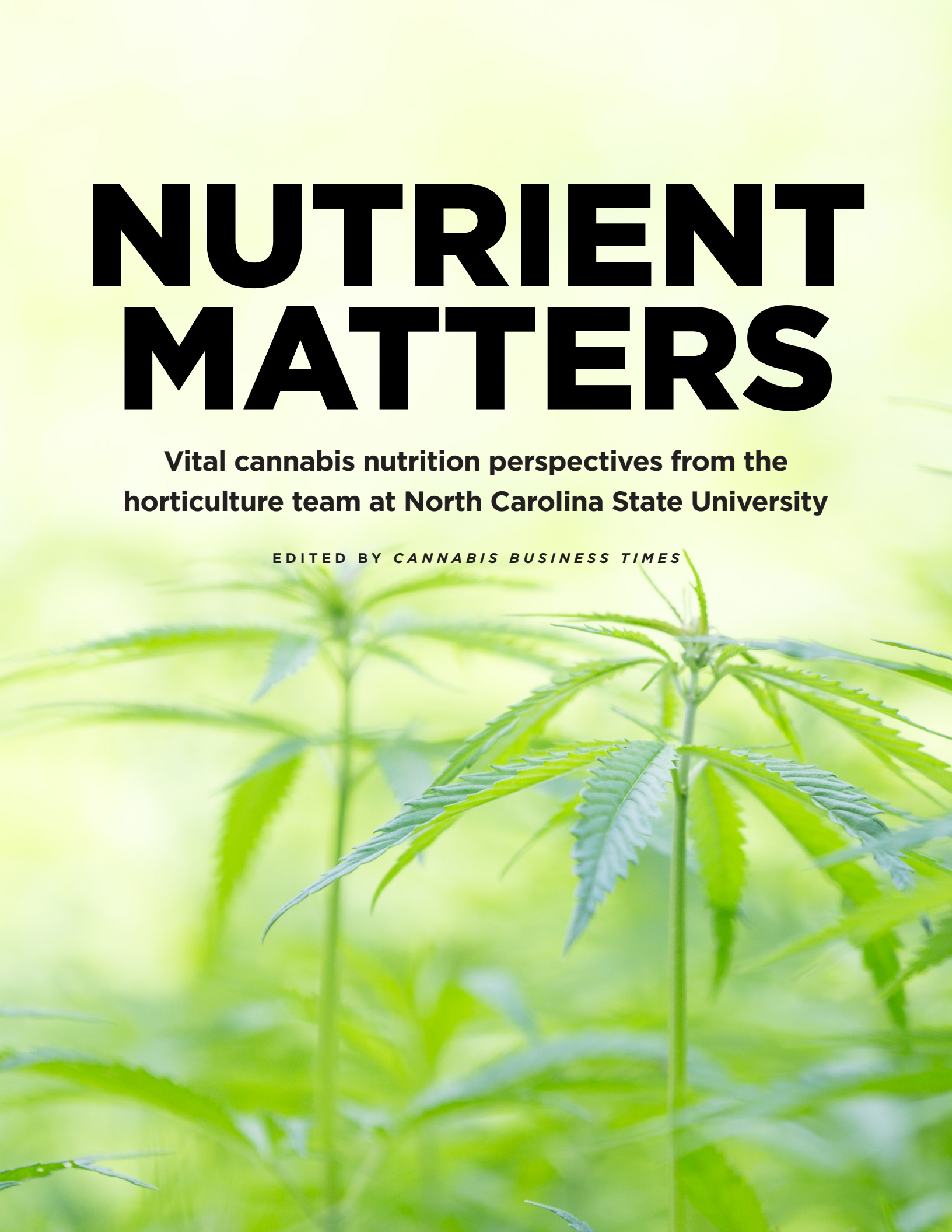
NUTRIENT MATTERS

Vital cannabis nutrition perspectives from the horticulture team at North Carolina State University

EDITED BY *CANNABIS BUSINESS TIMES*



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Introduction

Starting in the spring of 2019, a team of researchers at North Carolina State University, led by Dr. Brian Whipker, Ph.D., began writing the "Nutrient Matters" series of features for *Cannabis Business Times*. The articles capitalized on emerging cannabis research being conducted by Whipker and his team: a combination of well-established plant science and a growing body of work examining the biological structure of the cannabis plant.

Nitrogen, Magnesium, Silicon, Boron: the elemental approach to plant nutrition is placed alongside deeply researched reports on electrical conductivity, pH management and alkalinity control. Here, the NSCU team's "Nutrient Matters" collection is gathered in one place to help address all your nutrient questions. With the information compiled in this series, you will be able to use university-backed research to better develop ideal nutrition plans and monitoring programs, and control your nutrients and feedings to ensure a consistent, healthy and prosperous crop.

The NC State Floriculture Group would like to thank Triangle Hemp, Durham, NC, and Ryes Greenhouse, Broadway, NC for donation of hemp cuttings used in our research studies.

New Research Results: Optimal pH for Cannabis

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



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The recommended substrate pH for cannabis *(Cannabis sativa)* varies widely. A recommended substrate pH of 6.0 to 6.5 often is cited as the standard. However, we have observed pH ranges between 4.0 and 5.0 or greater than 7.0 during our visits to commercial greenhouses growing cannabis.

Our observations from those greenhouses indicated that plants grown at acidic (lower) pH appear to have normal growth and lack the symptomology of lower leaf blackening or bronzing typically seen with other greenhouse species at lower pH levels. In crops grown at higher pH, only in rare instances did we observe interveinal chlorosis of the upper (youngest) leaves (a common symptom of greenhouse crops grown at high pH). These observations suggest that cannabis is not prone to iron deficiencies when the substrate pH nears 7.0.

Returning to our labs at North Carolina State University (NCSU), we began our work to understand the underlying factors affecting pH in substrates and how those fluctuations

impact the *Cannabis sativa* plant in order to determine the optimal pH range for cannabis. This is what we discovered.

pH ON THE RANGE

Substrate pH is important to plant nutrition because it directly impacts plant nutrient availability.

Substrate pH levels below 5.0 result in increased micronutrient availability that can lead to iron (Fe) toxicity or manganese (Mn) toxicity, or both. Symptoms of Fe toxicity and Mn toxicity may appear as black speckling on older leaves (observed with zinnias or gerbera) or as bronzing (observed with marigolds or seed geraniums). While some crops display low pH symptoms on lower leaves, others may only display low pH through stunted growth, as is the case with poinsettias.

pH ADJUSTMENT RECOMENDATIONS

CORRECTIVE PROCEDURE	RATE	CONSIDERATIONS
Flowable Lime	1 to 2 quarts per 100 gallons of water	• Rinse foliage • Avoid damage to your injector by using rates of 2 quarts per 100 gallons of water, or less. • Can split applications • Using a rate of 2 quarts per 100 gallons of water will typically increase the substrate pH by roughly 0.5 pH units
Hydrated Lime	Mix 1 pound in 3 to 5 gallons of *warm* water	• Mix twice. Let settle. Decant liquid and apply through injector at 1:15. • Caustic (rinse foliage ASAP and avoid skin contact)
Potassium Bicarbonate ($KHCO_3$)	2 pounds per 100 gallons of water	• Rinse foliage immediately • Provides 933 ppm K • Leach heavily the following day with a complete fertilizer to reduce substrate EC and restore nutrient balance. • Rates greater than 2 pounds per 100 gallons of water can cause phytotoxicity. • A rate of 2 pounds per 100 gallons of water will increase the substrate pH by roughly 0.8 units.

In our initial experiments at NCSU, we did not observe symptomology of lower leaf blackening or bronzing on *Cannabis sativa* plants, only stunted growth. These preliminary results suggested that cannabis can regulate micronutrient uptake under low substrate pH conditions similar to a poinsettia.

When the substrate pH becomes too high, many species develop interveinal chlorosis (yellowing) on the youngest leaves. This is a common situation that occurs with many greenhouse-grown species (such as petunias) when the elevated pH makes micronutrients, such as Fe, unavailable to the plant, even if adequate levels are provided in the fertilizer.

We did not observe symptomology of interveinal chlorosis in cannabis plants grown at pH 7.0 in our initial experiments at NCSU, either. Iron uptake can also be hindered by over-irrigation, cold substrate temperatures or root disease such as Pythium. In other experiments at NCSU, we did observe the development of interveinal chlorosis on plants with a pH of 7.8. This observation provides more refinement of the upper pH limit and would suggest that the pH should be lower than 7.5.

The preliminary results of NCSU's research imply that vegetative stock plants of cannabis have a wide substrate pH range in which the plants will optimally grow. That range appears to be as wide as pH 5.0 to 7.0. Based on experience with other species, a narrower range of 5.5 to 6.5 may be more appropriate to target, as this will allow growers to more easily adjust as pH approaches the ends of the targeted range.

For growers, utilizing these pH values in a monitoring system such as the PourThru method implies that the safe pH zone to target would be a narrower 5.8 to 6.2. If pH drops below 5.8 or above 6.2, corrective procedures should begin to adjust the pH back into the 5.8 to 6.2 range.

(Note: These values are for plants grown in greenhouse conditions with a soilless substrate (growing medium). Optimal ranges for field-based growing conditions typically would move up the lower and the upper range by 0.5 pH units to 6.2 to 6.7—as field soils latch on to more nutrients than a soilless substrate such as peat or coir, and risk of nutrient lock-up is lessened.)

How to Correct pH

Again, when the pH drifts into unwanted territory, adjustments must be made. Below are standard corrective procedures used to modify substrate pH for plants grown in soilless substrates in greenhouses and adapted for cannabis.

1. Low Substrate pH Correction

When Fe toxicity and Mn toxicity become a problem, raise substrate pH to the recommended pH range. Corrective procedures to raise low pH levels are listed on p. 6. Switching to an alkaline fertilizer when substrate pH is nearing the lower limit will help stabilize the pH.

Flowable Lime

To make small adjustments of roughly 0.5 pH units, mix 1 to 2 quarts of flowable lime per

100 gallons of water. If using an injector, avoid using higher concentrations of flowable lime as it will damage it. If higher rates are needed, then split your applications to avoid damaging your injector. To avoid leaf burn, it is best to rinse the foliage after treatment if any flowable lime comes in contact with the leaves.

Hydrated Lime
For more stubborn low-pH problems, use a hydrated lime mixture. Mix 1 pound of hydrated lime in 3 to 5 gallons of warm water. Mix it twice and let it settle after each mixing. Once the sediment collects in the bottom of the container, pour the liquid through your injector system set at a 1:15 ratio. This product is corrosive, so rinse the foliage as soon as possible to avoid leaf burn, and avoid skin contact.

Potassium Bicarbonate ($KHCO_3$)
Potassium bicarbonate should be handled with care. It can throw off your substrate chemistry as it provides 993 ppm of potassium (K) in mixtures of 2 pounds per 100 gallons of water. Rinse the foliage immediately after application via injectors and leach heavily the following day with a complete fertilizer to reduce substrate electrical conductivity (EC) and restore nutrient balance. The 2-pound rate will increase the substrate pH by roughly 0.8 pH units. Rates greater than 2 pounds per 100 gallons of water can cause phytotoxicity

As always, remember to recheck your substrate pH to determine if reapplications are needed.

2. High Substrate pH Correction

The target pH for cannabis is between 5.8 and 6.2. Higher pH values may result in Fe deficiency and create interveinal chlorosis on upper leaves. Check the substrate pH to determine if it is too high. Be careful when lowering the substrate pH, as low pH can be more problematic and difficult to manage.

Acid-Based Fertilizer
If the substrate pH is beginning to increase, consider switching to an acid-based fertilizer. These ammoniacal nitrogen (N)-based fertilizers are naturally acidic, and plant nitrogen uptake will help moderate the substrate pH over a week or two.

Acid Water Drench
Some growers use this intermediate correction when pH levels are not excessively high and a quick lowering of substrate pH is desired. Sulfuric acid is recommended to acidify irrigation water to a pH 4.0 to 4.5. Apply this acid water as a substrate drench, providing 5 percent to 10 percent excessive leaching of the substrate. Rinse the foliage to avoid phytotoxicity. Results should be visible within five days. Retest the substrate pH and repeat if needed.

Iron Drench
If the levels are excessively high, then a Fe chelate application can be made to the substrate.

- Iron-EDDHA can be mixed at a ratio of 5 ounces per 100 gallons of water.
- Iron-DTPA can be mixed at a ratio of 5 ounces per 100 gallons of water.

- Iron sulfate can be mixed at a ratio of 4 ounces to 8 ounces per 100 gallons of water.

Apply the iron as a substrate drench with enough volume to leach the pot, and rinse the foliage immediately after application.

Conclusions

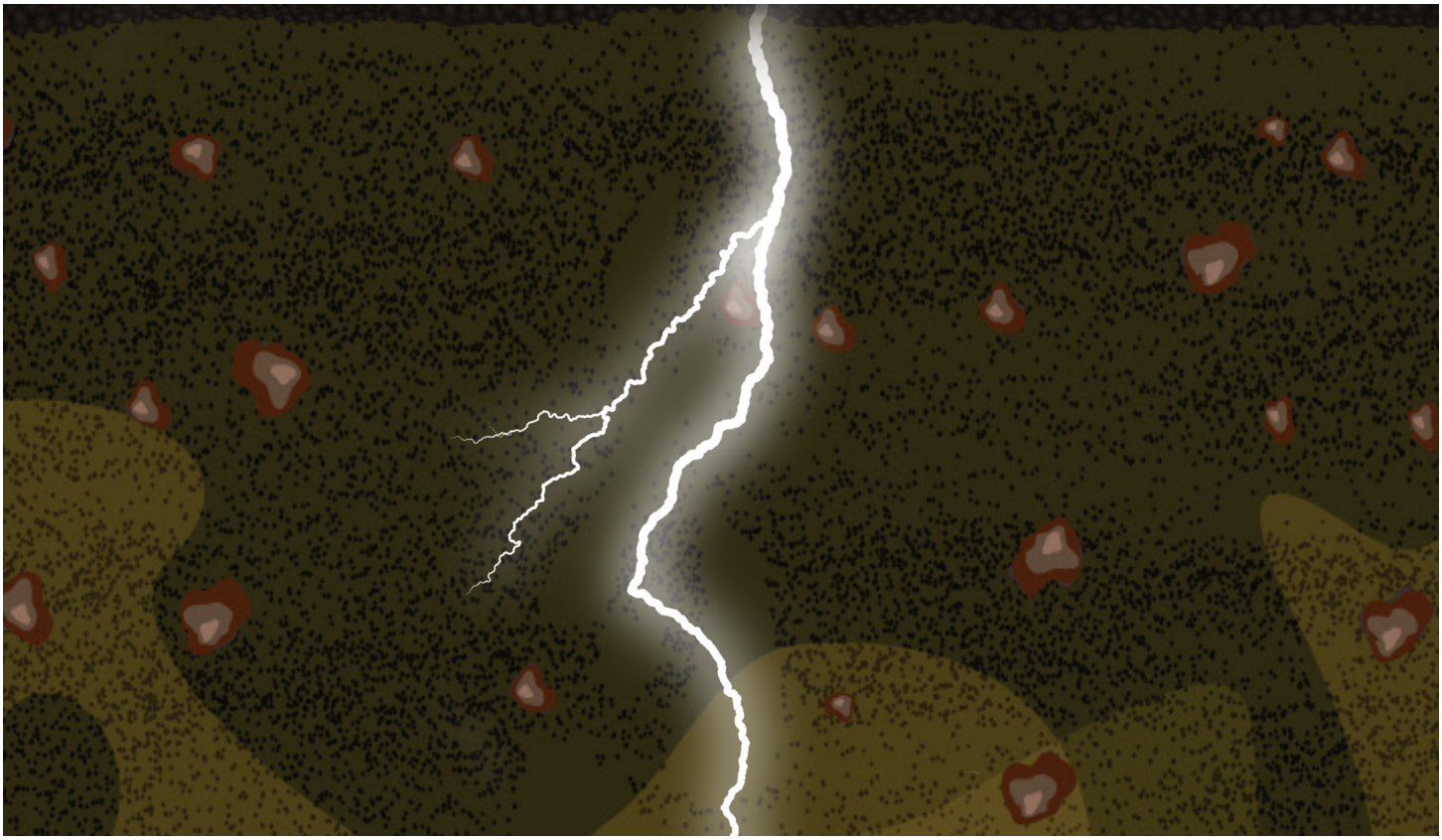
Based on grower observations and initial experiments at NCSU, it is possible to grow cannabis with a wider soilless substrate pH range than most other species. Cannabis plants do not appear prone to develop leaf symptomology when substrate pH is too low or too high compared to the current general greenhouse standards—only plant stunting occurs at sub-optimal conditions.

Therefore, based on research and experience with other species, a wider range of 5.5 to 6.5 may be used. When adapting these values to a monitoring system, the recommended pH zone to target would be 5.8 to 6.2. By monitoring the substrate pH over time, one can assure that plants are within the optimal range.

Optimizing Electrical Conductivity (EC) in Cannabis Cultivation

How solution and substrate EC can beused to enhance cannabis growth.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



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For controlled-environment-grown crops, substrate pH and electrical conductivity (EC) are two main factors that can easily be monitored to make sure your crop is on track for success. This monitoring principle has been used by the commercial floriculture industry for the past 40 years, and it can be adopted by the cannabis (*Cannabis sativa*) industry, too. Monitoring and managing the substrate pH and EC could help to avoid up to 80 percent of the plant nutrition problems that occur with controlled environment crops. In this chapter, we'll discuss what EC is, why it's so significant to crop health and how to measure it.

What is EC?

Electrical conductivity is the electrical charge that moves through a solution. The higher the salt concentration, the greater the electrical reading. This principle is applied to controlled environment production because the higher the concentration of fertilizer salts in the solution or in the substrate, the higher the EC reading will be. We can then monitor

the EC level to ensure that fertility levels are where they need to be.

What EC Does (and Doesn't) Measure

The EC is a measurement of the total amount of fertilizer salts in the solution. It does not provide specific information about each individual element or that individual element's concentration in solution.

The good news is that with controlled environment production, the primary nutrients we provide are nitrogen (N), phosphorus (P) and potassium (K). Therefore, with most cases in both theory and practice, the EC reflects the relative concentration of those elements. You can apply this concept to cannabis to confirm the accuracy of the fertilizer concentration you apply in the solution and to monitor the crop's nutritional status.

Lower-than-optimal EC readings typically indicate a nutrient deficiency, especially low levels of N (Fig. 1). High EC levels can indicate you are supplying too much fertilizer or that your plants are not absorbing the nutrients, both of which can lead to a salt toxicity leaf burn.

Measuring the Fertilizer EC

Doing the Math

If you are using a fertilizer such as 13-2-13 Cal-Mag, the label on the back of the bag provides EC guidelines to help you double-check the accuracy.

For example, if you want to provide 200 ppm of N to the crop from a 13-2-13 Cal-Mag solution, then you would need to mix 20.76 ounces in 100 gallons of water. (This is based on Jack's brand fertilizer. Manufacturers use different salts to achieve a similar analysis, so you need to utilize recommendations on their labels to be correct.) Alternatively, if using an injector set at a 1:100 ratio, that would mean adding 20.76 ounces of Jack's Cal-Mag into a gallon of water to make a concentrate that is then run through the injector. Either way, the corresponding EC of that final diluted fertilizer solution should be at 1.64 millisiemens per centimeter (mS/cm, the unit by which EC is measured), as listed on the

CORRECTIVE PROCEDURES FOR MODIFYING SUBSTRATE EC

When the EC drifts into unwanted territory, adjustments must be made. Below are the standard corrective procedures used to modify the substrate EC for controlled environment plants grown in soilless substrates and adapted for cannabis.

1. Low Substrate EC Correction
If the levels are lower than the recommended range (Fig. 2), this implies the plant's nutrient demand is higher than what is being supplied. In this case, you must increase the fertilizer rate. One or two applications of a higher N rate in the 250-ppm to 400-ppm range will boost the EC.

2. High Substrate EC Correction
EC levels that increase over time indicate the fertilizer is accumulating in the pot and the rate is higher than the demand by the plant. The first step in addressing this is dialing back the fertilizer rate to moderate the accumulation of fertilizer salts. (This also will help save money by not wasting fertilizer solution.)

The second option is to irrigate the plant substrate twice with clear water to leach out the fertilizer salts. This method is used to help avoid plant burn when EC levels are extremely high. It also flushes out your fertilizer investment. Monitoring the crop during production will help you avoid these elevated levels in the first place.



Figure. 1 Lower-leaf chlorosis (yellowing) is a typical indication that nitrogen levels are inadequate and, correspondingly, electrical conductivity (EC) would be below the optimal level.

product's label.

By measuring the EC, you can double-check your mixing procedure and confirm if your fertilizer injector is working accurately.

Accounting for Irrigation Water EC

You must also take into account the EC contribution of your irrigation water. If your irrigation water has high concentrations of alkalinity (calcium (Ca), magnesium (Mg) or sodium (Na)) then when you test the EC of your fertilizer solution or substrate, your values will be artificially elevated, too. When monitoring the fertilizer solution you are supplying to the plants, knowing the EC contribution of your irrigation water is important. This requires that you periodically have your water quality tested by a commercial lab.

In Raleigh, N.C., we have very pure water, and normally the EC is around 0.11 mS/cm. Therefore, we must add the EC contribution of the irrigation water to the EC contribution of the fertilizer to determine the corrected target EC. This would mean the final fertilizer solution EC should be 1.75 mS/cm (1.64mS/cm fertilizer contribution + 0.11 mS/cm water contribution). In contrast, for much of the Midwest, the EC of the irrigation water is much higher. If the water EC was 1.13 mS/cm, the same final fertilizer solution EC would instead be 2.77 mS/cm (1.64 mS/cm fertilizer contribution + 1.13 mS/cm water contribution) to also provide 200 ppm N from a 13-2-13 Cal-Mag fertilizer by Jack's.

Accuracy Check

Your fertilizer solution EC value can be used to check for fertilizer delivery accuracy. If it

PHOTO BY BRIAN WHIPKER

is not within 5 percent, then you need to double-check the mixing math, the accuracy of measuring out the fertilizer salts, or if the injector is malfunctioning. The EC values will be significantly lower as the injector begins to fail, which in turn will slow growth for plants grown in soilless substrates and, under prolonged conditions, cause lower-leaf yellowing due to inadequate fertility.

Hydroponic/Rockwool System
If you are growing a cannabis crop hydroponically or in an inert substrate such as rockwool, you can monitor the fertilizer EC value to ensure you are providing the correct fertilizer concentration.

Measuring the Substrate EC

If you are utilizing a soilless substrate containing sphagnum peat moss or pine bark, you can use another aspect of EC monitoring to make sure your fertilization program is on track.

Begin an In-House Nutrient Monitoring Program
A wide assortment of pH and EC meters is available on the market. At NCSU, we recommend combination pH and EC meters. The majority of growers we work with purchase a unit that costs less than $200.

After purchasing a combination pH and EC meter, you need to start using it! The majority of the commercial floriculture greenhouse industry relies upon the non-

FIG. 2 RECOMMENDED FERTILIZATION RATE AND POURTHRU BY CROP STAGE

DEVELOPMENT STAGE	FERTILIZER RATE (PPM N)	TARGET EC - TOP IRRIGATION (MS/CM)	TARGET EC - SUB-IRRIGATION OR CAPILLARY MAT (MS/CM)
Early Vegetative	100 to 125	1.0 to 1.5	0.67 to 1.0
Late Vegetative	150 to 200	1.5 to 2.0	1.0 to 1.3
Peak Flowering	200 to 225	2.0 to 2.5	1.3 to 1.7
Pre-Harvest	100 to 150	1.5 to 2.0	1.0 to 1.3

destructive PourThru monitoring method to test EC and pH. Weekly or biweekly sampling is the key to ensuring your EC and pH levels are on track. While cannabis-specific recommendations based on scientific research have not been published, sampling procedures (including the PourThru method) can be found at the nutrient monitoring website: **fertdirtandsquirt.com** and general EC guidelines are provided in Fig. 2.

Target Fertilization Rates and EC Levels for Stages of Plant Development

The nutrient demands of plants change over the course of development. Young transplants focus energy on establishing roots and add little leaf growth; as such, they require less fertilizer. As plants grow and bulk up, fertilizer needs increase. The number of leaf and flower nodes on each plant sets when the photoperiod changes and flower formation begins. This terminal inflorescence (flower production) establishes how much more growth will occur. At this stage, the amount of vegetative mass the plant adds is less, yet energy and resources are still required for flower/bud development. With this shift from vegetative growth to flower growth, the nutrient demand lessens. Given how a plant grows and adds mass, and how nutrient demands vary over time, it comes as no surprise that nutrient delivery needs to be customized to meet the changing demands of the crop throughout its different growth stages.

The EC is an indirect measure of the fertilizer salts contained in the substrate, so those target levels will also vary at different growth stages. By starting an in-house nutrient monitoring program and measuring the EC, you can make sure that sufficient levels of fertilizer are available to the plants. Recommended fertility levels and target EC levels based on the stage of cannabis plant development are listed in Fig. 2, as measured by the PourThru method.

Ammoniacal-Nitrogen, Urea and Organic Fertilizer Adjustments

Though measuring the EC is an excellent tool when utilizing water-soluble controlled environment fertilizers, there are limitations to this measurement. When it comes to measuring the contribution of N to the EC, nitrate-nitrogen (NO_3-N) can be measured; however, the other two common forms of nitrogen included in fertilizers—ammoniacal-nitrogen (NH_4-N) and urea—cannot be measured by EC. The EC charts on the fertilizer bag, or provided by the manufacturer, will reflect those lower target EC values. Likewise, most organic fertilizers rely upon ammoniacal-nitrogen (NH_4-N) and urea for their derived sources of N. Be aware of this fact when you are mixing the fertilizer solution. In addition, you must then adjust down the target EC ranges accordingly when testing the substrate EC.

The Bottom Line

Optimizing fertility management is a strategy of supplying the appropriate level of nutrients to cannabis to meet the demands for plant growth. If the supply is too low, then the genetic potential of the plant is hindered because of the deficiency, and the plant will flower less. Elevated fertilizer levels can lead to excessive leaf and shoot development at the expense of flower growth. Excessively high levels of fertilizer in the substrate can also lead to stunted growth.

The good news is that conducting periodic PourThru sampling of both the EC and the pH will help you monitor the nutrient status of your crop to ensure it is on track.

How to Meet the Nitrogen Needs of Cannabis

Here are the N needs of cannabis plants for each life stage, from rooting to flowering.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



RUGGEDCOAST | ADOBE STOCK

Of all the nutrients provided by growers to stimulate plant growth, nitrogen (N) is needed in the largest quantity.

Thus, meeting the N needs of cannabis is central to developing a successful fertilization strategy. Because of the volumetric importance of N, it is not surprising that symptoms of N deficiencies often are the first to manifest during production and are the most common plant health issue growers see. Symptoms of N deficiencies that cannabis plants can exhibit include pale green lower leaves and lower leaf yellowing, and as symptoms progress, necrosis and plant stunting. All of these symptoms occur when the available N supply is inadequate. Symptoms develop on the lower leaves because N is a mobile element. Plants will move (translocate) N from the lower leaves to the growing tip if inadequate levels are provided. On the opposite end of the spectrum, when N levels are excessive, lower leaf marginal necrosis (burn) occurs.

Nitrogen Management

The concentration of nitrogen plants need corresponds with where the plant is in its

development. Here are the N needs of cannabis plants for each life stage, from rooting to flowering.

Rooting

When plants are being propagated as clones, the nutrient reserves in the cutting can be leached out easily with mist or fog. Nutrient reserves could further be depleted if the cutting was taken from an old mother plant, as reserves in stock/mother plants also diminish over time. As such, it is important to supply a dose of essential nutrients to the cuttings to restore the nutrient reserves. Once roots are visible, provide the plants with 50 ppm to 75 ppm of N two to three times per week to help restore the nutrient levels within the cuttings.

Transplant

Smaller clones just transplanted into a container primarily are putting their energy into establishing a root system. Therefore, they require lower levels of N, so beginning a constant liquid fertilization program of 100 ppm to 125 ppm N will help jump-start growth.

Vegetative Fill Out and Pre-Flowering

Once the roots have reached the edge of the pot and the root system has developed, the plant will start producing vegetative growth. During periods of rapid vegetative growth, cannabis plants require a higher concentration of N, so initially you can ramp up N to 150 ppm to 200 ppm for every feeding during the vegetative stage, and then 200 ppm to 225 ppm of N can be used for feedings during the pre-flowering stage. This will help ensure that adequate levels of N are provided as the plant bulks up.

Flowering

As with any plant that has terminal flowers (including poinsettias and chrysanthemums),

RECOMMENDED FERTILIZATION RATE BY CROP STAGE

DEVELOPMENT STAGE	FERTILIZER RATE (PPM N)
Clonal Propagation (roots visible ~day 14)	50 TO 75
Early Vegetative	100 to 125
Late Vegetative	150 to 200
Pre-Flowering	200 to 225
Peak-Flowering	100 to 150



With advanced nitrogen (N) deficiency symptoms, the lower leaves will turn from a yellow coloration to a brown coloration, and finally necrotic.

the nutrient demands of a cannabis plant peaks and then decreases throughout the flower period. This makes sense: If the plant is not growing as rapidly, as one can easily measure by the change in plant dry weight, then the amount of N supplied should be dialed back. Thus, a lower level of 100 ppm to 150 ppm of N should be applied at every feeding during peak flowering.

Conducting in-house monitoring of the electrical conductivity (EC) in the substrate (as discussed in the "Nutrient Matters" article in the April issue of *Cannabis Business Times*) will help ensure that the nutrient levels are adequate, and not limiting or excessive.

Corrective Procedures

A straightforward procedure exists to correct an N deficiency: Simply increase the N supply for one or two applications to help restore the N reserves in the plant. Applying 300 ppm to 400 ppm of N from a balanced fertilizer such as 13-2-13 Cal-Mag will provide all the essential nutrients to the plant. Other alternative complete fertilizers include 17-4-17 Cal-Mag, 17-5-17 Cal-Mag, or 15-5-15 Cal-Mag.

Another option to consider is a dark-weather feed (15-0-15) if only N, potassium K, and calcium Ca are desired. If a higher ammoniacal nitrogen (NH_4-N) concentration and higher phosphorus concentration are desired to boost vegetative growth and fill out, then a fertilizer such as 20-10-20 can be applied. Apply these corrective procedures as a 10-percent flow-through leaching irrigation if the plants are grown in pots. This will stop the progression of deficiency symptoms, but will not reverse any severely affected chlorotic or necrotic leaves.

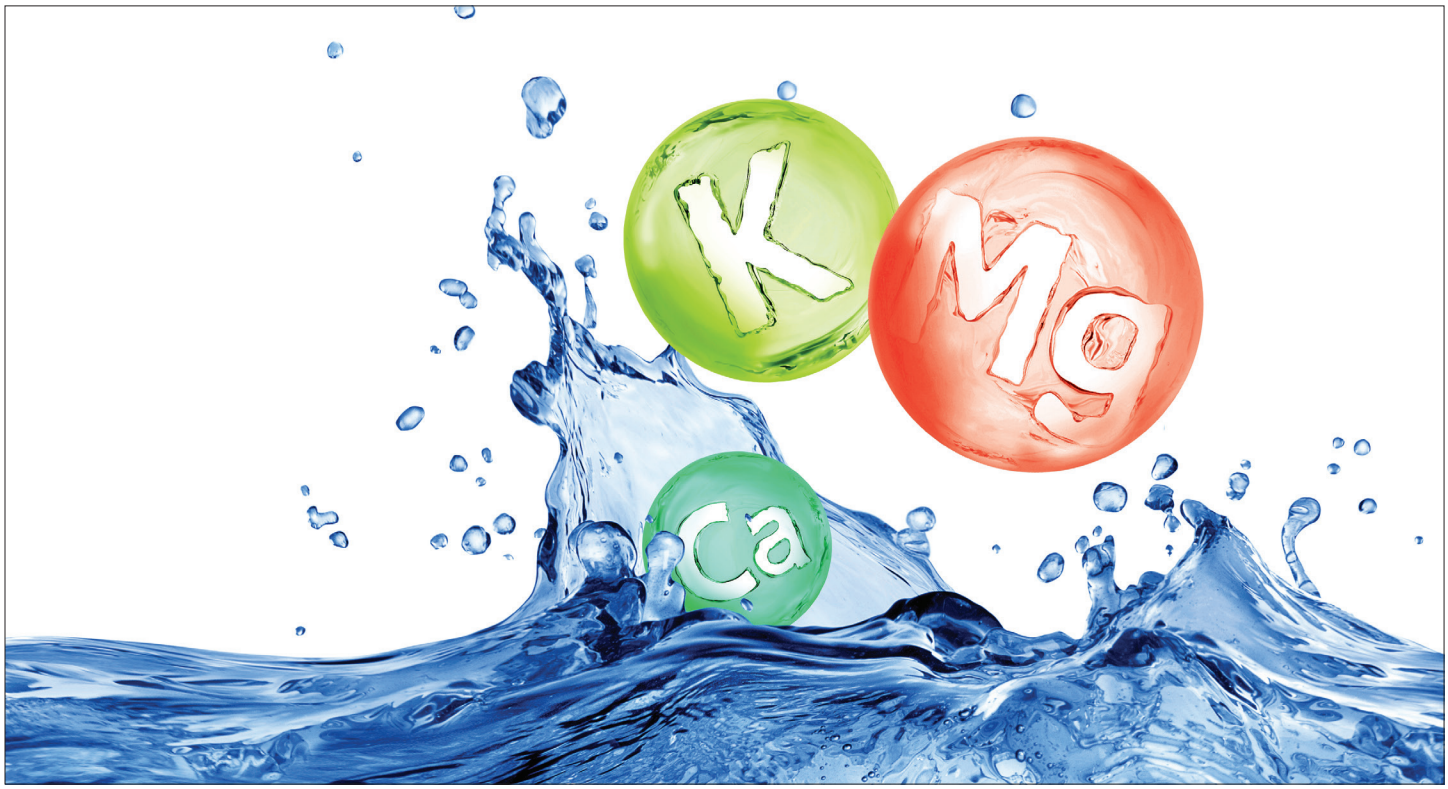
Having a balanced fertility program at the target N levels during each stage of production will help ensure that your cannabis plants have adequate nutrients and will help avoid the development of lower leaf yellowing.

PHOTO BY BRIAN WHIPKER

Magnesium: Part of a Balanced Cannabis Diet

Ensure your plants get the right amount of this essential nutrient to prevent lower-leaf interveinal chlorosis.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



KRAFLA | ISTOCKPHOTO

Magnesium (Mg) is sometimes a forgotten element.

In the many areas of North America that rest on limestone bedrock, adequate Mg is available in the groundwater used for irrigation. Concentrations of 25 to 50 ppm Mg are often available and provide adequate levels for plant growth for most plant species. In addition, supplemental Mg is also supplied via the dolomitic limestone used to adjust the substrate pH. But not all growing locations are blessed with a supply of Mg.

Magnesium deficiencies can occur due to a number of factors. In areas without Mg in the irrigation water, of course the free Mg source is lacking. We have observed in these locations with floriculture species that the level of Mg supplied by the dolomitic limestone will provide adequate levels of Mg through 50 percent to 75 percent of the season. After that time, leaf symptoms begin to develop. This is especially true during warm springs when the plants are irrigated more frequently and the Mg is most likely leached from the substrate.

For cannabis, it is common to observe mother stock plants exhibiting this



Figure 1. Typical symptomology of a magnesium (Mg) deficiency in cannabis is interveinal chlorosis (yellowing) of the lower leaves.

symptomology. This may be because the mother plants typically have a larger root system, and consequently, these plants have a higher water demand. Thus, the increased amount of irrigation applied to these plants may cause excess leaching of Mg from the substrate, resulting in the interveinal chlorosis we encounter on a regular basis in mother stock operations.

Magnesium uptake is also affected by the presence of other elements. In general, a nutrient balance is obtained by targeting a 4:2:1 ratio of potassium (K) to calcium (Ca) and Mg. This helps avoid antagonisms among these elements. For example, if one element is excessive in the nutrient solution, then that can limit the plant's ability to uptake adequate levels of the other two nutrients. Antagonistic situations commonly are observed with crops such as tomatoes, in which high levels of Ca are provided to avoid blossom end rot, or with geraniums, in which high levels of dolomitic limestone or flowable lime are added to avoid a substrate pH drop. Elevated levels of Ca limit the uptake of Mg, and these plants often develop deficiency symptoms.

Magnesium Deficiency Symptoms

Cannabis (*Cannabis sativa*) plants often develop interveinal chlorosis (yellowing) on the lower leaves (Fig. 1). A few areas of the leaves develop a slight interveinal chlorosis (Fig. 2a), which expands over time (Fig. 2b). With advanced symptoms, necrotic (brown) spotting will develop (Fig. 2c). These symptoms are associated with Mg deficiency. Symptoms have been observed in greenhouses in locations without Mg in the irrigation water supply as one would expect, but it is also common to observe symptomology in areas with moderate levels of Mg in the water. This leads to the conclusion that cannabis,

PHOTOS BY BRIAN WHIPKER



Figure 2. The initial symptom of a magnesium (Mg) deficiency begins as slight interveinal chlorosis (yellowing) of the lower leaves (a), which becomes more pronounced in yellowing (b), and then progresses to necrotic spotting (c).

similar to tomatoes and poinsettias, has a higher demand for Mg than most plant species. In general, the Mg leaf tissue sufficiency range for cannabis is between 0.40 percent to 0.81 percent, as suggested by Bryson and Mills in the "Plant Analysis Handbook IV."

Corrective Procedures

The fix for a Mg deficiency is easy. Epsom salts (magnesium sulfate) can be applied at the rate of 2 pounds per 100 gallons of water (2.4 kg/1000L). Apply this as a 5 percent to 10 percent flow-through leaching irrigation. This will stop the progression of symptoms, but will not reverse any interveinal leaf chlorosis or necrotic spotting. For areas that lack sufficient Mg in their irrigation water, and Mg is not part of the regular fertilization program (i.e., 20-10-20 does not contain Mg), monthly applications of Epsom salts at the rate of 1 pound per 100 gallons of water (1.2 kg/1000L) is the common production practice to green up plants and avoid deficiencies. (Also, note that mixing Epsom salts with Ca-based fertilizers will result in an insoluble precipitate forming in the fertilizer container, and should be avoided.)

Conclusions

Symptoms of Mg deficiency readily develop on cannabis because, as noted earlier, cannabis has a higher demand for Mg than most other species. Therefore, growers may need to increase the amount of Mg available from the irrigation water by providing supplemental Mg to the plants as needed to avoid the development of deficiency symptoms.

PHOTOS BY BRIAN WHIPKER

Understanding Sulfur Deficiency Issues in Cannabis Cultivation

Double your benefits with sulfur.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS

FIG. 1



The pattern of how the chlorosis (yellowing) begins at the leaf base and then works toward the leaf tip can be used as an aid in diagnosing a sulfur (S) deficiency.

PHOTO BY PAUL COCKSON

While magnesium (Mg) is sometimes a forgotten element, sulfur (S) is actually ignored. Few fertilizer bags even list the amount of S provided. Typically, it is only listed as an ingredient, and the main amount of S supplied is from the associated sulfate (-SO_4) attached to the micronutrients. This low amount provided as part of the micronutrients is generally insufficient to meet plant demands.

One reason S has not received much attention is because atmospheric S has been readily available due to the burning of high sulfur coal. In the 1966 book, "Sand and Water



Figure 2. The initial symptom of a sulfur (S) deficiency begins as a slight chlorosis (yellowing) of the mid-section leaves (A), which becomes more pronounced in yellowing (B), and then gives an overall yellowing (C).

Culture Methods Used in the Study of Plant Nutrition," author E.J. Hewitt states that in the United Kingdom, S deficiencies are rarely seen within close proximity to cities or towns due to the use of household coal-burning heating units. With the increased use of low-S containing coal and natural gas for electricity generation, the amount of atmospheric S available to plants is diminishing. To compensate for this shift, agricultural applications of S-containing fertilizers such as potassium sulfate ($K2SO_4$), calcium sulfate ($CaSO_4$), and magnesium sulfate heptahydrate ($MgSO_4.7H_2O$) have increased.

With greenhouse cannabis production, we require fertilizers to be readily water soluble. Sulfate-based fertilizers such as K_2SO_4, $CaSO_4$ and $MgSO_4.7H_2O$ easily precipitate out of solution into insoluble forms. The primary culprit is $CaSO_4$, which is gypsum and commonly used as wallboard in building construction. So the S fertilization strategy must be customized to meet the demands of the greenhouse environment.

Evaluate Your Fertilizer Program

The first step in determining if you are providing enough S is to evaluate your fertilization program. Sufficient levels of S usually are not provided by the irrigation water. (In most cases this is ideal, for S in the hydrogen sulfide form (H_2S) is associated with the rotten egg smell.) Ideally, fertilizer and the corresponding substrate S levels should be in the 50 to 200 ppm range. Assuming the availability of a baseline level of atmospheric S, the critical lower target range should be above 25 ppm S. Higher levels of S generally are considered to be non-toxic, but there is a limit above ~300 ppm. Elevated S levels can inhibit the plant's ability to uptake both boron (B) and molybdenum (Mo). The key for

PHOTO BY PAUL COCKSON



Figure 3. Plant growth is also affected when sulfur (S) is limited (left plant as compared with the complete control plant at the right).

plant nutrition is balancing all the factors that impact uptake to optimize growth.

Because S concentrations are typically not listed on most fertilizer bags, you will need to send a fertilizer solution sample to a commercial lab to obtain a complete analysis of the S and the other elements contained in your fertilizer.

Sulfur Deficiency Symptoms

Cannabis (*Cannabis sativa*) plants can develop symptoms of S deficiency, but the occurrence is much lower than, say, a nitrogen (N) deficiency. Sulfur and N deficiencies have very similar leaf symptomology. The key is observing where on the plant the symptoms first appear. Nitrogen is a mobile element, which means when the plant senses that N is low, it will remobilize N from the older leaves to the younger growth. That is why N deficiency symptomology of total leaf chlorosis (yellowing) initially appears on the older, lower leaves. (Note: With advanced N deficiencies, the symptomology will work its way up the stem into the middle section of the plant, which can confuse the diagnosis.)

Sulfur is a partially mobile element. In most S-deficiency situations, symptoms of leaf yellowing will appear in the middle section of the plant on the recently matured stage of leaves (Fig. 4). This is the case when N is also amply provided. If at the same time, N levels are inadequate, S deficiency symptomology can overlap in lower portions of the plant in the same region where N symptomology will appear. This makes diagnosing the situation more challenging and reinforces the need to submit a tissue sample to a commercial lab

PHOTO BY PAUL COCKSON



Figure 4. Typical symptomology of a sulfur (S) deficiency appearing in cannabis as chlorosis (yellowing) of the middle leaves.

for complete nutrient analysis to confirm your diagnosis.

The typical progression of S symptomology begins as an overall pale discoloration of the middle zone leaves (Fig. 2A). This yellowing is associated with a drastic decrease in chlorophyll concentration in the leaf due to the plant's inability to synthesize key amino acids. The pattern of how the chlorosis first appears on the leaf will aid in diagnosing S deficiency. Typically chlorosis first appears at the leaf base and progresses outwards toward the leaf tip (Fig. 1). As symptoms progress, the overall level of yellowing intensifies (Fig. 2B&C). With advanced conditions, due to the lack of chlorophyll, sun burning of the leaves will result in the appearance of necrotic spots. Plant growth will also be stunted (Fig. 3). In general, the S sufficiency range for cannabis is between 0.17 percent to 0.26 percent as suggested by Bryson and Mills in "Plant Analysis Handbook IV."

PHOTO BY BRIAN WHIPKER

ANOTHER OPTION: SULFUR EVAPORATORS

A very efficient method of providing sulfur (S) to plants is via the atmosphere. Plants readily absorb S via the openings in the underside of the leaves (stomates). This has been done with a sulfur evaporator for the past 100 years with greenhouse cut flowers. It works by heating the elemental sulfur pellets until they are vaporized, and the vapor is allowed to diffuse throughout the greenhouse.

To be effective, this is done at night when the greenhouse exhaust fans are not operating. Breathing the vapor should also be avoided; it can irritate skin, eyes, nose, throat and lungs, and cause "an asthma-like allergy," according to the New Jersey Department of Health. Because of these two factors, most sulfur evaporators are synchronized with the night interruption lighting that runs from 10 p.m. to 2 a.m. This way, the vapor can be made available to the plants, and then around sunrise, the greenhouse can be adequately ventilated to provide a complete air exchange.

Another added benefit besides providing S fertilization to cannabis plants is that evaporated S is very effective in preventing powdery mildew. In our research greenhouses at North Carolina State University, we have healthy green plants and have eliminated our powdery mildew problems, too, as illustrated in the photo. Please read and follow the instructions and precautions provided by the manufacturer before use.

IMPORTANT NOTE: It is uncertain if the corrosive nature of the vaporized S can be used within enclosed indoor growing operations.

Corrective Procedures

The fix for S deficiency is easy. Epsom salts (magnesium sulfate) can be applied at the rate of 2 pounds per 100 gallons of water (2.4 kg/1000L). Apply this as a 5 percent to 10 percent flow-through leaching irrigation. This will stop symptom progression but will not reverse any severe leaf chlorosis or necrotic spotting. For regions that lack sufficient S in irrigation water and S is not part of the regular fertilization program (i.e., 20-10-20 does not contain significant amounts of S), monthly applications of Epsom salts at the rate of 1 pound per 100 gallons of water (1.2 kg/1000L) is the common production practice to green up plants and avoid deficiencies. (Also note, avoid mixing Epsom salts with calcium (Ca)-based fertilizers, as this will result in an insoluble precipitate forming in the fertilizer container.)

Conclusions

Symptoms of S deficiency readily develop on cannabis. Growers need to increase the amount of S available from the irrigation water, and provide supplemental S to the plants as needed to avoid further deficiencies.

Troubleshoot Cannabis Nutrient Problems Before They Occur

Obtain baseline stats and prevent issues with PourThru monitoring.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



MICHAEL NOSEK | ADOBE STOCK

Fertility management can be challenging for many crops. Multiple steps and variables can occur along the fertility chain between plumbing and plant. For example, you may be providing enough iron (Fe) to your plants, but due to a higher or more alkaline pH of your growing substrate, that iron may not be available to the plant.

To ensure you provide plants the required fertility, a nutrient monitoring program should be implemented. One of the most useful nutrient monitoring techniques is the PourThru method, which allows growers to analyze the solution in the plant container and to troubleshoot potential problems by displacing a small portion of the solution in the plant container for analysis. This leachate then will be analyzed for pH and electrical conductivity (EC). These two metrics reveal the total quantity of dissolved fertilizer ions in the pot solution (EC) and how those ions will be available to the plant (pH).



How It Works

The PourThru nutrient monitoring system consists of eight simple steps.

1. Irrigate the crop. In order to displace some of the solution within the pot, there must be sufficient liquid in the pot so that when you add more, a small portion of the liquid leaches out. To complete this step, irrigate your plants thoroughly so they are almost saturated.

It is important that your monitoring program includes about three to five plants per zone in your greenhouse or indoor operation. A zone is defined as a distinct region, climate or growing condition. Zones or units could also be composed of different cultivars. For example, if you have a cultivar that produces a lot of biomass and another cultivar that is more compact, you would want to sample each cultivar separately to ensure that each crop is being provided the nutrients it needs. The smaller cultivar could have a higher EC due to a lower use of fertilizer ions, while the larger cultivar could experience nutrient shortages due to more biomass production.

2. Let the irrigation solution settle. After irrigating your crops, allow the solution to settle for about 30 minutes so the added solution distributes in the pot. Think of this step as letting the solution equalize throughout the pot. When you irrigate, you are applying a greater concentration of ions to the pot. The solution in the pot has a lesser concentration of ions due to plant uptake. By waiting after irrigation, you allow the new ions to evenly distribute through the pot profile. This step ensures an accurate reading.

3. Calibrate your meter. Next, calibrate your pH and EC meter. The readings are only as accurate as your last meter calibration. Many meters are available on the market;

FIGURES 1, 3-7 COURTESY OF BRIAN WHIPKER; FIGURE 2: MIJUN | ADOBE STOCK

TABLE 1. SUBSTRATE PH

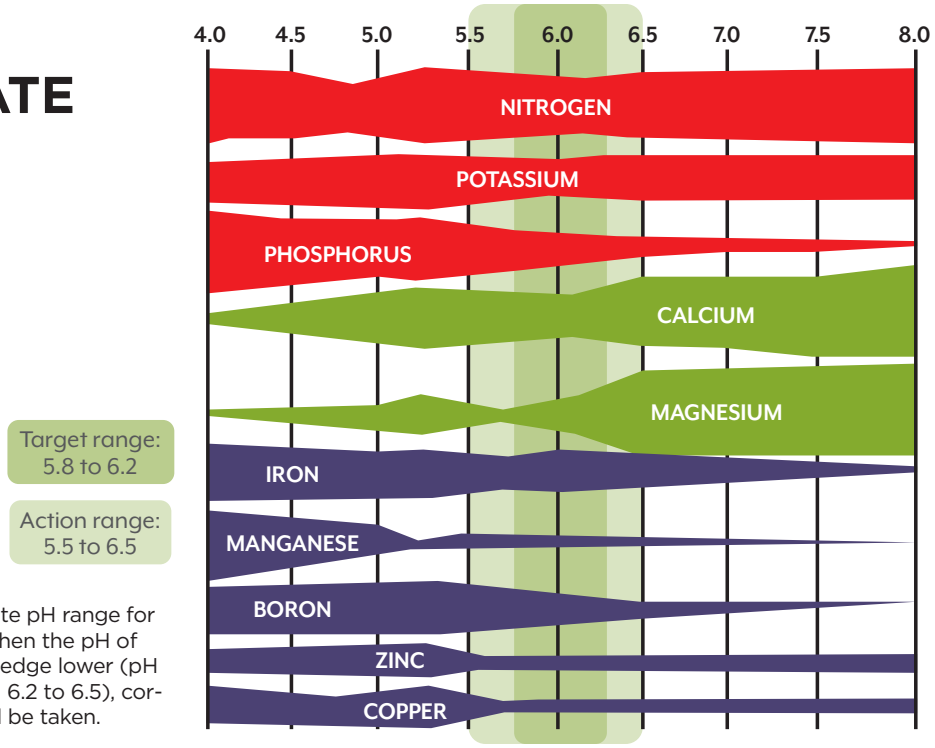


Table 1. Optimal substrate pH range for cannabis (5.8 to 6.2). When the pH of your containers start to edge lower (pH 5.5 to 5.8) or higher (pH 6.2 to 6.5), corrective measures should be taken.

however, any meter you purchase should have both a pH and EC function. Consult your manufacturer or your manual for instructions on how to calibrate the instrument.

4. Place a saucer underneath. You will need to place something under your containers, such as a plastic plate or a houseplant saucer, to catch the solution you will displace from the pot. The saucer should be able to hold 100 mL to 200 mL of solution. For analysis, you will need 50 mL to 100 mL of solution, so ensure your saucer has a greater capacity than what you need.

5. Apply more liquid to your pot. The pot should already be saturated, and the solution equalized through the container profile. When you add more liquid to the pot, a small volume of the container solution will be displaced. Use deionized water (DI) or distilled water if your irrigation water is not pure. This ensures that the solution you are adding to the container does not contaminate the results. Add 200 mL to 500 mL of DI or distilled water per container. Larger pots may require more solution. For larger or odd-shaped containers, add 100 mL of liquid at a time until enough leachate is obtained (50 mL to 100 mL) .

6. Collect the leachate. Next, you will obtain your leachate sample for analysis. There should be a small amount of displaced liquid from the container in the plate or saucer. Again, you will need about 50 mL to 100 mL of solution for an accurate reading. Collect the solution in a cup or container large enough to submerge the diode on your pH/EC meter. Do not lose or discard this solution before you are done, as you will analyze it in the next steps.

7. Analyze your leachate. Now that you have the leachate in a cup or container, it is

time to analyze it. Follow the instructions on your meter to obtain both your pH and EC measurement. For the most accurate results, ensure the numbers on your meter reach a stable reading.

8. Interpret your results. You should have two numbers from your unit. The first will be a pH reading. The optimal pH for cannabis can be found in Table 1. The optimal EC for cannabis can be found in Table 2.

Corrective Procedures

Before making any corrective measures, determine if the values are outside of the acceptable ranges (Tables 1 and 2). If the EC or pH values have drifted out of the acceptable range, then take corrective measures to ensure that the fertility program is back on track. As always, remember to recheck your substrate pH and EC within a few days to determine if reapplications are needed.

Summary

By monitoring your pH and EC through a PourThru program, you will be able to catch nutrient accumulations before they become an issue. This will not only save you time but will also allow you to provide nutrients in a more precise and economical fashion.

TABLE 2. RECOMMENDED FERTILIZATION RATE AND POURTHRU BY CROP STAGE

DEVELOPMENT STAGE	FERTILIZER RATE (PPM N)	TARGET EC - TOP IRRIGATION (MS/CM)	TARGET EC - SUB-IRRIGATION OR CAPILLARY MAT (MS/CM)
Early Vegetative	100 to 125	1.0 to 1.5	0.67 to 1.0
Late Vegetative	150 to 200	1.5 to 2.0	1.0 to 1.3
Peak Flowering	200 to 225	2.0 to 2.5	1.3 to 1.7
Pre-Harvest	100 to 150	1.5 to 2.0	1.0 to 1.3

Table 2. Optimal electrical conductivity (EC) PourThru values for cannabis at different stages of development. When the EC readings of your containers start to edge onto either extreme, corrective measures should be taken. EC Values vary with irrigation method (top versus sub-irrigation).

Balancing the Nutrient Equation in Cannabis Cultivation

Essential considerations for providing complete cannabis fertilization.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



ALPHASPIRIT; OLEKSANDRUM | ADOBE STOCK

How many times have we heard that a balanced diet is essential to our health? Plant nutrition isn't much different. Cannabis plants can thrive or struggle depending on how you design your fertilization programs. Plants require 17 essential elements for growth. They obtain hydrogen (H), oxygen (O), and carbon (C) from irrigation water or as a gas via the atmosphere. Growers must provide the remaining 14 elements to help cannabis plants thrive.

These include the macroelements:

- nitrogen (N)
- phosphorus (P)
- potassium (K)
- calcium (Ca)

- magnesium (Mg) and
- sulfur (S).

And they also include the microelements:
- boron (B)
- chlorine (Cl)
- copper (Cu)
- iron (Fe)
- manganese (Mn)
- molybdenum (Mo)
- nickel (Ni) and
- zinc (Zn).

The quantity of macroelements and microelements required varies by type of plant, but they are all required by the plant for growth.

Cobalt (Co), selenium (Se), silicon (Si) and sodium (Na) are four beneficial elements that promote plant growth but are not considered necessary to complete the plant life cycle. With cannabis production, many growers are providing Si to promote overall plant health.

Providing a complete fertilizer package that contains all the essential elements is important to maximize plant growth. When designing a fertility program, it is also important to keep in mind some key principles that ensure there is a nutritional balance. Just like with human health, where we must balance our intake of carbohydrates, protein, fats, vitamins and minerals, too much of one item can lead to imbalances in the plant due to antagonistic effects. For example, if too much P is provided, it can hinder the uptake of other elements and lead to Fe, Mn and Zn deficiencies.

Key Considerations

Nitrogen Form. Nitrogen in fertilizers primarily comes from three sources. Nitrate-nitrogen is the main form the commercial floriculture greenhouse industry uses for its plants. While the cost is higher, it's the preferred form of N because it promotes compact plant growth. In the cannabis industry, the market currently lacks plant growth regulators registered for use on cannabis, so you can opt for nitrate as a source for N to help avoid excessive overgrowth, also known as plant stretch.

The other two forms of N contained in most fertilizers are ammoniacal nitrogen and urea. Many organic fertilizers have N in these forms. In commercial floriculture greenhouse production, these two forms of nitrogen are strategically deployed but are only used to a limited extent. Many growers will use ammoniacal nitrogen and urea-based fertilizers during the first two weeks after plants have been transplanted into the final container to help establish the plants and encourage a flush of new growth. After that point, most growers rely upon a nitrate-nitrogen based fertilizer.

The key takeaway here is to supply most of your N from nitrate-nitrogen. Do an evaluation of your fertilizer type by reading the fertilizer label to ensure the N form you are providing is on target.



Figure 1. Understanding P Rates. The response of Alternanthera (pictured) to increasing concentrations of phosphorus (P) from 0, 5, 10, 20 or 40 ppm (left to right). Phosphorus concentration can be used to control excessive plant growth, but adequate levels must be provided to avoid deficiency situations.

Moderating P Applications. Phosphorous fertilization strategies have been studied extensively over the past five years. One of our graduate students, Josh Henry, worked on optimizing P fertilization rates for his master's degree thesis. In essence, plants require a baseline level of P to grow adequately (Fig. 1). For a continuous fertilization program for plants grown in a soilless substrate, the target concentration is between 8 ppm and 15 ppm of P. Providing levels below that will result in less plant growth, while concentrations above that level provide little benefit while costing more money. Phosphorus is also the primary contributor to plant stretch. Too much P will lead to excessive internode elongation and tall plants. That's why it's important to limit excessive P applications.

Plant nutrition experts are currently debating whether the P rate needs to be amplified just before flowering in cannabis to improve quality. Research led by Manitoba crop nutrition specialist John Heard on a dual-purpose hemp crop grown for seed and fiber suggests that extra P is not required by cannabis (Fig. 2).

The researchers found that hemp plants front-end load P during the first half of the growing season as seen with the plant's upward accumulation of P. At midseason, the total accumulation in the plant plateaus. This indicates that the plant uptakes limited additional P. Hemp relies upon those internal P reserves and translocates (moves) P if it is required in other parts of the plant. This suggests that adequate P levels should be provided to cannabis during the first half of the production cycle for the plant to accumulate an adequate reserve that can be translocated if needed later. Providing a P boost late in the growing season appears to not be needed. There is a need to conduct a scientifically based trial to clear up this uncertainty with greenhouse-grown cannabis.

PHOTO BY BRIAN WHIPKER

FIG. 2: CANNABIS P ACCUMULATION

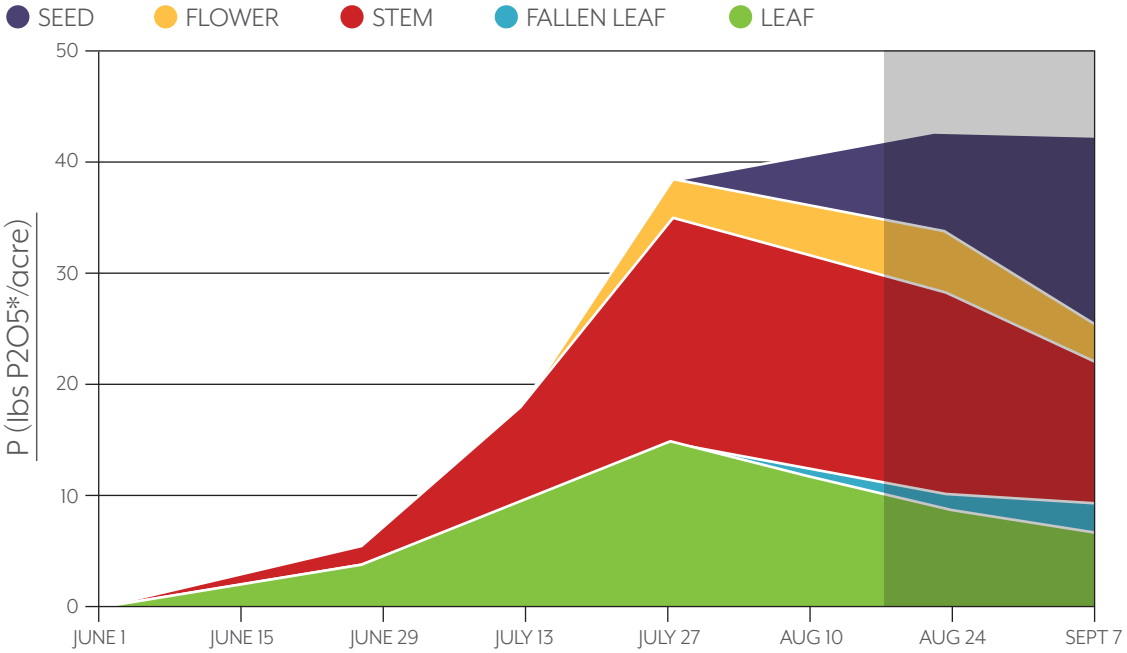


Figure 2: The uptake of phosphorus (P) by a dual-purpose hemp crop grown for seed and fiber. The illustration is modified from work conducted by Heard et al. in Manitoba, Canada. The gray box area represents the start of long nights and corresponding reproductive growth, which is assumed to occur with >9.5-hour night lengths in Winnipeg, Manitoba, starting around Aug. 15. Accumulation of P into the seed and during seed maturity would not apply to greenhouse-grown cannabis plants; therefore, higher levels of P should not be required. This brings into question the need to increase P applications during late flowering of greenhouse-grown cannabis crops. *Phosphorus pentoxide "Nutrient uptake and partitioning in industrial hemp." J. Heard et al., Manitoba, Canada

While the target level of P required by greenhouse-grown cannabis is not currently known, we would speculate based on the scientific data from other species that levels of 15 ppm to 20 ppm P supplied on a constant basis should be all that is required. At North Carolina State University, we have begun an experiment looking into optimal P rates supplied at a constant level throughout the cannabis crop cycle and will be able to further refine those recommendations in the near future.

Ratio of K to Ca to Mg. Providing the proper balance of K to Ca to Mg is important for greenhouse production of cannabis. Too much of one element does not in itself result in toxicity symptoms. Instead, excessive levels of one element has an antagonism against the others. For instance, excessive K will result in either a Ca deficiency or an Mg deficiency being observed in a plant. Many instances of Mg deficiency observed in cannabis may be due to excessive K being supplied and not due to the lack of available Mg to the plant. Figure 3 illustrates the trend that is observed in the leaf tissue concentration of a plant when K is excessive.

For cannabis, K, Ca and Mg all appear to be needed in larger quantities compared to other greenhouse floriculture species. In general, the rule is provide K, Ca and Mg in a 4:2:1 ratio to avoid antagonisms. For commercial poinsettia production, we recommend a similar ratio around 200 ppm K to 100 ppm Ca to 50 ppm Mg; this would be a good

starting point for cannabis (which, like poinsettias, is a short-day plant) until scientifically based research can determine optimal rates. Also, keep in mind that excessive sodium (Na), which can come from your fertilizer source or irrigation water, can also interfere in K, Ca and Mg uptake.

Dialing in the Micros. Managing microelements can be a challenge in most fertilizer programs. The concentration difference from deficient to adequate to excessive rates is very narrow. Until you become comfortable mixing your own micronutrient fertilizer salts, it's safer to rely upon premixed micronutrient packages or the micros provided in commercial fertilizer blends.

All in Balance. Providing all the essential elements is the key to optimizing plant growth. Equally important is balancing the proportion of elements provided to cannabis so plants remain healthy.

How to Control Alkalinity in Greenhouse-Grown Cannabis

Several options exist for neutralizing excess alkalinity to prevent pH creep.

BY BRIAN WHIPKER, JAMES T. SMITH, PAUL COCKSON, AND HUNTER LANDIS



SERGEY | ADOBE STOCK

We're typically cautious about what's in our drinking water, but how often do we think about the water our plants are consuming? The pH and alkalinity of your irrigation water can have a dramatic effect on the substrate pH and, consequently, plant production. That's why testing your irrigation water is important.

pH is a measurement of the relative hydrogen (H+) ion concentration in the water. By itself, it has only a minimal influence on your substrate pH. Alkalinity levels, on the other hand, can quickly influence the substrate environment and nutrient availability. Alkalinity is a measurement of the carbonate concentration in the irrigation water. The relative concentration of carbonate species—carbonates (CO_3^{2-}), bicarbonates (HCO_3^-), and carbonic acid (H_2CO_3)—is the main buffering system controlling irrigation water pH and substrate solution pH. If the irrigation water contains a high concentration

of carbonates and bicarbonates, the substrate solution pH can rise to undesirable levels for cannabis production.

Bicarbonates are not thought to be directly toxic, but they will interfere with essential element root uptake and increase the substrate solution pH. Iron deficiency, identified by yellowing or interveinal chlorosis of newly expanding and developing leaves, is the primary problem for plants growing in a high pH substrate (Fig. 1). Iron deficiency is more acute for crops being grown in a small volume of root substrate or those grown for a longer production time, which allows a gradual rise in substrate pH.

Alkalinity Levels: Why They Matter

High alkalinity levels in irrigation water can limit plant growth and cause economic losses for producers of container-grown cannabis crops. High alkalinity can occur in coastal areas or at locations over limestone bedrock. Much of the well water in the Midwest and Great Plains of the U.S., southern Ontario and the prairie provinces of Canada contain excessively high levels of alkalinity. Testing your water is the first step in determining a management plan.

Considerations for Alkalinity Testing

The level of alkalinity in irrigation water can vary with well location, well depth and time of the year. A standard water analysis usually includes pH, electrical conductivity and alkalinity. Cannabis growers may also want to test for macro-nutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S), and micronutrients boron (B), chloride (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) in their water. Water tests are recommended for each well and should be done annually. Because plugs contain a small volume of substrate, cannabis clone producers should consider monthly water tests while they are starting to monitor the water quality variations over the course of the year.

Taking an Alkalinity Sample

Obtaining a water sample for alkalinity testing is quick and simple. Here's how:

Sampling Procedure

1. Allow the water to run for five minutes to clear the line.
2. Rinse a clean, plastic 16-ounce container two to three times with the water to be tested.
3. Fill the container completely and cap tightly.
4. Label the bottle with your name, address and type of analysis requested.
5. Mail the sample so it arrives at the lab within 24 hours.

Alkalinity Testing

A number of commercial labs conduct water analysis for alkalinity and micronutrients. Make sure you send your sample into a commercial lab that will be able to provide acid injection recommendations. For analysis, check with your local extension personnel. Some states have free testing options, and some labs or states will only run a portion of the tests you may need.



Figure 1. Elevated levels of alkalinity will result in an increase of the substrate pH, which will tie up iron. This elevated substrate pH induced results in the manifestation of interveinal chlorosis of the new and expanding leaves in hemp and other plant species.

Methods to Neutralize Alkalinity

Every cannabis operation varies in water quality, root substrate type, fertilizer type (acidic or basic), watering practices, container size and length of time a crop is grown. Therefore, because alkalinity is the main component influencing the production system, it should be neutralized first before you determine and implement a fertilizer strategy.

Growers can use a few methods to overcome high alkalinity in their irrigation water depending on the operation. These are:

1. Acid Injection

Acid is injected into the irrigation water to neutralize the alkalinity. The amount of acid needed depends on the starting pH and alkalinity level of your irrigation water and the target endpoint alkalinity level desired. In general, a target endpoint alkalinity of about 2 milliequivalent (meq) [122 ppm bicarbonate (HCO_3-)] is recommend for most greenhouse-grown crops, including cannabis. (This also applies to container-grown cannabis indoors.) This should result in an endpoint water pH of 6.0 to 6.2. This target endpoint allows for seasonal variations of alkalinity that naturally occur in wells and allows for errors in measuring acids. Operations that produce clone plugs and are willing to monitor their alkalinity level weekly may desire to neutralize to 1 meq of alkalinity (which will result in a water pH near 5.7) to have greater control of their substrate pH.

The common acids used for alkalinity control are: phosphoric (H_3PO_4) (75% and 85%), sulfuric (H_2SO_4) (35% and 93%), or nitric (HNO_3) (61.4% and 67%). Each acid

PHOTO BY BRIAN WHIPKER

supplies beneficial nutrients to the plants. For instance, one ounce of each acid added per 1,000 gallons of water would supply: 2.92 ppm P with 75% phosphoric acid, 1.14 ppm S with 35% sulfuric acid, or 1.47 ppm N with 61.4% nitric acid. All acids are hazardous because of their characteristics, but some are more potent than others. Phosphoric acid, for example, is relatively safer than sulfuric, which is safer than nitric. Therefore, growers should wear protective clothing when handling acids. Citric acid can also be used but is the least economical.

Remember to always add acid to water! Do not add water to a concentrated acid (which could cause it to splatter up and result in severe burns). This means if you have to mix a tank, first fill up the tank with water and then add your concentrated acid. This will also ensure that you have a homogeneous mixture.

Most operations use sulfuric acid. It is the least expensive, moderately safe and provides adequate levels of sulfur. The simplest type to use is battery acid, which is 35% sulfuric acid. Phosphoric acid is suited for operations needing to neutralize up to 1 meq of alkalinity. When higher amounts of alkalinity must be neutralized, the amount of phosphorus (P) provided far exceeds the requirements of the plants. High levels of P can result in excessive plant stretching, especially for clone plugs.

(Some commercial floriculture growers use phosphoric acid to provide plants with sufficient levels of P and neutralize the remaining alkalinity with sulfuric or nitric acid.) Growers sometimes select nitric acid because it supplies N and allows them to decrease the amount of N fertilizer applied.

After adding acid, retest the water after one day and two to three weeks later to double check your water pH and alkalinity levels. Because cannabis is a bioaccumulator, it would be ideal to test the acid you use to ensure that it does not contain heavy metals.

2. Acidic Fertilizers

All fertilizers are labeled with their level of acidity or basicity, which is expressed in pounds of calcium carbonate equivalent per ton (an agricultural term that measures the basic or acidic effects of a fertilizer on the soil pH). Acidic fertilizers offer another option to neutralize alkalinity and lower the root substrate pH. The acidifying potential of acidic fertilizers is mainly due to the ammoniacal and urea forms of nitrogen. High levels of ammoniacal-nitrogen can lead to ammonia toxicity in some crops (identified as yellowing and possible curling of the upper leaves, which may progress to a marginal necrosis).

Ammonia toxicity is more likely to occur during the winter months (cool substrate and air temperatures and overcast conditions). In addition, ammoniacal and urea forms of nitrogen promote leaf expansion. Too high of a percentage of nitrogen in these forms can result in excessive plant growth. Greenhouse growers prefer fertilizers with more than 80% of the nitrogen in the nitrate form to avoid excessive growth rates.

The general recommendation from North Carolina State University for continuous fertilization of greenhouse-grown floriculture species is that ammoniacal-nitrogen (plus urea) should supply less than 33% of the total nitrogen (with the remainder being nitrate-nitrogen). This also applies to cannabis grown indoors. When an acidic fertilizer is used to counteract alkalinity, ammoniacal-nitrogen levels can be as high as 50%. Acidic fertilizers

with ammoniacal-nitrogen levels more than 50% are only recommended as short-term corrective measures.

3. Pond/Surface Water
Pond water is an excellent source for irrigating plants. Pond water does not contain excessive levels of alkalinity nor other nutrients. Levels of calcium and magnesium in pond water are usually low, and supplemental Ca and Mg applications may be required. Protecting the pond from contamination is a must for growers. Herbicide runoff is a concern, and water from surrounding farm fields must not drain into the pond. Filtration and algae control must be implemented before using pond water.

Stay on target

Regardless of the method selected, alkalinity neutralization is required for operations that have well water alkalinity levels greater than 2 meq [122 ppm bicarbonate (HCO_3)]. Growers will need to select a neutralization method that best suits their operation. It is best if you conduct routine analysis of your root substrate to monitor your pH and nutrient levels and to ensure that your fertility and alkalinity neutralization programs are on target.

Routine vs. Diagnostic Leaf Tissue Analysis for Cannabis

Tissue testing can tell you if your nutrient program is on target and is one of the best methods for diagnosing nutrient-related disorders.

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FIG. 1



MEXCHRISS | ADOBE STOCK

Foliar tissue analysis is an extremely useful tool for growers managing plant nutrition of cannabis. It falls into two major categories: routine analysis and diagnostic analysis. Routine analysis is for problem prevention, whereas diagnostic analysis is for problem solving.

The routine analysis allows growers to monitor nutrient uptake in the plant during production. This requires a grower to take multiple samples over the entire course of the growing season to identify problems or issues before they become serious concerns.

Growers can use diagnostic analysis to diagnose deficient or toxic nutrients when the plants are displaying negative symptoms. This process helps identify the specific problem and is primarily a corrective tool. Plant tissue analysis is especially useful in determining micronutrient levels in the plant and has a greater level of accuracy than a substrate test using a water-based extraction.

Tissue Analysis Strategies for Cannabis Growers

Routine analysis sampling is a general management tool when the plant is displaying no negative symptoms. The strategy here is to determine the nutrient status of the plant by plotting tissue values over time to ensure that a fertility program is on track.

For example, when growing a cannabis mother stock crop, a grower could collect samples monthly during the time the plant is developing prior to taking cuttings. This would provide valuable information to ensure that plants contain adequate nutrient levels going into the cutting season.

TABLE 1: Leaf tissue survey ranges for cannabis. Values published by Bryson and Mills are for nursery-based plants, and it is not identified as whether they are based on CBD- or THC-type plants. Values reported by Landis et al. are for greenhouse-grown cannabis stock plants.

ELEMENT	UNIT	SUFFICIENCY RANGE	GREENHOUSE MOTHER STOCK PLANTS SUFFICIENCY RANGE [MEANS IN ()[2]]
Nitrogen (N)	%	3.3–4.76	2.65–4.47 (3.75)
Phosphorus (P)	%	0.24–0.49	0.31–0.44 (0.35)
Potassium (K)	%	1.83–2.35	1.84–2.98 (2.42)
Calcium (Ca)	%	1.47–4.42	0.53–1.40 (0.88)
Magnesium (Mg)	%	0.40–0.81	0.25–0.46 (0.32)
Sulfer (S)	%	0.17–0.26	0.19–0.29 (0.24)
Boron (B)	ppm	56–105	22.6–57.3 (35.9)
Copper (Cu)	ppm	5–7.1	1.83–11.4 (3.46)
Iron (Fe)	ppm	100–150	59–139 (82.2)
Manganese (Mn)	ppm	41–93	24.3–71.9 (37.2)
Molybdenum (Mo)	ppm	0.50–1.5	0.53–2.36 (1.29)
Zinc (Zn)	ppm	24–52	23.2–46.2 (31.0)

How to Sample Leaves









Figure 1. Collect the most recently mature leaf (MRML), which is typically three to five leaves down from the growing tip.
Figure 2. For a representative sample, take 25 to 30 leaves from five to 10 plants.
Figure 3. For diagnostic analysis of problem situations, sample plants individually, taking leaves from the affected portion of the plant, as seen here with the yellow leaf.
Figure 4. Send samples in a paper bag or manila envelope to a commercial lab able to analyze cannabis samples.

Another valuable strategy could be to sample the plants just before taking cuttings and then periodically over the cutting season. Typically, with other floriculture species, nutrient levels decline over time as cuttings are harvested. Knowing the status of your stock plants enables growers to modify their fertilization practices to the stock plants during the cutting season to help ensure the cuttings are nutritionally charged when growers take them from the plant.

A third monitoring strategy would be to periodically sample the cuttings taken from the stock plant during the cutting season. This will determine if nutrient levels are being maintained in the stock. This will also verify that the cuttings themselves have adequate nutrients.

Each of these nutritional monitoring strategies requires that growers sample each cultivar separately, as nutrient levels can vary with each one. In addition, if there are differences in the plant's age or fertilization practices, cultivators should sample those blocks of plants separately.

Cultivators sampling plants for diagnostic analysis should sample them individually. To accurately diagnose a nutritional disorder, growers will need to take samples from the affected plant and/or symptomatic portion of the plant. For example, if the lower leaves display toxicity symptoms, then cultivators should sample those leaves. Because the critical lower deficiency ranges and toxic upper ranges for cannabis are not known at this time, if possible, cultivators should collect a "good" control sample to compare to their problem sample.

PHOTOS COURTESY OF BRIAN WHIPKER

Understanding Testing Parameters

Generally, a leaf tissue analysis will include the following macronutrients: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg). (Labs might not include sulfur (S) or may do so at an additional charge.) Tissue analysis also determines the following micronutrient concentrations: boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). Some labs charge extra and require a larger sample amount for molybdenum (Mo) determination, and some will also test for sodium (Na) and chloride (Cl). While Na and Cl are not considered essential for plant production, some fertilizers or source water may contain these nutrients. Cultivators should check with the lab where they are submitting their sample to determine the elements tested and cost.

Sampling Procedure 101

The leaf tissue sample should be representative of the plant or production area being monitored or the problem cultivators wish to analyze. As mentioned above, growers should sample plants of different ages and varieties separately. The process includes:

1. Collecting leaf samples.

- For routine analysis, collect the most recently mature leaf. This leaf is typically three to five leaves down from the growing tip (Fig. 1). For a representative sample, take 25 to 30 leaves from five to 10 plants (Fig. 2).
- For diagnostic analysis, sample plants individually, taking leaves from the affected portion of the plant (Fig. 3). Again, if possible, sample a "good" control so that comparisons can be made.

2. Washing and drying leaves.

If the crop has been overhead watered or micronutrients have been foliar applied, gently wash the leaves in distilled water for 20 seconds to remove any surface contaminants. Dry the leaves with paper towels after washing, prior to packaging them.

3. Packaging leaves for analysis.

Send the samples in a paper bag or manila envelope to the commercial lab authorized to analyze cannabis samples (Fig. 4). Label the bag with your name and address. Contact the lab to verify if there are any special requirements for delivery and documentation under current legislation.

4. Delivering the samples.

Immediately send the samples to a lab certified in your state to conduct leaf-tissue analysis. Try to collect the sample at the beginning of the week so delivery will not be delayed over the weekend. If delivery time to the lab (or to a drying oven) is expected to exceed 12 hours, then it's best to refrigerate or air-dry the samples.

At this point, nutrient sufficiency ranges for cannabis have not been developed for specific growth stage(s). Bryson and Mills (2014) published nutrient ranges for cannabis (Table 1). The database for cannabis nutrient sufficiency ranges is still a work in progress and will be further refined over time as scientific studies determine target nutrient levels

over the crop's production cycle as well as critical deficiency and toxicity levels. Refinement of tissue standard ranges for cannabis has been a project being studied by the North Carolina Department of Agriculture and Consumer Services, Agronomic Division and North Carolina State University. Those refined values for cannabis mother stock plants grown in a greenhouse just prior to the stage when cuttings would be harvested are also listed in Table 1.

Conclusion

Leaf tissue analysis provides insight into the nutrient status of a cannabis crop. Tissue analysis results will help growers determine if their fertilizer program is on target by providing current nutrient levels in the plant. In addition, tissue testing is one of the best methods for diagnosing nutrient disorders in cannabis.

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