The Basics of Zinc in Crop Production

IFDC
International Fertilizer Development Center

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Introduction

Zinc deficiency in soils and plants has become the most common of all the micronutrient deficiencies worldwide. Because zinc acts as a structural component of several enzymes in plants, an inadequate supply of zinc could result in serious physiological disturbances.

Functions of Zinc in Plants

Zinc is a bluish-white metallic element, which is recognized as one of the most required micronutrient fertilizers in the agricultural production system. Zinc has specific and essential physiological functions in plant metabolism. At least four enzymes contain zinc: carbon anhydrase (CA), alcohol dehydrogenase (ADH), copper-zinc-superoxide dismutase (Cu-Zn-SOD), and RNA polymerase. CA is localized in the chloroplasts and cytoplasm and is involved in photosynthetic CO_2 fixation. ADH plays an important role in anaerobic root respiration. Cu-Zn-SOD is involved in the detoxification of superoxide radicals (O_2^-) and protection of membrane lipids and proteins against oxidation.

Various other enzymes involved in carbohydrate metabolism are Zn dependent. Zinc is important in protein synthesis and for the synthesis of tryptophan, a precursor for the synthesis of indole acetic acid.

Zinc Deficiency and Toxicity

Plants — Although used in small amounts by plants, Zn applications can produce spectacular results in Zn-deficient soils. Plants absorb Zn as a divalent cation (Zn^{2+}). Zinc content of plants varies widely depending on the soil, climate, and plant genotype. The critical deficiency concentration (CDC) of Zn in leaves ranges from 15 to 30 mg/kg (Cakmak and Marschner, 1987), and the critical toxicity concentration (CTC) in leaves of crop plants ranges from 200 to 500 mg/kg.

In dicotyledons Zn deficiency results in short internodes (rosetting), formation of small leaves, stunted growth, and chlorosis of younger leaves. With increasing severity of the deficiency, leaves die

and fall off. In monocotyledons, interveinal chlorosis and violet-red spot-like discoloration of leaves are characteristics of Zn deficiency.

Plants particularly sensitive to Fe will become chlorotic if Zn is in excess. Crops that are sensitive to Zn deficiency include maize, rice, field beans, flax, apples, citrus, peaches, and pears. Crops that are moderately tolerant to Zn deficiency include wheat, barley, sorghum, soybeans, tomato, potato, sugar beet, cotton, and clover. Alfalfa, carrots, oats, peas, and rye are tolerant to Zn deficiency.

Zinc in Soils

Zinc occurs chiefly as the sulfide mineral sphalerite (ZnS). Zinc does not form independent silicates or generally occur to any great extent in quartz and feldspars (Lindsay, 1972). It also occurs as trace constituents of hydrous oxides of iron and manganese. Zinc forms silicates, oxides, carbonates, etc., but these are not stable.

Available Zinc

Most of the total Zn in soils exists in insoluble forms that contribute little to plant uptake. Soil Zn can be divided among generalized pools of plant availability. These are (Pickering, 1981):

Water-soluble pool: Zn present in soil solution.

Exchangeable and surface-adsorbed pool.

Organic pool: Zinc incorporated in organic matter in the soil.

Pool of metal oxides and carbonates.

Pool of primary and secondary minerals.

Water-soluble and exchangeable pools of Zn are considered readily available to plants. Organic Zn is also considered bioavailable. The carbonate pools are potentially available. Water-soluble and exchangeable pools are related to the intensity factor and form the basis of soil tests (Levesque and Mathur, 1988).

The amounts of bioavailable Zn are very small compared with the total Zn content of soils. In Indian soils, for example, bioavailable Zn forms no more than 1% of the total Zn (Katyal et al., 1982).

Geographic Distribution of Zn Deficiency

Zinc deficiencies are more common worldwide than those of any other micronutrients. The Zn status of the soils of some of the largest areas of the tropics, e.g., Congo Basin, Indochina Peninsula, Amazon Basin, and the Llanos has not been studied in detail. It is possible that soils may be deficient in zinc in these areas (Welch et al., 1991). However, zinc deficiency has been observed in the central plateau of Brazil, Colombia, and Peru (Jones, 1982). Zinc deficiency is found more frequently in the arid and semiarid regions of India and Thailand than in the humid and subhumid areas (Katyal and Vlek, 1985). Zinc deficiency has also been reported in the soils of the northern and central plains of West Java (Indonesia), the tropical soils of Taiwan, the poorly drained calcareous paddy soils of China, and in Sri Lanka (Matale). Sillenpää (1982) carried out a survey of the Zn status of soils globally and found that of all the countries surveyed, only Belgium and Malta did not report zinc deficiency (**Table 1**). Iraq, Turkey, Pakistan, and India had the lowest levels of zinc in soils. Brazil, Chad, Nigeria, and the Philippines have the most documented areas of zinc deficiencies (Sillenpää and Vlek, 1985).

In Africa, zinc deficiencies are widespread, in areas from Swaziland to Kenya and Uganda, including northern Zambia, Malawi, Tanzania, the west coast of Guinea, Cameroon, and Chad. Deficiencies have been reported in Côte d'Ivoire, Egypt, Ethiopia, Nigeria, Sierra Leone, Sudan, and Tanzania (**Figure 1**). Countries with zinc deficiencies in Asia include Bangladesh, Burma, India, Indonesia, Iraq, Japan, Korea, Lebanon, Nepal, Pakistan, Philippines, Syria, Thailand, Taiwan, Turkey, and extensive areas of China (**Figure 2**). Zinc deficiencies also have been reported in Finland, France, Hungary, Ireland, Italy, Switzerland, Sweden, and the United Kingdom (**Figure 3**) (Sillenpää, 1982). Zinc deficiencies are reported in Argentina, Brazil, Colombia, Ecuador, Mexico, and Peru in Latin America (**Figure 4**). Zinc deficiencies are also widespread in western Australia (Donald and Prescott, 1975), including Queensland, South Australia, Victoria, New South Wales, and parts of southern New Zealand (**Figure 2**). In the U.S.A., zinc deficiencies have been reported in the western, central, southern, and eastern regions of the United States although the deficiencies may be confined to small areas (**Figure 5**). The northeastern part of the United States has the lowest recorded incidence of zinc deficiency (Kubota and Allaway, 1972; Welch et al., 1991).

Factors Affecting Availability and Movement of Zinc

Plants absorb Zn mainly in the form of the ion Zn^{2+}. There is some evidence, however, that several Zn-organic complexes may also be absorbed by the roots (Kabata-Pendias and Pendias, 1984).

The plant availability of Zn is conditioned by a number of soil and environmental factors. These include:

Soil Parent Material — Parent materials have a great effect on the Zn content of soils. Basic rocks such as basalt and gabbro contain more Zn than acid-eruptive rocks, metamorphic rocks, or sedimentary rocks such as sandstones and limestones.

Soil pH — Availability of Zn decreases with increases in soil pH. Most pH-induced deficiencies occur within the range of pH 6.0 to 8.0. Alkaline soils are often Zn deficient even though total Zn content is relatively high.

Climate — Low temperatures and low light intensities reduce Zn uptake by plants. This may be due to restricted root development and decreased microbial decomposition of organic biomass at cool temperatures.

Interactions With Other Elements

Zinc interacts with various essential plant nutrients and other elements in soil and in plants.

Zinc Interaction With Other Nutrients

Zinc interacts with phosphorus, nitrogen, iron, calcium, copper, and manganese.

Zinc-Phosphorus — The antagonism between P and Zn has been researched extensively. The interaction is usually described as P-induced Zn deficiency. Beans, maize, potatoes, soybeans, sorghum, flax, citrus, rice, wheat, tomatoes, and hops have been reported to have experienced P-Zn interactions with a consequent detrimental effect on plant growth (Murphy et al., 1981). The most adverse effects occur when high levels of P are applied to Zn-deficient or higher pH soils.

Zinc-Iron — The metabolic function of Fe in plants is related to the supply of Zn. Increases of Zn in the soil depresses uptake of Fe by plants. Likewise, Zn deficiency increases Fe uptake by certain plants (Francois and Goodwin, 1972), sometimes to toxic levels (Adams and Pearson, 1967).

Zinc-Copper — High Zn availability in the soil can accentuate Cu deficiencies (Haldar and Mandal, 1981). Since Cu and Zn are presumably absorbed through the same mechanism, each competitively inhibits the uptake of the other (Bowen, 1979).

Zinc-Manganese — Zinc and Mn are antagonistic, and Mn uptake by plants is reduced with application of Zn fertilizers (Haldar and Mandal, 1981).

Zinc-Boron — Zinc fertilization may decrease B accumulation and reduce the risk of B toxicity in plants (Graham et al., 1987).

Zinc Interaction With Other Trace Elements

Zinc also interacts with other nutrients and heavy metals such as lead, chromium, selenium, and cadmium in soils. For example, application of Zn markedly reduced Cd concentration in wheat grown on soils of marginal Zn status (Tiller et al., 1993).

Zinc Fertilizers and Correction of Deficiencies

Evaluation of Zinc Availability to Plants

Zinc, like other nutrients, should be available in adequate amounts for the proper growth and development of plants. A soil test is a reasonably effective method for determining whether the soil has enough plant-available Zn to satisfy crop needs. The actual uptake of Zn can be more accurately assessed by plant tissue analysis.

Soil Test and Plant Analysis

The soil tests can often predict the possibility of zinc deficiency or toxicity occurring in the plants and provide information about the amount of Zn to be applied to correct deficiencies. Plant analysis provides information about the ability of the plants to absorb the nutrient from the soil and the concentration of the nutrient in plant tissues. Soil tests and plant analyses complement each other to help develop reliable fertilizer recommendations.

The plant analysis data will indicate the deficiency, sufficiency, or excess of Zn in the plants. For example:

Crop and Plant Part	Nutrient Status		
	Low	Sufficient	High
	(mg Zn/kg oven dry wt)		
Barley top	<15	15-70	>70
Maize top	<20	20-60	>60
Rice leaf	20-24	25-50	>50
Soybean leaf	10-20	21-50	51-75
Wheat (plant)	<15	15-70	>70
Tomato leaf	18-19	20-50	>50
Apple leaf	15-19	20-100	>100
Sorghum (aboveground)	<30	30-60	>60

Correction of Deficiencies

With intensification of crop production, removal of nutrients from the soil occurs at a rapid rate. When NPK fertilizers are used for some time, other deficiencies begin to develop and Zn is the one that often develops a deficiency after N, P, and K.

Many organic compounds, organic complexes such as ligninsulfonates, and synthetic chelates are used to correct Zn deficiency.

Zinc Fertilizers

Several fertilizers are available and inexpensive enough to use on crops in the market (**Table 2**). In addition to the manufactured compounds, animal manures and sewage sludge contain appreciable amounts of Zn and can also be used to correct Zn deficiencies. Sewage sludge, for example, may contain 150 to 12,000 mg Zn/kg. A typical sewage sludge may contain 5,000 mg Zn/kg dry weight (University of Illinois, 1975).

Zinc fertilizers can be grouped into four classes:

Inorganic fertilizers.

Synthetic chelates.

Natural organic complexes.

Slow-release fertilizers.

Inorganic Zn Sources — Inorganic sources of Zn include carbonates, chlorides, nitrates, oxides, and sulfates of Zn. Zinc sulfate is the most common source of Zn used in crop production. Historically, the basic raw material for the production of zinc sulfate has been slag and flue dust from zinc, copper, and lead smelter. These industrial wastes are treated with sulfuric acid to produce zinc sulfate. However, U.S. Federal and state environmental regulations have classified certain smelter slags and flue dusts as hazardous wastes, thus prohibiting their use in agriculture. Moreover, environmental regulations regarding sulfur dioxide and particulate emissions from smelters have resulted in the closure of many smelters. As a result, the availability of zinc-rich smelter slags and flue dust has decreased. Consequently, zinc sulfates are increasingly being prepared by reacting metallic zinc with sulfuric acid, which is a much more expensive method of producing Zn sulfate. Zinc sulfate is a white, finely divided crystal, sold in both crystalline and granular forms. Zinc sulfate monohydrate ($ZnSO_4$ H_2O) has 36% Zn, and heptahydrate ($ZnSO_4$ $7H_2O$) has 22% Zn. Both are soluble in water.

Zinc oxide (ZnO) is a white or yellowish amorphous powder. It is prepared by roasting naturally occurring mineral sphalerite (ZnS) or from zinc-rich smelter baghouse and flue dusts. ZnO contains 80.3% Zn. ZnO is not very water-soluble.

Zinc oxysulfate is a mixture of ZnO and $ZnSO_4$. Zinc oxysulfate is made by partial acidulation of ZnO with sulfuric acid. The ratio of oxide to sulfate and the amount of water-soluble Zn in the product are directly related to the degree of acidulation. Depending on the source of Zn and the method of processing, total Zn content in Zn oxysulfate may vary from about 18% to 60% but averages 52%. About 35% to 50% of Zn in granular Zn oxysulfate should be in water-soluble form ($ZnSO_4$) to be effective for crops. However, there are no labeling requirements for water solubility of the micronutrient in the fertilizer. The U.S. uniform state government regulations require only that the total amount of the micronutrient be guaranteed and labeled on each bag/container. Zinc oxysulfate is usually sold as gray-brown granules.

Other zinc fertilizer products include metal ammonia complexes such as ammoniated $ZnSO_4$ solution, which contains 10% N, 10% Zn, and 5% S; Zn ammonium nitrate (15% Zn); and zinc nitrate, which are used in liquid form in advanced agricultural systems in the United States, Canada, and Western Europe.

Heavy Metal Contaminants — As previously indicated some industrial byproducts such as smelter slags and hazardous waste K061 flue dusts used in the preparation of ZnO and Zn oxysulfates may contain heavy metal contaminants such as cadmium (Cd), chromium (Cr), nickel (Ni), and lead (Pb). Concentrations of these heavy metals are highly variable. Some of these heavy metals, especially Cd and Pb, are highly toxic. Though there is no definite rule, industry usually controls Pb content at not more than 3% and Cd at not more than 0.03% by weight. However, there are no labeling requirements for heavy metals in micronutrient fertilizers. Heavy metals persist for decades and perhaps for centuries after they are added to the soil. Fortunately, they form insoluble compounds, which are not taken up by plants.

Cadmium is toxic to higher animals at high levels causing neuropathological symptoms and renal dysfunction. The balance of other minerals such as phosphorus and calcium in the body is also disturbed. Exposure to low doses of Cd is suspected to cause cancer, genetic ill effects, and hypertension. Tolerable daily Cd intake for humans is 1 g Cd per kilogram body weight.

However, because micronutrients are applied in very small quantities, inputs of contaminant heavy metals to the soil would be very low. For example, application of 5 kg/ha Zn as $ZnSO_4$ H_2O containing 100 mg Cd/kg will result in the addition of only 1.38 g Cd/ha. Likewise, applying 10 kg ZnO containing 10 mg Cd/kg will add only 0.1 g Cd to the soil. Mortvedt (1985) has shown that concentrations of Cd in maize forage were not affected by Zn fertilizers containing 1 to 2,165 mg Cd/kg. However, Cd uptake by Swiss chard increased in an acid soil but not in an alkaline soil. These and similar studies suggest that plant uptake of heavy metals from industrial byproducts used as fertilizer is likely to be low if normal processing procedures and normal application rates are used. It is also important to remember that all safety precautions are to be taken while handling and applying fertilizers containing hazardous materials.

Synthetic Chelates — Synthetic chelates are produced by combining a chelating agent with a metal cation. The most common synthetic chelating agent used is ethylenediaminetetraacetic acid (EDTA). Zn EDTA is a finely divided or granular white material, which contains 9% to 14% Zn and is very stable.

Natural Organic Zn Complexes — Natural organic complexes are produced by reacting Zn with byproducts of the wood pulp industry, mainly lignosulfonates, phenols, and polyflavonoids. Zinc

lignosulfonates contain 5% to 12% Zn and Zn polyflavonoids, 7% to 10% Zn. These compounds are less stable than chelates and tend to form insoluble salts more quickly than chelates.

Slow-Release Zn Fertilizers — These included frits, coated fertilizers, Zn metal alloys, and Zn minerals. Zinc frits are prepared by mixing powdered silicates and micronutrients including Zn sulfate in proper proportion and melting the mixture in a furnace. Commercially available frits contain copper, boron, iron, manganese, and molybdenum in addition to Zn. Frits are usually sold as finely ground, brown, powdery materials. They are slowly soluble in water; the rate of dissolution is controlled by the particle size and composition of the matrix. Frits usually contain 7% to 9% Zn. Zn metal alloys are produced by smelting Zn with different metals. When they solidify they form mixed crystals, which are pulverized and used as fertilizer.

Other slow-release Zn fertilizers include Zn-ammonium phosphates ($ZnNH_4PO_4$), sulfur-coated $ZnSO_4$, and mineral sphalerite (ZnS).

Farm Availability of Zinc Fertilizers — Zinc deficiencies in soils are becoming more common in many countries due to more intense agricultural cropping practices. No reliable data are available concerning global supply and demand of zinc fertilizer since its application rate is very small and the total consumption of zinc in a country profile is insignificant compared to the consumption of major fertilizers.

Several Asian, West European, and North American countries manufacture/process organic and inorganic zinc fertilizers of various grades in the form of fine powders, granules, and liquids and as components of multiple nutrient fertilizers. Most production is concentrated in the United States and Western Europe, and these fertilizers are available under different company trade names. Some of the companies and their products are listed in **Annex I**. Many industrial byproducts (industrial wastes) are being processed for manufacturing zinc fertilizer, and these products are available in many countries as cheaper sources of zinc. Because there are no labeling requirements to indicate the amount of water-soluble Zn or heavy metal contaminants, these products require analysis to ensure their suitability for farm use.

Application Methods and Rates

Recommended application rates for Zn are determined by the crop, Zn source, soil characteristics, method of application, and the severity of the Zn deficiency. Zn may be applied either to the soil as a basal dose or to the plant foliage as sprays. Foliar sprays are particularly useful for alkaline (high pH) soils.

Zinc in NPK Fertilizers — Zn, like other micronutrients, is applied in very small quantities, and therefore, uniform distribution in the field is difficult. Both granular and fluid NPK fertilizers are used as carriers for Zn. Zn may be combined with NPK fertilizers during the manufacture of NPK granular fertilizers or added during bulk blending. Zinc also may be coated on fertilizer granules or mixed with fluid fertilizers.

Comparison of Sources — The effectiveness of Zn fertilizers depends on several factors including water-soluble Zn content in the fertilizer, soil pH, method of application, and soil physical properties.

In general:

On acid soils, different Zn compounds including chelates are equally effective when applied as fine powder and incorporated into the soil.

ZnO is not very effective on soils with high pH.

Zn chelates are more available than inorganic compounds. Availability of Zn from lignosulfonate and polyflavonoids is between that of chelates and inorganic compounds.

Some studies suggest that 1 kg Zn applied as Zn EDTA is as effective as 10 kg Zn applied as $ZnSO_4$. Others, however, show a ratio of 2 or 3:1 in favor of Zn EDTA.

Chelates are more effective when used on calcareous and alkaline soils.

On very acid soils, the efficiency of chelated Zn is the same as that of $ZnSO_4$ because the Zn may exchange with iron in the soil.

At high rates of application, Zn chelates and $ZnSO_4$ are equally effective. At lower rates, Zn chelate is more effective.

Agronomic effectiveness and cost per unit of Zn applied are primary factors to be considered when selecting the type of Zn compound to be used.

Soil Application

Zinc sulfate is the most common Zn source because of its wide availability, water solubility, and relatively low cost. Rate of application ranges from 4.5 to 34 kg Zn/ha. Zinc fertilizer is either broadcast, broadcast and incorporated into the soil, or banded. More Zn is needed to correct deficiencies on maize than on rice or sorghum. Zinc sulfate monohydrate is the most stable form in warm climates and is 100% water soluble.

Foliar Applications — Inorganic and organic sources of Zn may be used as foliar spray to correct Zn deficiencies. Foliar application is primarily used for tree crops.

Other Applications — Other application methods include seed coatings, root dips, and tree injections.

Residual Effects

Most of the zinc applied to soils reverts into plant-unavailable forms slowly when relatively large amounts of Zn are broadcast to correct deficiencies. The residual effect of applied Zn lasts for several years.

Toxic Effects — Since only small amounts of Zn are leached, reversion to unavailable forms is slow, and crop removal is small. Continued high application of Zn to the soil could raise Zn concentration to toxic levels; this is highly unlikely at normal rates. The U.S. Environmental Protection Agency (1983) has recommended that the total cumulative limits for Zn application to croplands are 280, 560, and 1,120 kg Zn/ha for soils with CEC levels <5, 5 to 15, and >15 $cmol_c$/kg, respectively, when sewage sludge is incorporated into the soil to correct Zn deficiencies.

Crop Response to Zinc Application

Spectacular increases in crop yields have been reported from the application of Zn to Zn-deficient soils. Hergert et al. (1984) have shown that application of as little as 0.11 kg/ha Zn band applied with a starter fertilizer on a Zn-deficient soil increased maize yield from 3,900 to 8,300 kg/ha.

Rice response to Zn, though not as dramatic as for maize, is significant in Zn-deficient soils. In Arkansas, application of 0.84 kg Zn/ha as Zn-EDTA increased rice yields from 3,584 kg/ha to 5,633 kg/ha. Application of 1.68 kg Zn/ha produced an additional yield of 3,091 kg/ha over yield with no Zn applied (Wells et al., 1973).

Significant increases in yield of grain sorghum have been reported from the application of Zn to nutrient-deficient soils. When 0.6 kg/ha Zn was broadcast and incorporated before planting, the yield of grain sorghum increased from 4,077 to 4,767 kg/ha. Increasing the rate to 2.2 kg Zn/ha increased the yield to 5,268 kg/ha (Follet et al., 1981).

Similar yield increases have been reported for soybean from Zn application to deficient soils in Kansas. Without Zn, the yield of soybeans was 2,016 kg/ha. Application of 2.2 kg Zn/ha increased yield by 1,075 kg/ha, and application of 4.5 kg Zn/ha increased yield by 1,344 kg/ha. Above 4.5 kg Zn/ha, there was a decrease in yield.

Significant increases in yield have been reported for other crops. Application of NPK fertilizers containing Zn to provide 3 kg Zn/ha increased the yield of dry beans from 12,300 to 16,700 kg/ha (Ellis et al., 1965).

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Table 1. DTPA Extractable Zn in Soils From Selected Countries

Country	No. of Samples Analyzed	Zn in Soils		
		Maximum	Minimum	Mean
		(mg/L)		
Argentina	119	12.00	0.41	2.03
Belgium	21	10.53	2.79	5.17
Brazil	71	123.90	0.20	3.81
Ecuador	16	2.90	0.24	1.41
Egypt	100	7.50	0.46	1.31
Ethiopia	54	9.90	0.49	2.07
Finland	94	13.13	0.34	2.17
Hungary	144	8.75	0.34	1.18
India	188	38.80	0.10	1.16
Iraq	119	3.50	0.07	0.28
Italy	118	47.50	0.17	2.31
Malta	25	39.40	2.02	10.29
Mexico	100	14.80	0.22	0.98
Nepal	50	6.70	0.11	0.75
New Zealand	14	5.10	0.28	1.45
Nigeria	42	3.10	0.28	0.78
Pakistan	156	12.10	0.10	0.82
Peru	13	30.20	0.42	3.66
Syria	20	7.40	0.10	1.21
Tanzania	5	0.10	0.06	0.09
Turkey	249	3.60	0.12	0.39

Source: M. Sillenpää, 1982.

Table 2. Some Sources of Fertilizer Zn

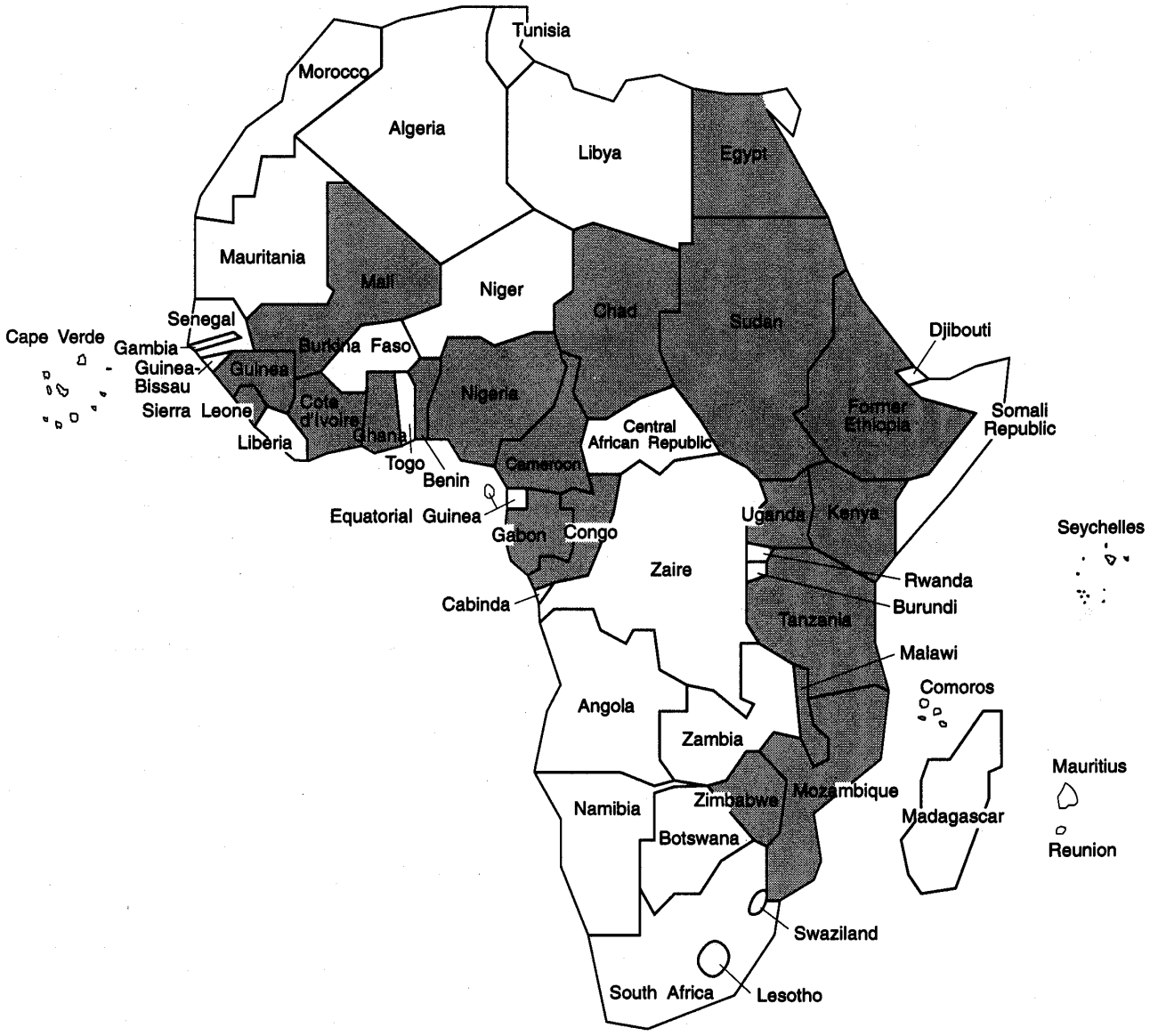
Sources	Formula	Percent Zn
Inorganic		
Zn sulfate monohydrate	$ZnSO_4\ H_2O$	36
Zn sulfate heptahydrate	$ZnSO_4\ 7H_2O$	22
Basic Zn sulfate	$ZnSO_4\ 4Zn(OH)_2$	55
Zn chloride	$ZnCl_2$	47
Zn carbonate	$ZnCO_3$	52
Zn oxide	ZnO	60-78
Zn oxysulfate	$ZnSO_4$ ZnO	25-60
Synthetic Chelates		
Zn chelates	Na_2 Zn EDTA	14
	Na Zn NTA	13
	Na Zn HEDTA	9
Organic Complexes		
Zn polyflavonoid		10
Zn ligninsulfonate		5

Table 3. Countries With Reported Zinc Deficiencies

Africa	Asia & Oceania	Europe	Latin America
Chad	Australia	Finland	Argentina
Côte d'Ivoire	Bangladesh	France	Brazil
Egypt	Burma	Hungary	Colombia
Ethiopia	China	Ireland	Ecuador
Guinea	India	Italy	Mexico
Nigeria	Indonesia	Sweden	Peru
Sierra Leone	Iraq	Switzerland	
Sudan	Japan	United Kingdom	
Tanzania	Korea		
Zimbabwe	Nepal		
	New Zealand		
	Pakistan		
	Philippines		
	Syria		
	Thailand		
	Turkey		

Figure 1

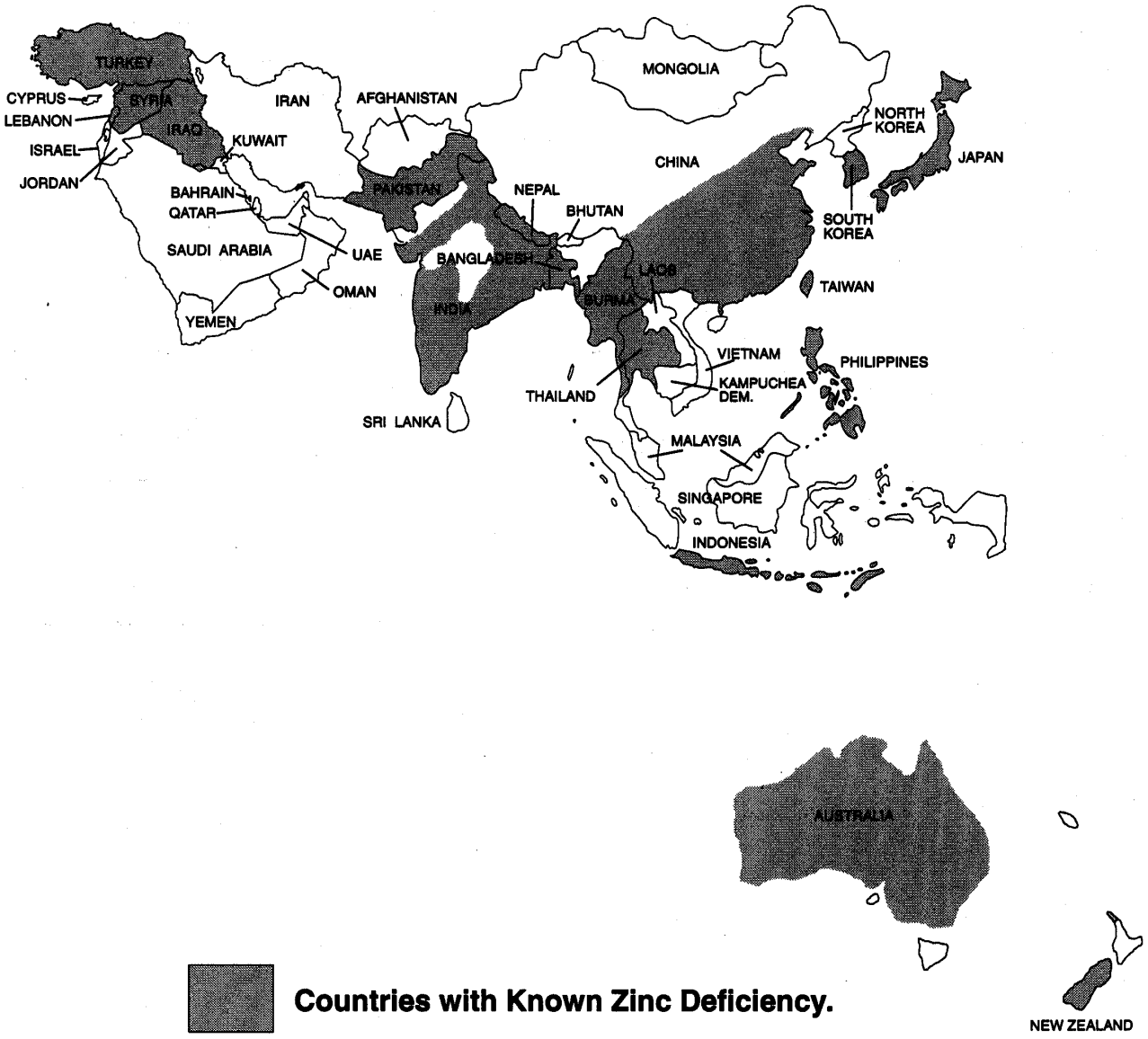
AFRICA



Countries With Known Zinc Deficiency.

Figure 2

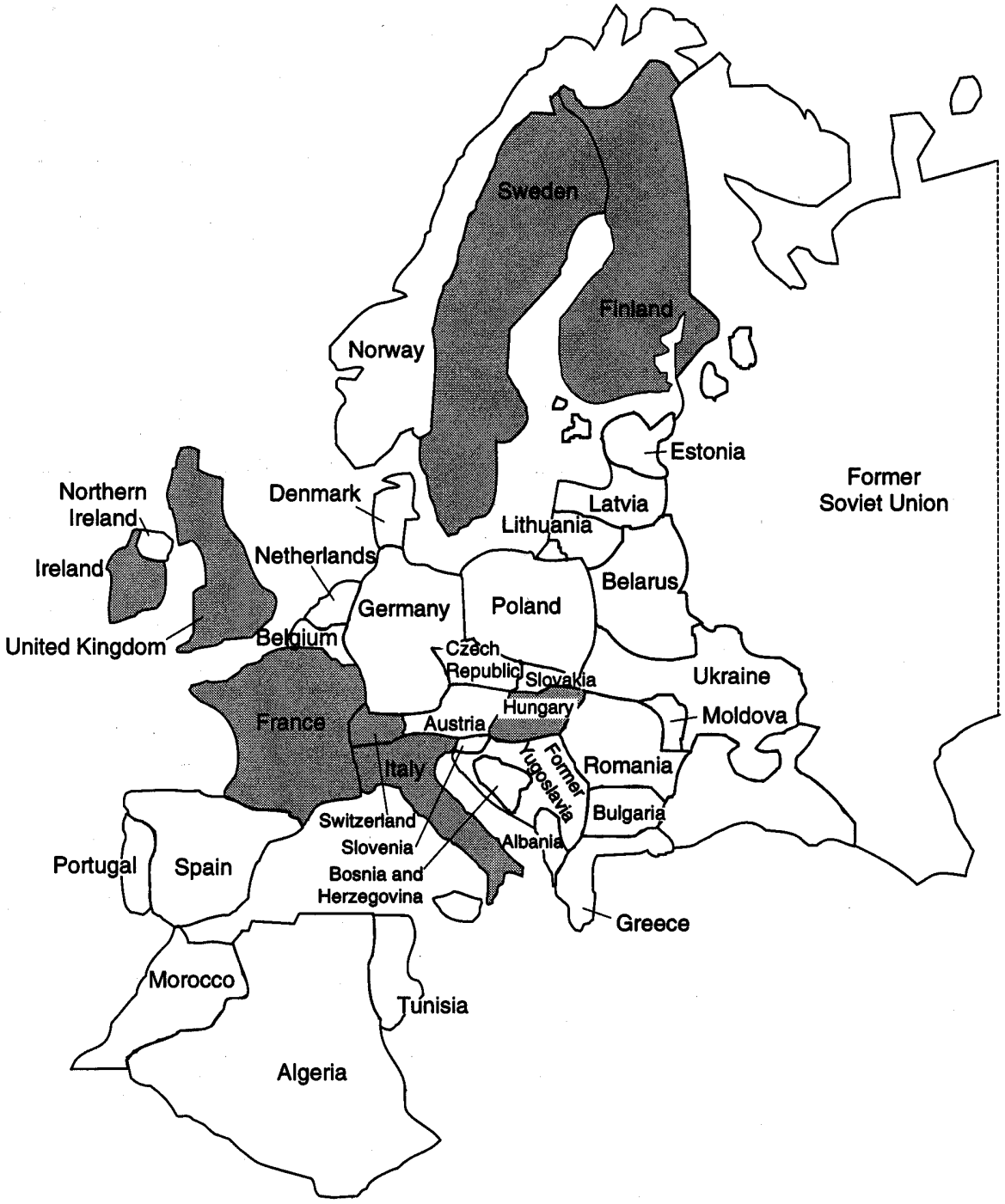
ASIA



Countries with Known Zinc Deficiency.

Figure 3

EUROPE



Countries With Known Zinc Deficiency

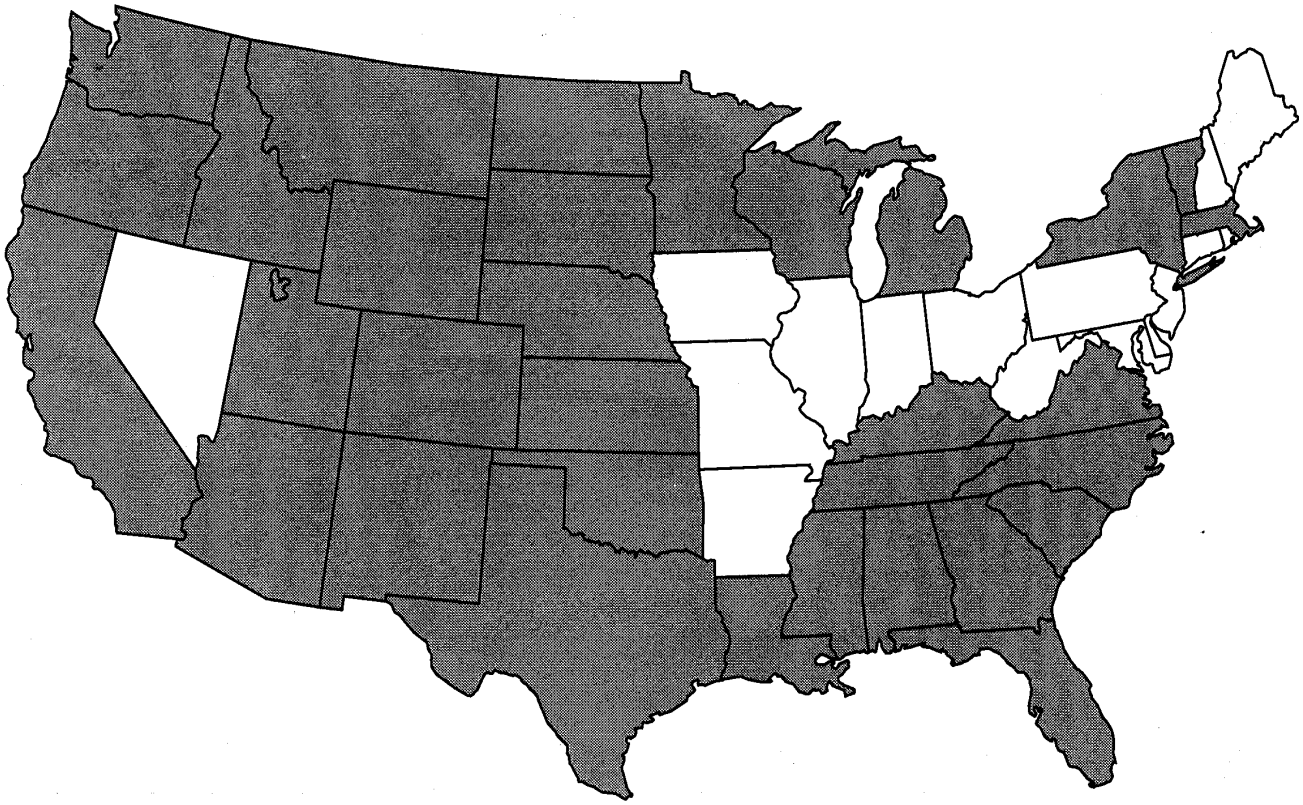
Figure 4

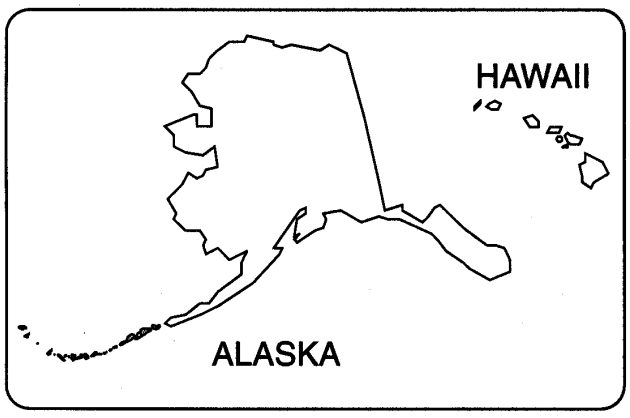
LATIN AMERICA

Countries With Known Zinc Deficiency

Figure 5

UNITED STATES OF AMERICA





States With Known Zinc Deficiency

Source: American Zinc Institute Inc., New York, N.Y.

Annex I

Commercial Zinc Products, Manufacturers, and Suppliers

Producer/Supplier	Product Trade Name	Description	Type
Australia			
Pasminco Metal-Ez Fertilizer Resdon Road Tasmania Telephone: (61-02) 784-921 Fax: (61-02) 784-930	Product trade name and description not available		
Tasbond LRL Ltd. 1027 Mountain Highway Bayswater, Victoria 3153 Telephone: (61-3) 685-6000 (61-3) 614-3569	Product trade name and description not available		
Austria			
AgroLinz P.O. Box 21 St. Peter Street 25 A4021 Linz Telephone: 43-732-5914 Fax: 43-732-3691	Folifert Super Volkorn	20-6-6+10% Mg, 1% Zn 15-5-18+2.5% MgO;Zn	Fine granular
Belgium			
Ameco Belgium N.V. Louizastraat 39 2000 Antwerp Telephone: (32-3) 255-2556 Fax: (32-3) 232-3832	Product trade name and description not available		
MicroNutrient N.V. Frankrijklei 65 Bus 3 B2000 Antwerp Telephone: (32-3) 225-1400 Fax: (32-3) 234-1967	Product trade name and description not available		
Colombia			
Abonos Colombianos S.A. Carrera 9a. No. 74-08, Ofc 1003 Santa Fe de Bogota, D.C. Telephone: (57-1) 288-6100 Fax: (57-1) 285-7203 Telex: 044781	Not available	17-6-18+0.2% Mg, 0.2% B, 0.1% Zn	Granular

Producer/Supplier	Product Trade Name	Description	Type
Monomeros Colombo Venezolanos S.A. (EMA) Planta via 40 Las Flores Apartado Aereo 3205 Barranquilla Telephone: (57-58) 565621 Fax: (57-58) 2811885;3420063 Telex: 31138 MCV Co	Not available	17-16-18+2% MgO, 1.5% S, 0.1% Zn, 0.2% B 14-14-14+2% MgO, 0.1% Zn, 0.2% B, S	Granular Granular
Czech Republic			
Synthesia AS, Zavod 01-Anorganika Zavod 01-Anorganika 53217 Pardubice-Semtin Telephone: (42-40) 493 Fax: (42-40) 46465 Telex: 196222	Not available Not available	11-9-14+1.5% MgO, Zn, B, Cu, Mo 15.50-7.50-10.0+3% MgO, Mo, B, Zn, Cu	Granular Granular
Germany			
Aglukon Spezialdunger GmbH P.O. Box 190343 D-40522 Dusseldorf Telephone: 49-211-506 4221 Fax: 49-211-506 4249	Hortazon Micro Wuxal Micro Wuxal Micro Zn	Multiple nutrient fertilizer with 0.5% Zn 10-0-0+2% Fe, 2% Mn, 2% Zn EDTA chelated 10-0-0+1% Fe, 2% Mn, 3% Zn EDTA chelated	Slow release Suspension Suspension
Metalldunger Jost GmbH Box 2052 58590 Iserlohn Telephone: (49-2371) 948523 Fax: (49-2371) 948535	Excello-Bor Excello-granuliert Excello-5% Cu Excello-Manesium Excello-Mangan Excello-Zink Excello-Weide Radigen (All these products are Zn-metal alloys containing different micronutrients) Folicin	3% Zn 3% Zn 3% Zn 1% Zn 0.5% Zn 8% Zn 3% Zn 0.5% Zn Zn-EDTA chelate	Granules Granules Granules Granules Granules Granules Granules Granules Powder or liquid
Stahler Agrochemei GmbH & Co. KG Stader Elbstrasse 21683 Stade Telephone: (49-4141) 2016 Fax: (49-4141) 45540	Not available Not available	14% Zn Compound micronutrient fertilizer with Zn	Granular Granular
Greece			
Chemical Industries of Northern Greece SA P.O. Box 10183 54110 Thessaloniki Telephone: (30-31) 760403 Fax: (30-31) 760422	Not available Not available Not available Not available Not available	8-12-12+0.5% B, 0.2% Zn 20-10-10+2% Zn SOP 14-5-14+2% Zn 24-0-0+1.5% Zn 13.5-0-0+10 Zn	Granular Granular Granular Granular Powder
India			

Producer/Supplier	Product Trade Name	Description	Type
Aries Agro-vet Industries Pvt. Ltd. Aries House 24, Deonor Govandi East Bombay 400043 Telephone: (91-22) 556-4052 Fax: (91-22) 515-3038	Agromin	Mixture of chelates containing Zn, Cu, Mn, and Fe	Powder
	Chelamin	12% Zn EDTA	Powder
Khatau Junker Ltd. Khatau House Mogul Lane, Mahim Bombay 400016 Telephone: (91-22) 444-9766 Fax: (91-22) 444-0826	Product trade name and description not available		
Nagarjuna Fertilizers and Chemicals Ltd. Nagarjuna Hills Panjaghutt Kakinada 533 003 Andhra Pradesh Telephone: (91-40) 227 589 Fax: (91-40) 226 788	Product trade name and description not available		
Italy			
Chemia S.P.A. Via Statale 327 44040 Dosso (Ferrara) Telephone: (39-532) 848477 Fax: (39-532) 848383	Nutrifix	13-5-38+B,Fe,Mg,Mn,Zn,Cu	Liquid
Mexico			
Grupo Bioquimicol Mexicano, S.A. de C.V. P.O. Box 238 Blvd. Jesus Valdez Sanchez 2369 Saltillo Coahuila 25290 Telephone: (52-84) 16-17-77 Fax: (52-84) 15-27-96	Poliquel Multi	4% Zn with other micronutrients	Liquid
	Poliquel Zn	8% Zn multichelated	Liquid
Netherlands			
B.V. Industrie-2 Handelsonderneming Simonis P.O. Box 620 7000 AP Doetinchem Telephone: 31-83-40-33700 Fax: 31-83-40-44167	Product trade name and description not available		
Melchemie Holland B.V. P.O. Box 143 6800 AC Arnhem Holland Telephone: 31-85-45-1251 Fax: 31-85-42-5093	Product trade name and description not available		
New Zealand			

Producer/Supplier	Product Trade Name	Description	Type
Fernz Corporation Ltd. P.O. Box 759 Auckland Telephone: (64-9) 379-3001 Fax: (64-9) 366-1394	Not available	$CoSO_4$, $ZnSO_4$	Granular
Pakistan			
Lyallpur Chemicals & Fertilizers Ltd. Lahore Road, Jaranwala District Faisalabad Telephone: (92-468) 310200 Fax: (92-468) 312628 Telex: 43373 LCF PK	Not available	Zinc sulfate	Powder
National Fertilizer Corporation of Pakistan 1st Floor Alfalah Building (Tail Wing) Shahrah-e-Quaid-e-Azam Lahore Telephone: (92-42) 630-2904 Fax: (92-42) 630-2918 Telex: 44726 NFC PK	Not available	Zinc sulfate 21% Zn	Powder
South Africa			
Kynoch Fertilizer Ltd.	Not available	6.3-21.5-7.6+0.5% Zn	Granular
P.O. Box 3836	Not available	8.6-29.3-10.4+0.5% Zn	Granular
Randburg 2125	Not available	6.7-22.9-16+1% Zn	Granular
Telephone: (27-11) 787-0419	Not available	3.8-28.0-0+0.5% Zn	Granular
Fax: (27-11) 789-5354			
Sasol Fertilizers	Not available	6.3-21.5-7.6+0.5% Zn	Granular
P.O. Box 1723	Not available	21-16-0+0.5% Zn	Granular
Randburg 2123	Not available	21.5-19-5+0.5% Zn	Granular
Telephone: (27-11) 886-3044 Fax: (27-11) 886-8643			
United Kingdom			
C.M.I. Ltd.	CM Zinc	7% Zn	Liquid
United House, 113 High Street	Superflor Mn	14% Zn EDTA	Powder
Collingham, Newark Notts NG23 7NG Telephone: (10636) 89-2078 Fax: (10636) 89-3037			
United States			
Agribusiness Supply	Agrinutrient	36% Zn, Zn oxysulfate	Granular
Albany, GA	Agristarter	10% Zn	Liquid

Producer/Supplier	Product Trade Name	Description	Type
Albion Laboratories Inc. P.O. Box 750 101 N. Main Street Clearfield, UT 84015 Telephone: (801) 773-4631 Fax: (801) 773-4633	Albion Metalosates	6.8% Zn chelate	Liquid
Allied Colloids Inc. P.O. Box 820 2301 Wilroy Road Suffolk, VA 23439-0820 Telephone: (804) 538-3700 Fax: (804) 538-0204	Librel Zn Librel RMX8	14% Zn EDTA Multiple nutrient fertilizer with 2.6% Zn EDTA	Granule/powder Powder
Alpine Plant Foods Inc. 3185 Cline Road Corydon, IN 47112 Telephone: (812) 738-1333 Fax: (812) 738-1199	Liqui Cal	9% Zn chelate	Liquid
American Micro Trace Corporation 569 Central Drive, Suite 201 Virginia Beach, VA 23454 Telephone: (804) 463-5013 Fax: (804) 463-8156	Coarse Zink Super Fine Zink Super TEL Zn Zink-33 Zink-Gro Zink-Gro AS	35.5% Zn sulfate monohydrate 35.5% Zn sulfate monohydrate 33.5% Zn sulfate monohydrate 33.5% Zn sulfate monohydrate 35.5% Zn sulfate monohydrate 35.5% Zn sulfate monohydrate	Fine granular Powder Powder Granular Granular Fine granular
American Minerals Inc. P.O. Box 2005 Dunedin, FL 34697-2005 Telephone: (813) 734-3284 Fax: (813) 733-0503	Granusol	36% Zn.Zinc sucrate	Granule
Arcadian Corp. 6750 Poplar Avenue, Suite 600 Memphis, TN 38138 Telephone: (901) 758-5200 Fax: (901) 758-5204	Liqui-zinc NZN	10%-12% Zn.Zn amine complex N + 5% Zn	Liquid
Bay Zinc Co., Inc. P.O. Box 167 301 W. Charron Rd. Moxee, WA 98936 Telephone: (509) 248-4911 Fax: (509) 248-4916	Blu-Min Blu-Min Blu-Min LHM	18% Zn.Zinc oxysulfate 10.5% Zn.Zinc sulfate 18% Zn.Zinc sulfate	Granular Liquid Granular
Chem One Corp. 15150 Sommermeyer Houston, TX 77041-5308 Telephone: (713) 896-9966 Fax: (713) 896-7540	Zinc	35.5% Zn.Zinc sulfate monohydrate	Powder/granular

Producer/Supplier	Product Trade Name	Description	Type
Chemical & Pigment Co. 600 Nichols Road Pittsburg, CA 94565 Telephone: (510) 689-2030 Fax: (510) 458-2410	Meteor Meteor Meteor	52% Zn.Zinc sulfate basic 36% Zn.Zinc sulfate monohydrate 62% Zn.Zinc chloride	Powder Granular Solution
Chemical Dynamics Inc. P.O. Box 486 Plant City, FL 33564-0486 Telephone: (813) 752-4950 Fax: 9813) 752-8639	Dyna Gold MZ Mix Dyna Gold MZF Mix Dyna Gold Zinc	3.6% Zn, 2.9% Mn, 3.5% S 1.6% Fe, 2% Mn, 2.4% Zn, 3.5% S 7% Zn	Liquid Liquid Liquid
Conklin Co., Inc. P.O. Box 155 551 Valley Park Dr. Shakopee, MN 55379 Telephone: (612) 445-6010 Fax: (612) 496-4285	Feast Feast CropMix	9% Zn EDTA fully chelated 4% Zn, 1% Fe, 1% Mn EDTA, HEDTA fully chelated	Liquid Liquid
Cornbelt Chemical Company P.O. Box 410 North Highway 83 McCook, NE 69001 Telephone: (308) 345-5057 Fax: (308) 345-3401	CornGro Super Blend Plus	3.5% Zn, 0.6% Mn, 0.4% Cu EDTA fully chelated 3% Zn, 1% Fe, 1% Mn, 0.5% Cu EDTA fully chelated	Liquid/powder Liquid/powder
CoZinco, Inc. 7400 Jefferson Avenue Denver, CO 80235 Telephone: (303) 969-9414 Fax: (303) 989-0322	CoZinCo CoZinCo CoZinCo SD36 CoZinCo	35.5% Zn.Zinc sulfate 12% Zn 35.5% Zn.Zinc sulfate 31% Zn.Zinc sulfate	Granular Liquid Powder Granular
Crystal Chemical Inter-America 10303 NW Freeway Suite 512 Houston, TX 77083 Telephone: (713) 956-6196 Fax: (713) 956-6835	Kelaplex Zinc Kelaplex Zinc Kelaplex Zinc Kelaplex Zinc Zinquel Zinc	14% Zn fully chelated 79% Zn.Zinc oxide 36%, 20% Zn.Zinc sulfate 10%, 12% Zn.Zinc sulfate 6.5% Zn, 4% S fully chelated 75% Zn.Zinc oxide	Soluble powder Liquid Soluble powder Solution Liquid Spray grade
Farmland Industries, Inc. P.O. Box 7305 Kansas City, MO 64116 Telephone: (816) 459-6000 Fax: (816) 459-5913	Farmland Farmland Farmland Farmland	Ammoniated Zn chloride, ammoniated Zn sulfate 10%-20% Zn 9% Zn chelate 20%-35.5% Zn.Zinc sulfate	Liquid Liquid Granular
Fertilizer Corporation of America 9370 Sunset Drive #A-240 Miami, FL 33173 Telephone: (305) 595-6738 Fax: (305) 595-9367	Balance 18ZN Balance 36ZN Balance $36ZnSO_4$ Microfol Zinc Microfol Zinc	18% Zn, 12% Fe, 1% Mn, 7% S 36% Zn, 6% S 36% Zn, 17% S 7% Zn, 4% S chelated 10% Zn, 5% S chelated	Granular blend Granular Prills Liquid Liquid

Producer/Supplier	Product Trade Name	Description	Type
Frit Industries	F420G	20% Zn	Granular
P.O. Box 1589	F317G	36% Zn	Granular
Ozark, AL 36361-1589	F305G	20% Zn micronutrient mixture	Granular
Telephone: (334) 774-2515	F307G	20% Zn micronutrient mixture	Granular
Fax: (334) 774-9306	CZN	10% Zn chelate	Granular
	Zn chelate	7% Zn	Liquid
	Zn chelate	10% Zn	Liquid
	Pro. sol.	25% Zn Zn citric acid chelate	Powder
Georgia Pacific Corp.	Zinc KE-MIN	14% Zn	Powder
P.O. Box 1236	Zinc KE-MIN	5.6% Zn	Liquid
300 W. Laurel St. (98225)	Z-M-KE-MIN	3.2% Zn, 1.6% Mn	Liquid
Bellingham, WA 98227			
Telephone: (800) 385-4348			
Fax: (206) 676-7217			
J. M. Huber Corp.	Zinc	36% Zn.Zinc sulfate	
P.O. Box 4005	Zinc	72% Zn.Zinc oxide	
3150 Gardner Expwy.			
Quincy, IL 62305			
Telephone: (217) 224-1100			
Fax: (217) 224-7957			
Hydro Agri North America Inc.	Not available	52% Zn.Zinc sulfate, basic	Powder
100 N. Tampa St., Suite 3200	Not available	36% Zn.Zinc sulfate	Spray dried
Tampa, FL 33602	Not available	26% Zn.Zinc sulfate-iron sulfate	Granular/powder
Telephone: (813) 222-5700	Not available	12% Zn.Zinc sulfate	Solution
Fax: (813) 875-5735	Meteor	Zinc sulfate	
Imperial Products, Inc.	IPI Zinc	15% Zn EDTA	Powder
1071 W. Morse Blvd.	IPI Zinc	36% Zn, 18% S.Zinc sulfate monohydrate	Powder, granular
Winter Park, FL 32789-3747			
Telephone: (407) 628-1494	Not available	80% Zn.Zinc oxide	Wettable powder
Fax: (407) 628-3676	Not available	36% Zn.Zinc sulfate monohydrate	Granular
Lidochem Inc.	Lidoquest Zinc 14P	Zinc ethylenediaminetetraacetic acid 14% Zn	Powder
Village Park Office Complex			
20 Village Court	Zinc sulfate	35% zinc	Fully soluble
Hazlet, NJ 07730			
Telephone: (908) 888-8000			
Fax: (908) 264-2751			
Mineral Research & Development	Mineral Research	17% Zn.Zinc nitrate	Liquid
Division of Chemical Specialist Inc.	Mineral Research	23% Zn.Zinc nitrate	Flakes
One Woodlawn Green Suite 250	Mineral Research	24%, 28%, & 31% Zn.Zinc chloride	Liquid
Charlotte, NC 28217		46.6% Zn, 80% solids zinc	
Telephone: (704) 525-2771	Mineral Research	carbonate	Dustless
Fax: (704) 527-8232		47%, 49% Zn.Zinc chloride	
	Mineral Research	anhydrous	
		58% Zn.Zinc carbonate	
	Mineral Research		Dry

Producer/Supplier	Product Trade Name	Description	Type
Monterey Chemical Co. (Trader)	Hamp-Ene Zinc	6% Zn EDTA chelate	Liquid
P.O. Box 5317	Hamp-Ene Zinc	14% Zn EDTA chelate	Powder
Fresno, CA 93755	Monterey Mix	3% S, 18.5% Zn, 7% Mn	
Telephone: (209) 225-4770	Monterey Mix	22% Zn, 10% Fe	
Fax: (209) 225-1319	Monterey Mix	52% Zn.Zinc oxysulfate	Powder
	Monterey Zinc	72%, 75% Zn.Zinc oxide	Suspendable powder
	Monterey Zinc	31% Zn.Zinc sulfate	Granular
	Monterey Zinc	36% Zn.Zinc sulfate	Powder/granular
	ULB Urea	20% Zn + ultra-low biuret urea	
Old Bridge Chemical Inc.	Zinc	30% Zn.Zinc chloride	Solution
P.O. Box 194	Zinc	13% Zn.Zinc sulfate	Solution
Old Bridge, NJ 08857	Zinc Sulfate	35.5% Zn	Powder
Telephone: (908) 727-2225			
Fax: (908) 727-2653			
Plant Health Technologies	Folo Spray Neutral Zinc	52% Zn	Slowly soluble
Crop Protection Products			
P.O. Box 15057	Folo Spray Nutra Wet	NPK + 20% Zn	-
Boise, ID 83715	Folo ZnK		
Telephone: (208) 345-1021	N-Zn-B	14-0-22 + 15% Zn, 2% Mn	-
Fax: (208) 345-1032		24-2-6, 5% S, 10% Zn	-
Prince Agri Products	Not available	36% Zn.Zinc sulfate	Granular/powder
P.O. Box 1099		72% Zn.Zinc oxide	-
Quincy, IL 62306			
Telephone: (217) 222-8854			
Fax: (217) 222-5098			
PureGrow Co.	LeafLife Heads-up	5% N, 5% Ca, 2.5% Zn	
1276 Halyard Drive	LeafLife Super Zinc 10	10% N, 10% Zn	Liquid
West Sacramento, CA 95691			
Telephone: (916) 372-7184	Super Sol-U K	12-8-30 + 4% Zn	Solution
Fax: (916) 372-7205	Super Sol-U Phos	12-46-4 + 2.75% S, 3% Zn	Solution
Ruffin Micronutrients	Ruffin Tuff 5-22-0	1.0% Zn	Liquid
P.O. Box 940	Ruffin Tuff 10-0-0	10% Zn	Granular/liquid
Dodge City, KS 67801	Ruffin-Ready-Zn	10% Zn	Liquid
Telephone: (800) 535-7479	Special crop mix 1	5% Zn	Liquid
Fax: (316) 225-7035			
Shield-Brite	NutraSpray Zinc 50	Not available	Wettable powder
Division of Pace International LP	NutraSpray	17.5% Zn, Mn 4%, Cu 4%	Wettable powder
P.O. Box 519	NutraSpray	18.5% Zn, Mn 7%	Wettable powder
500 7th Ave S.	NutraSpray	25% Zn, Mn 25%	Wettable powder
Kirkland, WA 98083	Zintrac 8	40% Zn	Suspension
Telephone: (206) 827-8711	Zinphos 7	28% phosphoric acid, 9.4% Zn	Liquid concentrate
Fax: (206) 822-8261			

Producer/Supplier	Product Trade Name	Description	Type
Sims AG Products, Inc. 3795 County Road 29 Mt. Gilead, OH 43338 Telephone: (419) 946-2015 Fax: (419) 946-6571	BinBuster Zinc 20% BinBuster Zinc 31% BinBuster Zinc 36%	20% Zinc oxysulfate 31% Zinc oxysulfate 36% Zinc oxysulfate	Granular Granular Granular
Traylor Chemical & Supply Co., Inc. P.O. Box 547937 Orlando, FL 32854-7937 Telephone: (407) 422-6151 Fax: (407) 423-5316	Hapta-Gro Liquid Metagro Corn Mix Metagro Traylor Zinc Traylor Zinc Traylor Zinc Traylor Zinc Traylor Zinc Traylor Zinc Zinc Ammonium Chloride Sulfate	9% Zn, 4% S 5% Zn, 1% Mn, 1% Cu, 4% S 10% Zn complex 50%-65% Zn.Zinc oxide 52%, 78%, 80% Zn.Zinc oxide 20%, 36% Zn.Zinc oxide 35.5% Zn.Zinc sulfate 10% Zn.Zinc ammonium sulfate 14% Zn chelate 17% Zn, 7% N.Zinc nitrate 13% N, 4.5% S, 15% Zn	Liquid Liquid Granular Granular/powder Wettable powder Granules Granular/powder Liquid Powder
Zinc Corporation of America 300 Frankfort Road Monaca, PA 15061 Telephone: (412) 774-1020 Fax: (412) 773-2269	Kadox 911; 920; 930 Zinc Sulfate Zinc Oxide Equidae Zinc Oxide	80% Zn 11% Zn.Zinc sulfate 79.5% Zn 70% Zn	Powder/granular Liquid Powder/granular Powder

Source: *Farm Chemicals Handbook*, 1995.

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