NCDA&CS
Plant Tissue Analysis Guide

Plant/Waste/Solution/Media Analysis Section
Agronomic Division
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February 2012

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Figure credits:
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a) the corn diagram in Figure 1, which was adapted, with permission, from the University of Illinois Cooperative Extension and
b) the cabbage/lettuce diagram in Figure 1, which was adapted from CorelDRAW® clipart.

1. OVERVIEW OF THE AGRONOMIC DIVISION

The Agronomic Division Mission is to provide N.C. residents with site-specific diagnostic and advisory services to increase agricultural productivity, promote responsible land management and safeguard environmental quality. The Agronomic Division is comprised of four sections: (1) Field Services; (2) Soil Testing; (3) Nematode Assay; and (4) Plant, Waste, Solution and Media Analysis.

The **Field Services** Section has a staff of 13 regional agronomists to advise and educate farmers, agricultural consultants, fertilizer dealers, homeowners and other state residents regarding agronomic sampling techniques, responsible and cost-effective fertilization practices, interpretation of agronomic lab results and the implementation of agronomic recommendations. For further information, see www.ncagr.gov/agronomi/rahome.htm.

Soil Testing provides soil nutrient levels as well as weight per volume, pH, acidity, percent humic matter, soil class and soluble salt levels as described in Crop Fertilization Based on North Carolina Soil Tests. The Soil Test Report provides site-specific lime and fertilizer recommendations for specified crops. For further information, see www.ncagr.gov/agronomi/sthome.htm.

Nematode Assay identifies plant-parasitic nematodes and estimates population size and relative hazard to the crop. The Nematode Assay Report provides recommendations for management of plant-parasitic nematodes. For further information, see www.ncagr.gov/agronomi/nemhome.htm.

Plant Tissue Analysis measures nutrient levels within crop tissue and identifies nutrient deficiencies and toxicities. The Plant Analysis Report provides recommendations for monitoring and adjustment of crop fertilization programs. For further information, see www.ncagr.gov/agronomi/uyrplant.htm.

Waste Analysis determines nutrient levels in farm (such as animal manure), industrial, municipal and composted waste materials. The Waste Analysis Report provides estimates of nutrient availability and recommendations for the environmentally sound use of waste material as a plant nutrient source. For further information, see www.ncagr.gov/agronomi/uyrwaste.htm.

Solution Analysis measures nutrient concentrations as well as pH, electrical conductivity (soluble salts) and total alkalinity levels of water used in agricultural production, such as irrigation water, nutrient solutions and livestock drinking water. The Solution Analysis Report provides an assessment of potential problems and recommendations for their management. For further information, see www.ncagr.gov/agronomi/uyrsoln.htm.

Media Analysis measures nutrient concentrations as well as pH and electrical conductivity (soluble salts) of soilless media used for containerized plant production. The Media Analysis Report helps growers troubleshoot problems and fine-tune fertilization programs. For further information, see www.ncagr.gov/agronomi/uyrmedia.htm.

2. INTRODUCTION TO PLANT TISSUE ANALYSIS

Plant tissue analysis, or tissue testing, is a chemical measurement of essential plant nutrients within a sample of plant tissue. It can be used to identify nutrient-related problems (deficiencies, toxicities or imbalances), rule out nutrition as the source of a problem, monitor nutrient status as a basis for managing a crop fertility program and/or evaluate the effectiveness of a fertility program. Additionally, plant analysis can help determine the optimal time for harvest of flue-cured tobacco.

The following 16 nutrients are essential for a plant to complete its life cycle: carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B), molybdenum (Mo) and chloride (Cl^-). Carbon, hydrogen and oxygen are obtained from air and water and are not generally limiting factors. The other nutrients are provided by soil minerals, soil organic matter, limestone, amendments (such as crop residue, animal manure, compost, agricultural waste and industrial waste) and/or fertilizer.

The NCDA&CS Agronomic Division lab provides interpretive guidelines for 11 of the essential nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B) as part of its standard plant tissue analysis ($5 per sample). Standard analysis also includes a measurement of sodium (Na) concentration. Although Na is not a nutrient, it can affect plant growth and may be phytotoxic at concentrations of 0.25–0.50%.

In addition to standard plant tissue analysis, tests for Mo and Cl^- are available, by request, for an extra fee of $2 per test per sample. For certain crops, measurement of Mo is required because of its importance to quality. Therefore, tissue tests for samples of poinsettia and *Brassica* crops (e.g., broccoli, cabbage, canola, kale, mustard, turnip) always cost $7 per sample, even if the test for Mo is not requested.

3. COLLECTING A GOOD SAMPLE

Tissue sampling methods depend on the crop and the purpose of the sample. The plant part to select depends on the crop and sometimes on the stage of growth as well (see Appendix A). Guidelines for sample collection may differ based on whether you are trying to diagnose a problem or just monitor nutrient status. In all cases, it is important to collect enough material to represent the entire area of interest. To receive good interpretations, you must submit a good sample!

Advisors and growers use tissue analysis to measure concentrations of nutrients in an “indicator” plant part collected at a specific stage of crop development. Then, they compare those measurements to established standard values known as sufficiency ranges. Therefore, you must submit the correct plant part(s) at the correct growth stage to receive valid interpretations and recommendations on a *Plant Analysis Report*. Sampling incorrectly can result in misleading findings and inappropriate nutrient management decisions.

For most crops, interpretations are based on sampling the most recent mature leaf (MRML). The MRML is the most fully expanded or mature leaf and is generally the third to fifth leaf below the growing point (Figure 1). It is neither dull from age nor shiny green from immaturity. Other possible indicator plant parts include the whole plant, top of the plant, ear leaf, petiole, outermost undamaged leaf and harvest leaf (Table 1). The correct plant parts to sample for specific crops are listed in Appendix A, as well as the corresponding codes to enter on the *Plant Sample Information* form.

For several crops (small grains, corn, forage grasses), the appropriate indicator plant part varies with the growth stage. However, when the sampling protocol for a specific crop is unknown, selection of the MRML will generally provide the best indication of nutritional status. Table 1 provides explanatory information about plant-part code choices available on the *Plant Sample Information* form.

In addition to indicator plant part, sufficiency ranges are based on specific growth stage(s). Interpretations on the Plant Analysis Report will generally be based on established sufficiency ranges (nutrient levels) for the specific growth stage listed in Appendix A. When samples are collected at other growth stages, the advisor and/or grower must consider principles of plant nutrition when reviewing results and interpretations. For example, potassium (K) levels in leaves of a plant will decrease as the plant moves into reproductive growth, so K sufficiency levels of a MRML during the early or blooming growth stage will be higher than levels during the fruiting growth stage.

For the high-value and/or agronomically important crops of strawberry and cotton, criteria have been developed for the nitrate-nitrogen (NO_3-N) concentrations in the petioles associated with indicator leaf samples (Fig. 1). Petiole analysis provides a snapshot of nutrient uptake from the soil to the leaves at the time of sampling. Results can be used for fine-tuning in-season nutrient management. For these crops, an additional $2 per sample is charged for measurement of petiole NO_3-N, even if this test is not requested.

Lab results and interpretations depend on the quality of the sample. A good *representative sample* is comprised of tissue obtained randomly from multiple plants within the area of interest. Although only a very small amount of plant material is required for the test (< 1 gram), each sample must include material to adequately represent the area of interest. For crops with small leaves (e.g., azalea), 75–100 leaves make a good sample. For larger-leaved crops (e.g., corn or tobacco), significantly fewer leaves are needed. See Appendix A for the recommended number of leaves to sample for a specific crop.

The way that plant tissue samples are handled between time of collection and arrival at the laboratory greatly affects the quality of analytical results. If delivery time to the laboratory (or to a drying oven) is expected to exceed 12 hours, then it is best to refrigerate or air-dry the samples. Refer to the publication Plant tissue sampling: proper handling for more detailed instructions.

Table 1. Indicator plant-part codes, descriptions and example crops.

Indicator plant part		Example crops
Code[1]	Description	
M	Most recent mature leaf (MRML)	Most plants, including cotton & strawberry[2]
W	Whole plant (cut ½–1″ above soil surface)	Seedling or young plants
T	Top 3–6 inches or top 2–4 leaves	Turf; forage grass and small grains prior to reproductive growth stages
E	Ear leaf (opposite and below ear)	Corn (from tasseling through silking)
P	Petiole[3] only	Vinifera grape
O	Outermost undamaged leaf	Lettuce and other leaf vegetables
H	Harvest leaf	Tobacco

[1] This is the code from Appendix A that must be written on the *Plant Sample Information* form.
[2] Even though cotton and strawberry tissue samples include both leaf blades and petioles (separated), the appropriate plant-part code is M.
[3] Petiole is the leaf stem (Fig. 1).

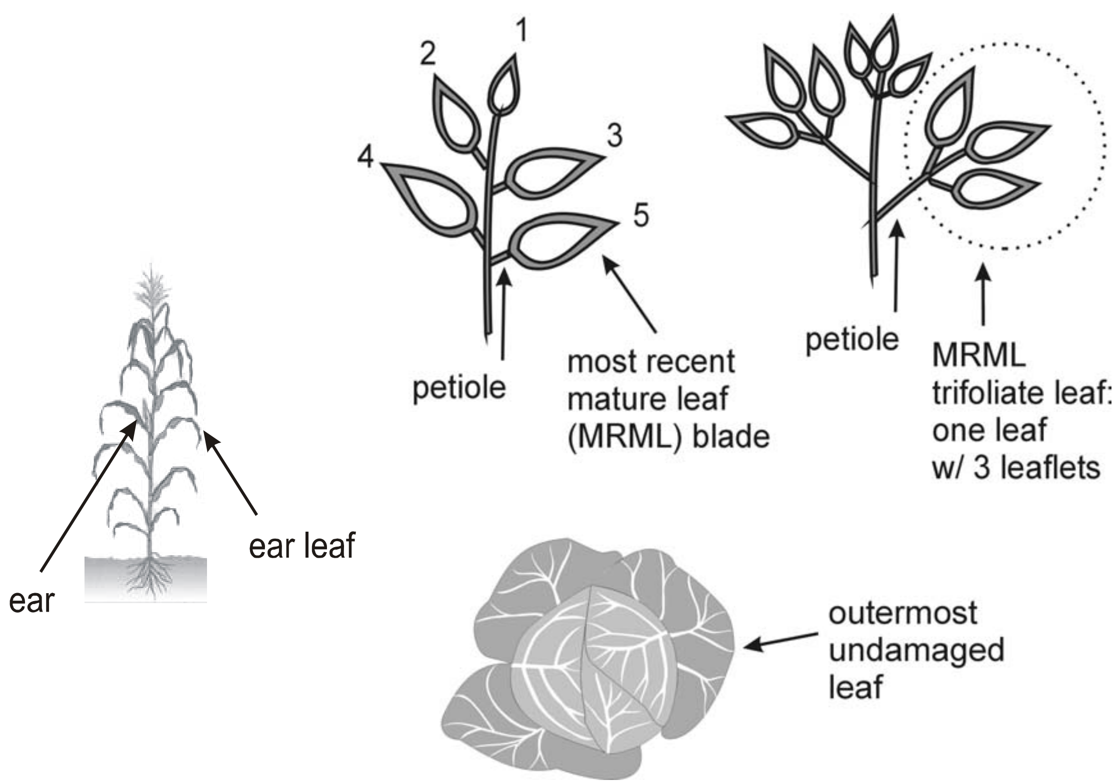

Figure 1. Some examples of appropriate (indicator) plant parts for tissue sampling.

4. UNDERSTANDING THE PLANT ANALYSIS REPORT

Laboratory results are interpreted by comparing nutrient concentrations within a sample to known nutrient sufficiency ranges for a specific indicator plant part and/or growth stage. The sufficiency ranges have been developed from research, survey data, field observations and/or experience. Reliability varies depending on the extent of research conducted on each crop. Campbell (2000) provides further detail regarding the history, scientific basis and application of plant analysis.

For each nutrient measured, the NCDA&CS Plant Analysis Report provides an index value ranging from 0 to 124 and an interpretation category of deficient, low, sufficient, high or excess (Table 2) in addition to the actual concentrations. The critical value (Figure 2) is the point at which a nutrient shortage causes a 5 to 10% loss in yield or growth; the point of mild toxicity indicates the same degree of loss due to nutrient excess.

- *Deficient* (0–24) and l*ow* (25–49) index values indicate that the nutrient concentration is below the desired level and may be contributing to reduced growth, yield and/or quality. As the index level decreases, the predicted crop response to nutrient application increases (Table 2). When nutrient indexes are low or deficient, it is important to determine the cause before making a corrective action. Causes for low nutrient levels in the indicator plant part can include low soil nutrient levels or nutrient imbalances in the growing substrate; low or high soil pH; very wet or dry soils; very low or high soil and air temperatures; soil compaction; heavy fruit load; insect, disease and/or nematode pressure; and chemical damage from herbicides or air pollutants (ozone).

- A *sufficient* (50–74) index indicates that the nutrient concentration is optimum for growth and yield.

- *High* (75–99) and *excess* (100–124) index values indicate the nutrient concentrations are above the desired level. *High* concentrations are not normally detrimental to growth or yield, but the potential to impact crop quality increases as the index approaches 100. *Excess* concentrations may cause problems due to plant toxicity or nutrient imbalances. Nutrient concentrations can be very high due to high levels in the growing substrate; contamination from a foliar spray of a pesticide or nutrient; soil contamination; very high or low soil pH; or as a side effect of limited plant growth caused by another problem.

A look at nutrient ratios can also be informative. Plant reports provide values for ratios of nitrogen to sulfur (N:S), nitrogen to potassium (N:K) and iron to manganese (Fe:Mn) because of the effects these nutrients have on each other. As a general guideline, the ratio value should be 1.2–2.2 for N:K and >1 for Fe:Mn.

The most important ratio is N:S, which has an acceptable value of 10–15 for most crops. Values approaching and exceeding 18 indicate that there is not enough sulfur present for the plant to use nitrogen efficiently. This situation can occur even when sufficient plant tissue concentrations of both nitrogen and sulfur are present (Campbell 2000).

Table 2. Predicted response of nutrient application by index value

Index	Interpretation	Crop Response
0 – 24	Deficient (D)	High
25 – 49	Low (L)	Medium
50 – 74	Sufficient	Low to None
75 – 99	High	None
100 – 124	Excess (E)	None

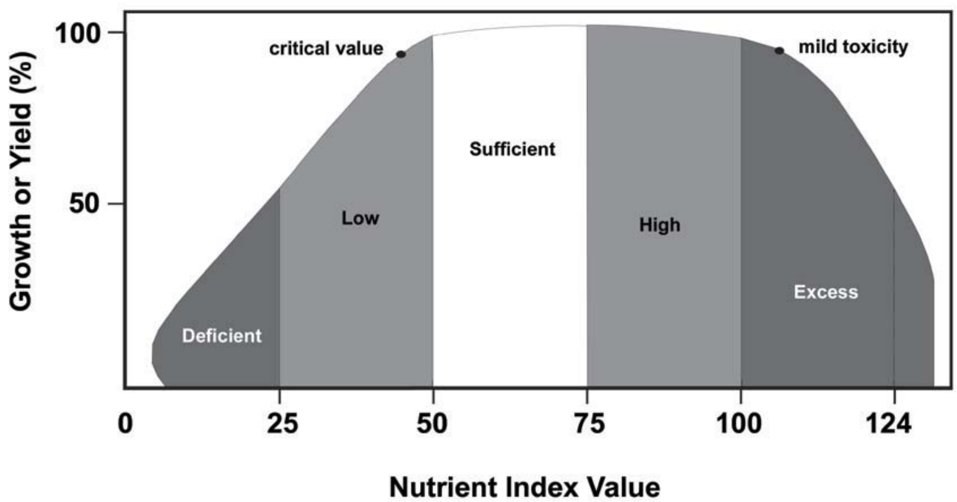

Figure 2. Expectation of yield or growth (%) in response to increasing nutrient concentration and interpretation index

5. SUMMARY

Plant tissue analysis is a tool used to identify problems and manage nutrients in an economically and environmentally responsible manner. Other factors to be considered in conjunction with plant analysis include recent soil pH and fertility levels, fertilization history, soil texture, environmental conditions (such as soil moisture, soil temperature and recent rainfall events), cropping history, crop age or growth stage, distribution of problem in the field or greenhouse, disease, insect and nematode pressure, visual appearance of the crop and pesticide use injury.

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Appendix A. Sampling procedures for plant tissue analysis

Crop	Growth Stage [1]: When to collect samples	Growth Stage [1]: Code	Plant Part [2]: Plant part to collect (Indicator plant part)	Plant Part [2]: Code	Leaves: # to collect	Extra tests	Cost	References
African violet	Mature plants of flowering size	B, M	Most recent mature leaf	M	25	—	$5	—
Alfalfa	Prior to or early bloom	E, B	Most recent mature trifoliate leaves from the top $^{1}/_{3}$ (6″) of plants	T	30	Mo	**$7**	—
Apple	5 to 10 weeks after full bloom (mid-June to mid-July)	M	Most recent mature leaf from mid shoot, leaves near base of current year's growth, or leaves from spurs; 4–8 leaves per plant from 20–30 plants	M	50	—	$5	—
Asparagus	Mid-summer	E	Top 4–6″ of most recent mature fronds	M	20–30	—	$5	2011 SE Vegetable Handbook
	Late-summer	M	Top 18″ of most recent mature fronds	M				
Azalea	Prior to flowering	E	Most recent mature leaf	M	75–100	—	$5	—
Bahiagrass	*see* Grass (Forage & Pasture)							
Barley	*see* Small Grain							
Bean	Seedlings (less than 12″)	S	All the above-ground portion	W	20–30	—	$5	2011 SE Vegetable Handbook
	Prior to, or during initial bloom	E, B	Most recent mature leaf	M				
Beet	Early to mid-growth	E, B	Most recent mature leaf	M	20–30	—	$5	2011 SE Vegetable Handbook
Begonia (*Rieger elatior*)	Prior to heavy flower formation	E, B	Most recent mature leaf (1st leaf from top that is 2″ wide or greater)	M	20	—	$5	—
Bentgrass	*see* Grass (Turf)							
Bermuda, coastal (hybrid)	*see* Grass (Forage & Pasture)							
Bermudagrass (turf)	*see* Grass (Turf)							

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Blackberry	Postharvest (10 to 14 days after final harvest)	M	Most recent mature leaf on primocane (nonfruiting laterals)	M	20–40	—	$5	—
Blueberry	Early or during bloom	E, B	Most recent mature leaf from mid-portion of current season's growth	M	50–60	—	$5	—
Bluegrass	*see* Grass (Forage & Pasture)							
Bluestem, big	*see* Grass (Forage & Pasture)							
Boxwood	Summer	M	2–3″ cuttings from terminal growth	M	20 cuttings	—	$5	—
Broccoli	Early or prior to head formation	E, B	Most recent mature leaf	M	25–30	Mo	$7	Southern Cooperative Series Bulletin 394
Bromegrass	*see* Grass (Forage & Pasture)							
Cabbage	Early to midgrowth	E	First mature leaf from center of whorl; should be oldest undamaged leaf	M	25–30	Mo	$7	—
Cabbage, Chinese (heading types)	8-leaf stage	E	Oldest undamaged leaf	M	25–30	Mo	$7	—
Camellia	Summer	M	Most recent mature leaf	M	25–30	—	$5	—
Caneberries	*see* Blackberry or Raspberry							
Canola	Prior to bloom	E	Most recent mature leaf	M		—	$5	—
Cantaloupe	*see* Melons							

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Carnation	Unpinched plants	E	4th or 5th leaf pair from base of plant	M	20–30	—	$5	—
	Pinched plants	B, F, M	5th or 6th leaf pair from top of primary laterals	M				
Carrot	Early growth (60 days after seeding)	E	Most recent mature leaf	M	20–30	—	$5	2011 SE Vegetable Handbook
Cauliflower	Early or prior to head formation	E	Most recent mature leaf	M	25–30	Mo	$7	—
Centipede	*see* Grass (Turf)							
Cherry	5 to 10 weeks after full bloom	M	Leaves near base of current year's growth ***or*** from spurs; 4–8 leaves per plant from 20–30 plants	M	50–100	—	$5	—
Chinese cabbage (heading types)	8-leaf stage	E	Oldest undamaged leaf	M	25–30	Mo	$7	—
Chrysanthemum	Prior to or at flowering	E, B, F	Most recent mature leaf from top of plant ***or*** upper leaves on flowering stem	M	20–30	—	$5	—
Clover	Prior to bloom	E	Top 4–6 inches of the plant	T	40–50	—	$5	—
Collards	Early	E	Oldest undamaged leaf	M	25–30	Mo	$7	—

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Corn, field	Seedling (<4″)	S	Entire top of plant cut 1″ above soil	W	15–20 plants	—	$5	NC Corn Production Guide (2000)
	Early (4–12″)	E	Entire top of plant cut 1″ above soil	W				
	Prior to tasselling (>12″)	E	First fully developed leaf below the whorl; This leaf should be totally unrolled and have developed a sheath (collar) on the stalk.	M	10–15			
	Tasselling & shooting to silking	B, F	Leaf opposite and below the uppermost developing ear (earleaf)	E				
	Maturity	M	Leaf opposite and below the uppermost developing ear	M				
	Sampling after silking is not recommended	—	—	—	—			
Corn stalk (end of season)	1–3 weeks after black layer has formed on 80% of the kernels of most ears	M	8″ segment collected at 6–14″ above the soil line	H	15	Only test: NO_3-N	$5	Cornstalk Testing to Evaluate Nitrogen Management
Corn, sweet	Prior to tasselling	E	First fully developed leaf below the whorl; This leaf should be totally unrolled and have developed a sheath (collar) on the stalk.	M	15–20	—	$5	2011 SE Vegetable Handbook
	At tasselling	B, F	Leaf opposite and below the uppermost developing ear (earleaf)	E				

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Cotton	Seedling: Four weeks following emergence of 2–3 true leaves	S Weeks 1, 2, 3, 4	Most recent mature leaf and petioles. Separate petioles in the field.	M	25–30	Petiole NO_3-N	$7	Using Tissue Analysis to Monitor Cotton Nutrition NC State Cotton Website
	Early: Four weeks following seedling (S) stage, includes pinhead square formation	E Weeks 1, 2, 3, 4						
	Bloom: Begins when plants have at least 5 open blooms per 25 row feet	B Weeks 1, 2, 3, 4						
	Fruit: Begins 5th week after beginning of bloom	F Weeks 1, 2, 3, 4						
	Mature	M						
Cucumber	Early to early bloom	E, B	Most recent mature leaf (generally 4th to 5th leaf from a growing point)	M	15–20	—	$5	2011 SE Vegetable Handbook
Cucumber, greenhouse	Early to early bloom	E, B	Most recent mature leaf (generally 4th to 5th leaf from a growing point)	M	8–10	—	$5	2011 SE Vegetable Handbook
Fescue	*see* Grass (Turf or Forage & Pasture)							
Fir	During dormancy (~Sept–Dec)	M	Two or three shoots from the upper 1/3 or ½ of 8–12 trees. DO NOT sample from leader or top whorl.	M	15–30 shoots	—	$5	Agronomic Services for Christmas Tree Growers SoilFacts—soil and plant analysis for Christmas trees
Daisy, gerber	All growth stages	E,B,F,M	Most recent mature leaf	M	25–50	—	$5	—
Gammagrass	*see* Grass (Forage & Pasture)							
Gardenia	Summer	B	Most recent mature leaf	M	25	—	$5	—

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Garlic	Early growth prior to root/bulb enlargement	E	Center mature leaves	M	20–30	—	$5	—
Geranium	All growth stages	E,B,F,M	Most recent mature leaf	M	25–50	—	$5	Fertility Management for Geraniums
Grape, muscadine	Mid to late summer but prior to final swelling of fruit (end of bloom through Aug); Best Time – June to early July	B, F	Most recent mature leaf opposite fruit clusters from well-exposed shoots (generally the 1st or 2nd fruit cluster from the base of the shoot)	M	60–80	—	$5	Agronomic Services for Grape Production
Grape, vinifera	Full bloom through veraison (ripening of fruit)	B, F	PETIOLES ONLY from Most recent mature leaf opposite fruit clusters from well-exposed shoots (generally the 1st or 2nd fruit cluster from the base of the shoot)	P	80–100	—	$5	
Grass (Forage & Pasture)	Tillering (Less than 6″ tall)	S	Entire top of plant cut ½″ above soil	T	2 handfuls	—	$5	—
	Greater than 6″ tall and prior to seed head formation (after tillering to before boot stage)	E	Top 6 inches of plant or the upper half of the plant (top 4 leaves)	T	20 tops			
	After seed head formation (recommended only when troubleshooting)	F	Most recent mature leaf (leaf below seed head)	M	20–30 leaves			
Grass (Turf)	During normal growing season; at least two days regrowth	M	Two handfuls of freshly mowed grass (with trash removed)	T	2 handfuls	—	$5	Agronomic Services for Turfgrass Management NCSU TurfFiles Website
Holly	Summer	M	Most recent mature leaf	M	30–50	—	$5	—
Hydrangea	Early summer	M	Most recent mature leaf	M	30–50	—	$5	—
Impatiens	All growth stages	E,B,F,M	Most recent mature leaf	M	25–50	—	$5	—

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Kale	Early or during bloom	E, B	Most recent mature leaf	M	25–30	Mo	$7	Southern Cooperative Series Bulletin 394
Lettuce	Anytime during growing season	E	Outermost undamaged leaf	M	10–20	—	$5	2011 SE Vegetable Handbook
Lettuce (leaf), greenhouse	Anytime during growing season	E	Outermost undamaged leaf	M	10–20	—	$5	—
Lima bean	*see* Bean							
Marigold	All growth stages	E,B,F,M	Most recent mature leaf	M	25–50	—	$5	—
Melons (watermelon, muskmelon)	Prior to or during bloom; prior to fruit set	E, B	Most recent mature leaves (generally the 5th leaf from the growing tip)	M	12–30	—	$5	2011 SE Vegetable Handbook
Millet	*see* Grass (Forage & Pasture)							
Milo	*see* Sorghum							
Mung bean	*see* Bean							
Muskmelon	*see* Melons							
Mustard greens	Early or during bloom	E, B	Most recent mature leaf	M	25–30	Mo	$7	—
Oats	*see* Small Grain							
Onion	Early growth prior to root/bulb enlargement	E	Center mature leaves	M	20–30	—	$5	
Orchardgrass	*see* Grass (Forage & Pasture)							

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Ornamental shrubs & trees	During active growth	M	Most recent mature leaf on current year's growth	M	30–100	—	$5	—
Pansy	All growth stages	E,B,F,M	Most recent mature leaf	M	25–50	—	$5	Commercial Pansy Production
Peach	Mid-season; 12 to 14 weeks after bloom	F, M	Leaves near base of current year's growth; 4–8 leaves per plant / 20–30 plants	M	50–100	—	$5	—
Peanut	Prior to, or at bloom.	E or B	Most recent mature tetrafoliate leaves (about 3rd to 5th leaf from growing point)	M	25–30	—	$5	—
Pear	5 to 10 weeks after full bloom	M	Leaves near base of current year's growth or leaves from spurs; 4–8 leaves per plant from 20–30 plants	M	50–100	—	$5	—
Peas (English, southern)	Prior to or during initial flowering	E, B	Most recent mature leaf (about the 3rd set of leaf from the growing point).	M	30–60	—	$5	2011 SE Vegetable Handbook
Pecan	6–8 weeks after bloom; 8–12 weeks after catkin fall (July 7 to August 7)	M	Middle pairs of leaflets from a compound leaf on a terminal shoot	M	30–45	—	$5	—
Pepper (bell, hot, banana)	Prior to bloom	E	Most recent mature leaf	M	20–30	—	$5	2011 SE Vegetable Handbook
Petunia	All growth stages	E,B,F,M	Most recent mature leaf	M	25–50	—	$5	—
Pine	Summer	M	Needles from upper $^1/_3$ crown; select dominant trees with good form and crown; primary lateral branches from first flush of past season's growth; strip needles (include sheaths and fascicles)	M	200 needles	—	$5	—
Poinsettia	Prior to or at bloom	E, B	Most recent mature leaf	M	15–20	Mo	$7	—

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Potato, Irish	Prior to or during early bloom	E, B	Most recent mature leaf (3rd to 6th leaf from the growing tip)	M	20–30	—	$5	2011 SE Vegetable Handbook
	Early flowering to half-grown tubers	M	Most recent mature leaf (3rd to 6th leaf from the growing tip)	M				
Raspberry	Postharvest (10 to 14 days after final harvest)	M	Youngest mature leaves on primocane (nonfruiting laterals)	M	20–40	—	$5	—
Rhododendron	Summer	M	Most recent mature leaf	M	20–30	—	$5	—
Rose	During flower production	F	Upper leaves on the flowering stem ***or*** 5-leaflet leaf below bud	M	20–30	—	$5	—
Rye	*see* Small Grain							
Ryegrass	*see* Grass (Forage & Pasture)							
Small Grain	Seedling stage to early jointing; GS 3–6 (Feekes) or GS 26–31 (Zadoks)	S	Entire top of plant cut ½″ above soil	W	2 handfuls	—	$5	NCDA&CS Pictorial Guides to Plant Tissue Sampling Small Grain Production Guide
	Early jointing to just prior to heading (ie just prior to boot); GS 7–9 (Feekes) or GS 32–39 (Zadoks)	E	The 2–4 uppermost leaves (Top 4–6″)	T	25–40			
	Just prior to heading (boot stage); GS 10–11 (Feekes) GS 45–100 (Zadoks) [sampling after heading is not recommended]	B	Flag leaf	M	30–40			
Snap Bean	*see* Bean							

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Sorghum (Milo, Grain sorghum)	Early or Bloom	E, B	If E, first leaf out of the whorl; if B, second leaf from the top	M	20	—	$5	—
Sorghum-Sudan	Early or Bloom	E, B	Top 4″ to 6″ of plant	T	15–20 plants	—	$5	—
Soybean	Seedlings (less than 12″)	S	Entire top of plant cut 1″ above soil	W	20–30	—	$5	—
	Prior to, or during initial bloom; before pod set [sampling after pods begin to set is not recommended]	E, B, F	Most recent mature leaf	M				
Spinach	Mid-growth	M	Most recent mature leaf	M	20	Mo	$7	2011 SE Vegetable Handbook
Spinach, greenhouse	All growth stages	M	Most recent mature leaf	M	20	Mo	$7	—
Spruce	Mid-season to late summer	M	2–3″ terminal cuttings	M	25 cuttings	—	$5	—
Squash	Summer	B, F, M	Most recent mature leaf (about 5th leaf from the growing point)	M	15–20	—	$5	2011 SE Vegetable Handbook
Strawberry, field	Early	E Weeks 1–8	Most recent mature leaf and petioles. Separate petiole in the field	M	20–25	Petiole NO_3-N	$7	Strawberry Tissue Analysis
	Bloom/Fruit: Initiated when there are 5–10 blooms on >75% of the plants or 2–3 blooms on most plants; Harvest usually begins at B/F week 5 or 6	B/F Weeks 1–12	Most recent mature leaf and petioles. Separate petiole in the field	M	20–25	Petiole NO_3-N	$7	
	Mature	M Weeks 1–4	Most recent mature leaf and petioles. Separate petiole in the field	M	20–25	Petiole NO_3-N	$7	

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Strawberry, high tunnel	All growth stages	E,B,F,M	Most recent mature leaf and petioles. Separate petiole in the field	M	20–25	Petiole NO_3-N	$7	Strawberry Tissue Analysis
Strawberry, greenhouse	All growth stages	E,B,F,M	Most recent mature leaf and petioles. Separate petiole in the field	M	20–25	Petiole NO_3-N	$7	
Sweetpotato	Midgrowth; prior to root enlargement	E	Most recent mature leaf (generally the 4th to 5th leaf)	M	20–30	—	$5	2011 SE Vegetable Handbook
Tobacco, burley	Seedling	S	Entire top of plant cut 1″ above soil	W	8–12	—	$5	Production Tools for Tobacco Growers: Solution & Plant Analyses
	Prior to bloom	E	Most recent mature leaf (about 4th leaf from growing point)	M				
	During bloom	B, F		M				
	Maturity	M		M				
Tobacco, flue-cured	Seedling (greenhouse transplants)	S	Entire top of plant cut 1″ above soil	M	1 tray	—	$5	Production Tools for Tobacco Growers: Solution & Plant Analyses Harvesting Tobacco Based on Tissue Analysis
	Before bloom	E	Most recent mature leaf (about 4th leaf from growing point)	M	8–12			
	During early bloom	B		M				
	During late bloom	F		M				
	Mature	M		M				
	Harvest leaf	M	Upper leaves (tips) (Position U) (~21st to 30th nodes from the bottom)	H			$5	
	Harvest leaf	M	Middle leaves (smoking) (Position M) (~11th to 20th nodes from the bottom)	H			$5	
	Harvest leaf	M	Lower leaves (lugs & cutters) (Position L) (~1st to 10th node from the bottom)	H			$5	

Appendix A. Sampling procedures for plant tissue analysis *(continued)*

Crop	Growth Stage [1]		Plant Part [2]		Leaves: # to collect	Extra tests	Cost	References
	When to collect samples	Code	Plant part to collect (Indicator plant part)	Code				
Tomato, field	Early growth (5-leaf stage through first flower)	S, E	Most recent mature leaf (4th to 5th compound leaf back from the growing point)	M	8–10	—	$5	2011 SE Vegetable Handbook Tomato Production Fertilization Guide
	Early flower through first fruit set (golf-ball-sized fruit)	B		M				
	First fruit set through harvest	F, M		M				
Tomato, greenhouse	Early growth through first fruit set	S, E, B	Most recent mature leaf (4th to 5th compound leaf back from the growing point)	M	8–10	—	$5	Tissue Sampling & Analysis for Greenhouse Tomatoes
	First fruit set through harvest	F, M						
Triticale	*see* Small grains							
Turnip greens	Early or during bloom	E, B	Most recent mature leaf	M	25–30	Mo	$7	—
Walnut	6 to 8 weeks after bloom	M	Middle pairs of leaflets from a compound leaf on a mature shoot	M	30–35	—	$5	—
Watermelon	*see* Melons							
Wheat	*see* Small grains							
Zucchini	*see* Squash							

[1]Growth-stage codes: S = Seedling, E = Early, B = Bloom (prior to first fruit), F = Fruiting, M = Mature. To receive meaningful recommendations on a plant analysis report, you must collect and submit tissue samples from the growth stage indicated in this table and write the associated code on the *Plant Sample Information* form. Analysis of tissue collected at other growth stages may still provide useful information even though there are insufficient data for the lab to issue recommendations.

[2]Plant -part codes: W = Whole plant, T = Top, E = Ear leaf, M = Most recent mature leaf (MRML), O = Outermost undamaged leaf, P = Petiole, H = Harvest leaf. To receive meaningful recommendations on a plant analysis report, you must collect and submit the plant tissue part indicated in this table for the crop you are sampling and write the associated code on the *Plant Sample Information* form. Samples of other tissue may still provide useful information even though there are insufficient data for the lab to issue recommendations based on it.

Appendix B. NCDA&CS Agronomic Division methods for plant tissue analysis

Sample handling

Prior to analysis, samples are dried overnight (12–24 hr) at 80 ^{o}C, then processed through a stainless steel grinder (Wiley Mini-Mill; Thomas Scientific; Swedesboro, NJ) with a 20-mesh (1-mm) screen (Campbell and Plank 1992).

Nitrogen

Total nitrogen concentration is determined by oxygen combustion gas chromatography with an elemental analyzer (NA1500; CE Elantech Instruments; Lakewood, NJ) (AOAC 1990b; Campbell 1992) on a 10-mg aliquot of the dried and ground sample. Results are expressed in percent (%) on a dry-weight basis.

Phosphorus (P), potassium (K), calcium (Ca), sulfur (S), magnesium (Mg), boron (B), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), sodium (Na), nickel* (Ni), cadmium* (Cd), lead* (Pb) [*analyzed for research, by special request only]

Total concentrations of P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Na, Ni, Cd and Pb are determined with an inductively-coupled-plasma (ICP) spectrophotometer (Optima 3300 DV ICP emission spectrophotometer; Perkin Elmer Corporation; Shelton, CT) (Donohue and Aho 1992; adapted USEPA 2001), after open-vessel HNO_3 digestion in a microwave digestion system (MARS & MDS2100 microwaves; CEM Corp.; Matthews, NC) (Campbell and Plank 1992). A 0.5- or 1.0-g dried and ground aliquot is digested in 10 mL 15.6N HNO_3 for 5–30 minutes in a microwave, and the prepared sample volume is brought to 50 mL with deionized water prior to measurement. Elements are measured at wavelengths listed in Table B-1. Results are expressed either as a percentage (%) or in parts per million (ppm) [as milligrams per kilogram (mg/kg)] on a dry-weight basis.

Table B-1. Wavelengths to quantify total elemental concentrations in Plant Analysis Lab

Element	Wavelength (nm)	Element	Wavelength (nm)
Boron (B)	249.772	Manganese (Mn)	257.610
Cadmium (Cd)	214.440	Nickel (Ni)	231.604
Calcium (Ca)	317.933	Phosphorus (P)	178.221
Copper (Cu)	324.752	Potassium (K)	766.490
Iron (Fe)	259.939	Sodium (Na)	589.592
Lead (Pb)	220.353	Sulfur (S)	181.975
Magnesium (Mg)	285.213	Zinc (Zn)	213.857

Appendix B. NCDA&CS Agronomic Division methods for plant tissue analysis *(continued)*

Nitrate nitrogen

Nitrate-nitrogen concentration is determined with an ion-sensitive electrode (ISE) (Orion Model 93-07; Thermo Fisher Scientific Inc., Waltham, MA) following a 0.25-M $Al_2(SO_4)_3$ extraction (25 mL) (Baker and Smith 1969) on a 0.25-g, dried and ground aliquot of sample. Results are expressed in parts per million (ppm) [as milligrams per kilogram (mg/kg)] on a dry-weight basis. Nitrate nitrogen will be analyzed on all strawberry and cotton samples for an addition cost of $2 (total cost of $7 per sample). Nitrate nitrogen can also be analyzed on any sample per request for an additional cost of $2 (total cost of $7 per sample).

Molybdenum

Molybdenum is measured colorimetrically at 600 nm with a fiber-optic, colorimetric probe (Brinkmann PC 900; Brinkmann Instruments, Westbury, NY), following a muffle-furnace ashing (Barnstead Thermolyne 6000, Dubuque, IA) and Rhodamine-B (5 mL) digestion (Haddad and others 1974) on a 1.0-g aliquot of dried and ground sample. Results are expressed in parts per million (ppm) [as milligrams per kilogram (mg/kg)] on a dry-weight basis. Molybdenum will be analyzed on all *Brassica* crop, poinsettia and spinach samples for an additional cost of $2 (total cost of $7 per sample). Molybdenum can also be analyzed on any sample per request for an additional cost of $2 (total cost of $7 per sample).

Chloride

Chloride is measured colorimetrically at 510 nm with a fiber-optic, colorimetric probe (Brinkmann PC 900; Brinkmann Instruments, Westbury, NY), following a muffle-furnace ashing (Barnstead Thermolyne 6000, Dubuque, IA) and silver-nitrate (2 mL) digestion (AOAC 1990a) on a 0.25-g aliquot of dried and ground sample. Chloride analysis can be performed, by request, on any sample for an additional cost of $2 (total cost of $7 per sample).

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Appendix B. NCDA&CS Agronomic Division methods for plant tissue analysis *(continued)*

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