wide difficult topography areas where free-choice mineral supplementation may be limited. Jackson et al. AAFCO, (1998) evaluated several single-use, pulse-dose trace mineral products (injectable, drench, paste, and bolus) and found that injectable trace minerals were effective at rapidly increasing trace mineral concentrations in plasma and liver, whereas long-acting boluses may be useful if a gradual increase in liver trace mineral concentrations is desired.

2.10. Challenges of organic trace mineral supplementation

Factors that complicate trace mineral nutrition at the farm level include the existence of a large number of antagonisms affecting bioavailability of individual trace minerals and uncertainty in terms of requirements under all physiological and management conditions; thus, determining the optimum level and source of trace minerals under each specific situation continues to be a challenge. The absorption antagonisms for many trace minerals are well-known (Spears, 2000), but are going to vary from farm to farm based upon variations in other feedstuffs and their composition and the micronutrient content of water.

The higher bio-availability of organic trace minerals can answer the new challenges arising from the legislation in favor of reducing the input and output of minerals while supporting animal health and welfare issues. Thus, the relevance of organic trace minerals is increasing from day to day in the situations where the pressure exerted by legislation and consumers is growing. These additives positively support sustainability along the production chain by providing safety to workers handling the product; maximizing return on investment by reducing the cost of supplements and improving performance through lower supplementation. Finally, their bio-availability reduces the environmental impact by lowering the mineral output that leads to soil pollution and a long-term toxicity risk. Lowering the level of trace element supplementation is key to extending this timescale and minimizing the environmental impact. They also enable better quality products in line with public health regulations to be produced for the end consumer.

Even if organic mineral sources are more bioavailable than inorganic sources, cost of these sources will be a major factor in the decision on whether or not to use them. One approach to this problem would be to supply only a portion of the supplemental minerals in the organic form. Deficient soils and forage TM content necessitate TM supplementation of animals in most tropical areas to ensure they have the adequate stores required for growth, production, and immune function. Additionally, if soils or pastures are containing high concentrations of minerals such as sulfur, molybdenum, and iron, the absorption of other TM can be adversely affected (McDowell & Arthington, 2005; Suttle, 2010).

Seasonal variations in forage trace element concentrations largely depend on the geographical and climate conditions. For example, the Se content of plants is lower in areas with high rainfall and its uptake by plants is largely determined by the temperature (higher rate at temperatures >20°C), whereas Fe concentration in pasture shows seasonal fluctuations, with peaks in spring and autumn (Kabata-Pendias, 2011). Trace element concentrations are also influenced by the stage of plant development: higher contents of Fe, Zn and Cu were detected in alfalfa leaves in the first stage of plant development (Markovic et al., 2009), and concentrations of Mo and Zn are also known to vary with plant development stage (Kabata- Pendias, 2011).

Preservation of forage also affects the trace element content, and for example the process of fermentation of silage appears to increase the Fe bioavailability (Hansen & Spears, 2009). Various factors affect TM bioavailability and include the amount of TM in the diet, pH of the rumen and abomasum, antagonistic interactions with other TM, and breed and genetic variations in TM absorption and metabolism (Ashmead, 1993; McDowell & Arthington, 2005; Suttle, 2010).

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