

Soil Testing for Nutrient Availability Procedures and Interpretation for California Vegetable Crop Production

T.K. Hartz
Extension Vegetable Specialist
Dept. of Plant Sciences, UC Davis

Soil sample collection

Nutrient content of soil can vary greatly by depth. The top 4-6 inches, the zone into which most fertilizer is placed and most crop residue is incorporated, often has much higher levels of organic matter, nitrogen (N), phosphorus (P), potassium (K) and micronutrients than the soil below. To accurately reflect overall nutrient availability a soil sample should be collected with a coring device that collects an equal amount of soil over the entire depth of the sample. In samples collected with a shovel the top few inches are usually over-represented, and the test results will exaggerate the actual fertility of the field. Variability across a field can also be an issue, particularly in fields with a range of soil textures or parent materials. To encompass field variability, a composite sample of at least a dozen soil cores should be gathered, representing all areas of the field. In fields in which significant soil variability exists, sampling different areas of the field separately may be warranted. This is particularly true of fields with areas that repeatedly have low yield; sampling low-yielding areas separately can identify problems that would otherwise be masked if only a single composite soil sample from the whole field was analyzed.

The appropriate depth to sample depends on the crop to be grown. Sampling the top 6 inches may be appropriate for shallowly rooted crops such as onion. However, for most vegetable crops sampling the top 12 inches is preferable; this is particularly the case where furrow irrigation or buried drip irrigation is used; with both methods the top few inches of soil may be too dry for root activity for a significant portion of the season.

Soil sampling usually takes place between crops, which in the California vegetable industry can be any time of the year. Most soil fertility properties are quite stable over time, meaning that sampling soon after terminating a crop and incorporating the residue will yield results similar to those obtained by sampling just prior to the establishment of the next crop. The exception is nitrate-nitrogen (NO₃-N), which fluctuates significantly over relatively short periods of time due to the combined effects of soil microbial activity and leaching by rain or irrigation.

Sample handling

The way in which a sample is handled between collection and analysis can affect the analysis. NO₃-N concentration is always in flux in moist soils due to the activity of soil microbes. If samples are not shipped to the testing laboratory immediately, air drying at room temperature will minimize any changes in NO₃-N concentration. Oven drying soil samples at temperatures above 120°F should be avoided as it can change the results of extractable cation analysis in some soils.

Analytical methods

A number of laboratory extraction techniques have been developed to estimate soil nutrient availability. The choice of which technique to use for a particular nutrient depends on the chemical characteristics of the soil, in particular its pH. Soil chemistry is highly complex; most nutrients exist in different chemical forms, and not all forms are equally plant-available. For most nutrients, the commonly used extraction procedures attempt to rank relative nutrient availability, not the total soil content of that nutrient. Therefore, soil tests should be viewed as an index of nutrient availability, not as an absolute number. When evaluating soil test results it is critical to know what laboratory techniques were used because, for a particular nutrient, two laboratory techniques may give very different numerical results. It is also important to realize that for some laboratory techniques utilized by some commercial laboratories there is insufficient data upon which to base interpretive standards. In this document only the most widely accepted and documented analytical techniques are discussed.

Nitrogen

Soil N exists both in mineral (inorganic) forms, available for plant uptake, and in complex organic forms that are not readily available. The most common analytical approach to determine mineral N concentration is potassium chloride extraction. There are two mineral N forms, NO₃-N and ammonium-nitrogen (NH₄-N); the NO₃-N form usually predominates, and often is the only form reported. NO₃-N exists only in a soluble form and is easily extracted from soil, and therefore the soil test result unambiguously describes soil NO₃-N concentration.

Organic N can be characterized in several ways. A “Kjeldahl” digestion dissolves soil organic matter (containing N) in a strong acid solution; results are reported as “Kjeldahl N” or “TKN”. Soil can also be heated in a furnace to combust organic matter, with N measured in the furnace exhaust; this is usually referred to as “total N”. These measures of organic N may be useful to rank the relative potential of soils to supply N over time, but do not give an indication of current N availability. It should be noted that total N by combustion will include mineral N forms, but in most soils mineral N is a very small fraction of total N (usually < 5%); TKN does not include nitrogen in NO₃-N form.

Phosphorus

The “Olsen”, or bicarbonate, extraction test is the laboratory method most appropriate for P determination in California soils with pH greater than 6.2. In this method dry soil is extracted with a weak solution of sodium bicarbonate; the extracting solution is adjusted to pH 8.5 to prevent the extraction of P that would not normally be plant-available in alkaline soil. For soils with pH < 6.2, the “Bray” extraction test is most appropriate. The Bray extraction solution is mildly acidic, and therefore similar to soil solution pH in these soils. Both the Olsen and Bray techniques extract only a small portion of total soil P, and therefore should be considered to be indexes of relative soil P availability rather than quantitative measures of soil P content.

Potassium

The most common analytical technique for soil K availability is ammonium acetate extraction. In this method dry soil is extracted with an ammonium acetate solution; the NH₄-N ions in solution displace K on soil cation exchange sites; for that reason this procedure is often referred to as the “exchangeable” K test. However, this technique can also extract K from “fixation sites” within the structural layers of some types of silt and clay particles. In soils derived from vermiculitic parent material, and having high silt and clay content, as much as 25% of “exchangeable” K can actually represent “fixed” K. Since in some soils the total amount of fixed K can be much larger than the amount of K on exchange sites, and much of the fixed K may become plant-available over time, the extractable K soil test should be considered to be an index of relative soil K availability rather than a quantitative measure of soil K content

Calcium, magnesium and sodium

The concentration of these cations can be measured in the same ammonium acetate extract used to determine K availability; many laboratories do just that, reporting “exchangeable” calcium (Ca), magnesium (Mg) and sodium (Na). While this is a valid measure of Na, it does not accurately describe Ca or Mg availability in alkaline soils containing Ca and Mg carbonates; such soils are common in California. The test that more accurately describes soil Ca and Mg availability is saturated paste extraction; in this procedure dry soil is mixed with enough distilled water to create a slurry, which is then filtered under vacuum. Results are often reported as “soluble” or “saturated paste” Ca and Mg. Saturated paste extraction is also the preferred method for evaluating soil salinity.

Micronutrients

Zinc (Zn), iron (Fe), manganese (Mn) and copper (Cu) exist in a variety of chemical compounds in the soil, and determining the fraction that is plant-available is difficult. The most commonly used technique is extraction with DTPA, a chelating compound. Where boron (B) concentration may be low enough to be a limiting factor in crop growth, soil extraction with hot water is a common analytical technique; where the concern is that B may be present in sufficient concentration to be toxic to a crop, saturated paste extraction is the appropriate technique.

Interpreting laboratory results

Commercial laboratories report soil test results in a variety of ways, complicating interpretation and making comparison between labs difficult. Results from saturated paste extraction are typically reported as either parts per million (PPM) or milliequivalents (meq) per liter of extract. For other analyses most laboratories report results on a dry soil weight basis. PPM is commonly used, which is equivalent to mg/kg, a unit favored by some labs. Soil cation results may be reported either as PPM or meq/100g.

Some laboratories report test results in pounds of nutrient per acre. To convert such results to a dry weight basis two assumptions must be made: the soil depth assumed by the laboratory, and the weight of soil that would be represented by that depth. Laboratories reporting results in pounds per acre typically assume either a 6” or a 12”

sample depth; that assumption maybe printed on the lab report. Although individual soils can vary significantly in bulk density, on average California soils weigh approximately 1.8 million pounds per acre per 6 inches of depth, or 3.6 million pounds per acre per foot of soil. The major exception to this rule would be soils with high organic matter content (> 5%), which would be significantly lighter.

The following table describes how to convert between these various units.

To convert column 1 into column 2, divide by	Column 1	Column 2	To convert column 2 into column 1, multiply by
390	PPM K	meq K/100g	390
200	PPM Ca	meq Ca/100g	200
121	PPM Mg	meq Mg/100g	121
230	PPM Na	meq Na/100g	230
39	PPM K	meq K/liter	39
20	PPM Ca	meq Ca/liter	20
12	PPM Mg	meq Mg/liter	12
23	PPM Na	meq Na/liter	23
1.8	lb/acre (6 inch depth)	PPM	1.8
3.6	lb/acre (12 inch depth)	PPM	3.6

The following interpretive standards are structured to suggest soil test levels at which an agronomically significant crop response is likely, possible or unlikely. Where soil testing suggests that fertilization is appropriate, determination of fertilization rates may depend on a number of factors. Information on fertilization rates are given in other documents on the UC Vegetable Research and Information website (<http://vric.ucdavis.edu>).

Nitrogen

Soil NO₃-N concentration is a direct measure of current soil nitrogen availability. In vegetable rotations, where heavy N fertilization is the norm, high levels of NO₃-N are common; this is particularly the case in coastal regions, where two or three vegetable crops may be produced annually. Historically, soil testing was often done in the fall, to provide information to guide preplant P and K application. Unfortunately, soil NO₃-N testing in the fall is of questionable value. In regions of the state where substantial winter rainfall occurs much of the NO₃-N measured in the fall may be leached or denitrified before spring planting. Even in regions with minimal winter rain (the San Joaquin, Coachella and Imperial Valleys) heavy pre-irrigation can be sufficient to leach fall NO₃-N from the root zone of the next crop.

Soil testing just prior to or shortly after crop establishment can be very useful in estimating the amount of residual NO₃-N still present and available for plant uptake; in California vegetable rotations soil residual NO₃-N can range from virtually none to enough to completely supply the next crop. In general, NO₃-N concentration less than 10

PPM NO₃-N suggests limited residual soil N, and normal fertilization practices are appropriate. Concentrations greater than 20 PPM indicate that adequate soil N is present to support crop growth for at least several weeks, and additional N fertilization can be delayed or, in some cases, eliminated.

Organic N content (whether estimated by Kjeldahl digestion or a combustion technique) is most often reported as a percent of soil dry weight. Because organic N exists in many complex forms in soil, and these test procedures do not discriminate among these forms, test results cannot be used to directly estimate soil N mineralization potential (ability of the soil to convert organic N to mineral N, available for plant uptake). However, some generalizations can be drawn. Soils with less than 0.07% total N will have limited N mineralization potential, while soils with > 0.15% total N would be expected to mineralize a significant amount of N during the following crop cycle.

Phosphorus

Correct interpretation of soil P test results require consideration of what crop is to be grown, and what soil temperature range that crop will encounter. That is because vegetable crops vary in their P uptake requirement, and in their efficiency in removing P from soil. Also, soil P is more available in warm soil than in cool soil. Lettuce and celery require relatively high soil P availability for maximum growth, while the growth of tomatoes and cucurbits (cucumbers, squash and melons) can be maximized at a relatively low level of soil P availability. The following chart provides soil test P interpretation guidelines.

Crop	Bicarbonate-extractable soil P (PPM)*		
	crop response likely**	response possible***	response unlikely
Lettuce and celery	< 40	40 - 60	> 60
Other cool-season vegetables	< 25	25 - 35	> 35
Warm-season vegetables (tomato, pepper, potato, cucurbits)	< 15	15 - 25	> 25

* for Bray extraction multiply values by 2.5

** regardless of soil temperature

*** particularly in cool weather plantings

These guidelines are based on a 12" soil sample depth. Because soil P availability generally declines with depth, soil samples taken to only 6" depth will overestimate soil P availability by as much as 20%, and these interpretation values should be adjusted accordingly.

Potassium

Vegetable crops vary widely in K uptake, and therefore have different soil K requirements. In addition to the crop to be grown, other factors affecting soil test K interpretation are soil physical characteristics, the relative abundance of other soil cations, and irrigation practices. Rooting density greatly affects a plant's ability to extract

K from the soil; any soil characteristic (subsurface compaction, poor structure, etc.) that limits rooting density or depth will restrict K uptake. Other soil cations can compete for plant cation uptake; therefore, soil K availability should be evaluated both on a PPM basis, and as a percentage of exchangeable soil cations (on a meq basis). Cation competition is generally not a problem in soils in which K makes up > 3% of exchangeable cations, whereas soils in which K makes up < 2% of exchangeable cations may have restricted K availability, even with relatively high exchangeable K levels. Lastly, any irrigation practice that concentrates rooting in a small area (i.e. drip irrigation) may restrict soil K uptake compared to an irrigation approach that wets the entire soil volume. The following chart contains generalized recommendations based on PPM exchangeable soil K.

Crop	Ammonium acetate exchangeable K (PPM)		
	crop response likely	response possible	response unlikely
Celery	< 150	150-200	> 200
Other cool-season vegetables	<100	100-150	> 150
Potato, tomato, pepper	<150	150-200	> 200
Cucurbits	< 80	80-120	> 120

These guidelines should be modified based on the other characteristics discussed.

Calcium and magnesium

Nearly all California soils contain sufficient Ca and Mg to meet the nutritional requirements of vegetable crops. Calcium typically accounts for 40-85% of exchangeable cations on a meq basis, while Mg accounts for 10-50%; in most soils the amount of Ca and Mg on soil exchange sites is much greater than that necessary to satisfy crop uptake requirements. Physiological disorders such as blossom end rot of tomato and blackheart of celery still occur, but generally not from lack of available soil Ca. In most cases Ca-related physiological disorders are caused by water stress (which disrupts Ca uptake and transport within the plant), or heavy NH₄ fertilization (which suppresses Ca uptake); soil Ca application is seldom effective in reducing these disorders.

Ca : Mg ratio is often included on soil test results. This parameter is useful primarily as a guide to soil structure rather than nutrient availability; higher Ca : Mg ratios are associated with better soil structure, tilth and water infiltration rate. As previously stated, available soil Ca and Mg is best estimated by a saturated paste extraction, not an ammonium acetate extraction. Soils with a saturated paste Ca : Mg ratio less than 2:1 (meq basis) may benefit from Ca application (typically as gypsum or lime), although the cost may outweigh the agronomic benefit.

Micronutrients

Historically, Zn deficiency was reasonably widespread in California, with deficiency of other micronutrients less common. Due to micronutrient applications over years of production soil micronutrient deficiency is now uncommon in agricultural soils.

Consequently, relatively little research on soil micronutrient issues has been done in California in recent decades, and there is limited data on which to base interpretive standards. Given this limitation, the following soil standards are suggested:

Crop	DTPA extractable micronutrients (PPM)		
	crop response likely	response possible	response unlikely
Zinc (Zn)	< 0.5	0.5 – 1.5	> 1.5
Iron (Fe)	< 5.0	5.0 – 10	> 10
Manganese (Mn)	< 1.5	1.5 – 3.0	> 3.0
Copper (Cu)	< 0.5	0.5 - 1.0	> 1.0
	Hot water extraction (PPM)		
Boron (B)	< 0.1	0.1 – 0.2	> 0.2

Vegetable crops differ in their ability to extract micronutrients from the soil, with sweet corn and some varieties of legumes (beans and peas) more likely to show deficiency symptoms than most other vegetables. Where micronutrient deficiency is suspected, in-season analysis of plant tissue may be warranted as an adjunct to soil testing.