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## SMALL GRAIN PRODUCTION MANUAL PART 4

# Fertilization of Small Grains

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This publication, *Fertilization of Small Grains*, is the fourth in a fourteen-part series of University of California Cooperative Extension online publications that comprise the *Small Grain Production Manual*. The other parts cover specific aspects of small grain production practices in California:

- *Part 1: Importance of Small Grain Crops in California Agriculture*, Publication 8164
- *Part 2: Growth and Development*, Publication 8165
- *Part 3: Seedbed Preparation, Sowing, and Residue Management*, Publication 8166
- *Part 5: Irrigation and Water Relations*, Publication 8168
- *Part 6: Pest Management—Diseases*, Publication 8169
- *Part 7: Pest Management—Insects*, Publication 8170
- *Part 8: Pest Management—Vertebrates*, Publication 8171
- *Part 9: Pest Management—Weeds*, Publication 8172
- *Part 10: Small Grain Forages*, Publication 8173
- *Part 11: Small Grain Cover Crops*, Publication 8174
- *Part 12: Small Grains in Crop Rotations*, Publication 8175
- *Part 13: Harvesting and Storage*, Publication 8176
- *Part 14: Troubleshooting Small Grain Production*, Publication 8177

Nitrogen fertilizer is usually needed every season by small grain crops. The amount needed depends on soil type, previous crop, rainfall, irrigation, projected yield, and quality goals. Under some circumstances, it may be necessary to apply phosphorus, potassium, sulfur, or zinc; perform soil tests before sowing to determine whether fertilizers are needed. The nitrogen status of a small grain crop is best monitored during the season using tissue analysis. Since tillers and heads are formed in the very early growth stages, adequate nutrient levels in the root zone at this time are important for attaining maximum yield. Careful soil sampling and analysis are necessary for determining soil nutrient levels and fertilizer requirements.

### SOILS AND SOIL FERTILITY

Small grain crops are grown on many soil types in California. Soil textures vary from gravel to clay to the Sacramento–San Joaquin Delta’s peat soils. Crop rooting depths vary with soil texture, soil profile development, drainage, and the presence of restrict-



ing layers. Roots of small grains can penetrate 7 feet (2.1 m) deep on well-drained deep soils if there are no restricting layers, but penetration of 3 to 5 feet (0.9 to 1.5 m) at maturity is more common. Soils in many rainfed areas are shallow claypans or hardpans. Nitrogen loss can be very high on these soils during high-rainfall years since denitrification occurs under waterlogged soil conditions. Nitrogen losses can be minimized on shallow or coarse-textured soils by making split applications of nitrogen.

## **NITROGEN**

### **Role of Nitrogen in the Plant**

Adequate nitrogen stimulates vegetative growth and increases yield and protein content. Excessive nitrogen increases lodging, delays maturity, increases the severity of some diseases, contributes to groundwater pollution, and causes rainfed crops to deplete available moisture too early in the season. The nitrogen requirement of the crop is directly related to the final grain yield. Plants obtain nitrogen from residual nitrogen in the soil, from nitrogen released from decaying organic matter (including the residue of the previous crop), and from applied fertilizer. On most soils 100 to 180 pounds per acre (112 to 202 kg/ha) of nitrogen may produce 3 to 3.5 tons per acre (6.7 to 7.8 t/ha) of wheat grain, depending on the previous crop, winter soil moisture, and rainfall conditions. Durum wheat may require higher rates of nitrogen, up to 240 pounds per acre (269 kg/ha). Barley and oat require less nitrogen, with optimal yields attained with applications of 50 to 120 pounds per acre (56 kg/ha).

### **Nitrogen Deficiency Symptoms**

Nitrogen deficiency symptoms are characterized by an overall yellowing of leaves, beginning with the bottom (older) leaves. Younger leaves remain green and appear healthy. Plants are smaller and produce fewer tillers than plants with adequate nitrogen.

### **Nitrogen Requirements and Rates**

The amount of nitrogen required by the crop depends on the type of small grain, the previous crop in the rotation, the soil type, and weather conditions and cultural practices during the growing season. Barley, oat, triticale, and wheat require different amounts of nitrogen; the amount depends on the yield potential of the crop and the intended use (grain production requires higher nitrogen levels than forage production). More nitrogen is required when wheat follows crops such as rice, cotton, or wheat than when wheat follows vegetable crops, since more residual nitrogen normally remains after the harvest of vegetables. Large amounts of residue from any previous crop may require more nitrogen at sowing to provide enough available nitrogen for small grain growth and residue breakdown. Nitrogen may be lost on gravelly or sandy soils due to leaching below the root zone. Losses can occur from waterlogged soils when nitrogen is lost to the atmosphere as nitrogen gas ( $N_2$ ) or nitrogen dioxide ( $N_2O$ ) through a biological process called denitrification. Waterlogging is likely on heavy soils and/or soils with a hardpan or claypan. Excessive winter rains and excess irrigation can cause nitrogen loss from any soil. Sowing on raised beds rather than on flat ground provides better drainage, reduces nitrogen loss, and provides better soil conditions for root growth.

If the crop is sown in late fall and makes little growth before the onset of cold weather, little nitrogen uptake will occur during winter. In the Central Valley, a substantial amount of nitrogen uptake normally occurs beginning in late January to early February. The rate of accumulation increases through the spring, peaking at about flowering and then decreasing as the crop reaches maturity.

### *Rates for rainfed production*

Three types of cropping are common in rainfed small grain production: 3-year or longer rotations (pasture-fallow-small grain), 2-year rotations (fallow-small grain), and annual cropping. Less nitrogen is applied under 3-year rotations than under annual cropping because nitrogen accumulates in soils during pasture and fallow years. Fields that produce abundant annual clovers require less applied nitrogen if annual clovers are pastured and plowed under as green manure crops. As little as 10 to 20 pounds per acre (11.2 to 22.4 kg/ha) of nitrogen at sowing is sufficient if legumes are plowed under as a summer fallow. If the fallow green manure crop consists entirely of grasses or broadleaf weeds, an application of 20 to 40 pounds per acre (22.4 to 44.8 kg/ha) of nitrogen is recommended at sowing. Residual soil fertility is adequate for optimal yield for some long-term rainfed rotation acreage.

Since moisture is generally the limiting factor for rainfed yield, nitrogen rates should be adjusted for lower yield potential, rainfall patterns, and soil moisture holding capacities. All nitrogen normally is applied preplant for rainfed production.

### *Split applications*

Split applications of nitrogen are usually beneficial for irrigated production, although all nitrogen can be applied at once during sowing on well-drained soils not normally subject to leaching and waterlogging. When splitting the nitrogen on heavy or claypan soils, apply one-half to two-thirds of the nitrogen at sowing and apply the remainder as a topdressing. On extremely gravelly or sandy soils or on poorly drained soils of high clay content, split the nitrogen application with half applied preplant and half top-dressed to reduce nitrogen losses. On peat soils, apply about half the amount of nitrogen normally used on mineral soils; no preplant nitrogen is required, but a low rate of nitrogen should be part of the starter fertilizer (high phosphorus content) at sowing.

### *Topdressing for yield*

When topdressing, make one or two applications of 30 to 50 pounds per acre (33.6 to 56 kg/ha) of nitrogen, depending on the amount of rain during the winter. Nitrogen applications made during the tillering stage, followed by rain or an irrigation, are most effective for attaining maximum grain yield; applications made as late as boot stage are less effective, while applications made at heading or later have little effect on grain yield. If rain or irrigation occurs within a few days after application, little nitrogen is lost to the air. If conditions are dry and cold (typical during tillering), losses are minimal if rain or irrigation occurs within 2 weeks. Volatilization of nitrogen to the air is greatest under warm, moist conditions.

Stem nitrate-nitrogen (NO<sub>3</sub>-N) tissue tests are an effective way to monitor the nitrogen status of the crop. [Table 1](#) provides critical stem NO<sub>3</sub>-N levels for wheat and barley as the crop develops from the third and fourth leaf stage to boot stage. These

**Table 1.** Critical stem NO<sub>3</sub>-N levels during vegetative growth for wheat and barley

Growth stage	NO <sub>3</sub> -N (ppm dry weight)		
	Deficient	Adequate	Excessive
3 to 4 leaf	< 7,000	7,000–12,000	> 12,000
tillering	< 6,000	6,000–11,000	> 11,000
jointing	< 5,000	5,000–10,000	> 10,000
boot	< 4,000	4,000–9,000	> 9,000

tests are not effective for managing nitrogen fertility after heading when the goal is to achieve high grain protein. Proper tissue sampling is important to attain a valid, informative analysis. Collect 20 to 40 stems at random from typical areas of the field. Cut off the roots and plant tops and send the bottom 1 to 2 inches (2.5 to 5 cm) of the stems to the laboratory for analysis. Be certain the stem tissue sample is not contaminated with soil or leaves. Submit the tissue samples for analysis the same day they are collected.

### *Applications to improve grain quality*

Wheat grown for bread flour should be managed to attain high bushel weight and a grain protein content above 13 percent, as well as maximum grain yield. An irrigated wheat crop with high yield potential should receive 100 to 180 pounds per acre (112 to 201.6 kg/ha) of nitrogen in a combination of preplant and topdressed (during tillering) applications. After heading, wheat may require one more nitrogen application of 20 to 50 pounds per acre (22.4 to 56 kg/ha) to produce a high protein content in the grain. Nitrogen can best be applied during the 3 weeks from just after the spikes have emerged from the flag leaf sheath to about 2 weeks after flowering. An application is effective only when coordinated with an irrigation or rainfall. Low rates are appropriate for low-yielding crops, while higher rates are best suited for yields above 3 tons per acre (6.7 t/ha).

Late-season application of nitrogen may not be needed to attain high grain protein content if the wheat grain yield potential is less than about 2.25 tons per acre (5.0 t/ha), and if nitrogen was applied preplant and topdressed during the tillering stage. Cool, dry weather during grain filling generally results in higher grain yields; management for protein is more critical under those conditions.

Nitrogen application near the boot stage (before heading) typically increases the grain protein content about 0.5 to 1.0 percent. The increase is not as large as when nitrogen is applied at flowering, when nitrogen applications usually increase grain protein content by 1.0 to 1.5 percent or more.

### **Water-run Nitrogen**

Water-run applications of anhydrous ammonia, UAN-32, aqua ammonia, or urea applied at the beginning of an irrigation set are preferred for late-season fertilization. This provides an effective means of applying the necessary nitrogen and water for maximum yields. Foliar nitrogen applications are also effective at raising grain protein content but are usually more expensive and may damage the leaves under many conditions.

### **Forms and Costs of Nitrogen Fertilizers**

The choice of fertilizer material depends on current weather conditions, weather forecasts, and fertilizer costs. Urea (46-0-0) is the highest-analysis nitrogen fertilizer available and is usually the least expensive dry form of nitrogen. It is particularly effective when broadcast and followed by at least 0.5 inches (2.5 cm) of rain within 5 days after application. Urea is converted to ammonium nitrogen and then to nitrate nitrogen by soil microbial processes, so it is released over a longer period of time and is less prone to leaching from the root zone than are some other forms of nitrogen. Urea is relatively unstable when broadcast onto the soil surface, however, and volatilization (loss to the air) can occur.

Ammonium nitrate (34-0-0) is an alternative to urea, if it is available, but it is more expensive. It is preferable to urea when the crop is severely deficient because both the nitrate and ammonium forms of nitrogen are readily taken up by the crop and recovery is more rapid. Ammonium sulfate (21-0-0) containing 24 percent sulfur is desirable if there is a likelihood of sulfur deficiency, but this material is usually more expensive than urea. A blend of mostly urea with some ammonium sulfate is available in some areas.

### **Applying Nitrogen in Dairy Lagoon Water**

Dairy lagoon nutrient water (including liquid manure and wastewater) can supply most or all of the nitrogen, phosphorus, and potassium needs of small grain forage crops. However, these nutrients must be managed carefully. Misused, they can kill or

damage crops, contaminate ground and surface waters, and produce forage that is toxic to animals consuming it. It is critical to understand the forms and concentrations of nutrients and how they behave in the soil, and to apply the appropriate amount of nutrients during or just prior to the time the crop will take the nutrients up.

### *Forms of nitrogen in lagoon water*

Lagoon water contains ammonium forms and organic forms of nitrogen. The ammonium in lagoon water behaves the same as ammonium in fertilizers. Ammonium is positively charged and adheres to soil particles, which are mostly negatively charged. When lagoon water is applied, most of the nitrogen remains in the upper foot of the soil because the ammonium adheres to the soil. As long as nitrogen is in the ammonium form, it is resistant to leaching. However, ammonium is converted to nitrate by microorganisms in the soil. This process occurs rapidly when the soil is warm and slowly when the soil is cold; ammonium applied in early fall on warm soils converts to nitrate within days of application. Nitrate is negatively charged and leaches readily during irrigation or heavy rainfall.

Organic nitrogen in lagoon water is bound up in particles of organic matter and must be broken down into ammonium or nitrate by microorganisms before it becomes available to the crop. The rate of breakdown depends on moisture content, soil temperature, and the resistance of the material to decay. The presence of organic nitrogen complicates the use of lagoon water on crops because if a crop does not take up organic nitrogen as it is released, the nitrogen may become a source of groundwater contamination. In determining rates of nitrogen fertilizer application, take into account the release of available nitrogen from current and past applications of lagoon water and reduce applications of available nitrogen accordingly.

Like ammonium, organic nitrogen also remains in the upper foot of soil because, depending on the porosity of the soil, the particles do not move far through the soil. If the lagoon water has a high level of solids, the largest particles may remain on the soil surface as a crust until incorporated by tillage.

### *Application rates and timing*

Winter forages planted during November in the Central Valley typically take up less than 50 pounds per acre (56 kg/ha) of nitrogen in the aboveground portion of the crop prior to mid-January. Uptake is higher under conditions of increased growth, such as earlier planting or sustained unseasonably warm temperatures. Under normal circumstances, earlier-maturing winter forages begin to take up more significant amounts of nitrogen starting in late January to early February. The rate of nitrogen uptake peaks in March and April but continues until crop maturity. The nitrogen uptake pattern for later-maturing cereal forages is similar to the early-maturing types, but peak uptake occurs somewhat later than in the earlier types. Nitrogen applications should be timed to provide available nitrogen during or immediately prior to the period when the crop will use them.

Application rates of available nitrogen should not exceed the amount of uptake expected between the time of application and the next anticipated heavy rainfall or irrigation that exceeds the amount needed to refill the soil profile. A preplant irrigation containing lagoon water in early fall may not meet the demands of spring growth, especially in years with heavy winter rains. The bulk of lagoon water should be applied in late January to early February, with only light application in fall preplant irrigation. No more than about 120 pounds (54 kg) of available nitrogen should be applied at any one time; if more than this is needed, a second spring application should be made. If the fertilization history of the field includes dry manure or lagoon water containing significant organic nitrogen, in many cases the organic nitrogen will supply all the nitrogen the

crop needs until the early spring. On heavier soils it may be necessary to plant on beds to prevent crop waterlogging injury from midwinter lagoon water applications.

If it is necessary to apply lagoon water in the early fall, one way to use the nutrients is to sow cereal forages in late September or early October so that the crop will make sufficient growth and take up the applied nitrogen before the onset of cold temperature that slows growth. This forage can be cut during the winter and allowed to regrow during the spring. Forage yield and nitrogen uptake in such a system can be higher than in a single-cut system. The major drawback to cutting during the winter is that a period of dry weather is needed to dry the soil enough to allow access by equipment and to wilt the forage to a suitable moisture for ensiling. Sowing very early in the fall and leaving the crop uncut can lead to lodging and disease problems.

Applying undiluted lagoon water in most cases results in excess nutrient applications that not only threaten groundwater but also may reduce yields due to waterlogging, salt burn, and lodging. If high amounts of nitrogen remain in the soil near harvest, nitrates may accumulate in the crop to levels that are toxic to livestock.

In most cases, lagoon water must be blended with fresh water. This can be done by using a flow meter and throttling valve on the lagoon pump output to mix the correct amount of lagoon water into the irrigation water. Pipelines must be correctly sized to prevent plugging from solids when reducing the flow rate of lagoon water. In addition to installing a flow meter system, it may be necessary to increase lagoon capacity, install additional pipelines, or make other modifications. Separators, settling basins, and other technology that minimizes the buildup of solids in the pond are also important components of a lagoon nutrient management system. Changes to the irrigation system itself may also be necessary, because if the irrigation is not uniform, all parts of the field may not get the same amount of nutrient, resulting in excess nitrogen in some areas of the field (usually the head end) and not enough in others.

## PHOSPHORUS

### Role of Phosphorus in the Plant

Phosphorus is a component of cell membranes and plays a role in the transfer and storage of energy within plant cells. It makes up part of the structure of key molecules, including DNA. Phosphorus nutrition is particularly important for seedling vigor, root development, and early-season growth. Normal root and shoot growth and the rate of photosynthesis are governed by phosphorus status. Phosphorus also has a regulating role in tillering, leaf expansion, leaf size, and the rate of assimilate production per leaf area.

### Phosphorus Deficiency Symptoms

Phosphorus deficiency is most likely on shallow upland (terrace and foothill) soils. Symptoms of phosphorus deficiency include slow early growth, lack of tillering, and sometimes a slight purpling of plants. As in nitrogen deficiency, symptoms appear first on older leaves and advance to younger leaves as phosphorus deficiency becomes more severe. Deficient plants usually mature later than normal plants.

### Phosphorus Requirements and Rates

In California, small grains are generally grown when soil temperatures are low and phosphorus availability is reduced. If phosphorus is needed, placement with or near the seed is best. On mineral soils a soil test (sodium bicarbonate extraction method) on samples taken to plow-layer depth can serve as a guide for phosphorus fertilization. Responses to phosphorus application are likely if phosphorus levels are less than 6 ppm, variable if phosphorus levels are from 6 to 15 ppm, and unlikely if phosphorus levels are above 15 ppm. Many growers apply a low-nitrogen, high-phosphorus fertilizer, such

as 11-48-0, 11-52-0, 10-50-0, or liquid 10-34-0, at sowing time with or near the seed. Monoammonium phosphate, with an approximate 1:4 to 1:5 nitrogen to phosphorus ratio, is more desirable than a diammonium phosphate (1:3 ratio) because little, if any, toxic ammonia is released. Urea, urea phosphate, or diammonium phosphate (18-46-0) are more hazardous because the initial reaction in the soil releases ammonia that can kill seedlings.

If a soil test indicates phosphorus deficiency, apply 30 to 40 pounds per acre (33.6 to 44.8 kg/ha) of  $P_2O_5$  drilled with seed for irrigated crops, and 20 to 30 pounds per acre (22.4 to 33.6 kg/ha) of  $P_2O_5$  for dryland crops. To avoid injuring seed, no more than 25 to 30 pounds per acre (28 to 33.6 kg/ha) of nitrogen should be drilled. If phosphorus is broadcast, use higher rates, up to 80 pounds per acre (89.6 kg/ha) of  $P_2O_5$ . Application of nitrogen at rates greater than 10 to 15 pounds per acre (11.2 to 16.8 kg/ha) combined with the higher rates of phosphorus stimulates the growth of grassy weeds.

The bicarbonate extraction method and phosphorus levels cited above are not reliable if small grains are sown directly after a crop of rice. An increased yield response to phosphorus is nearly always expected following rice, particularly if rice has been grown for several seasons.

Phosphorus applications are often needed on peat soils because phosphorus becomes unavailable when soil pH is low, which is typical in peat soils. In the Sacramento–San Joaquin Delta, wheat yield increases of up to 800 pounds per acre (896 kg/ha) can often be obtained by applying 50 pounds per acre (56 kg/ha) of  $P_2O_5$  with the seed at planting. Phosphorus also becomes unavailable in very alkaline soils; application rates on high-pH soils should be increased to 30 to 50 pounds per acre (33.6 to 56 kg/ha) of  $P_2O_5$  and drilled with the seed.

### **Phosphorus and Dairy Lagoon Water**

Soils that receive large amounts of dairy manure, especially solids and liquid high in solids, can develop high levels of phosphorus. In areas of the Central Valley where there is no surface runoff to carry away phosphorus particles, soils are heavier, and groundwater is deep, no deleterious effects of excess phosphorus in soil have been demonstrated. Do not overapply phosphorus in areas where soils are sandy, groundwater is shallow, and water applied to fields enters waterways through tile drains or direct connection.

## **SULFUR**

### **Role of Sulfur in the Plant**

Sulfur is an essential constituent of the amino acids cysteine, methionine (required for protein synthesis), several coenzymes (e.g., biotin, co-enzyme A, thiamine pyrophosphate, and lipoic acid), thioredoxins, and sulfolipids. Sulfur is an important factor in wheat bread-making quality (protein level, loaf volume, and loaf texture). Nitrogen and sulfur requirements are closely linked since both are required for protein synthesis.

### **Sulfur Deficiency Symptoms**

Sulfur-deficient plants become spindly and develop a pale yellow color. The symptoms are very similar to nitrogen deficiency. Sulfur deficiency reduces the number of grains per spike; the number of tillers and grain weight are less affected unless the deficiency is severe.

### **Sulfur Requirements and Rates**

Sulfur deficiency most often occurs on gravelly or sandy soils. It is more common during winter to early-spring periods when soils are cool and wet or waterlogged. Sulfur enters the plant through the roots in the form of sulfate. Nitrogen metabolism and sul-

fur metabolism are strongly interdependent: when sulfur is deficient relative to nitrogen, nonprotein compounds such as amines accumulate, resulting in a nitrogen to sulfur (N:S) ratio of greater than 15:1. Wheat is likely to be sulfur deficient if it has a total sulfur of less than 0.20 percent and a N:S ratio greater than 17:1 in the upper fully developed leaves at flag leaf to anthesis. The concentration of sulfur in grain and the N:S ratio have been used to retrospectively diagnose sulfur deficiency, with critical values of 0.12 percent and 17:1 N:S.

Small grains have a lower sulfur requirement, 10 to 30 pounds per acre (11.2 to 33.6 kg/ha), than many other crops, but an adequate level of sulfur is necessary for satisfactory crop growth and for optimal levels of S-containing amino acids in grain. Sulfur deficiency is best corrected by planting-time application of fertilizer that has nitrogen and sulfate-sulfur, such as ammonium sulfate (21-0-0). Applications of relatively low rates of readily available sulfate-sulfur sources can be effective corrective treatments during the active early spring growth period; elemental sulfur is much less effective. If elemental sulfur is used, applications must precede the growing season by sufficient time (probably several months) to allow conversion of sulfur to the sulfate form for plant use. Moisture is also required for this process. Gypsum is also an immediately available but slow releasing form of sulfur. Sulfur deficiency symptoms disappear in most instances as soil temperatures warm, moisture levels drop below saturation, and plant growth progresses.

## POTASSIUM

### Role of Potassium in the Plant

Potassium is essential for plant growth and development. It activates enzymes needed for growth and is necessary for the formation and transfer of starches, sugars, and oils; the absorption of nutrients; and the efficient use of water. It enables plants to grow strong roots and resist drought, winter-kill, and root diseases. It also helps develop strong stems and decreases lodging.

### Potassium Deficiency Symptoms

Potassium deficiency symptoms generally appear on the older leaves first. Depending on the severity of the deficiency, the entire plant may be affected, and all leaves may have an unthrifty, spindly appearance. During the early states of deficiency, the leaf tips and

margins are chlorotic. Necrosis appears on leaves under severe deficiency as speckling along the length of the leaf and spreads quickly to the tip and margins. An “arrow” of green tissue remains from the base upward to the center of the leaf. Complete death of older leaves is common, and plants appear to have dried prematurely, as with drought stress.

### Potassium Requirements and Rates

In California, yield responses by small grains to applications of potassium are highly unusual and occur only on the most deficient soils, such as soils with ammonium acetate extractable potassium levels less than 60 ppm. Plants need as much potassium as nitrogen during rapid growth periods. Potassium sufficiency in wheat depends on the stage of growth (table 2). Several sources of potassium (potash) are used as commercial fertilizers (table 3).

**Table 2.** Potassium sufficiency in wheat for selected growth stages

Growth stage	Plant part	Sufficiency range (low to high)
3 to 4 leaf	underground stem	2.0–3.0%
	whole plant	2.4–4.0%
tillering	aboveground stem, lower 2 inches (5 cm)	2.0–3.0%
	top 4 leaves	2.4–4.0%
jointing	aboveground stem, lower 2 inches (5 cm)	1.5–2.7%
	top 4 leaves	2.0–3.0%
boot	aboveground stem, lower 2 inches (5 cm)	1.0–2.4%
	top 4 leaves	1.5–2.7%

Sources: California Plant Health Association 2002.

**Table 3.** Commercial fertilizer sources of potash

Fertilizer material	Formula	Water-soluble potash (K <sub>2</sub> O) %	Other nutrients
monopotassium phosphate	KH <sub>2</sub> PO <sub>4</sub>	32–34	50–52% P <sub>2</sub> O <sub>5</sub>
potassium chloride (MOP)	KCl	60–62	—
potassium magnesium sulfate	K <sub>2</sub> SO <sub>4</sub> · 2MgSO <sub>4</sub>	22	18% S, 11% Mg, 0.1% Ca
potassium nitrate	KNO <sub>3</sub>	44–46	13% N
potassium sulfate (SOP)	K <sub>2</sub> SO <sub>4</sub>	50–53	18% S
potassium thiosulfate	K <sub>2</sub> S <sub>2</sub> O <sub>3</sub>	25	17% S

Sources: California Plant Health Association 2002.

Potassium is rapidly absorbed and very mobile, making it a good additive to foliar fertilizers. The crop response to foliar nutrition depends on the soil, the crop, and environmental conditions.

## ZINC

### Role of Zinc in the Plant

Zinc is an essential micronutrient for crop growth. It is needed for the production of auxins, growth-promoting substances that control the growth of shoots. A critical level of zinc is required in the soil for roots to grow or function effectively.

### Zinc Deficiency Symptoms

Zinc deficiency is probably the most widespread micronutrient deficiency in small grains. It can occur in cold and warm climates, acid and alkaline soils, and heavy and light soils. In general, stems and leaves of deficient plants fail to develop to normal size, and some of the tissues between leaf veins contain so little chlorophyll that they turn yellow. The first symptoms of zinc deficiency normally appear on middle-aged leaves. Initial symptoms include a change in leaf color from healthy green to muddy grey-green in the central portion of the blade. Leaves appear drought-stressed, and necrotic areas, beginning as small spots, develop and extend to the leaf margins. Leaves may take on an oily appearance, and the necrotic areas may become large and surrounded by mottled yellow-green areas. Zinc-deficient leaves eventually collapse in the middle regions. Severe zinc deficiency can result in stunted, chlorotic plants with many collapsed leaves due to necrosis in the center of the leaves.

### Zinc Requirements

Zinc deficiency arises from a low content of zinc in soil, unavailability of zinc in high-pH soil, or management practices that depress the availability of zinc. Although most mineral soils contain 80 to 300 ppm of total zinc, DTPA extractable zinc is usually less than 1 ppm; the remainder is fixed in an unavailable form. The unavailability of zinc can be attributed to soil alkalinity: when the soil pH is above 7.0, zinc availability is generally reduced. Zinc availability is low in some soils with high organic matter, in some clay soils with high magnesium content (these soils fix zinc in an unavailable form by strong adsorption on the clay minerals in place of magnesium), and in soils high in phosphorus. Low zinc levels combined with high phosphorus levels enhance accumulation of phosphorus in old leaves to concentrations that are toxic; this enhances necrotic symptoms in old leaves. Yield responses to applications of zinc occur only on the most deficient soils, such as soils with zinc DTPA extractable levels below 0.3 ppm.

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