Fertilization Of Sunflower

Special Supplement To *The Sunflower*

Articles were prepared by Don Lilleboe unless otherwise noted.

— Introduction —

Maximizing input efficiency and yield is a common motto in agriculture today — and in this special insert on sunflower fertility. Leaving things to "chance" is not acceptable in high-management agriculture. An important management component in achieving high yield in sunflower is fertility.

It appears in the discussion that follows that fertility in sunflower is not an exact science. Some of the most significant early fertility research was done in the 1970s by North Dakota State University soil scientist Joseph Zubriski. His work remains a primary resource for recommendations of basic fertility inputs throughout the production region, from Manitoba to Texas, and it has served this industry well. Additional research has mostly "nibbled around the edges."

But a great deal has changed since Zubriski's work took place. Here are just a few examples:

- Fallow is no longer part of most rotations.
- Corn is a common part of many sunflower rotations.
- No-till and minimum-till systems are very common.
- Sunflower is grown over a much broader geographic region with a host of different soil types.
- Fertilizer application equipment is dramatically different.
- And, of course, sunflower hybrids are improved as well.

Zubriski's work highlighted the effect of nitrogen on sunflower yield, and the 50-lb recommendation for 1,000 lbs of yield continues to be the general rule. The attached stories attempt to take the reader to another level of understanding for fertility decision making.

The first area is soil testing. This technology is rapidly changing. The common system of soil sampling with probes and laboratory analysis is being enhanced and, in some cases, updated with electronic devices that take into account field topography and production zones within a field. All of this lends itself to variable rates of fertilization and variable plant populations within a field — all in an effort to maximize yield and lower costs.

Another issue of expanding interest is the use of minor constituents to maximize yield. You will find here discussion relating to zinc, sulfur, boron and other minor elements. This is an area of fertility recommendation that is likely to change in the coming years as we gain a better understanding of where and how these components fit into intensive sunflower production.

An exciting area of discussion is what can be expected in fertility carryover from the previous crops. We know that sunflower is deep rooted and can utilize unused N at levels six feet below the surface. Then there is the breaking down of the previous crops' residue and its availability to sunflower in the reproductive stage.

A likely conclusion emanating from the information contained on the following pages is that there is no "one size fits all" rule when it comes to sunflower fertility. There are many variables, as you well understand, and these are highlighted in the following pages.

We look forward to your comments and questions, and we have set up a page on the NSA website where you can do just that. You can go to www.sunflowernsa.com under the "Grower" section and then go to "Surveys." This is a learning process for all of us, and we look forward to your participation in the conversation. **— Larry Kleingartner** ■

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Reason 5: Grower success

"Mycogen brand sunflower hybrids have worked out well for me because they have the full package," Patterson says.

"I haven't seen anything in the industry that will beat Mycogen 8H288DM as far as high oil content, yield and drydown." — Clint "Boomer" Patterson, Bottineau, N.D.

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Fertilization Trends: A Northern Plains Perspective

***Jason Hanson** is a regional agronomist with Winfield Solutions. Based at Webster, N.D., he works with sunflower and other crops throughout the North Dakota and northwest Minnesota production region.*

***The Sunflower:** Does some fertilization of upcoming sunflower ground in your area occur in the fall, or has it been almost exclusively spring-applied in recent years?*

Hanson: From the questions I field, there seems to be more fertility getting put on in the spring. More growers are putting on nitrogen and phosphorus for sure in the spring — either as a "one-pass" or trying to band as much of their needs as they can.

The weather cycle seems to be pushing growers toward more spring applications, as it is taking most of the fall just to get the harvest done.

How much at-planting and/or sidedressing goes on in sunflower?

There is a trend toward more starter or 2x2 applications. First, it's more efficient; and second, it's just showing more-consistent results. With fertilizer getting into the current price ranges, growers are just trying to use all their assets to maintain costs.

A lot of sunflower these days is produced under a minimum-till or no-till system. How has that impacted fertilizer application timing and methodology, as compared to conventional 'flowers?

Equipment has really driven this. As far as the no-till impact, the use of pre-emergence herbicides like the Spartan brands has been important, as is the improved ability (equipment) to place products. That spills over into a lot of interest in products like Agrotain, ESN or Nutrisphere N as urea (if used) and no-till issues with surface-applied urea.

Regarding nitrogen (soil + applied), is the old rule of "5 Lbs N Per 100 Lbs Yield Goal" still a valid one to follow?

We conducted a tissue sampling program this past year called "NutriSolutions," which is an attempt at getting dealers to do a planned season-long nutrition program. What I saw in my area is that we are doing a very good job of supplying N to sunflower. That nutrient is not an issue. Most to all of it was based off the 5 lbs/100 lbs yield goal, so I think that is very adequate.

Do most growers adequately test for and apply phosphorus and potassium as needed, or do these two nutrients tend to get underemphasized?

I believe they adequately test for both nutrients. I know there isn't much to any potash put on, and phosphorus is getting applied mainly in starters. There are some deficiencies showing up on tissue samples with P, but a lot more with K — especially later in the season.

Do you encounter any micronutrient deficiencies in your area? Are there situations where including a micronutrient application would pay?

The NutriSolutions tool showed a couple things with respect to secondary and micronutrients. One was that calcium was probably the largest deficient nutrient. Another micro that did not show up — but one that some folks pay attention to — was boron. It would appear that sunflower doesn't have an issue with extracting boron from North Dakota soils. But zinc did show up as somewhat low or deficient, suggesting that maybe there's more work to be done looking at zinc either in a starter or foliar application.

From my experience this past year, it would appear that timing would play a huge part in making micronutrient applications effective. Most treatments that we put on were later in the season, and the effectiveness just wasn't there. I'd also say that any spring that gives us cool, wet conditions would be where we have the best chance of seeing a response. ■

Nutrient Levels 2010: A Central North Dakota Sampling

This past year, Winfield Solutions, through its NutriSolutions program, tissue sampled 72 sunflower fields in central North Dakota. Samples were taken at three plant growth stages: (1) two- to four-leaf; (2) four- to 10-leaf; (3) immature bud stage. The general levels of select macro, secondary and micronutrients present in the analyzed samples were as follows:

Nitrogen
- Excessive – 54 samples
- Adequate – 18 samples
- Low – none
- Deficient – none

Phosphorus
- Excessive – 33 samples
- Adequate – 28 samples
- Low – 3 samples
- Deficient – 8 samples

Potassium
- Excessive – 8 samples
- Adequate – 35 samples
- Low – 7 samples
- Deficient – 22 samples

Calcium
- Excessive – none
- Adequate – 21 samples
- Low – 18 samples
- Deficient – 33 samples

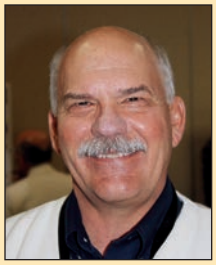
Sulfur
- Excessive – 11 samples
- Adequate – 45 samples
- Low – 6 samples
- Deficient – 10 samples

Boron
- Excessive – 50 samples
- Adequate – 16 samples
- Low – none
- Deficient – 6 samples

Zinc
- Excessive – none
- Adequate – 46 samples
- Low – 12 samples
- Deficient – 14 samples

Manganese
- Excessive – 15 samples
- Adequate – 56 samples
- Low – none
- Deficient – 1 sample

Fertilization Trends: A High Plains Perspective



***Ron Meyer** is area extension agronomist with Colorado State University, based at Burlington. He has worked with High Plains sunflower producers for many years, and likewise has conducted numerous research trials on a variety of topics related to producing sunflower in east central Colorado and adjacent areas.*

***The Sunflower:** Does any fertilization of upcoming sunflower ground in your area occur in the fall, or is it almost exclusively spring-applied?*

Meyer: Fertilizer in High Plains sunflower fields is mostly applied in the spring. This season (2010), corn harvest was finished early, and a fair amount of fertilizer was applied to irrigated circles — but most of that was intended for corn production. Only a small amount of sunflower acreage is fertilized in the fall, mainly because the focus is on corn production at that time of year.

While fall fertilization finishes that activity on a field and spreads out the workload in the spring for other activities (*i.e.*, seedbed preparation, planting, herbicide applications), the tradeoff is that this activity also ties up capital over the winter, adding interest costs to production.

How much at-planting and/or sidedressing goes on in sunflower? Are there any evolving trends in this regard?

Possibly about a third to half of the N fertility needs are placed at planting with 2x2. Most of the phosphorus needs are placed this way as well (about 20-30 lbs of P per acre). No sidedressing currently takes place in sunflower production in our region.

A small amount of fertigation takes place with nitrogen (about 30 lbs/ac actual in some fields). Strip-till practices allow flexibility, so quite a bit of the nitrogen — and some phosphorus — is placed during the strip-till pass.

Less chemigation occurs with sunflower than with corn. Most sunflower fertilizer is placed ahead of planting and at planting — as compared to corn, where there is always some N placed in-season. That's mostly a function of the N application amounts needed for corn.

A lot of the sunflower is produced under a minimum-till or no-till system. How has that impacted fertilizer application timing and methodology, as compared to conventional 'flowers?

It is the reason a lot of fertilizer is placed in a strip-till application ahead of planting. The balance is applied with the planter.

Regarding nitrogen (soil plus applied), is the standard High Plains rule of "6-7 Lbs N Per 100 Lbs Yield Goal" still a good one to follow?

This still works well — mostly due to the ability of sunflower to "harvest" deep fertilizer that other crops in the rotation cannot get to.

Do most growers adequate test for and apply P and K as needed, or do these two nutrients tend to get under-emphasized?

There is a general tendency to not soil test on every field of every farm. As a result, many growers apply maintenance levels yearly.

In the High Plains region, phosphorus tends to be applied at 20-30 lbs/ac per year when yield goals are optimistic due to soil moisture levels. Our heavy soils test at over 800 lbs/ac of K, so therefore we don't use much potash. North of Burlington about 60 miles, the soils are lighter and sandier. Potash is deficient there and applied similar to phosphorus.

Do you encounter any micronutrient deficiencies in your area? Are there situations where including micronutrient applications would pay?

Micronutrient deficiencies are rare in sunflower in the High Plains. In a number of years of testing micronutrient applications in sunflower, I could not find economic yield increases. Sunflower has not shown responses to any micronutrients I've applied at the locations where I've tested.

I believe that in sandy, lighter-colored soils, micronutrients may be beneficial. However, I don't have data to support that; it's just a guess. My "elevator speech" to growers says, "Test micronutrients on your farm and let the combine tell you if they pay for themselves." ■

Remember to Take Organic Matter Credits into Account

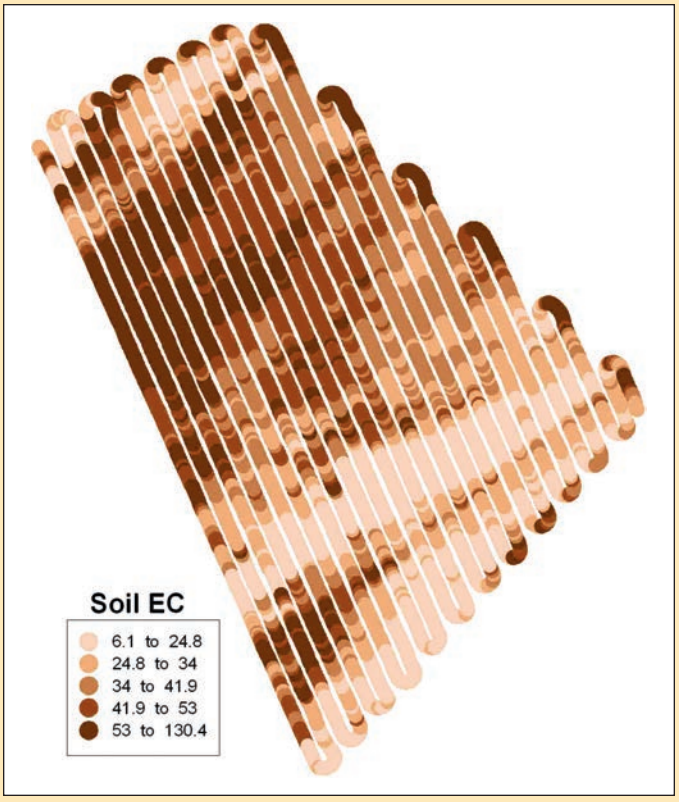
Merle Vigil, soil scientist and research leader at the USDA-ARS Central Great Plains Research Station at Akron, Colo., reminds growers of the importance of organic matter credits.

"Nitrogen can come from soil residual N from previous fertilization and from soil organic matter, and should be considered from at least the top two feet of the soil profile," he notes.

"We have found that a grower can expect 20-40 lbs of N from mineralization for each percentage unit of soil organic matter found in his soil in the top six inches. So a farmer with 2% OM could expect 40 to 80 lbs of N from mineralization during the season (average of 60).

"If the residual inorganic N in that soil was 20 lbs, that farmer would have enough N (60-100 lbs) without adding any fertilizer N for an 850- to 1,400-lb crop of sunflower.

"If he put on, say, 30 lbs of N, he would have enough to meet the needs of a 1,285- to 1,860-lb crop of 'flowers." ■



Map Credit: Veris Technologies, Salina, Kan.

Left: Soil electrical conductivity maps, which determine soil variability, are utilized as the base layer for some zone management systems.

New Technology In Soil Sampling

Sunflower Productivity Stands to Gain

Though the cost of nitrogen and other fertilizer has dropped slightly from the record-high mark in 2008, paying particularly close attention to soil fertility levels and crop nutrient requirements is more important than ever. Growers need to come as close as possible to figuring out the formula for "just enough" fertilizer application to achieve optimum yield.

Recommendations for N, P and K in sunflower are based on the amount of nutrients present in the first two feet of soil. The recommendation for N stands at 50 lbs in the top two feet of soil for every 1,000 lbs of desired yield. But because these recommendations were based largely on studies done in the late 1970s and early 1980s, many soil scientists stress the importance of going well beyond university fertility recommendation tables to determine the best plan of action concerning their crops' needs.

The nutrient content of the soil, as determined by a soil test, is the only practical way to predict probability of a response to applied nutrients. Information garnered from soil testing is also the most reliable means for growers to save money and obtain projected yield goals. With soil levels determined, growers save by avoiding unnecessary application. Years ago, when fertilizer was inexpensive, growers were of the mindset that adding a little fertilizer couldn't hurt if they get some yield gain. But that has changed dramatically in the past few years, particularly because of nitrogen costs.

The technology associated with soil sampling has improved greatly over the past few years. Variable-rate application options help growers maximize fertilizer rates and costs. Grid sampling and zone management are ways crop consultants and soil scientists can customize fertilizer recommendations for specific fields.

Dennis Berglund with Centrol Ag Consulting, Twin Valley, Minn., says his company began utilizing grid soil sampling in Minnesota/eastern North Dakota Red River Valley sugarbeet acres in the mid-1990s. Grid sampling is a way of collecting data in sections to allow for variable rate application. In other words, tests from different areas would determine where fertilizer is needed, and saving money by putting less fertilizer in areas with sufficient nutrient base. Like sunflower, sugarbeets are a nitrogen-sensitive crop.

Grid sampling a section of land, for example, creates a square grid comprising up to 36 samples. "This was very popular at one point and is still used," Berglund explains. "But we end up with a lot of soil samples, making it costly and time consuming. Now what we do more often is zone sampling."

Zone management utilizes a combination of information sources such as satellite images, topography and yield map data from previous crop years to create soil maps. This method improves the soil sampling data in many ways — including taking less samples (four or five), therefore being less costly and taking less time. Satellite imagery also follows the contour of the land instead of a flat square as in grid sampling.

Brett Peterson, crop consultant with Centrol based in central North Dakota, says zone management has drastically changed the world of soil sampling. Satellite imagery breaks the field into three separate zones — higher yielding acres, average and poor — based on field data of vegetation from the past 10 years. Soil samples give information on the breakdown of the nutrient profile in each of the zones. "Our goal is to increase that green area because that's where the best potential is for high yield, meaning that's the best soil," explains Peterson. "It's taking the best parts of a field and making them better."

Flat fertilization rates don't make sense from an environmental or economic standpoint. Why apply fertilizer to areas that don't need it or have poor potential for growth? In geographical areas with high variability of both the contour of the land and soil types, variable-rate application is a huge advantage in maximizing yield.

Brian Michels, crop advisor and owner of Production Service, Inc., near Mohall, N.D., has worked with zone management for a few years. He sees the benefit of this practice for producers as a soil management system, with emphasis on "system." There are a number of tools available to effectively determine the nutrient needs of soil.

During this past growing season, Michels enlisted the services of MZB Technologies located in Watertown, S.D. MZB utilizes a Veris cart in the system of zone management. A Veris cart, developed by a company in Salina, Kan., is a small two-wheeled cart pulled across a field, collecting electrical conductivity (EC) data from the soil and geo-references them using a GPS receiver. EC is a measure of the ability of a material to transmit (conduct) an electrical charge. The data will determine how various soil types in a field differ in their ability to conduct electricity. Michels explains that, for instance, heavier soil conducts more electricity than sandy soil. Likewise, salty soil conducts more electricity than non-salty soil.

As the cart is pulled through the field, one pair of coulter-electrodes injects electrical current into the soil, while the other coulter-electrodes measure the voltage drop. While these coulter-electrodes only need to penetrate the soil a few inches, the

Photo: The 3100 pull-type model, the original Veris EC system and still most popular.

electrical arrays employed by the Veris system investigate the soil to a depth of approximately 36". The EC data collected by the Veris cart produce a map of soil texture variability. Wade Marzhan, of MZB Technologies, says his company has three units that they use in their zone management programs. "As a small current is injected into the soil, the unit is trying to complete a circuit," Marzhan explains. "It's reading resistance of the flow of electricity and converts it to conductivity."

Essentially, the Veris cart is used to determine where to take soil samples to get a more accurate reading of what types of soil are present. The process is a fast and effective measurement of soil properties comparative to about 50 samples per acre taken in a conventional manner. Conventional soil sampling and lab analysis at this rate would be cost-prohibitive.

Michels and Marzhan stress that the soil mapping generated by the Veris cart is not a stand-alone component. Electrical conductivity of the soil, along with GPS-guided topography mapping and yield potential, are used to create accurate management zones. Fertilizer can be variably applied according to best management practices in each of the different productivity zones, maximizing each acre.

All of the information is gathered in order to generate prescription maps for the growers' fertilizer plans. "We're helping the grower find the most productive areas where the fertilizer needs to go," Michels notes. "We've dealt with low-protein wheat in this area in recent years, and in many cases it's because the wheat runs out of nitrogen. With zone management, the producer can be more efficient at placing the right amount of fertilizer in the areas of the specific field that are capable of producing." Based on the zone management and variable rate application of fertilizer, Michels has helped growers produce a crop of wheat that showed more protein response, saving money and pushing yields.

This spring, Michels will be testing the zone management system on sunflower ground to get a feel for how it works. But he figures with an N-sensitive crop like sunflower, the technology will have big payoffs.

Zone management technology has also come in to play for variable seeding rates. Satellite images can show, for example, the sandy hilltop areas that are prone to sparse production — and conversely, the lower ground with dense, fertile soil where production has excellent potential.

Achieving consistent plant stands continues to be a challenge for sunflower growers and a yield-limiting factor. The maps generated with zone management can assist the grower in adjusting seeding rates and, in turn, save input cost and increase yield. While most of the testing to date has been done with corn, sunflower could benefit greatly from more research into variable seeding rates using zone management. **— Sonia Mullally** ■

Soil Testing: Key Considerations

Two key issues to address in soil testing are timing and depth.

• **Timing —** Debate surrounds the recommendation for timing of soil sampling. Most soil sampling is conducted on fields in the Northern Plains states in the fall. The weather is generally more cooperative, and the information can be learned well ahead of the decision-making period for fertility and crop planning for the following growing season.

But some agronomists say that spring is the best time to sample. That is due to microbial activity working on organic matter in the soil being tied to soil temperature and moisture. The microbes are naturally more active in early April and May. So therefore, a soil sample in the spring when microbial activity has begun might provide more-current soil profiles.

Weather and soil moisture conditions in different geographical areas can dictate the timing recommendation as well. In the northern states, typically a late spring would not allow for accurate testing. By the time the ground thaws and soil testing is done, planting decisions are already complete. Regions further south may lend themselves more to spring testing, as ground thaws earlier and soils dry sooner, allowing access to fields.

• **Depth —** Since sunflower is a deep-rooted crop, a deeper probe into the soil would give a better idea of N that might be there for sunflower's taking. Generally, anywhere from 6 to 24" is recommended; but with sunflower you can go deeper to determine what nitrogen is there. Research has shown that sunflower roots will go to a depth of 6'.

Dennis Berglund, of Centrol Ag Consulting in Twin Valley, Minn., says that generally a 2' test is sufficient, but there certainly is nitrogen below that depth that a deep-rooted crop such as sunflower can use. Seldom does Centrol recommend testing deeper, unless a grower hasn't tested the soil previously or hasn't for some time.

"Say you have a grower who hasn't tested in a number of years. That particular person may not have been applying correct amounts of fertilizer during those years, and therefore could have a buildup. Our growers, since they test every year, know the input on their soil, so we're confident in that 2' test," Berglund explains.

• **Other Factors —** Even with soil testing information, many farmers won't be going beyond the 2' soil level, so growers should also address other key issues before determining a field's fertilizer needs: (1) what crops have been on that ground, (2) yields of the crops on that ground the past two or three years, and (3) what has the fertility program been.

Nutrients not used by the previous crop are not lost and can be utilized by the following crop. In a drought year, for instance, crops don't utilize nutrients in a sufficient manner and therefore leave nutrient residue in the soil. The same holds true for a crop failure. Conversely, in wet years crops tend to use more N, but moisture will also push N down faster, leading to a surplus at a deeper level.

Field history is a key component in determining fertilizer tactics. The more nitrogen, phosphorus, potassium and other nutrients routinely put on the ground, the better chance there is subsoil N that sunflower can do go down and use. This is particularly evident with soil that's been in a no-till system for a good number of years. Nutrients are present in soil from the breakdown of organic matter from previous crops.

Every pound of N in the soil lets the producer reduce by the same amount when calculating how much fertilizer the next crop needs. Bruce Due, agronomist with Mycogen Seeds, calls that "soil bank nitrogen." This is a big factor with corn and sunflower, given they are late-season crops. They make use of soil nutrients at different stages than early maturing crops like wheat, barley or canola.

Due says there are fields that are four or five years into a rotation without sunflower that could have 20 to 40 lbs of N below the 2' soil test zone, and more if sunflower hasn't been on that ground longer than that time period.

Due adds that a soil test in the fall or spring, and traditional nitrogen recom-

mendations, don't fully account for the biology that goes on during the growing season. Microbial activity is breaking down organic matter, making soil nitrates available to developing crops. A lot of this breakdown in organic matter in May and June becomes available and is used by late-season crops such as corn and sunflower in July and August. The microbial activity is greater in soils with higher organic matter (>3%) and in areas that receive more moisture.

"You fertilize for 2,000 lbs, and get 3,000 lb 'flowers. How does that happen, if you only put down enough N to meet 2,000 lbs? You don't get good yield unless you have good moisture. If you have good moisture, you're getting good organic matter breakdown," says Due. "It's causing some in the industry to think that maybe the variable-rate application thinking is backward. Maybe you need the extra fertilizer on your poor ground, and not as much on your good ground, because if you're getting good moisture, there's enough organic N becoming available in the field to take care of extra yield needs."

Due says a number of growers with adequate to high fertility levels — or on fields that haven't seen a deep-rooted crop like sunflower in four or more years — put down a good amount of starter nutrient and allow the sunflower to scavenge for the rest. With the cost of fertilizer where it is, growers are trying to figure out how to get by with less. Since sunflower uses much of its N later in the season, there's good return there in residual soil N.

Soil-banked N can allow quite a lot of nutrients to become available that were not reported on the soil test. Due illustrates this with a scenario where you take two similarly populated fields, say with 22,000 plants each.

One has adequate N and the other has surplus amounts, keeping in mind that both fields had adequate rainfall. The plants with surplus N will utilize that nutrient to put on more foliage and result in a tall, robust plant. There is much less air movement throughout the field. The field looks great at a distance, causing the grower to anticipate high yields. This extremely healthy-looking canopy can create an ideal environment for fungal diseases.

The field with adequate N, on the other hand, with average plants in terms of size and foliage, will have much better air movement, thus limiting the potential for fungal diseases. The likelihood of fostering disease in the plants that used the excess N is quite a bit higher. That disease can prove to be a detrimental yield-limiting factor.

Due says that soil sampling is merely a tool and not some magic answer to the complicated soil equation. "Whether you take the soil samples in the spring or the fall, it's going to tell you what's there right now — and the grower then has to fill in the blanks when it comes time to apply fertilizer."

Above and beyond a soil test, those aspects growers should consider to fill in the blanks are field history in terms of what crops have been on that ground and the yields achieved, as well as past fertilizer tactics. These factors need to be looked at in order to utilize both residual and applied nutrients, allowing for adjustments to be made for long-term profitability. **— Sonia Mullally** ■

Applied Micronutrients:

Do They Have a Fit in 'Flowers?

Micronutrients have long been a source of debate in the sunflower world. University fertilizer specialists normally downplay the usefulness of most micronutrients, based on results of their trials, while others — including some growers — contend micros can provide economic benefits in various situations.

Studies at the USDA-ARS Central Great Plains Research Station at Akron, Colo., in the early 2000s, for example, found that micronutrients applied foliarly two times during the season "did not provide a return on investment that was great enough to pay for the micronutrient application," reported Akron soil scientist Merle Vigil. Similar results occurred in a Colorado State University study. "In that study, neither soil-applied granules nor foliar applications [of micronutrients] provided any yield advantage, regardless of soil moisture conditions," Vigil noted.

North Dakota State University soil scientist Dave Franzen says studies done at NDSU in the 1980s looked at micronutrients for both sunflower and corn. The researcher, Joseph Zubriski, "never saw a yield increase in 'flowers, but he did with corn," Franzen says. "Zinc is one micro we've often used with corn because our soils are somewhat low in zinc."

Franzen says "certain crops are able to extract [nutrients] out of even the low-level soils, and sunflower appears to be one of those crops. In North Dakota, we don't need to be putting on zinc, iron, manganese or boron. Boron was the one I worked with several years ago, and we really didn't see a response."

Tom Johnson is president of TJ Technologies, a Watertown, S.D.-based company that has been developing and marketing micronutrient packages for various crops since the early 1990s. Its TJ Micromix® (available in both liquid and dry formulations) contains calcium, magnesium, boron, copper, iron, manganese and zinc in various percentages. "This product is designed for blending with nitrogen, phosphorus and potassium sources to produce a complete fertilizer to be used as a starter in furrow or in band," TJ Technologies states.

Johnson's view on micronutrient use in sunflower is that "a proper combination of nutrients will give a consistent yield response, while the application of individual micronutrients will give a response only when severely deficient."

He notes that research on sunflower in the latter 1990s at NDSU-Minot and NDSU-Carrington looked at different ratios and combinations of micronutrients to determine whether a difference in ratios would influence final results. "Indeed, it did make a difference," Johnson says. "As the research progressed, those ratios that did not perform would be eliminated or altered, and the more successful ones stayed in the trials. This was the process used to determine the analysis and formulations of the products we [market] today."

In Johnson's opinion, "individual micronutrients [tend to be] applied in quantities that are too high — and the result is a toxicity response that reduces yield." That's a broad generalization, he admits, but "in sunflower, boron is important in the development of the reproductive parts of the plant. Too much boron will often produce a response that's similar to inadequate boron," he says, adding that TJ Micromix is formulated to keep safe micros that might otherwise cause problems.

Johnson says that micronutrients generally produce the best response when the crop is subject to significant stress (*e.g.*, too hot, too cold, too wet, too dry). Obviously, however, micros are not going to help a plant that's under extreme stress (*e.g.*, severe drought). "Soil types are not necessarily the deciding factor," he adds. "But a high pH (7.5 to 8.2) will give a greater yield response than a 6.5 to 7.5. When pH is below 6.0, liming is needed to get proper micronutrient response." ■

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N.D. Sunflower Fertility Guidelines: *Time for an Update?*

North Dakota State University's sunflower fertilization recommendations are, to put it kindly, "well aged." They were actually developed three decades ago and are long overdue for an update, concedes NDSU soil fertility specialist Dave Franzen. The reason they haven't been updated more recently is, quite simply, a matter of limited human resources — especially when spread across some two dozen major and minor crops for which NDSU offers fertilizer recommendation tables and equations.

So the question then becomes, 'Do the current sunflower recommendations still adequately serve North Dakota sunflower producers?' Given the new generations of higher-yielding hybrids being grown by today's producers, that's a subject open to debate. In Franzen's view, the answer has a two-pronged component.

Dave Franzen

"I think they're still doing a reasonable job for the average to slightly above-average producer," he states. "They're probably not as good as they should be for the exceptional sunflower producer, however."

Franzen says one mitigating factor — a "cushion" of sorts when it comes to growers not running short on nitrogen due to any shortcomings of the recommendation formulas — has been "the farmer's general lack of knowledge of his deep N." By that he's referring to quantities of nitrogen that are left unused by preceding wheat or other crops. "That nitrogen is going someplace — usually down to a deeper depth, especially in these wet years. And the sunflower is picking it up.

"That's a big reason why, in some cases, you're seeing 3,000-lb sunflower yields even though just enough nitrogen was applied to support a crop of maybe two-thirds that amount."

There's a caveat for 2011 sunflower fields, however. "We're coming off two superb wheat crops — and small grain crops in general," Franzen points out. "So that deep N probably isn't there in the amount it used to be. Those 60- to 100-bu spring wheat, durum or barley crops have used up much of what was applied and released. So replenishment of the deep N hasn't happened."

For any producer shooting for that high-end 2011 sunflower yield, the bottom-line emphasis obviously is, as always, knowing what you have and providing what you'll need — *i.e.*, a sound soil test and the addition of adequate applied N. "The exceptional grower who hit 2,500 to 3,000 lbs this past year really needs to focus on his production goal for this coming season — and then fertilize accordingly," Franzen affirms.

"The real productive grower should be thinking somewhere in the neighborhood of 150 lbs of total known available N from 2' soil test nitrate, any previous crop N credits and added N." ■

— North Dakota (NDSU) Sunflower Fertilizer Recommendations —

Yield Potential	Soil N + Fertilizer N Required		Soil Test Phosphorus, ppm					Soil Test Potassium, ppm				
		Bray-1 Olsen	VL 0-5 0-3	L 6-10 4-7	M 11-15 8-11	H 16-20 12-15	VH 21+ 16+	VL 0-40	L 41-80	M 81-120	H 121-160	VH 161+
Lbs/Ac	*Lbs/Ac - 2'*		*------ Lbs P_2O_2/Ac ------*					*------ Lbs K_2O/Ac ------*				
1,000	50		20	15	9	4	0	36	25	14	3	0
1,500	75		31	22	14	5	0	53	37	21	5	0
2,000	100		41	30	18	7	0	71	50	28	6	0
2,500	125		51	37	23	9	0	89	62	35	8	0

Nitrogen recommendation = 0.05 YP-STN-PCC
Bray-1 P recommendation = (0.0225-0.0011 STP) YP
Olsen P recommendation = (0.0225-0.0014 STP) YP
Potassium recommendation = (0.041-0.00027 STK) YP

YP = yield potential PCC = previous crop credit
STN = soil test nitrogen
STP = soil test phosphorus
STK = soil test potassium

— South Dakota (SDSU) Sunflower Nutrient Recommendations —

Yield Goal	Soil N + Fertilizer N Required	Bray-1 Olsen	Soil Test Phosphorus, ppm VL 0-5 0-3	L 6-10 4-7	M 11-15 8-11	H 16-20 12-15	VH 21+ 16+	Soil Test Potassium, ppm VL 0-40	L 41-80	M 81-120	H 121-160	VH 161+
Lbs/Ac	*Lbs/Ac - 2'*		*------ Lbs P_2O_2/Ac ------*					*------ Lbs K_2O/Ac ------*				
1,000	50		20	15	10	0	0	36	25	14	0	0
1,400	70		29	21	13	0	0	50	35	20	0	0
1,800	90		37	27	17	10	0	64	45	25	10	0
2,200	110		45	33	20	10	0	78	55	31	10	0
2,600	130		53	38	24	10	0	93	64	36	10	0
3,000	150		61	42	27	10	0	107	74	42	10	0

Nitrogen recommendation = 0.05 YP-STN-PCC
Bray-1 P recommendation = (0.0225-0.0011 STP) YP
Olsen P recommendation = (0.0225-0.0014 STP) YP
Potassium recommendation = (0.041-0.00027 STK) YP

Comments from Ron Gelderman, SDSU soil scientist:

Most of our recommendations with sunflower have come from North Dakota work and are quite old. We had some N studies with 'flowers in the early '80s which appeared to agree with North Dakota's work.

I don't foresee any updates in at least the next five years. There are a lot of higher priorities (*i.e.*, higher-acreage crops) and little opportunity for funding.

The requirement of 5 lbs nitrogen per 100 lbs of yield may actually be on the high side. As with corn or wheat, I believe sunflower is using N more efficiently now than it did 30 years ago, as the productivity of the crop today is so much better. Improved hybrids, improved weed and insect control, earlier planting dates and better plant stands all have contributed to better plant growth and more-efficient soil nitrogen uptake.

High Plains N, P & K Basics

The information below is excerpted from the "Nutrient Management" section of the High Plains Sunflower Production Handbook. *The lead author of this section was Merle Vigil, soil scientist and research leader with the USDA-ARS Central Great Plains Research Station near Akron, Colo.*

The entire High Plains Sunflower Production Handbook *can be accessed on the National Sunflower Association's website — www.sunflowernsa.com. Go to "Growers" and then click on "Production Resource Books." The nutrient section provides tables and formulas pertaining to nitrogen, phosphorus and potassium recommendations, as well as more details on these nutrients importance and utilization in sunflower production.*

Nitrogen

Nitrogen (N) is the nutrient of greatest accumulation in the above-ground portion of the sunflower crop. Nitrogen recommendations vary with yield expectations associated with soil, climate, soil moisture, cropping sequence, and residual nitrogen in the soil.

The results of a seven-year study conducted at the USDA-ARS Central Great Plains Research Station, Akron, Colo., indicated that sunflower requires 6 to 7 lbs of nitrogen for every 100 lbs of production. This has led to an increase from a previous recommendation of 50 lbs of nitrogen for every 1,000 lbs of potential grain production, to 65 lbs of nitrogen for every 1,000 lbs of expected yield.

If fertilizer is placed in contact with the seed, the starter material should contain no more than 10 lbs of actual nitrogen plus potash per acre. The nitrogen and potash can cause germination damage because of their high salt index when placed with the seed. Much higher amounts can be applied in a 2x2 band or broadcast without seedling damage.

Nitrogen application for sunflower can be made preplant, sidedress or a combination of these methods with equal results. Applications should be timed so nitrogen is available for rapid plant growth and development.

Since sunflower is efficient in recovery of residual N, a soil test for available nitrogen is strongly encouraged. Profile nitrogen samples should be taken to a depth of at least two feet. On deep, well-drained soils, sampling may be justified to four feet.

Phosphorus

Phosphorus (P) application should be based on a soil test. Consistent sunflower response to phosphorus fertilization has generally occurred on soils testing very low or low in available phosphorus where yield potential is not restricted by lack of moisture or other environmental factors. With medium-testing soils, yield responses have been erratic and normally quite small. Phosphorus applications are recommended with medium and low soil tests for potential yield response and to maintain the soil in a highly productive condition.

Phosphorus should be applied preplant-broadcast, preplant-knifed, or banded at seeding. Starter applications are most efficient, particularly when small amounts are applied on soils low in available phosphorus. Phosphorus can be placed in direct contact with the seed or to the side or below the seed with no restrictions in economical rates. If placed in contact with the seed, the starter material should contain no more than 10 lbs of actual nitrogen plus potash per acre.

Potassium

Like phosphorus, a soil test is the best guide to potassium (K) need. Potassium removal is much greater with silage than with grain production. Potassium deficiencies are not likely unless soil test levels are low, which normally occurs in sandy soils.

Potassium should be applied preplant-broadcast or as a starter. Remember, sunflower is sensitive to fertilizer salts (nitrogen and potassium). When applying starter applications with the seed, limit application to no more than 10 lbs actual nitrogen plus potash per acre. Preferred fertilizer placement is 2x2. ■

— Urea on Top —
The Concern in No-Till

Anyone familiar with Great Plains sunflower trends over the past couple decades understands the dramatic shift toward minimum- and no-till systems. Of all North Dakota fields evaluated during the 2009 National Sunflower Association crop survey, for instance, 33% were considered "minimum-till" and 34% were "no-till." In South Dakota, a whopping 82% of fields surveyed in 2009 were "no-till"; in Kansas, it was 60%; in Colorado, 50%.

How do no-till producers of sunflower apply their crop's nitrogen fertilizer needs? Quite a bit, of course, goes on at planting. "But a lot of no-tillers still put urea on the surface — and I think that's a mistake," says North Dakota State University soil fertility specialist Dave Franzen. Why? Product loss to volatilization. When urea comes into contact with moisture and urease (a naturally occurring soil enzyme) and crop residue, it is broken down and released into the atmosphere as ammonia.

For growers who see no other way of applying their crop needs, Franzen says at the very least they should use Agrotain®, "the only urease inhibitor that works." Agrotain is a nitrogen stabilizer suitable for any crop where urea of 28%, 30% or 32% liquid nitrogen fertilizers are used. It will not work with other forms of N.

"There are urease enzymes in all soils," Franzen explains. "But it's particularly high in no-till soils because the crop residue itself contains hundreds of times the concentration of urea that bare soil does. And even in bare soil, conventional till, if you put it on top in a high-pH situation, you can get significant volatization. The higher the pH, the more problem you have. And in no-till, it's bigger yet."

The North Dakota soil scientist says that in a worst-case scenario, a no-till producer who surface spreads all his fertilizer could lose 30-40% of its efficacy. "Let's say you put it on and get a little drizzle within a couple days — maybe 0.1" or less. It wets up the residue, wets the very surface of the soil, but doesn't go any deeper. The pellets have all dissolved, there's a crust on the surface, temps are above freezing — and the wind picks up.

"You could lose 10-20% in the first week and another 20% the second week if it continues to rain lightly but sporadically. It's not something to be taken lightly."

Compared to earlier-planted crops, sunflower doesn't need the nitrogen as quickly in the spring; but losing some of it to volatilization can still be expensive. "If you figure you may need to sidedress later on because the plants are starting to look yellow when they're a foot tall or so, that will mean putting another $20-$30 an acre into the crop," Franzen notes.

While putting most of one's N down at planting is a more-efficient alternative, the NDSU specialist realizes that time-wise and logistically (*i.e.*, reconfiguring one's planter), it's not always realistic. So he reiterates that "if they do decide to put it on top, they should at least use the Agrotain — unless they're absolutely sure they'll get a half inch of rain within a couple days. And most people aren't that sure."

Franzen knows most no-till farmers have a lot of ground to cover at planting time. "Farmers don't like to be slowed down in the spring; I understand that. But I also understand the agronomy of it." ■

— Sulfur —

A Secondary With Good ROI Promise

Terry Wendell doesn't have hard research numbers to back it up, but he's convinced that routinely adding sulfur for his dryland sunflower crop is a consistently worthwhile investment.

Wendell, who farms near Colby in northwestern Kansas, is predominantly a row-crop producer: sunflower, corn and a smaller acreage of milo comprise his rotation, with wheat being an exception rather than the rule. The Thomas County producer has been including sulfur as a standard part of his sunflower fertility program for a number of years — even when soil tests suggest it may not be necessary.

The sulfur goes on at planting along with the crop's nitrogen and phosphorus needs, either on top or as a 2x2 treatment. "I'm on an all-liquid program: 32%, some 10-34-0 and then 12-0-0-26 (ammonium thiosulfate)," Wendell notes. He'll apply about five gallons of the 12-0-0-26 at a cost of around $8 per acre. "But we're getting some nitrogen there too, so we've probably looking at more like $5 to $6" in sulfur cost, he says.

"The sulfur in the combination works as a urease enzyme inhibitor," Wendell points out, "so it tends to keep the nitrogen in a more-stable state. It doesn't volatize as quickly when I'm putting it on top of the soil." Some of his soils are high in magnesium, he adds, and "we know that by putting some sulfur on with the nitrogen in a high-magnesium soil, it tends to give us better nitrogen efficiency,"

Wendell has not conducted check strips to gain hard numbers on what the sulfur addition is doing for his sunflower yields. "But I think sunflower responds favorably late to nutrient uptake if there's some sulfur out there," he states. A confection grower, "I always have a high percentage of large seeds," he adds. "Even in a year like [2010] where we got dry during the tail end, I still had 85% larges. I think the sulfur affects that quality issue."

Wendell became a sulfur advocate during his prior career in fertilizer sales (he logged 28 years in that business). "I started selling it as part of a program when I was in Nebraska, and it seemed like we always saw good results," he recalls. Now, on his own farm, "I feel comfortable enough that I just apply it as a standard practice."

North Dakota State University soil fertility specialist Dave Franzen does not expect a good return on investment from most applied secondary or micronutrients for sunflower in his state. But he makes an exception for sulfur.

"Sulfur is different," Franzen allows, noting that soil sulfur deficiencies in North Dakota are more common than they were 15-20 years ago. Why? One reason, ironically, has been tougher emission standards nationally, which has meant less sulfur being discharged into the air from industrial and transportation sources. Another factor has been the wet cycle experienced of late in much of the Northern Plains. But perhaps most important have been the higher crop yields compared to a couple decades ago.

"In a heavy clay soil and depression area, you're not likely to see a sulfur problem," Franzen says. "But on hills and slopes, where you tend to have coarser soils, you're very susceptible in a wet year" due to leaching.

The current sulfur soil test is unreliable, the NDSU fertility specialist adds. "People use it because we don't have anything better," he says.

"So I suggest people do two things: First, look at where any coarser-textured soils — the sandy loams or loamy sands — are located. If they're in depressed elevations, don't worry — the water table is high, and it contains sulfates. But the hilltops and slopes need watching.

"The second thing [is precipitation history]: last fall's rainfall amounts; winter snow amounts; early season rainfall. If any of those are high, you'll likely need to put sulfur on those soils, because you will have a problem" due to leaching.

Price, availability and other nutrient needs will help determine the best source of sulfur. However, dealers should make sure that their customers use the right type of sulfur at the right time.

In general, elemental sulfur is converted over time to the sulphate form, which plants require. "The time involved in this conversion may be several months or more, depending on the specific sulfur source and the particle size," Franzen points out. "Since most crops require sulfur in a deficiency situation rapidly, not slowly, elemental sulfur is not recommended for initial deficiency correction by itself, without most of the sulfur requirement being met by a sulfate-S form. "Sulphate sulfur is readily available to the crop and is most suitable for rapid correction of a sulfur deficiency." ■

An 'Edge' That Leaves Nothing to Chance

Kansas Producer Kriss Schroeder's Intensive Mgmt.

Photo: The Mosaic Company

In 1991, when Kriss Schroeder put away his veterinary license and came home to farm near Colby, Kan., he knew he'd need an edge to make a living in the dryland cropping region.

Schroeder adopted an intensive management program that took a 180-degree approach to traditional summer-fallow wheat production. By switching to continuous no-till, he now raises a crop every year, on every acre.

"Water is by far our number-one limiting factor to crop production. By switching to no-till, I felt I would be able to conserve enough moisture to grow a crop every year," relates Schroeder. "We do this by keeping as much residue on the surface as possible and not letting anything grow that doesn't produce income."

With 70% of his acres in corn, he follows a two- to three-year cycle of the same crop, rather than rotating yearly. This enhances weed control and reduces the risk that can come from needing to drill wheat immediately following the combine in the fall.

Residue preservation involves stripper-headers during wheat harvest and keeping the header as high as possible during corn, sorghum and sunflower harvest so more residue stands longer. Stubble and stalks are moisture-management assets providing shade, snow-holding capacity and protection from drying winds. Weeds are killed before they can steal moisture.

Beyond conserving moisture, the northwest Kansas farmer believes good genetics and a balanced soil fertility program are the most important facets of his success. Each year, he studies seed and fertilizer test plots and does his own on-farm testing of new genetics as well as other crop production products.

"On-farm research is the fun part of farming. There are a lot of differences in soils, and something that might work 200 miles from here may not work here," Schroeder explains. "On-farm research is risk management. Before you spend thousands of dollars on something, you'd better know it works."

Soil Testing Every Year

Another risk-management tool he employs is annual soil testing of every field. While he has experimented with 2.5-acre grid sampling, he currently samples every 8 to 10 acres and combines samples from like soils within each field.

"Through the years, the greatest variability we've seen from a nutrition standpoint is due to mineralization of nutrients from the previous crop's residue," Schroeder explains. "Some years we have a fair amount of rain and heat. That mineralizes a lot of nutrients. If the following year is dry, we may not have as much mineralization, so we'll need to apply more fertilizer." He estimates this variability can range from a nearly insignificant amount to the crop's full requirement from the lowest to highest years; therefore, he is not confident in building a nutrient program based strictly on estimated crop removal.

Levels of mobile nutrients, nitrogen (N), chloride (Cl) and sulfur (S) also are hard to predict without annual soil tests because of leaching. Soil samples typically are pulled from 0 to 6" and also at 6 to 24". In years in which nutrient leaching is suspected, N, Cl and S are evaluated at 24 to 48" depths.

Nutrient Plan Adjusted, Balanced Each Year

Using a spreadsheet built following nutrient recommendations from Kansas State University, Schroeder develops a balanced nutrient program for each field, each year, adjusting the rates up or down a bit depending on expectations for the growing season. He stresses the importance of formulating a program every year on every field and balancing nutrition for his crops.

"If you're taking vitamins, you don't load up on vitamin C and forget about vitamin A, calcium and other nutrients," he says. "Plants are no different. If you load up one nutrient and another nutrient is limiting, that will limit your yields. I strive to make sure nothing I can control limits my yields."

At planting, granular fertilizer is applied as a starter with the planter or drill. He uses MicroEssentials® SZ™ as his source for P, N, Zn and S and supplements it with additional K as needed. Liquid nitrogen in the form of UAN is streamed on in a band every 15" in the fall or winter after the soil temperature drops below 50 degrees. If moisture conditions are favorable for a bumper crop, additional N is occasionally applied in the spring.

Yields are proof Schroeder has found the "edge" he needs for success. His whole-farm averages for each crop are well above average for the area. ■

To learn more about balanced crop nutrition, visit www.Back-to-Basics.net.

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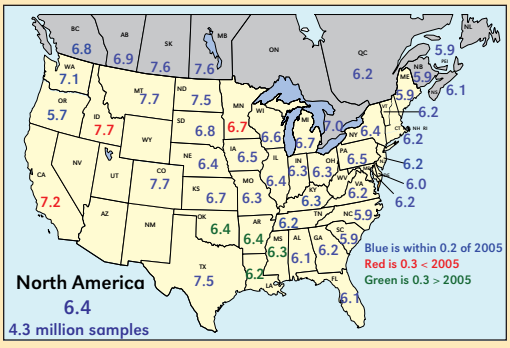
Low pH: Big Issue for Some High Plains Soils

Dealing with low-pH soils is not, fortunately, on the "need-to-do" list for most sunflower producers. Acid soils — those with pH levels below 6.0 — are relatively uncommon across the Great Plains, where most sunflower is grown.

Nationally, low-pH soils are a yield-impacting issue for many ag producers. A recent report from the International Plant Nutrition Institute (IPNI) titled "The Fertility of North American Soils, 2010" summarized findings on about 4.4 million soil samples tested by some 60 private and public laboratories (making it the largest summary of soil samples ever conducted in the U.S. and Canada). Soil pH was one of the categories summarized. The median pH for North America was 6.4, with 27% of samples testing below 6.0. "Median pH is lowest in the southeastern U.S. and generally increases toward the west," the report states. *(See the map below).*



Source: IPNI

Median soil pH in 2010 and change from 2005 (for states/provinces with at least 2,000 pH tests).

Where acid soils do exist, affected growers need to be aware, concerned and, sometimes, take steps to correct the issue. Reduced-tillage systems may be especially prone. "Repeated surface applications of nitrogen in conservation-till systems can lead to pH stratification," exemplifies IPNI North Central regional director Scott Murrell. "As ammonium and urea forms of nitrogen convert to nitrate, acidity is produced. With reduced tillage, this acidity may become concentrated in the upper [two to three inches] of the soil profile."

"Symptoms of low pH include stunted plant development, uneven crop growth, faster aging of lower leaves and yellowing between veins on upper leaves," relates Steve Barnhart, a regional agronomist with Croplan Genetics. "Additionally, bacterial activity is reduced under low-pH conditions, slowing the breakdown of soil organic matter, crop residues and organic fertilizer sources like manures. As a result, nutrient release from these sources is lessened."

Within the sunflower world, low pH soils are perhaps found most commonly in parts of Kansas and Oklahoma. A review of soil test results in 2005 by the Potash & Phosphate Institute (IPNI's predecessor), indicated that 46% of the Oklahoma tested samples and 22% of those from Kansas had a pH below 6.0. For Nebraska and Texas, the low-pH numbers were 31% and 23%, respectively.

"Soil acidity has a great impact on nutrient availability and nutrient use efficiency, [because] as the pH drops, so does the ability of the plant to uptake and use the applied nutrients," explains Brian Arnall, soil scientist with Oklahoma State University. His state's wheat producers have had access to aluminum-tolerant wheat varieties to help counter the effect of acid soils; but as more and more Oklahoma farmers look to expand their rotations by including crops like sunflower and sorghum, they find little or no aluminum tolerance.

As shown in the photo below of sunflower in a 4.0 pH soil, the results can be dramatic, in a bad way. "The low pH releases aluminum — which is toxic to the plant and prevents root growth," Arnall notes. Even with a pH of 5.0, root growth is retarded. "So if we go into a dry period, you'll see drought stress moreso than you would with a healthy root system."

The answer for low-pH soils, other than tolerant crop varieties, is liming. Adding appropriate quantities of lime will raise pH levels and maintain soils for healthy crop production. "Lime is recommended for sunflower on all soils with a pH of 6.0 or less," notes USDA-ARS soil scientist Merle Vigil. "If sunflower is grown in a cropping system that includes legumes, liming to obtain a higher pH (6.2 to 6.5) should be maintained."

"Lime is a slow-acting soil amendment," OSU's Arnall notes. "So it's going to take weeks or months (or even longer in Northern Plains states) before it becomes effective. You want that soil pH up to a good level before you put your seed in the ground, so it can germinate under the best possible conditions."

Soil pH also has a big impact of phosphorus availability, Arnall adds, with soil P being most available to plants when the pH range is between 6.0 to 6.7.

The main liming activity in North Dakota to date has been among sugarbeet producers in the Red River Valley, notes Dave Franzen, North Dakota State University soil fertility specialist. These growers actually use spent lime from the region's sugarbeet factories, where it is a byproduct of the beet sugar purification process. Along with raising pH levels of acidic soils, beet growers benefit from the lime's nutritional value (especially phosphorus) and its proven ability to help reduce Aphanomyces root rot, a serious disease for the region's sugarbeet industry.

Franzen says very little liming has been carried out in other parts of North Dakota to date, although some locales do have low soil pH levels. He believes sunflower has an advantage over other vulnerable crops because it roots so deeply "that maybe it's tapping into some subsoil carbonates."

Croplan's Steve Barnhart says the best time to be liming "is right before fall tillage, so you can work the lime into the soil profile. Another benefit to liming prior to tillage is that the winter winds won't blow it off your fields. This is also a good time to treat no-till acres, and blowing won't be as much of a concern on these fields because it will adhere to the crop residue that's left over." The lime's acidity-neutralizing effect takes longer to accomplish in no-till fields as compared to field where it is incorporated through tillage, he adds. ■

How does sunflower do on extremely low pH soils? This photo is from an Oklahoma State University plot with a pH of 4.0.

Photo: Brian Arnall