Reviews

Efficiency Ranges for Nitrate-Nitrogen and Potassium for Vegetable Petiole Sap Quick Tests

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Summary. Petiole sap N and K quick tests offer fast and accurate in-field analysis for N and K and have been calibrated for some vegetable crops in Florida. This paper summarizes 10 years of research conducted in Florida on petiole sap testing for N and K. Petiole sap nitrate-N and K concentrations correlated highly with whole-leaf N and K concentrations and decreased through the season for all vegetable crops tested. Optimum early season fresh sap nitrate-N and K concentrations were highest for pepper, and optimum late-season concentrations were lowest for tomato. Petiole sap nitrate-N and K concentrations were not affected by storing petioles on ice for up to 16 h or freezing them for 24 h.

Results from plant nutrient tests are used to diagnose nutrient deficiencies and provide information for adjusting fertilization programs (Jones, 1985; Plank, 1992). Typical commercial nutrient tests involve nutrient analyses of dried whole leaves or leaf petioles. These tests can be time-consuming and costly and often require sophisticated laboratory equipment.

Fresh plant sap nutrient concentration has been used as an indicator of plant nutrient status for many years. One of the earliest reports suggesting the usefulness of plant sap testing was by Gilbert and Hardin (1927). These authors developed sufficiency values for N, P, and K for several vegetables including lettuce, celery, beets, and cabbage. During the 1930s and 1940s, several researchers in the United States and Europe evaluated plant sap testing for determining plant nutrient status for several elements including N, P, K, Mg, and Mn (Bray, 1945; Carolus, 1935; Emmert, 1932, 1934a, 1934b, 1940; Krantz et al., 1948; Morgan, 1935; Nicholas, 1948; Pettinger, 1931; Poehlman, 1935; Syltie et al., 1972; Ulrich, 1948). Although plant sap was easily obtained, the analytical methods were varied and cumbersome and did not easily lend themselves to in-field

quick-test capability.

In the 1970s and 1980s, work began with quick-test procedures for determining nitrate-N, P, and K in plant sap (Burns and Hutsby, 1984; Jemison and Fox 1988; Prasad and Spiers, 1982, 1984, 1985; Raushkolb et al., 1974; Scaife and Bray, 1977; Scaife and Stevens, 1977, 1983). Quick-test procedures used were usually those involving nitrate-N or K test strips (Merck, Darmstadt, Germany) or colorimetric methods (HACH, Loveland, Colo.) Test strip and ion-specific electrode methods for nitrate-N and K have been used to establish sufficiency concentrations of N and K in tomato (Coltman, 1987a, 1987b, 1988; Coltman and Riede, 1992). More recently, ion-specific electrodes have been used for determining petiole sap concentrations of nitrate-N in potato (Vitosh and Silva, 1994) and pepper (Hartz et al., 1993). Sufficiency levels of petiole sap K were determined recently for eggplant using hand-held ion-specific electrodes (Cardy meters; Horiba, Kyoto, Japan) (Hochmuth et al., 1993b).

Research in Florida has been conducted for the past 10 years to evaluate petiole sap testing as a procedure to determine plant N and K status. The intent has been to develop sap quick-testing procedures and sufficiency concentrations for petiole sap nitrate-N and K for use in the field by vegetable producers. Petiole sap N and K quick tests would be useful for farmers to monitor plant N and K status and assist farmers in managing N and K fertilization. This paper summarizes some of the research conducted in Florida on petiole sap testing and presents the testing procedure and sufficiency ranges for sap nitrate-N and K for several vegetables in Florida.

Materials and methods

Research to evaluate petiole sap testing was conducted at several Univ. of Florida research centers and on many commercial vegetable farms in Florida. Studies were conducted on field and greenhouse tomato (*Lycopersicon esculentum* Mill.), pepper (*Capsicum annuum* L. var. *annuum*), watermelon [*Citrullus lanatus* (Thumb.) Matsum. and Nakai], eggplant (*Solanum melongena* L.), potato (*S. tuberosum* L.), cucumber (*Cucumis sativus* L.), broccoli (*Brassica oleracea* L., Botrytis Group), collard (*B. oleracea*

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L., *Acephala* Group), muskmelon (*Cucumis melo* L., *Reticulatus* Group), and summer squash (*Cucurbita pepo* var. *melopepo*) using various cultivars. The vegetables were grown under a range of N and K fertilization programs in which N and K application rates were varied to determine the relationship of petiole sap nitrate-N and K concentrations to plant growth and fruit yield. For all crops, except potato and greenhouse tomato, all fertilizer was incorporated in the soil before planting and the crop was grown on polyethylene-mulched beds. For potato, one-half of the fertilizer was applied at planting and the rest was applied 35 days later to the sides of the unmulched beds. N and K were applied to greenhouse tomato in a nutrient solution composed of N and K at 120 and 200 mg·liter⁻¹, respectively.

At various periods in the crop lifecycle, most-recently matured whole leaves with petioles were collected. Whole leaves were dried at 65°C, ground to pass through a 1-mm screen, and analyzed for N using rapid-flow colorimetry after digestion with sulfuric acid and hydrogen peroxide and for K by plasma emission spectroscopy after dry-ashing at 500°C in a muffle furnace (Hanlon et al., 1990). Fresh petioles were collected at the same time as whole-leaf samples. Petioles were chopped and pressed in a hydraulic press to express plant sap. Fresh sap was analyzed immediately for nitrate-N and K concentrations. Nitrate-N was analyzed in fresh sap by two colorimetric quick-test procedures [HACH colorimeter and Merckoquant test strips (Merck, Darmstadt, Germany, and EM Science, Cherry Hill, N.J.)] and by a hand-held ion-specific electrode (Cardy meter; Horiba, and Spectrum Technologies, Plainfield, Ill.). Potassium concentrations were measured with the Cardy meter.

Briefly, the procedure for the Merckoquant test strips was to dip a test strip into the freshly extracted petiole sap and allow the strip color to develop for 60 s. Developed color was compared to a chart (accompanied by the test kit) to determine approximate nitrate concentration. A reflectometer also is available for use with the test strips to facilitate nitrate determinations (Schaefer, 1986). Often, the fresh sap required dilution to allow a reading within the range of the calibrated color scale on the chart. Dilution was

usually one part fresh sap to 19 parts distilled water.

For the HACH test kit, diluted sap was placed in two viewing tubes (supplied with kit). One tube was placed in its slot in a hand-held comparator. The contents of one reagent powder container were emptied into the second viewing tube and the solution was mixed by shaking for 1 min. After mixing, the second viewing tube was placed in its slot in the comparator. The color disk on the comparator was rotated until the color on the wheel matched the color in the tube with the reagent. The resulting nitrate-N concentration was read from the comparator.

For the Cardy meters, a drop of fresh sap was placed in a continuous film over the electrodes of the hand-held meter and the resulting ion concentration was read from the digital nitrate or K meter. Frequently, early-season N (but usually not K) concentrations for some crops had to be determined from diluted sap to keep the determinations within the range of the calibrated standard curve.

Details on field plot techniques, yield responses, and complete analyses of whole-leaf and sap nutrient data are described for many crops: tomato (Hochmuth et al., 1988; 1991b), pepper (Fletcher et al., 1993), watermelon (Vann et al., 1993), eggplant (Hochmuth et al., 1991a; 1992; 1993b), cucumber (Hochmuth and Hochmuth, 1991), and potato (Hochmuth et al., 1993a). Sufficiency ranges for broccoli, collard, squash, muskmelon, and greenhouse tomato were developed from unpublished data.

A study was conducted with tomato petioles to compare petiole sample-handling procedures. Whole leaves of 'Trust' tomato were collected from a mature commercial greenhouse tomato crop near Gainesville, Fla., on 27 June 1994. Sample-handling treatments were 1) petiole nitrate-N and K concentrations determined immediately upon leaf harvest; 2) whole leaves placed in an open, uncooled (25°C) polyethylene bag, with petiole nitrate-N and K concentration determined 2 h from leaf harvest; 3) whole leaves placed in a polyethylene bag on ice in an ice chest immediately after harvest, with petiole nitrate-N and K determined 2 h later; 4) petioles placed in an open, uncooled (25°C) polyethylene bag, with petiole nitrate-

N and K determined 2 h later; 5) petioles placed in polyethylene bag in an ice chest, with nitrate-N and K determined 2 h later; 6) petioles placed in polyethylene bag in an ice chest, with nitrate-N and K determined 6 h later; 7) petioles placed in polyethylene bag in an ice chest, with nitrate-N and K determined 16 h later; and 8) petioles placed in a polyethylene bag and frozen, with nitrate-N and K determined 24 h later. Each treatment was replicated four times.

Results and discussion

Three quick-test kits (Merckoquant, HACH, and Cardy meters) were used successfully to measure plant petiole sap nitrate-N and K concentrations. In determinations made on the same petiole sap sample, the Merckoquant test kit yielded slightly higher nitrate-N determinations compared to the HACH system. The difference was 50 to 100 mg·liter⁻¹ and usually did not affect the interpretation of the results relative to plant's N status (Hochmuth et al., 1988). The colorimetric methods and the hand-held ion-specific electrode were not compared.

A summary of sufficiency ranges for petiole sap nitrate-N and K, drawn from 10 years of research with 11 vegetables, is presented in Table 1. Corresponding ranges for N and K concentrations (dry weight basis) in whole leaves also are presented. Values for whole-leaf N and K were summarized from reports from which the petiole sap ranges were obtained and from Hochmuth et al. (1991b).

Petiole sap nitrate-N and K concentrations were correlated with whole-leaf N and K concentrations (Hochmuth et al., 1991, 1993b). Nitrate-N and K sufficiency ranges decreased through the season for all vegetables. For most vegetables tested, early-season (before flowering) nitrate-N sufficiency ranges were >1000 mg·liter⁻¹ (Table 1). Pepper, potato, and eggplant had highest early season sufficiency ranges—1200 to 1600 mg·liter⁻¹. Sufficiency concentrations for K generally ranged from 4000 to 5000 mg·liter⁻¹ early in the season to 2000 to 3000 mg·liter⁻¹ at harvest.

The sufficiency ranges for all crops, except potato and greenhouse tomato, summarized here were developed in production systems in which all N and K was applied before planting. The

seasonal sufficiency range profiles may be different for systems in which N and K are applied in small amounts throughout the season. One example would be a production system using a drip irrigation system through which N and K could be injected during the season.

Over the course of petiole sap testing research, questions arose concerning the testing procedures, most often about sample preparation and handling. Our research and results of other workers on the testing protocol were used to develop the following recommendations for petiole sample preparation and handling.

Summary of sap testing protocol

Time of day. All measurements were made on sunny days between 9:00 and 16:00 HR. Time of day had little practical significance on the results of sap tests for nitrate-N (Coltman 1987a; Scaife and Stevens, 1983).

Leaf age. The sufficiency ranges in Table 1 were developed from petioles of most-recently matured leaves, which had essentially ceased expanding in size. Sampling variation was minimized with most-recently matured leaves compared to younger or older

leaves (Burns, 1988). For example, the most-recently matured tomato leaf was the sixth fully expanded leaf from the tip of the plant. Most-recently matured leaves had turned from a juvenile light-green to a darker olive-green color.

Leaf part. The petiole consisted of all the tissue from the bottom of the leaf blade to the point of attachment of the leaf to the plant stem. For compound leaves, all leaflets and petiolules were removed from the leaf petiole.

Number of leaves per sample. Each sample consisted of 20 leaves from each plot. Petioles were excised,

Table 1. Sufficiency concentration ranges for plant leaf petiole fresh sap nitrate-nitrogen and potassium developed from research in Florida.

Crop	Growth stage	Nutrient concn			
		Petiole sap ² (mg-liter ⁻¹)		Whole-leaf dry wt (g·kg ⁻¹)	
		Nitrate-N	K	N	K
Broccoli and collard	Six-leaf stage	800-1000	NA ³	35-50	35-45
Collard	Just before first harvest	500-800		30-45	15-40
	First harvest	300-500		30-40	15-40
Cucumber	First blossom	800-1000	NA	40-50	20-30
	Fruit 8 cm long	600-800		25-50	20-30
	First harvest	400-600		25-35	15-25
Eggplant	First fruit (5 cm long)	1200-1600	4500-5000	45-55	45-60
	First harvest	1000-1200	4000-4500	45-50	35-50
	Midharvest	800-1000	3500-4000	35-45	30-40
Muskmelon	First blossom	1000-1200	NA	45-50	50-60
	Fruit 5 cm long	800-1000		40-50	45-50
	First harvest	700-800		35-45	20-40
Pepper	First flower buds	1400-1600	3200-3500	45-50	50-60
	First open flowers	1400-1600	3000-3200	40-45	45-50
	Fruit half-grown	1200-1400	3000-3200	40-45	40-50
	First harvest	800-1000	2400-3000	35-40	35-45
	Second harvest	500-800	2000-2400	25-30	30-40
Potato	Plants 20 cm tall	1200-1400	4500-5000	30-60	35-60
	First open flowers	1000-1400	4500-5000	30-40	30-50
	50% Flowers open	1000-1200	4000-4500	30-40	30-40
	100% Flowers open	900-1200	3500-4000	25-40	25-40
	Tops falling over	600-900	2500-3000	20-30	15-30
Squash	First blossom	900-1000	NA	30-50	30-50
	First harvest	800-900		30-50	20-30
Tomato (field)	First buds	1000-1200	3500-4000	30-50	40-50
	First open flowers	600-800	3500-4000	35-40	35-40
	Fruit 2 cm in diameter	400-600	3000-3500	35-40	35-40
	Fruit 5 cm in diameter	400-600	3000-3500	30-40	30-40
	First harvest	300-400	2500-3000	25-35	25-35
	Second harvest	200-400	2000-2500	20-35	20-30
Tomato (greenhouse)	Transplant to second cluster	1000-1200	4500-5000	40-60	40-50
	Second cluster to fifth cluster	800-1000	4000-5000	40-50	35-40
	Harvest season (Dec.-June)	700-900	3500-4000	35-40	25-35
Watermelon	Vines 15 cm long	1200-1500	4000-5000	50-60	40-50
	First fruit 5 cm long	1000-1200	4000-5000	40-50	35-40
	Fruit one-half mature	800-1000	3500-4000	35-40	25-35
	At first harvest	600-800	3000-3500	30-40	20-30

²Broccoli, collard, muskmelon, and field tomato nitrate-N values were determined with the HACH system; nitrate-N values for other crops and all K values were determined with Cardy meters.

³Not available.

Table 2. *Effects of petiole sample-handling procedures on petiole sap nitrate-N concentrations*

Treatment	Petiole sap nitrate-N concn (mg·liter ⁻¹)
1. Immediate measurement	900
2. Petioles from whole leaves after storage in uncooled, open polyethylene bag on ice for 2 h	1570
3. Petioles from whole leaves after storage in closed polyethylene bag on ice for 2 h	1000
4. Petioles (only) stored in open uncooled polyethylene bag for 2 h	1100
5. Petioles stored in polyethylene bag on ice for 2 h	1000
6. Petioles stored in polyethylene bag on ice for 6 h	800
7. Petioles stored in polyethylene bag on ice for 16 h	835
8. Petioles frozen in polyethylene bag for 24 h	1050
LSD (<i>P</i> = 0.05)	200

chopped, mixed, and subsampled to obtain the amount of petiole to be crushed for sap.

Sample handling. Petiole sample-handling procedure affected nitrate-N concentrations of tomato sap (Table 2). Petiole sap nitrate-N concentration increased when whole leaves were kept in an open polyethylene bag at room temperature before excising the petioles. The increase probably resulted from leaf wilting and the associated reduction in water content of the leaf blades and petioles. Storing petioles (without leaf blades) on ice for up to 16 h or freezing petioles for 1 day did not appreciably affect nitrate-N concentrations (Table 2). Petiole-sap K measurements on the same sap yielded results similar to the nitrate-N results. Sap K concentration averaged 3800 mg·liter⁻¹ for measurements made on petioles used immediately or stored on ice or frozen, but sap K concentration increased significantly to 4400 mg·liter⁻¹ for petioles excised from leaves stored for 2 h in an open, uncooled polyethylene bag.

Equipment. Sap was expressed from petiole pieces with a hydraulic press, although for small samples or fleshy petioles a garlic or lemon press can be used. Other utensils used included a sampling knife, scissors, paper towels, a distilled water rinse, a chopping knife and board, an eye dropper, containers for sap, and a sap-testing kit.

Conclusion

Plant sap analysis can help achieve optimum fertilization of vegetable crops. Petiole sap testing is not intended to replace standardized laboratory analytical procedures for whole leaves or dried petioles. However, analyzing fresh plant sap for N and K concentrations is a quick procedure to

determine the N and K status of plants, the results of which can be used in guiding N and K applications to vegetable crops. Proper use of plant sap testing equipment requires careful calibration and standardization of the testing equipment. Samples can be collected between 9:00 and 16:00 HR and should consist of petioles of most-recently matured leaves. Petiole sap nitrate-N or K analyses should not be seriously affected by storing petioles in a polyethylene bag on ice for up to 16 h or by freezing for 24 h.

Costs for the equipment for the three analytical systems were affordable, under \$100 for the Merckoquant and HACH systems and \$300 for each N and K ion-specific meter. Replacement test strips and reagents were needed for each determination for the Merckoquant and HACH kits, respectively, and replacement electrodes were needed for the meters after ≈500 determinations.

Literature Cited

- Bray, R.H. 1945. Nitrates tests for soils and plant tissues. *Soil Sci.* 60: 219–221.
- Burns, I. G. 1988. The use of rapid tests for measurement of plant nutrient status. *Anal. Proc.* 25:122–124.
- Burns, I.G. and W. Hutsby. 1984. Development and evaluation of rapid tests for the estimation of phosphate and potassium in plant sap. *Commun. Soil Sci. Plant Anal.* 15:1463–1480.
- Carolus, R.L. 1935. Experiences with rapid chemical tests for the determination of nutrient deficiencies in vegetable crops. *Proc. Amer. Soc. Hort. Sci.* 33:579–583.
- Coltman, R.R. 1987a. Sampling considerations for nitrate quick tests of greenhouse-grown tomatoes. *J. Amer. Soc. Hort. Sci.* 112:922–927.
- Coltman, R.R. 1987b. Yield and sap nitrate responses of fresh market field tomatoes to simulated fertigation with nitrogen. *J. Plant Nutr.* 10:1699–1704.
- Coltman, R.R. 1988. Yields of greenhouse tomatoes managed to maintain specific petiole sap nitrate levels. *HortScience* 23:148–151.
- Coltman, R.R. and S.A. Riede. 1992. Monitoring the potassium status of greenhouse tomatoes using quick petiole sap tests. *HortScience* 27:361–364.
- Emmert, E.M. 1932. Field method for estimating nitrate, phosphate, and potassium in plants. *Plant Physiol.* 7:315–321.
- Emmert, E.M. 1934a. Tests for phosphate, nitrate, and soluble nitrogen in conducting tissue of tomato and lettuce plants, as indicators of availability and yield. *Kentucky Agr. Expt. Sta. Circ.* 43.
- Emmert, E.M. 1934b. Tests for nutrients in conducting tissue as indicators of the nutritional status in horticultural crops. *Proc. Amer. Soc. Hort. Sci.* 32:604–609.
- Emmert, E.M. 1940. Plant tests as a guide to fertilizer treatment of tomatoes (preliminary report). *Proc. Amer. Soc. Hort. Sci.* 38:621–622.
- Fletcher, J., R. Hochmuth, and G. Hochmuth. 1993. Calibration of N and K fresh sap quick-test procedures for polyethylene-mulched peppers. *Proc. 24th Natl. Agr. Plastics Congr.* 24:147–152.
- Gilbert, B.E. and J.L. Hardin. 1927. The current mineral nutrient content of the plant solution as a possible means of chemical control of optimum fertilization. *J. Agr. Res.* 35:185–192.
- Hanlon, E.A., G. Kidder, and B.L. McNeal. 1990. Soil container media, and water testing. Interpretations and IFAS standardized fertilization recommendations. *Florida Coop. Ext. Serv. Circ.* 817.
- Hartz, T.K., R.F. Smith, M. LeStrange, and K.F. Schulbach. 1993. On-farm monitoring of soil and crop nitrogen status by nitrate-selective electrode. *Commun. Soil Sci. Plant Anal.* 24:2607–2615.

- Hochmuth, G.J., P.R. Gilreath, E.A. Hanlon, G.A. Clark, D.N. Maynard, C.D. Stanley, and D.Z. Haman. 1988. Evaluating plant N status with plant sap quick-test kits. Proc. Tomato Inst. Florida Coop. Ext. Serv. Spec. Ser. SS-VEC-801:6-14.
- Hochmuth, G.J., E.A. Hanlon, G. Kidder, D. Hensel, W.A. Tilton, J. Dilbeck, and D. Schrader. 1993a. Fertilization demonstrations for the tri-county potato production area of northeast Florida. Proc. Florida State Hort. Soc. 106:190-198.
- Hochmuth, G.J., R.C. Hochmuth, M.E. Donley, and E.A. Hanlon. 1993b. Eggplant yield in response to potassium fertilization on sandy soil. HortScience 28:1002-1005.
- Hochmuth, G., B. Hochmuth, E. Hanlon, and M. Donley. 1991a. Nitrogen requirements of mulched eggplant in northern Florida. Florida Coop. Ext. Serv. Suwannee Valley Agr. Res. and Educ. Center Res. Rpt. 91-14.
- Hochmuth, G.J., B.C. Hochmuth, E.A. Hanlon, and M.E. Donley. 1992. Effect of potassium on yield and leaf-N and K concentrations of eggplant. Florida Coop. Ext. Serv. Suwannee Valley Agr. Res. and Educ. Center Res. Rpt. 92-2.
- Hochmuth, G., D. Maynard, C. Vavrina, and E. Hanlon. 1991b. Plant tissue analysis and interpretation for vegetable crops in Florida. Florida Coop. Ext. Serv. Spec. Ser. SS-VEC-42.
- Jemison, J.M. and R.H. Fox. 1988. A quick-test procedure for soil and plant tissue nitrates using test strips and a hand-held reflectometer. Commun. Soil Sci. Plant Anal. 19:1569-1582.
- Jones, Jr., J.B. 1985. Soil testing and plant analysis: Guides to the fertilization of horticultural crops. Hort. Rev. 7:1-67.
- Krantz, B.A., W.L. Nelson, and L.F. Burkhart. 1948. Plant-tissue tests as a tool in agronomic research, p. 137-156. In: H. B. Kitchen (ed.). Diagnostic techniques for soils and crops. Amer. Potash Inst., Washington, D.C.
- Morgan, M.F. 1935. The universal soil testing system. Connecticut Agr. Expt. Sta. Bul. 372.
- Nicholas, D.J.D. 1948. The application of rapid chemical tests to the diagnosis of mineral deficiencies in horticultural crops. I. Crops grown on a manurial trial. J. Hort. Sci. 24:72-105.
- Pettinger, N.A. 1931. The expressed sap of corn plants as an indicator of nutrient needs. J. Agr. Res. 43:95-119.
- Plank, C.O. (ed.). 1992. Plant analysis reference procedures for the southern region of the United States. Georgia Agr. Expt. Sta. Southern Coop. Ser. Bul. 368.
- Poehlman, J.M. 1935. Some limitations of plant juice analyses as indicators of the nutrient status of plants. J. Amer. Soc. Agron. 27:195-207.
- Prasad, M. and T.M. Spiers. 1982. Evaluation of a simple sap nitrate test for some ornamental crops. Proc. 9th Intl. Plant Nutr. Colloq., Warwick Univ., England. p. 474-479.
- Prasad, M. and T.M. Spiers. 1984. Evaluation of a rapid method for plant sap nitrate analysis. Commun. Soil Sci. Plant Anal. 15:673-679.
- Prasad, M. and T.M. Spiers. 1985. A rapid nitrate test for outdoor tomatoes. Scientia Hort. 25:211-215.
- Raushkolb, R.S., A.L. Brown, J. Quick, J.D. Prato, R.E. Pelton, and F.R. Kegel. 1974. Rapid tissue testing for evaluating nitrogen nutritional status of corn and sorghum. California Agr. 28(6):10-13.
- Scaife, M.A. and B.G. Bray. 1977. Quick sap tests for improved control of crop nutrient status. Agr. Dev. Adv. Serv. Quarterly Rev. 27:137-145.
- Scaife, A. and K. Stevens. 1977. Two-minute sap test takes guesswork out of N levels. The Grower 88:1223-1227.
- Scaife, A. and K.L. Stevens. 1983. Monitoring sap nitrate in vegetable crops: Comparison of test strips with electrode methods, and effects of time of day and leaf position. Commun. Soil Sci. Plant Anal. 14:761-771.
- Schaefer, N.L. 1986. Evaluation of a hand-held reflectometer for rapid quantitative determination of nitrate. Commun. Soil Sci. Plant Anal. 17:937-951.
- Syltie, P.W., S.W. Melsted, and W.M. Walker. 1972. Rapid tissue tests as indicators of yield, plant composition, and soil fertility for corn and soybeans. Commun. Soil Sci. Plant Anal. 3:37-49.
- Ulrich, A. 1948. Plant analysis—Methods and interpretation of results, p. 157-198. In: H.B. Kitchen (ed.). Diagnostic techniques for soils and crops. Amer. Potash Inst., Washington, D.C.
- Vann, C.D., R.C. Hochmuth, and G.J. Hochmuth. 1993. Watermelon N and K petiole sap testing. Proc. 1993 Watermelon Inst. Florida Coop. Ext. Serv. Spec. Ser. SS-HOS-003.
- Vitosh, M.L. and G.H. Silva. 1994. A rapid petiole sap nitrate-nitrogen test for potatoes. Commun. Soil Sci. Plant Anal. 25:183-190.