

# Soil Fertility and Bean Production

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## Introduction

Beans require adequate amounts of all essential plant nutrients for optimum growth but only a few nutrients are documented to be needed for southern Idaho soils. These nutrients include phosphorus (P), nitrogen (N), zinc (Zn), potassium (K), sulfur (S), and to a much less extent B, Cu, Mn and Fe. University of Idaho Agricultural Experiment Station research as well as research from throughout the Pacific Northwest (PNW) is the basis for current fertilizer recommendations for Idaho dry beans. This article is not intended to be a complete review of the extensive plant nutrition literature on dry beans. The intent is to acknowledge the PNW research that has contributed significantly to Idaho recommendations.

Soils used for dry bean production in southern Idaho and the Columbia Basin are primarily well drained mineral soils under surface or overhead irrigation. Most soils are silt loam or lighter textures. The soils are typically neutral to calcareous although some soils are either naturally acidic or have been acidified through management. Management practices that acidify soils include N fertilization using ammoniac sources, base cation removal with harvested crops, irrigation with waters low in base cations, and applied elemental sulfur.

Beans are grown in rotation with a variety of cereal, forage, seed, vegetable, and specialty crops throughout the irrigated PNW. In general the higher the elevation the less diverse the cropping options. Previous crops can have appreciable effects on nutrient availability.

Production practices related to fertility have not changed dramatically since the widespread use of fertilizers following World War II. However, commercial industries that address the nutritional needs of dry beans have grown substantially. A highly competitive fertilizer industry serves the needs of dry bean producers throughout the PNW. This industry has undergone substantial consolidation recently to maximize economic returns. One result of this consolidation is that fewer professionals with graduate level training in plant nutrition are now employed and less nutrition related research is sponsored by commercial interests.

There has also been a reduction in public institution plant nutrition research addressing dry bean nutritional issues. This is particularly true within ARS in both the Columbia Basin and southern Idaho.

Perhaps the greatest change related to soil fertility in the last forty years is reflected in the increased number of private soil and plant testing labs providing analytical services for growers, as well as the number of private consultants available for providing prescriptive recommendations for plant nutrients. For example, there were few if any private laboratories or consultants in 1960 serving the needs of growers, as much of this need was served by University of Idaho County or State Cooperative Extension faculty, and the Analytical Services Laboratory

on the Moscow campus. Today the need for these services has far surpassed the availability of state personnel and resources. The vast majority of these services are currently provided by private laboratories and consultants. There are three well established private testing enterprises within a 20 mile radius of Twin Falls alone, Twin Falls being the historical and geographical center of dry bean seed production in Idaho.

### **Phosphorus (P)**

A deficiency of P can reduce bean yield. Symptoms of P deficiency appear as a general stunting of the plant as internode length is reduced, there is less branching, and leaves appear more slowly. The affect of low P is primarily through reduced leaf area development rather than reduced photosynthetic capacity of the leaves that develop (Lynch et al., 1991) In southern Idaho a shortage of P is generally associated with calcareous low organic matter subsoils exposed due to land leveling or erosion.. But P can be deficient in any field cropped sufficiently to deplete soil P reserves.

Phosphorus fertilization is generally required for bean seed production (LeBaron et al., 1971). For best results P should be incorporated to a depth of 4 to 6 inches. Fertilizer P can be added with other non-mobile nutrients in the fall or spring. Banded P has generally proven equal to broadcast plowed or disked-in P (Westermann, personal communication) but seldom superior. Starter, or popup fertilizer P banded with the seed had no advantage. Fertilizer P sources are not known to differ in effectiveness for dry beans.

In southern Idaho, P rates of application should be adjusted based on the soil test for P. The soil test, commonly known as the Olsen test, was originally developed for calcareous soils in Colorado (Olsen et al., 1954). The test is useful for beans and other crops grown in southern Idaho. The test involves extracting P from soil with a 0.5M sodium bicarbonate solution. No fertilizer P is recommended for beans if the soil test P concentration is above 12 ppm. The maximum P recommendation for the lowest testing soils was 106 lb P/A (240 lb P<sub>2</sub>O<sub>5</sub>/A).

Soil lime contents and pH influence the availability of P in soils. The probability of a response to applied P when increasing lime content reduces available P for crops was demonstrated early in southern Idaho (Ensminger and Larsen, 1944). The effect of lime is primarily to reduce P soluble in the soil solution. Lower soil solution P concentrations then reduce plant P uptake (Westermann, 1992). Recommended P rates should increase 40 lb P<sub>2</sub>O<sub>5</sub>/A as lime content increases 5%.

### **Zinc (Zn)**

In addition to stunting of the plant, symptoms of Zn deficiency include interveinal chlorosis, bronzing, browning and death of leaf tissue, poor vining after emergence, and delayed maturity. Beans typically can grow out of a Zn deficiency but significant delays in maturity increase the risk of frost damage prior to maturity. Of the micronutrient deficiencies, Zn by far is the most common. A southern Idaho survey of the micronutrient status of 58 dry bean fields was conducted in 1974 using both soil and tissue analyses (Leggett et al., 1975). All micronutrients other than Zn were found adequate for high yielding bean crops. Zn deficiencies typically occur

in similar landscape positions as where P shortages occur, exposed subsoils. Zn shortages also occur in fields that were fallowed the previous year, fields following sugarbeets, and where manure or P was excessively applied.

Lower bean production on exposed southern Idaho subsoils is common and applied Zn does not fully restore the productivity of these soils (Carter et al., 1985). The effects of previous cropping and amendments added to these soils were studied (Robbins et al., 1997). In this study, available Zn appeared to be a limiting factor to bean production in an exposed subsoil cropped for three seasons before planting beans. Zn applied at the rate of 1.3 lb/A as EDTA Zn at the beginning of a four year rotation did not supply adequate Zn for beans in the fourth rotation year regardless of the rotation. Manure applied before the first rotation crop contained 5.5 lb Zn/A and was the only management practice evaluated that had comparable whole plant Zn concentrations and bean yields with those from topsoil treatments.

Zn deficiencies are more frequently encountered following some crops than others. Deficiencies of Zn in dry beans following sugarbeets were reported at least as early as 1964 in southern Idaho (Deremer and Smith, 1964). Similar results were reported for sweet corn following sugarbeets in the Columbia Basin (Boawn, 1965). Poor growth of dry beans due to Zn deficiency following sugarbeets, as well as after fallow, was documented again later (Leggett and Westermann, 1986). In contrast to the detrimental effects of sugarbeets on Zn availability, previous cropping with sorghum-sudan hybrids has improved Zn availability (Robbins, 1986; Robbins et al., 1997).

Poor colonization of roots by vesicular-arbuscular mycorrhizae (VAM) was implicated in the Zn shortages associated with exposed subsoils and the beneficial effects of manure in them (Tarkalson et al., 1998) as well as the sugarbeet or fallow induced Zn deficiency (Hamilton et al., 1993). Although mycorrhizal spores did not differ in field soils to which manure was added four years previous, adding manure or composted manure improved mycorrhizal colonization of beans grown in the greenhouse, but only non-composted manure increased bean growth and Zn uptake. Apparently increased Zn cycling via the added organic materials also contributed to increased Zn availability.

Mycorrhizae can infect bean roots and assist the plant in accessing nutrients such as P, Zn and Cu. Sugarbeets, a non-host for mycorrhizae, effectively reduced beneficial mycorrhizae colonization in subsequent beans (Leggett and Westermann, 1986). Similar effects were demonstrated after fallow treatments in the same study. Apparently, without a suitable host to sustain VAM populations, the bioavailability of Zn is reduced from lower VAM colonization. Similar conditions may also reduce the availability of P and other nutrients to crops that depend on mycorrhizal associations for improving nutrient availability (Bittman et al., 1999). Other mycorrhizae non-host crops grown in rotation with dry beans may include canola, mustard, or other brassicas. VAM populations may also be susceptible to fumigation. The residual effects from fall fumigation on available P with **Metam-sodium**® was recently measured in wheat, another mycorrhizal host crop, more than a year after the fumigation treatment. Moderate to high concentrations of soil test P generally preclude mycorrhizal colonization.

Commercial mycorrhizae inoculants are available but their effectiveness has not been demonstrated for dry beans and there is little commercial use. Seed treatment with mycorrhizae

may encounter limitations with protective fungicidal seed treatments similar to those with *Rhizobium* inoculants and bacterial seed treatments.

Phosphorus fertilization has reduced Zn availability to beans in some studies (Dow et al, 1973; Halvorson and Bergman, 1983) but not others (Boawn et al., 1954). In the latter, Zn deficiency symptoms could not be induced even though tissue P concentrations were doubled with P fertilization. Precipitation of zinc phosphate in soils or roots has been ruled out (Boawn et al., 1954). In most field situations where P has induced a Zn deficiency, a Zn application corrects the apparent deficiency.

Bean varieties can differ in their tolerance to limited Zn availability (Brown and Leggett, 1967; Leggett and Westermann, 1986). Sanilac, a great northern variety, was shown to be particularly sensitive to low Zn in both the cited studies. Significant reductions in bean growth and yield were found in some varieties even though obvious deficiency symptoms other than stunting were not always present (Brown and Leggett, 1967).

Soil testing is useful for indicating Zn requirements. The test is an extraction of the soil with a solution of .005M DTPA (Diethylenetriaminepentaacetic acid) with .005M CaCl<sub>2</sub> and 0.1M TEA (triethanolamine) buffered at pH 7.3 (Lindsay and Norvell, 1978). Soil test Zn concentrations above the 0.8 ppm critical level have a low probability of a response to applied Zn fertilizer. For concentrations below the critical level the recommendation is to apply up to 10 lb/A of Zn.

Plant analysis is also useful for indicating Zn shortages. Dry bean plant Zn contents were related to Zn deficiency symptoms in the Columbia Basin (Viets et al., 1954). Tissue Zn levels in whole plants and leaf blades were related to the delay in maturity of dry beans (Boawn et al., 1969). Maturity was delayed when whole plant or leaf Zn concentrations at the four compound leaf stage or maturity were below 20 ppm. Zn concentrations below 15 ppm could delay maturity as much as 30 days.

Preplant soil applications of Zn are preferable to foliar applications. Foliar Zn (2.5 lb Zn/A) can be used to treat affected plants during the first six weeks of growth but later applications are less effective at restoring plant growth and increasing yield (Lebaron et al., 1971).

Several Zn fertilizers are available for use with dry beans. Many of these soil applied Zn sources were evaluated for their ability to supply Zn to dry beans (Brown and LeBaron, 1970; Halvorson and Bergman, 1983). Organic Zn sources (polyflavenoids or chelates) were generally superior to inorganic Zn sources (oxide or sulfate). Foliar Zn sources have also been evaluated (Lauer, 1982; Halvorson and Bergman, 1983). Foliar Zn in combination with foliar N increased bean plant Zn concentrations more than Zn only sources, but did not increase yields when these nutrients were applied to the soil. Zn sources were also evaluated for seed treating beans (Rasmussen and Boawn, 1969) but seed treatment was not an effective substitute for preplant Zn fertilization.

## Nitrogen (N)

A number of research efforts have addressed the fertilizer N requirements for beans. Part of these efforts stem from the fact that although beans are known to be legumes and to enter into symbiotic associations with *Rhizobium* bacteria for fixing atmospheric N, beans are generally recognized as being relatively poor N fixers (Franco et al., 1979). The limited ability of beans to fix N may have to do in part with ineffective symbiosis, stress conditions, high or low temperatures, saturated soils and the associated sloughing off of the nodules. Sloughed nodules do not contribute fixed N to the plant unless they decompose and their N contents are released during bean growth.

Several studies in the Columbia Basin demonstrated the need for nitrogen in dry beans when soil N was low (Dow; 1956; Dow, 1957; Dow, 1960; Dow, 1962; Roberts et al., 1972; Roberts and Weaver, 1971; Dow et al. 1973). It was suggested that N was generally not needed unless large amounts of previous crop residues were inadequately decomposed and their nutrient contents not released for beans to use. The large crop residues were likely small grain or corn residues as these are typically the greatest in quantity and the most difficult to decompose due to their high carbon to N ratio. The maximum N rate at one time was 50 lb/A (LeBaron et al, 1971) but more recent revisions of the Idaho Fertilizer guide for dry beans suggest that 50 lb/A is needed to compensate for just the small grain and corn residues previously incorporated. Even higher N rates are suggested if soil test N is low.

With early fall residue incorporation, N fertilization should be based on a spring soil N test; a late fall or spring residue incorporation will require additional fertilizer N for residue decomposition above that indicated by the spring soil N test. Where appreciable cereal residues are returned to the soil, fertilizer N is probably most efficiently used by dry beans when applied either late fall after soil temperatures fall below 50° F or preplant in the spring as was shown for corn and sugarbeets (Brown, 1988).

Incorporated cereal residues increase the N requirement for beans in general. But poor distribution of the residues can exacerbate the problem. Uniform fertilizer N applications may not be adequate if straw residues are not uniformly distributed behind the combine. Straw choppers on combines greatly facilitate and improve residue distribution.

Dry beans are sometimes grown after alfalfa or alfalfa seed. Fertilizer N should not be needed for beans following alfalfa crops given the appreciable release of N from alfalfa residues. Dry beans may not use the N released from alfalfa or other legumes as effectively as crops with higher N requirements.

There are conflicting reports on the form of N to use for beans. The nitrate form was found superior to the ammonium form in the presence of fusarium root rot in Idaho (Huber, et. al., 1965) and California (Toussoun, et al., 1960; Weinke, et. al., 1962) but these results could not be confirmed in Columbia Basin field studies (Burke and Nelson, 1967; Burke and Nelson, 1968 ). Ammonium N was superior to nitrate in the Columbia Basin studies primarily due to slower N release and greater N use efficiency due to reduced nitrate leaching. Ammonium N sources did not prove superior in other studies (Bezdicsek et al., 1981).

Varieties differed in their response to N fertilizer in Columbia Basin fields with little or no infection with fusarium (Burke and Nelson, 1967). Varieties in southern Idaho were also shown to differ in their response to N (Westermann, et al., 1981; Westermann and Kolar, 1978). In these studies, varieties also differed in their N fixing ability. Varieties having greater biomass had greater potential for N use and the greatest capacity to fix N. Varieties differed as much as six fold in their seasonal N fixing ability. The N fixed by beans ranged up to 80 lb/A and was 40 to 50% of the total N in the plant at maturity. Many varieties have been released since this work but their relative N requirements are seldom routinely evaluated. Also, different N requirements of cultivars or market classes have not been incorporated into current N fertilizer guide recommendations. Most southern Idaho soils are known to have relatively high soil N mineralization rates which also reduce fertilizer N requirements for beans as well as for other crops (Westermann et al., 1981)

Inoculation of bean seed with appropriate *Rhizobium* strains for insuring the presence of symbiotic N fixers is not recommended unless the soils were not previously cultivated and beans grown. Inoculation with *Rhizobium* strains is more problematic when bean seed is treated with bactericides for controlling bacterial blight, as the inoculated strains might be susceptible to the treatment as well. Inoculation may be ineffective if residual soil N is sufficient to meet the N requirements of the crop. Adequate soil N will also preclude effective nodulation even if there is ample inoculant present. Consequently inoculation is not economic with high residual N.

Foliar applied N has been evaluated for dry beans. Foliar NPKS treatments caused variable degrees of phytotoxicity in dry beans at Prosser (Lauer, 1982) with the effects more evident with later applications. However, in this work the phytotoxicity did not appear to influence seed yields. We evaluated NPKS foliar applications as well at Parma in three varieties and NPKS solutions caused twice the phytotoxicity that solutions containing only urea N caused. Leaf burn did not appear to effect yields at Parma either. Evidence from these studies suggest no compelling reason to use foliar applied N.

The N rate recommendations in some US bean production areas may be related to potential yield levels, the N requirement increasing as the target yield estimate increases. But in southern Idaho there has been little research to determine the effect of yield potential on optimum N rates to use.

### **Potassium (K)**

Potassium is seldom low enough to limit bean production in southern Idaho. Soil test K does reflect relative amounts of K available to beans and is commonly determined by testing labs. Soil test K using the bicarbonate extractant should be above 70 ppm. Soil test K concentrations below 70 are rare in southern Idaho. Beans in rotation with other commodities such as corn, wheat, sugarbeets, or other field crops will generally have the lowest requirements for K. Fertilizer K applied to meet the need for K in the other rotation crops should be ample to satisfy the K requirements for beans.

## **Sulfur (S)**

Sulfur is seldom required for dry beans. Dry beans are typically grown with irrigation water that contains sufficient S (unlike N, P, and Zn) to meet the S requirements of the crop. This is particularly true for water diverted from the Snake River, as well as waters derived from runoff of other fields. Shortages of S are so rare in the dry bean production areas of the Columbia Basin and southern Idaho that critical plant tissue and soil test S concentrations have not been established.

A shortage of S for dry beans is most likely to occur where the irrigation water is low in S, fertilizers containing little or no S have been historically used, and the soils are coarse textured with high leaching potential. Irrigation waters possibly low in S include some well waters, and fresh water from the Boise and Payette Rivers diverted prior to receiving significant agricultural return flow.

Common dry N fertilizers that contain no S include urea, ammonium nitrate, and calcium nitrate. Fertilizers that contain appreciable S include ammonium sulfate (21-0-0-24), potassium sulfate (0-0-52-18), gypsum (0-0-0-17), and elemental S (0-0-0-100).

The soil test for S is less reliable than for P, Zn, and N. Soil samples collected from only the first foot do not reflect the entire rooting depth from which appreciable S can be extracted. Sulfate sulfur, the form taken up by roots, is mobile and can be moved to lower soil depths with winter precipitation or sprinkler irrigation. If moved to depths where calcium concentrations are higher the sulfate can precipitate as calcium sulfate or gypsum. Gypsum can be an appreciable source of S to dry beans at lower rooting depths. Soil samples should be collected from the first two feet to most accurately document available S for dry beans. If S to the two foot depth measures less than 30 lb/A and irrigation water is known to be low in S, beans may respond to low applications of S, i.e. 20 to 30 lb/A.

## **Boron (B), Copper (Cu), Manganese (Mn), and Iron (Fe)**

Little research has been conducted on the needs for micronutrients other than Zn as they are rarely if ever deficient in southern Idaho dry bean production. Responses of Fe, Cu, and B have not been documented for dry bean seed production in southern Idaho. Thus, soil tests for these micronutrients have not been calibrated for dry beans largely because the nutrients seldom limit production. The DTPA test was developed for Cu, Mn, and Fe, as well as for Zn but there has been little opportunity to evaluate the test for these micronutrients other than Zn. Necessary tissue Cu, Mn, and Fe concentrations have not been reported in the PNW for dry beans for the same reason. Tissue Fe concentrations are generally poorly related to Fe shortages in plants. The authors are aware of only one situation where apparent visible Fe deficiency symptoms were present on a bean variety not normally grown in this area. Since soil applications of Fe or Mn are not very effective on calcareous soils, only foliar sprays are recommended for correction of potential Fe or Mn deficiencies. Bean varieties developed on acid, high organic matter soils might be more susceptible to deficiencies of those nutrients whose solubilities decrease as pH increases.

The soil test for B is a hot water extraction and is notoriously misleading in regards to predicting soils that require B for maximum production. There is more risk in applying B to soils than for other micronutrients due to potential B toxicity. Beans are particularly sensitive to excessive B. B should not be applied unless there is a demonstrated need and even then boron should be applied with caution and at low rates.

### **Fertilizer Placement**

Generally immobile nutrients such as P and Zn should be incorporated during seed bed preparation or banded such that roots can intercept the nutrient band. However, no fertilizer should be banded with the seed itself. Banded fertilizer should not be placed closer than one inch from the seed. Some bean agronomists suggest that banded P rates can be reduced from broadcast P rates under limited P conditions due to greater use efficiency. But there is limited data to support these recommendations in southern Idaho bean production soils. Banded starter N, P, and Zn fertilizer applications improved early season bean growth and yield in Wyoming despite adequate to high soil test levels for these nutrients (Blaylock, 1996). But the response to starter P and N were not consistent in southern Idaho dry bean studies (Westermann, personal communication).

Mobile nutrients such as N and S can be sidedressed on bed shoulders under furrow irrigation if necessary since the wetting front can be expected to carry the fertilizer salts to the root system. Sidedressed applications may contribute to less early season weed growth. Banded applications of all nutrients have potential for reducing the amount of nutrients carried by runoff waters.

### **Excessive salts and Arsenic**

Beans are one of the most salt intolerant crops known. Soil salts are measured in a saturated soil paste extract using a conductivity bridge. Soil conductivity readings as low as 2.0 millimhos/cm<sup>2</sup> are sufficient to cause salt injury. In addition to salts in general, beans are sensitive to sodium salts in particular as indicated by pH values above 8.5, a saturated paste extract sodium adsorption ratio (SAR) of 4-6 or an exchangeable sodium percentage (ESP) above 15%. For additional information on soil salts and the interpretation of salinity ESP or SAR values refer to *Salt and Sodium-Affected Soils*, Bulletin 703.

Beans are also very sensitive to residual soil arsenic (As). Lead arsenical pesticides were commonly used in orchard crops for codling moth control up through the late 40's. Arsenate residues in these soils are relatively immobile and are taken up and removed in limited quantities by crops. The residues are inorganic and consequently don't break down as synthetic organic pesticides can. Thus, these residues persist in soils. Their concentrations can be indicated by determining the total arsenic in a nitric acid extract of the soil. Extractable arsenic concentrations can be high in these old orchard sites and bean growth can be affected with total crop loss.

Various measures have been used to treat these old orchard sites. High amounts of fertilizer P applied to As affected soils can reduce the affects of toxic As levels. The phosphate from the fertilizer competes with arsenate for uptake into the plant. But seldom can the toxic affects of As

be completely ameliorated with high P applications. Deep plowing and the physical displacement of the As to deeper depths in the profile has been the most effective treatment for reducing As effects but the treatment is costly.

## **Future Needs**

The different response of selected varieties to N, Zn, Fe and possibly other nutrients has been documented but additional studies are needed to further define the fertilizer requirements of different bean market classes and cultivars, particularly the differences between dry and green bean plant types. There are also very few studies where cultivar differences in nutrient deficiency susceptibilities are genetically defined. As production costs continue to rise this knowledge will become more critical. There will be the need to re-evaluate fertilizer recommendations as new varieties with higher yield potential become available.

The effect of soil lime on the P fertilization requirement for bean production is not as well defined as for other crops. In conjunction with lime contents, documenting the effects of other management practices such as fumigation on mycorrhizal colonization of beans would also be useful. This information is critical for exploiting currently available precision ag technology for variable rate P applications.

Increasing the N fixing capabilities of beans under both favorable and stress conditions could reduce the current dependence on fertilizer N for bean production under low N conditions. More accurate and convenient measures of potentially mineralizable N might also improve N recommendations for dry beans and allow for more site specific N applications. A better understanding of the spatial variability of mineralizable N in fields would also be useful with respect to variable rate N applications.

Improvement in the soil tests for S and B for predicting these nutrient deficiencies is needed. Critical soil test S and B values reported in the literature do not serve irrigated dry bean production very well in southern Idaho.

In general, nutrient requirements for dry beans are currently met with existing practices and materials. But fertilizer expenses represent significant production costs for dry beans. Future improvements in the economics of nutrient applications can be expected in the future with precision agriculture technology, provided better functional relationships are established for soil test values, other soil characteristics, and the probability of yield increases from nutrient applications. Better understanding of the interactions between specific management and cropping practices and nutrient availability should also be beneficial.

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