University of Idaho Extension

CIS 1174

*Southern Idaho Fertilizer Guide*

# Sugar Beets

*by Amber Moore, Jeffrey Stark, Bradford Brown, and Bryan Hopkins*

## Introduction

Sugar beet profits are based on three key factors: beet yield, sucrose content, and sucrose recovery efficiency. Optimizing beet sugar yields can be a challenge. Nutrients can affect all three factors, especially nitrogen (N). Excess N in the soil can both reduce sucrose content and increase nitrate impurities that lower sucrose recovery.

Conversely, N deficits in the soil can reduce root and sugar yields. While easier to manage than N, maintaining sufficient amounts of phosphorus (P), potassium (K), sulfur (S), and micronutrients are also critical for achieving optimum sugar yields.

In this guide, you will find recommendations for fertilizer applications needed to achieve optimum beet and sugar yields, based on the most current information available, information on farming practices that impact nutrient availability, and suggestions on how to improve nutrient use efficiency and lower input costs for your sugar beet cropping system.

## Soil Sampling

An accurate, representative soil sample is important for developing a fertilizer recommendation. Details on effective soil sampling practices, including number of subsamples, sampling equipment, and sampling location selection can be found in *Soil Sampling*, University of Idaho Extension Bulletin 704 (see Additional Information section).

Note that sugar beets can extend roots to a soil depth of 5 feet or greater. For this reason, soil samples should be retrieved in 1 ft. increments to a depth of 2 ft., at a minimum. For accurate results, soil sampling is best done 2 to 4 weeks prior to preplant fertilization applications. To observe long-term changes in soil fertility, soils should be sampled and tested at the same time every year.

## Nitrogen (N) Fertilization

The sugar beet seed contains adequate N reserves to sustain the plant through germination. Once the seedling reaches cotyledon stage, N in the soil is accessed by plant roots for leaf (canopy) development. Adequate N is needed at this stage for optimum seedling growth and subsequent canopy development. However, once the sugar beet root and the canopy have developed, continued uptake of nitrates from soil can stimulate excessive canopy growth at the expense of the sugars stored in the root. In other words, higher beet sugar content is normally related to low available N during late growth. Excessive amounts of late season available N also increase concentrations of nitrates, salts, and other impurities in the beet. Unfortunately, growers often mistake a vigorous sugar beet canopy for high sugar yields, thus tempting growers to apply more N than is needed for optimal sugar production.

**Root impurities hinder sugar extraction**, which decreases the quantity of sugar recovered from the harvested beet and increases sugar extraction costs. Brei nitrate concentrations, or concentration of remaining nitrate impurities in the beet root, should not exceed 250 ppm to optimize sugar content in the beet (Figure 1). Average brei nitrate concentrations reported by the Amalgamated Sugar Company increased steadily over a 13-year period from 324 ppm in 1992 to 435 ppm in 2004 (Kerbs, 2005). Growers can help reverse this trend by controlling their N fertilizer application rates.

**Nitrate leaching.** Another concern with excessive N applications is nitrate leaching. The movement of nitrates into groundwater and waterways not only poses serious environmental and health risks, but also represents an economic loss to growers.

**Common sources of N** for sugar beet production are chemical fertilizers (urea, ammonium sulfate, mono-ammonium phosphate (MAP), urea ammonium

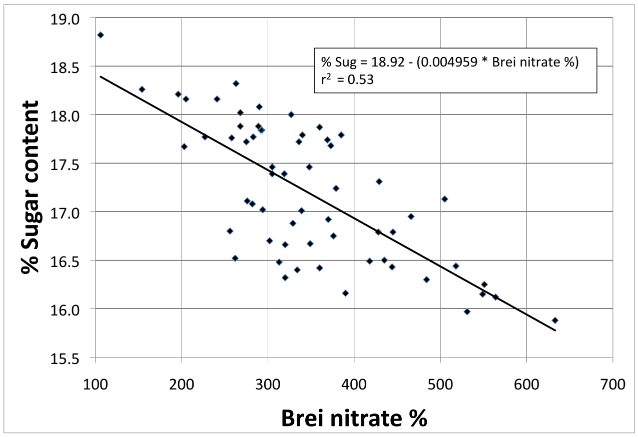


**Figure 1.** Brei nitrate concentrations and % sugar content in the sugar beet root reported by the Amalgamated Sugar Beet Company in 2008. Data refers to the company-wide station averages during the 2008 crop year. Courtesy of Leonard Kerbs, Amalgamated Sugar Beet Company's Twin Falls District Ag Manager.

nitrate, etc.), organic fertilizers (manure, composts, etc.), and soil N in the forms of organic N, ammonium, and nitrate. Chemical N fertilizers are comprised mostly of urea, or nitrate and ammonium, and are readily available forms of N for plant uptake. Organic N fertilizers must be converted, or mineralized, by microbes to nitrate and ammonium. Stanford et al. (1977) found that between 15 and 22% of soil organic N in southern Idaho soils would be converted to plant-available forms over a typical growing season for sugar beets.

**Yields and fertilizer rates.** The N fertilizer recommendations in Table 1 reflect appropriate fertilizer rates for a typical well managed commercial sugar beet field in Southern Idaho. These values take into account average levels of N use efficiency, N mineralization, and soil N variability observed in growers' fields. The recommended N rates are based on yield goal and soil test inorganic N in the top two feet. To avoid over-fertilization, select a realistic yield goal by averaging the three best beet yield years out of five years of sugar beets produced on a given field.

The values in Table 1 should serve only as a guideline and not as an absolute recommendation, realizing that N requirements will vary based on factors such as soil type, geographical location, climate, water table, organic matter content, microbial activity, and so on. We recommend long-term monitoring of soil nitrate and ammonium concentrations, beet sugar content, brei nitrate concentrations, and beet tonnage to determine optimal N requirements for your fields.

## Nitrogen Fertilizer Timing

To maximize N use efficiency and to minimize N leaching and losses, the most efficient and effective time to apply N fertilizer is in the spring, prior to planting. Smith et al. (1973) found that nitrogen uptake by beets and total uptake by beets and tops were greater for spring applications than for fall applications, while the total percentage of N in the beets was not affected. Also, ammonium derived from fall applied urea, especially at rates of 200 lb N/acre or greater, may be slow to convert to nitrate via nitrification over the winter, as cold temperatures and dry conditions inhibit the nitrification process. Excessive concentrations of ammonium in the soil can be toxic to germinating seedlings.

**Splitting N applications** between preplant and in-season applications has been shown in some cases to increase beet tonnage, sugar content, and economic returns, especially on sandy soils. Split applications may also limit loss of applied N to the environment and increase N use efficiency. However, applying N to beets grown on silty, loamy, or clayey soils after the 4-6 true leaf stage will likely cause excessive accumulations of nitrates later in the season, which can lower sugar content and increase impurities, as described above.

## Cropping History

Knowing the crop history is important so that nutrient availability from crop residue and prior fertilization practices may be taken into account when determining the fertilizer recommendation. Factors to consider are: the application of manure or compost and time before crop uptake, irrigation methods, fertilization practices, previous crops, date of residue plow down for grain and green manure crops, and disease, weed and insect pressures.

**Following small grains.** Following small grain (or grain corn), the N recommendation is increased by 15 lb N/acre per ton of straw residue returned to the soil up to a total of 50 lb N/acre. The optimum timing for applying N following small grains is in the spring or fall after soil temperatures drop below 50°F to minimize microbial immobilization of fertilizer N. The N rate may also depend on how the residues are managed.

***Summer fields.*** Small grain residues incorporated in summer in fields with adequate soil moisture should partially decompose by late fall, leaving less residue affecting N immobilization during the sugar beet season.

***Fall fields.*** Conversely, residues not incorporated until fall, such as corn stalks, are minimally decomposed and should be fully compensated for with additional N.

**Table 1.** Nitrogen requirements for sugar beets grown under southern Idaho conditions.

| Soil test N[1] | Realistic yield goal (beet tons/acre) 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ppm | N application rate (lb N/acre) | | | | | | | | | | | |
| 0 | 130 | 145 | 160 | 175 | 190 | 210 | 230 | 250 | 270 | 290 | 310 | 330 |
| 5 | 110 | 125 | 140 | 155 | 170 | 190 | 210 | 230 | 250 | 270 | 290 | 310 |
| 10 | 90 | 105 | 120 | 135 | 150 | 170 | 190 | 210 | 230 | 250 | 270 | 290 |
| 15 | 70 | 85 | 100 | 115 | 130 | 150 | 170 | 190 | 210 | 230 | 250 | 270 |
| 20 | 50 | 65 | 80 | 95 | 110 | 130 | 150 | 170 | 190 | 210 | 230 | 250 |
| 25 | 30 | 45 | 60 | 75 | 90 | 110 | 130 | 150 | 170 | 190 | 210 | 230 |
| 30 | 0 | 0 | 40 | 55 | 70 | 90 | 110 | 130 | 150 | 170 | 190 | 210 |
| 35 | 0 | 0 | 0 | 35 | 50 | 70 | 90 | 110 | 130 | 150 | 170 | 190 |
| 40 | 0 | 0 | 0 | 0 | 30 | 50 | 70 | 90 | 110 | 130 | 150 | 170 |
| 45 | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 70 | 90 | 110 | 130 | 150 |
| 50 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 70 | 90 | 110 | 130 |
| 55 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 70 | 90 | 110 |
| 60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 50 | 70 | 90 |

[1]Soil test N = Sum of nitrate-N ($NO_3$-N) and ammonium-N ($NH_4$-N) in the first- and second-foot depths of the soil profile. When soil test values for the 2nd foot are not available, multiply values from the first foot by 2.

Fewer grain residues are left on many fields now that there is a good market for straw bedding and feeding.

***Poor straw residue distribution.*** However, poor straw residue distribution behind larger combines (with wider headers) can leave chaff rows that can reduce available N. The position of chaff rows are frequently evident the following season if applied N fertilizers don't completely mask their effects on N availability. These chaff rows make it difficult to uniformly apply fertilizer to equally satisfy the N requirements of sugar beets in and between the chaff rows. For more information on wheat residues and N, refer to *Wheat Straw Management and Nitrogen Fertilizer Requirements* CIS 825.

**Following alfalfa.** Including alfalfa in a rotation will significantly reduce the need for fertilizer N application for the following crop. The N recommendation in Table 1 should be reduced 80-100 lb per acre for alfalfa killed and incorporated the previous fall, depending on the alfalfa growth at the time of killing.

**Following other crops.** The majority of residues from potatoes, beans, and onions are decomposed in the soil by spring planting, and therefore no adjustments in the N recommendation is required. Fertilizer N remaining in the soil should be reflected in the soil test.

## Cultural Practices

**Irrigation.** Irrigating sugar beets and other crops in amounts exceeding evapotranspiration rates has been shown to increase nitrate leaching potential and irrigation costs. Such losses can potentially reduce yields while increasing negative health and environmental impacts.

Information on managing irrigation for optimal sugar beet production can be found in the publications *Sugar beet Irrigation Management – Using Watermark Moisture Censors* – University of Idaho Extension Publication CIS 1140, and *Irrigation Scheduling* – PNW 288.

**Glyphosate resistant varieties**

The recent introduction of glyphosate-resistant sugar beets in 2008 has raised concerns from growers on the possible affects that this may have on nutrient uptake. Manganese, zinc, and iron deficiencies in glyphosate resistant soybeans and corn have been documented in the midwestern states. Suspected causes of the deficiencies include the binding of soil micronutrients to glyphosate and gene-alterations that reduce manganese uptake by roots.

While micronutrient deficiencies in glyphosate-resistant sugar beet cropping systems have not been identified or thoroughly researched at this time, growers should still be aware of this phenomenon.

**If you notice interveinal chlorosis in the leaves**, a visible sign of manganese deficiency, submit chlorotic leaf blades to a plant tissue-testing lab to be analyzed for manganese concentrations. Leaf blade manganese deficiency symptoms have been observed with leaf blade concentrations within the 4 to 20 ppm range, while sufficiency levels range from 25 to 360 ppm. Glyphosate-induced deficiencies in corn and soybeans have been managed with applications of the deficient micronutrient.

Considering the use of N, P, and other macronutrients, preliminary data from a limited number of grower fields in Michigan and Minnesota showed no difference in nutrient uptake or yields between conventional and glyphosate-resistant sugar beets. While this information is helpful, more information on glyphosate-resistant beets grown under Idaho conditions is needed.

**Tillage method.** The traditional and most common method of tillage in sugar beets is moldboard plowing. However, glyphosate-resistant sugar beets have motivated some growers to switch to strip-tillage when planting into small-grain residues because intensive plowing and cultivation are no longer needed for weed control. As previously mentioned, N fertilizer rates need to be increased 15 lb N/acre per ton of small grain residue to compensate for immobilization of plant available N.

Preliminary results from ARS Kimberly indicate that tillage method (moldboard plow, chisel plow, or strip tillage) had no significant effect on beet tonnage or sugar content during the first year of implementation. However, if sugar beets are grown in rotation with other no-till or strip-till crops, long-term effects of conservation tillage may **improve crop production** in sugar beets. Research from Montana, North Dakota, and Nebraska illustrates that over 6 to 12 years, organic matter, N content, and wheat yields were significantly higher in no-till and/or minimum tilled soils compared to tilled soils.

***Broadcasting fertilizers*** into a minimal till system with surface residues can cause ammonia volatilization of urea N and stratification of P and K. To avoid these issues, use sub-surface fertilizer applications in strip-till systems. Strip tillage equipment can often be outfitted to shank or band N during tillage. Finally, when feasible, increase soil nutrient levels prior to strip-tillage. For more information, refer to *Nutrient Management in No-till and Minimum Till Systems* – Montana State University Extension Publication EB0182.

**Tillage timing.** If residues of small grains are fully incorporated into the soil, early incorporation will reduce immobilization of fertilizer N applications. For example, Smith et al. (1973) found in a study near Kimberly, Idaho that plowing straw into the ground in September increased sucrose percentage and yield and decreased impurities in comparison to November plowing. Early incorporation provides additional time and heat units for the residues to decompose before the sugar beets are fertilized. Greater decomposition of incorporated residues reduces the potential for N immobilization. Residues incorporated late may require additional N fertilizer to satisfy sugar beet N requirements. The effects from seasonal timing of strip tillage have yet to be fully determined.

**Manure.** Manures or composts are more available for use in sugar beet fields due to the dairy industry expansion in southern Idaho. These materials can be useful for sugar beet production if they contain specific nutrients that are deficient in the soil, as long as they are applied judiciously.

***A concern*** with the use of manure and compost for sugar beet production is the application rate and timing of N release, since excessive late season N can reduce beet sugar concentration and total recoverable sugar. Mineralization of soil organic N, even without applying amendments, is typically highest during mid to late summer. The addition of manures or composts could exacerbate the problem of excessive late season available N.

In research conducted at the UI Parma R&E Center, soils with fall applied composts and manures released more late-season N than unamended soils, with heifer manures releasing approximately twice as much late season N as dairy compost. Nevertheless, only a small fraction of the total N in the manure or compost was released during the first season. Based on the N measured in the plant at season's end, only about 6.9% of manure total N and 3.6% of compost total N were used by the beet plant. In contrast, 43.5% of the conventional sidedress fertilizer N was recovered by beets. Beet conductivity was higher for manure and compost than for the conventional fertilizer.

Since the late season N release from manures and composts is contrary to efficient beet sugar recovery, these materials should not be used as the sole N source for sugar beets. However, they are effective sources of other nutrients such as P and K. Using composts and manures to replace P and K should not adversely affect recoverable beet sugar if the amendments are used sufficiently early in the rotation to minimize late season N release for sugar beets.

The N release in the second growing season is generally half of what it is in the first growing season. The N in manures or composts applied after sugar beets in a three or four year crop rotation should not adversely affect sugar content in sugar beets, but can provide residual P and K for the sugar beets as well as the other crops in the rotation. Compost may be preferable to manures for providing P and K within the rotation, as the concentrations of P and K in compost are typically higher than in manures. Also, the lower and more stable N content of composts will have less influence on sugar beet sugar recovery. Soil testing for nitrate-N and ammonium-N in early spring can help reflect the N contributions from previous manure and compost applications.

**Lagoon waters.** Finally, it should be noted that lagoon waters applied to sugar beets have considerably less organic N in comparison to composts and manures, since the majority of N is ammonium-N, which generally is as plant available as conventional N fertilizers that are applied through the irrigation system.

## Phosphorus (P) Fertilization

Phosphorus is needed by sugar beets for energy transfer in the plant (ATP) and to support cell walls (phospholipids). Phosphorus binds strongly to aluminum in acidic soils, to calcium (free lime) in alkaline soils, and to aluminum oxides and iron oxides in all soils. For this reason, P does not move long distances to the roots with the soil water flow as N does. To insure contact between the root and P in the soil, P must be placed in the same location as the largest portion of the root system, which is typically the upper 0 to 12 inches of the soil profile.

**Broadcast applications** of P fertilizer should be incorporated into the soil to get the P into the root zone. Broadcast applications of P are often needed to ensure that the bulk soil P concentration is sufficient.

**Root system.** Sugar beets are unique in that they do not develop an extensive fibrous root system to explore the topsoil until several weeks after emergence. Therefore, banded P fertilizer applications on low P soils are also important to ensure that sufficient soluble P is in a position for root interception early in the season when the root architecture is dominantly focused downward and poorly developed.

**Band placement** should be directly below the seed, with at least 2 to 5 inches between the fertilizer band and the seed to avoid salt toxicity and seed burn. Deeper placement of P ensures that the roots will grow directly into the band and that the plant will have access to the P early in the season with minimal salt toxicity risk. While sugar beets are very salt tolerant, they are unusually susceptible to salt damage at emergence and early seedling stages. Band-applied P also tends to be more soluble for a longer time than broadcasted and incorporated P fertilizers. Liquid ammonium phosphate (10-34-0) is an ideal P (and N) source for banding applications.

**Plant-available P** in the soil is determined using extraction methods specific to soil pH categories.

- For soils containing **calcium carbonates (pH>5.5)**, use the Olsen or sodium bicarbonate method.
- For **acidic soils (pH <6.5)**, use the Bray I method is ideal.

Confirm with your soil testing lab which P extraction method will be used in the analysis of your soil sample, as P recommendations will vary based on extraction method used.

**Recommended broadcast P fertilizer rates** are based on soil test P values and percent free lime in the soil (Table 2). The lime adjustment is made to account for the reduced P availability resulting from P precipitation by free lime. When band applying P, reduce P application rates by approximately 50%.

**Table 2.** Phosphorus requirements for sugar beets grown under southern Idaho conditions.

| Olsen P[1] (pH > 6.5) | Bray-I P[1] (pH < 6.5) | Percent Free Lime 0 | 4 | 8 | 12 |
|---|---|---|---|---|---|
| ppm | ppm | -------Application rate (lb $P_2O_5$/acre)-------- | | | |
| 0 | 0 | 280 | 320 | 360 | 400 |
| 5 | 7 | 200 | 240 | 280 | 320 |
| 10 | 14 | 120 | 160 | 200 | 240 |
| 15 | 22 | 40 | 80 | 120 | 160 |
| 20 | 29 | 0 | 0 | 40 | 80 |
| **25+** | **37+** | **0** | **0** | **0** | **0** |

[1]Soil test P (ppm) for the top 0 to 12 inch depth of soil.

## Potassium (K) Fertilization

Potassium has been shown to greatly improve early vigor and growth of sugar beets, particularly when producing optimum yield. Potassium also affects sugar content, as sugar produced within the plant depends upon K for movement to the storage root. Between 240 and 540 lbs $K_2O$/acre are removed at harvest through tops and roots, and therefore must be replaced to maintain optimum yields. Recommendations for K application rates for optimal sugar yield are listed in Table 3.

**Table 3.** Potassium requirements for sugar beets grown under southern Idaho conditions.

| Soil test K[1] ($NaHCO_3$/Olsen method) | Soil test K[1] (Acetate method) | Realistic yield goal (beet tons/acre) 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|
| ppm | ppm | ---Application rate (lbs $K_2O$/acre)--- | | | | |
| 40 | 47 | 210 | 240 | 270 | 300 | 330 |
| 60 | 70 | 150 | 180 | 210 | 240 | 270 |
| 80 | 93 | 90 | 120 | 150 | 180 | 210 |
| 100 | 117 | 30 | 60 | 90 | 120 | 150 |
| 120 | 140 | 0 | 0 | 30 | 60 | 90 |
| 140 | 163 | 0 | 0 | 0 | 0 | 30 |
| 160 | 187 | 0 | 0 | 0 | 0 | 0 |

[1]Soil test K for the top 0 to 12 inch depth of soil.

## Sulfur (S) Fertilization

Sulfur is a constituent of several amino acids and therefore is essential for protein synthesis. Sulfur is usually not deficient in the major sugar beet-growing regions of Idaho that are irrigated with Snake River water. Application of S is sometimes needed in areas where soil S levels are below 10 ppm and S concentrations in the irrigation water are naturally low. Broadcast applications of 30-40 lb S/acre should be applied to soils testing less than 10 ppm at the 0- to 12-inch soil depth.

Sulfur can be applied as a sulfate source or as elemental S. Sulfate-S is readily available for plant uptake, but is susceptible to leaching. Elemental S, on the other hand, needs to be oxidized to sulfate-S before being taken up by the plant roots. When applying elemental S, there often is a significant time lag in the conversion to sulfate-S due to the initially low activity of S-oxidizing bacteria. This is particularly true for cold, wet soil conditions that further slow the oxidation process.

Elemental S applications are commonly made to potatoes grown the year prior to sugar beets, and it is reasonable to assume that a portion of this S will oxidize during the sugar beet growing season. Where ammonium sulfate (21-0-0) or potassium sulfate (0-0-52) is used in the rotation, sulfur should not be limiting for sugar beets.

## Micronutrients

In general, yield responses to additions of micronutrients have not been widely observed. However, in soils where zinc concentrations are below 1.0 ppm at the 0- to 12- inch soil depths, or where land leveling has exposed white, high lime subsoil, apply zinc fertilizer at a rate that will supply 10 pounds of water soluble zinc per acre or equivalent.

It is possible that other micronutrient fertilizers will provide a yield response if soil test values are low. However, very little research is available to establish the critical values and documented deficiencies are rare. It is unlikely that sugar beets would respond to calcium or magnesium due to the deep exploration of the tap root in the subsoil typically rich in these essential nutrients.

*Fertilizer recommendations in this guide are based on relationships established through research by the University of Idaho, The Amalgamated Sugar Company, the USDA-ARS Northwest Irrigation and Soils Research Laboratory and the Cooperative Fertilizer Evaluation Project (a cooperative research program comprised of producers, agronomists, consultants and the U of I). Results and experience indicate that these recommendations will produce above average yields if other factors are not limiting production.*

## Additional Information

**Note:** All University of Idaho Extension and PNW publications listed here can either be downloaded for free at the URL listed. Order publications not free online from UI CALS Publications, PO Box 442240, Moscow, Idaho 83844-2240, or call (208) 885-7982, or e-mail calspubs@uidaho.edu. Prices listed do not include shipping and handling.


Brown, B. 1988. *Wheat Straw Management and Nitrogen Fertilizer Requirements.* CIS 825. University of Idaho Extension. $1. (Not available to download).

Cooke, D.A., and R.K. Scott (Eds). 1993. *The Sugar Beet Crop.* Chapman & Hall. London, United Kingdom. 675 pp.

Dinkins, P.D., C. Jones, and K. McVay. 2008. *Nutrient Management in No-till and Minimum Till Systems.* EB 0182. Montana State University Extension. Free at http://www.msuextension.org/publications/AgandNaturalResources/EB0182.pdf

Draycott, A.P. (Ed). 2006. *Sugar Beet.* Blackwell Publishing. Suffolk, United Kingdom. 474 pp.

Kerbs, L. 2005. What has happened to our company's nitrates? *The Sugarbeet Newsletter.* Spring Issue 2005:16-19.

Mahler, R.L. and T.A. Tindell. 1997. *Soil Sampling*. University of Idaho Extension. BUL 704. Free at http://info.ag.uidaho.edu/resources/PDFs/EXT0704.pdf.

Mahler, R. 2001. *Fertilizer Placement*. CIS 757. University of Idaho Extension. Free at http://info.ag.uidaho.edu/pdf/CIS/CIS0757.pdf

Mahler, R. 2002. *Fertilizer Primer: Terminology, Calculations, and Application.* CIS 863. University of Idaho Extension. Free at http://info.ag.uidaho.edu/pdf/CIS/CIS0863.pdf

Reddy, S., J. Neufeld, J. Gallian, H. Neibling, J. Ellsworth, and S. Gortsema. 2007. *Sugar beet Irrigation Management – Using Watermark Moisture Censors.* CIS 1140. University of Idaho Extension. Free at http://info.ag.uidaho.edu/pdf/CIS/CIS1140.pdf

Smith, J.H., C.L. Douglas, and M.J. Lebaron. 1973. Influence of straw application rates, plowing dates, and nitrogen applications on yield and composition of sugar beets. *Agronomy Journal.* 65:797-800.

Staben, M.L., J.W. Ellsworth, D.M. Sullivan, D. Horneck, B.D. Brown, and R.G. Stevens. 2003. *Monitoring Soil Nutrients Using a Management Unit Approach.* PNW 570-E. Free at http://extension.oregonstate.edu/catalog/pdf/pnw/pnw570-e.pdf

Stanford, G., J.N. Carter, D.T. Westermann, and J.J. Meisinger. 1977. Residual nitrate and mineralizeable soil nitrogen in relation to nitrogen uptake by irrigated sugar beets. *Agronomy Journal.* 69:303-308.

Trimmer, W. and H. Hansen. 1994. *Irrigation Scheduling.* PNW 288. University of Idaho Extension, Oregon State University Extension, and Washington State University Extension. Free at http://extension.oregonstate.edu/catalog/pdf/pnw/pnw288.pdf

**The Authors—Amber Moore** is an assistant professor and University of Idaho Extension Soil Specialist at the Twin Falls Research and Extension Center, **Jeffrey Stark** is a research agronomist at the Idaho Falls Research and Extension Center, **Bradford Brown** is UI Extension Soil and Crop Management Specialist at the Parma Research and Extension Center, and **Bryan G. Hopkins** is an associate professor at Brigham Young University, Provo, Utah.

University of Idaho Extension

Issued in furtherance of cooperative extension work in agriculture and home economics, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Charlotte V. Eberlein, Director of University of Idaho Extension, University of Idaho, Moscow, Idaho 83844. The University of Idaho provides equal opportunity in education and employment on the basis of race, color, national origin, religion, sex, sexual orientation, age, disability, or status as a disabled veteran or Vietnam-era veteran, as required by state and federal laws.

Published December 2009