Chapter 19

Nutritional Disorders

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Introduction

In Latin America, beans are grown on many different soil types where different nutritional deficiencies or toxicities may limit plant development and yield. In Central America and western South America, beans generally are grown in mountain areas where Andosols (Inceptisols) predominate. Phosphorus and nitrogen deficiencies are most common, although deficiency of minor elements and aluminium/manganese toxicity can limit yield seriously in certain areas.

Between mountain ranges, beans are grown in valleys which generally have alluvial soils of high fertility but which may be low in certain minor elements. In many parts of Venezuela and Brazil, beans are grown on rather acid, low fertility Oxisols and Ultisols. On these soils beans may suffer from aluminium and/or manganese toxicity, as well as a deficiency of phosphorus and occasionally zinc.

A nutritional problem generally is diagnosed with the use of soil and tissue analyses and visual observation of symptoms. Soil samples are taken with a soil auger in the root zone of the plants, and several subsamples from the same general area may be combined into one sample. Leaf samples (without petioles) generally are taken at the top of the plant from the uppermost leaves present at the time of flower initiation. The leaves are oven-dried at 60° to 80°C for 24 to 48 hours, ground and analyzed. If plants show symptoms of nutritional disorders, soil and plant samples are taken from areas with and without symptoms and the analyses compared to identify the element causing the symptoms.

Sometimes, a range of different elements is applied to either soil or foliage to observe any improvement of growth or disappearance of symptoms so as to identify the element which is limiting growth. The latter method is more time-consuming but is useful if laboratories are not available to analyze soil and plant tissue.

In order to use these diagnostic techniques, researchers must recognize symptoms of nutritional disorders and know the critical levels for

deficiency and toxicity symptoms to occur in the soil and plant. These are described later for each element.

Effect of Soil pH on Nutrient Availability

Beans grow best on soils with pH's from 6.5 to 7.5. In this range, most plant nutrients have their maximum availability. However, soils in Latin America have a pH below 6.5, and there are important agricultural areas with a pH above 7.5. Beans will tolerate a low pH of about 4.5 to 5.5 but below that, generally they suffer from aluminium and/or manganese toxicity.

In alkaline soils, beans will tolerate a pH below 8.2 (19), but many soils with high pH also have problems with excess salt (salinity), excess sodium (alkalinity), deficiency of minor elements and poor drainage. According to FAO maps, there are 55 million hectares which have salt problems in South America (20). Salinity can be caused by an excess of sodium chloride, calcium chloride, sodium sulfate and magnesium sulfate. However, it is mainly chloride salts which cause stunted growth, yellowing, flower abortion, hastened maturity and low bean yields (20). Excess sodium salts reduce plant uptake and disperse clay minerals in the soil, thereby causing poor drainage. Beans will tolerate a sodium saturation percentage up to 8 or 10% and an electrical conductivity (measure of salinity) up to 1 mmho/cm. Above these levels, yields drop sharply (19).

Soil salinity problems can be controlled by planting salt-tolerant species and cultivars. In soils with good internal drainage, the application of elemental sulfur or gypsum in combination with large quantities of water may reduce the problems, but at a very high cost.

Nutrient Deficiencies and Toxicities

Aluminium Toxicity

Aluminium toxicity occurs in large areas of Latin America with acid Oxisols, Ultisols and Inceptisols.

Figure 1 shows symptoms of aluminium toxicity. If the toxicity is very severe, plants may die shortly after germination. In less severe conditions, lower leaves become uniformly yellow with necrotic margins, plant growth is stunted and yields depressed. Beans are particularly susceptible to aluminium toxicity. There are large varietal differences for susceptibility (30, 31). Black beans have been reported to be less susceptible than beans of other colors (14). However, this observation is biased by limited sampling of other colors.

Fig. 1 - Stunted plant growth and leaf margin necrosis caused by aluminium toxicity.

Aluminium toxicity is controlled by deep incorporation of agricultural lime, calcium oxide or calcium hydroxide until the pH is above 5.2 to 5.5, or the aluminium content is less than 25 to 30% (25); however, this may not always be economically feasible. Application of 1.5 to 2 ton per hectare of lime will neutralize one milligram equivalent of aluminium per 100 grams of soil. Six tons lime/ha was effective on an acidic volcanic ash soil, as indicated by improved plant growth. Application of basic slag and certain rock phosphates also may reduce aluminium toxicity, while acid-forming fertilizers such as ammonium sulfate and urea may intensify the problem.

Boron Deficiency and Toxicity

Boron deficiency commonly occurs in coarse-textured soils low in organic matter and high in aluminium and iron hydroxides (6, 64). It also can be very serious in alluvial soils with a high pH and low total boron content (15, 16, 17).

Boron deficient plants have thick stems and leaves with yellow and necrotic spots (Fig. 2 and Fig. 3). In less severe cases, leaves are crinkled and curl downwards, similar to symptoms caused by virus or Empoasca

Fig. 2 - Leaf symptoms induced by boron deficiency.

Fig. 3 - Abnormal plant growth (left) induced by boron deficiency.

Fig. 4 - Yellowing and necrosis of leaf margins caused by boron tox- icity.

attack. Under conditions of severe boron deficiency, plants remain stunted or die shortly after germination. The critical level for boron deficiency is 20 to 25 ppm in leaves (38) and 0.65 ppm hot-water extractable boron in soil.

Boron deficiency can be controlled by soil application at planting of 1 to 2 kilograms of boron per hectare as Borax, Solubor or other sodium borates, or by foliar application of 1% Solubor or Borax. There are large varietal differences for susceptibility to boron deficiency. Black beans generally have been more susceptible than red beans (17).

Boron toxicity causes yellowing and necrosis of the margins of primary leaves shortly after emergence (Fig. 4), and of older leaves. The critical level for boron toxicity is 40 to 45 ppm in leaves and 1.6 ppm in soils (38). Fox (29) reported that beans are more susceptible to boron toxicity than corn, cotton and alfalfa. Toxicity symptoms appear when the soil content exceeds 5 ppm boron. The toxicity generally occurs after non-uniform application of fertilizer or when the fertilizer is band-applied too closely to the seed, especially during dry weather.

Calcium Deficiency

Calcium deficiency is seldom observed in beans, although plant growth and nitrogen fixation can be affected in many acidic soils with a low calcium status (4). Calcium deficiency generally is observed in combination with aluminium toxicity in acid Oxisols and Ultisols. Beans grown in such soils generally respond to liming. The effect is due to a decrease in exchangeable aluminium and/or manganese ions, and the increased availability of calcium, magnesium and molybdenum.

Calcium deficiency symptoms are apparent as the leaves remain dark green with only slight yellowing at the margins and tips and the leaves
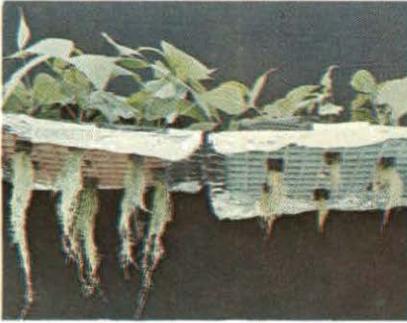
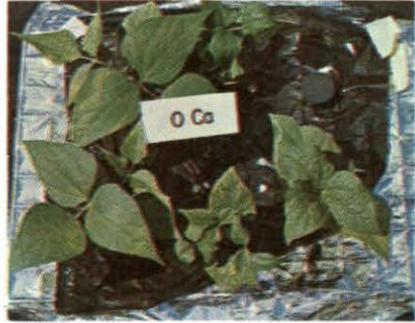Fig. 5 - Poorly developed root system (right) caused by calcium deficiency.

Fig. 6 - Shortened internodes and rosette-type plant growth (foreground) caused by calcium deficiency.

crinkle and curl slightly downward. Calcium deficient plants remain small and root growth may be reduced seriously (Fig. 5). Internodes often are short, producing a rosette-type of plant growth (Fig. 6). Optimum calcium levels in leaves are 2%(1), while values of 5 to 6% have been detected (7, 10).

A critical calcium level of 1.44% occurred in upper mature leaves at flower initiation (18). Since little calcium retranslocation occurs within the plant, apical leaves depend upon a continuous calcium uptake by the root system (8, 9, 41). Calcium contents of leaves decrease with increasing potassium applications (28).

Calcium deficiency is controlled by deep incorporation of calcitic or dolomitic lime or calcium oxide or hydroxide. Low rates, such as 500 kg/ha generally are sufficient to relieve calcium deficiency, but higher rates often are employed to neutralize toxic amounts of aluminium. Calcium phosphate sources, such as basic slag, rock phosphate and superphosphate, may contribute significantly to calcium nutrition.

Copper Deficiency

Copper deficiency has occurred in the Everglades of Florida (62), and in organic or very sandy soils, but it has not been studied in Latin America. Beans are relatively insensitive to copper deficiency when compared to other crops (43).

Copper deficient bean plants are stunted, have shortened internodes, and young leaves become gray or blue-green. Normal copper content of leaves is 15 to 25 ppm in upper leaves.

Copper deficiency is controlled by soil applications of 5 to 10 kg copper/ha as copper sulfate. Foliar applications of 0.1% copper as copper sulfate or copper chelates also are effective.

Iron Deficiency

Iron deficiency is not common but can occur in certain organic soils or mineral soils with a high pH, especially if free calcium carbonate is present.

Iron deficient plants have light yellow to white upper leaves with veins which are initially green (Fig. 7). Normal iron levels in bean leaves may reach 100-800 ppm (7, 10).

Iron deficiency can be controlled by applying iron ethylenediaminotetraacetic acid (EDTA) or other chelates to the soil. Inorganic iron is precipitated easily, especially in high pH soils (37). The application of EDDHA (ethylene diaminedi-o-hydroxyphenylacetic acid) increased iron transport within the plant by decreasing copper uptake, while DTPA (diethylenetriaminepentaacetic acid) increased the uptake of copper, manganese, zinc and iron (63). Foliar application of iron chelates also can control iron deficiency if initial plant growth has not been affected greatly by the deficiency.

Magnesium Deficiency

Magnesium is a basic component of chlorophyll, and optimum levels therefore are vital to photosynthesis. Magnesium deficiency commonly occurs in acid infertile soils with low base status and in volcanic ash soils relatively high in calcium and potassium.

Interveinal chlorosis and necrosis appear first on older leaves (Fig. 8), later spreading over the entire leaf and to younger foliage (Fig. 9). Magnesium is not very mobile. During stress more magnesium goes to younger leaves, thereby causing a deficiency in older leaves. Magnesium deficient plants commonly contain 0.22 to 0.3% magnesium in leaves (18, 56), while normal plants contain 0.35 to 1.3% (7, 10).

Magnesium deficiency can be controlled by soil application of 10 to 20 kilograms of magnesium per hectare as dolomitic lime, magnesium oxide or magnesium sulfate; or as a foliar application of 1% magnesium sulfate solution if the deficiency is not too serious. Lime and magnesium oxide should be broadcast and incorporated, while magnesium sulfate may be more effective when band-applied. Magnesium is absorbed rapidly by primary leaves but is not readily translocated (12). However, it is rapidly distributed throughout the plant when applied to the root system.

Manganese Deficiency and Toxicity

Manganese deficiency occurs in organic soils, mineral soils with a high pH or over-limed acidic soils (27). High calcium levels depress both iron

Fig. 7 - Interveinal chlorosis of leaves caused by iron deficiency.

Fig. 8 - Magnesium deficiency symptoms on older foliage.

Fig. 9 - Magnesium deficiency symptoms on young foliage.

and manganese uptake. Under these conditions, the optimum iron: manganese ratio is nearly 2.

Manganese deficient plants are stunted and upper leaves become golden-yellow between small veins, giving a mottled appearance (Fig. 10). Deficient plants contain less than 30 ppm manganese, while normal plants may contain 75 to 250 ppm.

Manganese deficiency can be controlled by soil application of 5 to 10 kilograms manganese per hectare as manganese sulfate or manganous oxide (27), or by foliar applications of manganese chelates. Application of manganese-ethylenediaminotetraacetic acid (EDTA) was not effective, because it increased iron uptake and induced more severe manganese deficiency in organic soils (40). Manganese and zinc are absorbed primarily during the first 40 days of plant growth (5).

Manganese toxicity has been observed in poorly drained, acidic volcanic ash soils in Colombia (18) and in hydromorphic soils in Brazil (23).

Figure 11 shows symptoms of manganese toxicity which include interveinal chlorosis of young leaves. In more severe cases, plants become completely chlorotic, and the upper leaves are small, crinkle and curl downwards (Fig. 12). Symptoms of manganese toxicity are easily confused with those of zinc and magnesium deficiency.

Both manganese toxicity and magnesium deficiency occur in acid soils, but the former produces symptoms in the young leaves while the latter affects the older leaves. Zinc deficiency is more common in high pH soils. Beans are more susceptible to manganese toxicity than corn, and the toxicity seriously affects plant growth, nodule formation and nitrogen fixation (23). Plants suffering from manganese toxicity may contain 1000-3000 ppm (18).

Manganese toxicity can be controlled by liming (18, 23) and by improving field drainage.

Nitrogen Deficiency

Although beans are a legume and therefore capable of symbiotic nitrogen fixation with the appropriate *Rhizobium* strain (33, 34), soil, varietal or inoculation difficulties can limit fixation (16, 23, 58), thereby forcing the plant to rely on soil or fertilizer nitrogen. Nitrogen deficiency is most common in soils with low organic matter. It also is found in acidic soils in which toxic levels of aluminium or manganese, or deficient levels of calcium and magnesium, limit microbiological decomposition of organic matter and nitrogen fixation by *Rhizobium*.
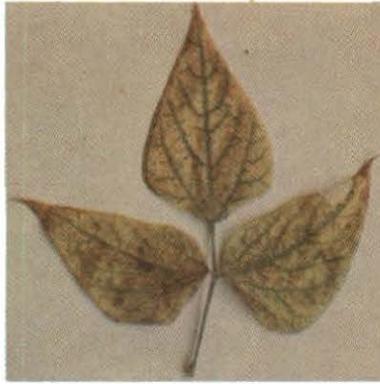
Fig. 10- Manganese deficiency symptoms in bean.

Fig. 11 - Interveinal chlorosis caused by manganese toxicity.

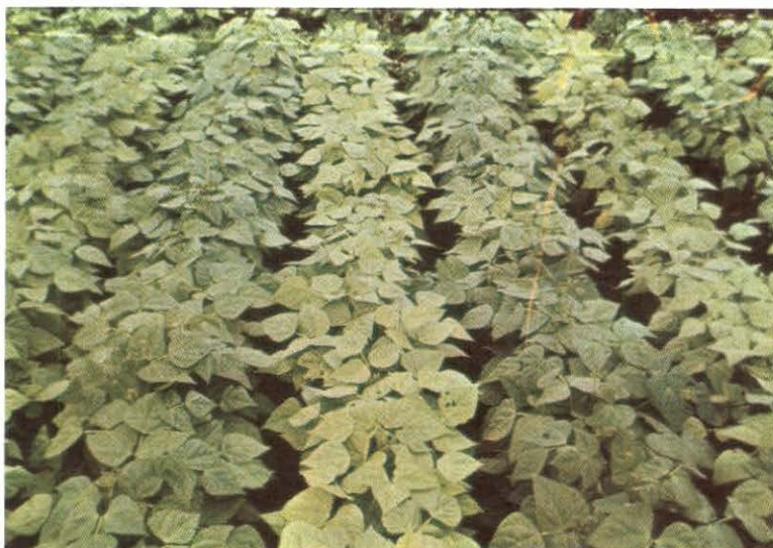Fig. 12 - Plant symptoms induced by severe manganese toxicity.

Fig. 13 - Plant chlorosis induced by nitrogen deficiency.

Nitrogen deficiency symptoms are evident when leaves near the bottom of the plant turn pale green and eventually yellow, and the discoloration progresses gradually upward (Fig. 13). Plant growth is stunted and yields may be affected. Upper leaves of plants which exhibit deficiency symptoms generally have a nitrogen çontent of less than 3% during flower initiation (10, 56), compared to an optimum of 5% in normal plants (44). Carvajal (13) reported that petioles are more useful in the diagnosis of nitrogen deficiency than are leaf blades. He reports critical petiole levels of 600 ppm for nitrates, 200 ppm for soluble organic nitrogen and 800 ppm for total soluble nitrogen.

Nitrogen deficiency may be controlled by applying a nitrogen fertilizer or by the incorporation of animal manure (59) and green manure (2, 48, 50, 52). No significant differences have been noted between nitrogen sources such as urea, ammonium nitrate, sodium nitrate or calcium ammonium nitrate (47, 58), or between application times (47). On acid soils, sources such as calcium ammonium nitrate, and on alkaline soils, sources such as ammonium sulfate may be beneficial. In general, however, the choice of the nitrogen source is determined by its cost per kilogram of useable nitrogen. Responses to nitrogen application rates varied from no response in many trials in Brazil (25, 35, 51), to large responses to levels as high as 200 (24) and 400 kilograms of nitrogen per hectare (17). Of 232 NPK trials conducted in Brazil, only 67 showed a positive response to nitrogen fertilization (45). Nitrogen fertilizers generally are band-applied at or shortly after seeding, or as a split application at seeding and flower initiation.

In an acid, volcanic ash soil in Colombia, a negative response (fertilizer burn) occurred to band application of urea above 80 kilograms of nitrogen per hectare during a drought. In the same soil, application of 320 and 640 kilograms of nitrogen per hectare produced negative results due to a lowering of soil pH and a subsequent induction of manganese toxicity. Manganese levels in leaves increased from 250 ppm in the check to 600 ppm with the high nitrogen application (19).

In soils where phosphorus is the principal limiting factor, beans may not respond to nitrogen until sufficient phosphorus is applied (61). Nitrogen fixation may be ineffective in the absence of adequate amounts of lime and phosphorus (16, 23, 55), since *Rhizobium* spp. are sensitive to high aluminium or manganese levels and low calcium and phosphorus levels. Liming may increase the efficiency of nitrogen fertilizer application (55) and nitrogen fixation (23). Whenever soil and temperature conditions are conducive to nitrogen fixation, it may be advisable to inoculate seed with *Rhizobium* to replace or supplement chemical nitrogen fertilizers.

Phosphorus Deficiency

Phosphorus deficiency probably is the most common nutritional problem of beans in Latin America. Phosphorus deficiency limits bean yields in many areas of Brazil, especially in the Campo Cerrado (35), in the Oxisol and Ultisol soils of Puerto Rico (1), and in Andosol soils of Colombia (16, 17) and Central America (22, 46).

Phosphorus deficient beans are stunted, have few branches (Fig. 14) and lower leaves are yellow and necrotic before senescing (Fig. 15). Upper

Fig. 14 - (left) Stunted plant growth and sparse branching induced by increasing levels of phosphorus deficiency, left to right.

Fig. 15 - (right) Chlorotic and necrotic leaf symptoms induced by phosphorus deficiency.

Fig. 16- Reduced flowering and small leaf formation caused by phosphorus deficiency.

leaves often are dark green but small. Phosphorus deficiency reduces flowering and affects maturation (Fig. 16). Plants become taller and more vigorous when more phosphorus is applied.

Deficient plants generally contain less than 0.2% phosphorus in their leaves (56). In the uppermost mature leaves, phosphorus contents of 0.2 (21) to 0.4% (44) are optimum levels during the 10% flowering stage. At CIAT (17) the critical level was calculated to be 0.35% phosphorus. The critical phosphorus content (Mehlich extractant) of soils in Minas Gerais (Brazil) was 8 ppm (11), while at CIAT (18) the critical level was found to be 10 to 15 ppm (Olson, Bray I and II extractants).

Phosphorus deficiency generally is corrected by applying phosphorus fertilizers such as triple superphosphate, single superphosphate, rock phosphate or basic slag. These materials should be broadcast and incorporated, except for the superphosphate which should be applied in bands in high phosphorus-fixing soils. Best results generally are obtained by application of triple superphosphate or single superphosphate in soils that also are sulfur deficient. Basic slag and rock phosphates are better suited to acid soils where their relatively large calcium or calcium carbonate content can have a neutralizing effect. The effectiveness of ground rock phosphates varies considerably depending on the crystalline structure of the mined rock. The phosphorus availability of each source is determined by its solubility in ammonium citrate. Bean experiments in Colombia showed a good correlation between this solubility index and the agronomic effectiveness of rock phosphates (18).

The phosphorus availability of rock phosphates can be improved by acidifying them partially with sulfuric acid or by mixing them with sulfur and sulfur-producing bacteria (17, 18). In most soils, beans respond to low

phosphorus application rates (22, 35), while in some soils beans respond to 400 kilograms P_2O_5 per hectare (18).

In a high phosphorus fixing soil of Colombia, beans responded to broadcast applications of triple superphosphate as high as 2060 kilograms P_2O_5 per hectare. However, when the phosphorus was band-applied, similar yields could be obtained with 300 kilograms of P_2O_5 per hectare (19). Thus, in phosphorus-fixing soils, highly soluble sources, such as triple superphosphate, should be band-applied to reduce the soil/fertilizer contact. Less soluble sources, such as basic slag and rock phosphates, need good soil contact to dissolve and are more effective when broadcast and incorporated (19, 57).

In Brazil, beans responded positively to phosphorus application in 103 of 232 trials (45). However, high phosphorus applications may induce zinc deficiency (3, 42).

Potassium Deficiency

Potassium deficiency seldom is observed in beans, but it can occur in infertile Oxisols and Ultisols, or in soils high in calcium and magnesium. In Brazil, a positive potassium response was obtained in only 15 of 232 NPK trials (45).

The symptoms of potassium deficiency consist typically of yellowing and necrosis of leaf tips and margins. These appear first in lower leaves and gradually extend upward (Fig. 17). Necrotic spotting may occur in cases of severe deficiency. The optimum leaf content is 2% potassium (44). Blasco and Pinchinat (10) and Berrios and Bergman (7) report that slightly higher levels occur in field-grown beans. Deficient plants have less than 2%

Fig. 17 - Leaf symptoms induced by potassium deficiency.

Fig. 18- Chlorotic leaf symptoms caused by a deficiency of sulfur.

potassium in upper leaves at flower initiation, and this level may be lower in plants grown on high calcium or magnesium soils.

Potassium deficiency can be controlled by band application at planting of 50 to 100 kilograms potash (K_2O) per hectare in the form of either potassium chloride or potassium sulfate. The sulfate form is recommended for soils which are low in available sulfur.

Sulfur Deficiency

Sulfur deficiency is not common in Latin America but may occur in infertile Oxisols and Ultisols, especially those far removed from industrial centers (49).

Symptoms of sulfur deficiency are evident as uniformly yellow upper leaves (Fig. 18), similar to symptoms caused by nitrogen deficiency. Although top growth is reduced, root growth is little affected by sulfur deficiency. Sulfur deficiency occurs in soybeans if plants contain less than 0.15% sulfur (32), while in beans the critical level is about 0.2 to 0.25% (19). A proper nitrogen: sulfur balance is important for protein formation (60). The optimum nitrogen: sulfur ratio in bean tops is near 15:1. Sulfur deficiency causes an accumulation of inorganic and amide nitrogen in leaves and inhibits protein synthesis. In sulfur deficient soils, nitrogen fertilization should be accompanied by sulfate application at a ratio of nitrogen: sulfur of 15:1.

Sulfur deficiency can be controlled by applying 10-20 kg/ha of elemental sulfur, or by using sulfur-containing fertilizers such as ammonium sulfate, simple superphosphate, potassium sulfate or the application of elemental sulfur. Certain fungicides, such as Elosal, may contribute to the sulfur nutrition of the plant.

Fig. 19 - Interveinal chlorosis of younger leaves induced by zinc deficiency.

Fig. 20 - Symptoms of zinc deficiency on older leaves.

Zinc Deficiency

Zinc deficiency occurs in soils with a high pH or in acid soils that have had high rates of lime and/or phosphorus applications.

Zinc deficiency symptoms begin as an interveinal yellowing of younger leaves (Fig. 19) and older leaves (Fig. 20) which may advance into necrotic spots at a later stage.

The critical level of zinc in bean tissue is 15 to 20 ppm (42), while normal levels are 42 to 50 ppm zinc (39). Levels greater than 120 to 140 ppm zinc can decrease yields (3). Zinc deficiency may be induced by large applications of lime, phosphorus, iron (3) or copper (53, 54).

Cultivars differ in susceptibility to zinc deficiency. A low zinc supply reduced the content of starch and soluble starch synthetase of a cultivar susceptible to zinc deficiency, suggesting that zinc may be essential for starch synthesis (39).

Zinc deficiency can be controlled by soil application of 5 to 10 kilograms of zinc/ha as zinc sulfate (3), or foliar application of 0.3 to 0.5% zinc sulfate or zinc chelates (3, 36). Soil application of zinc sources should be hand-mixed, because incorporation into fertilizer granules reduces their solubility (26), except when mixed with ammonium polyphosphates.

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