HortScience 37(2):313–316. 2002.

Seasonal Dry Matter, Starch, and Nutrient Distribution in 'Concord' Grapevine Roots

Terence R. Bates, Richard M. Dunst, and Paula Joy
Department of Horticultural Sciences, Cornell University Vineyard Laboratory, Fredonia, NY 14063

Additional index words. Vitis labruscana, carbohydrates, juice grape

Abstract. **Three-year-old field-grown 'Concord' (*Vitis labruscana* Bailey) grapevines were destructively harvested at eight growth stages during 1998 to quantify growth, carbohydrate distribution, and nutrient concentrations of different organs. The roots were the major storage organ for carbohydrates and nutrients, accounting for 84% of the starch and 75% of nitrogen stored in the vines at the beginning of the season. About 78% of the reserve starch in the vine was used for prebloom root and shoot growth. Early-season fine-root growth was a sink for stored vine nitrogen; however, the fine roots quickly became a nitrogen uptake source, providing at least 84% of the spring growth nitrogen. Total root biomass increased from bloom to leaf fall, but reserve carbohydrates and nutrients lost in the prebloom period did not begin to recover in roots until the end of rapid shoot development in late July. Crop removal at harvest, and a late-season root flush, further increased vegetative carbohydrate and nutrient reserves in the short postharvest period.**

The seasonal growth, carbohydrate, and nutrient patterns in grapevines have been studied in several varieties and grape-growing regions of the world (Conradie, 1980; Hanson and Howell, 1995; Williams, 1987; Yang and Hori, 1979). General vine growth patterns are similar in these studies; however, vine age, variety, climate, crop load, and environmental stress can alter the general patterns of photosynthesis and nutrient uptake. Nevertheless, the following patterns emerge. Between bud swell and bloom, shoot growth is supported by stored carbohydrates and nutrients from the previous growing season as well as from new nutrient uptake in the spring. Rapid shoot and berry development 3 to 4 weeks after bloom prevents the replenishment of stored resources despite rapid current carbon assimilation and nutrient uptake. As shoot growth slows, fruit and wood maturation takes place simultaneously (albeit at different rates depending on crop load, environmental stress, etc.). The postharvest period is considered the recovery period for stored resources because carbon assimilation and nutrient uptake is then dedicated to vegetative structures. The length of the postharvest period varies with variety, crop load, or climate.

All woody perennial permanent structures store carbohydrates in the overwintering stage; however, woody roots tend to have higher concentrations of stored carbohydrates than do aerial wood in many woody plants, including grape (Loescher et al., 1990). Carbohydrates are stored in perennial structures mainly as starch (Mullins et al., 1992; Yang and Hori, 1979). In ^{14}C studies with 'Delaware' grapevines, a greater proportion of assimilated carbon was found in the roots than in aboveground organs. This was especially true for late-season assimilates that were first used for spring shoot growth (Yang and Hori, 1979, 1980a). Similarly, in a study with 'Chenin blanc' vines in California, more starch was found in the root system than in the trunk and cordons. However, that study also indicated that roots were a sink, not a source, for carbohydrates early in the season (Mullins et al., 1992; Roper and Williams, 1989). The patterns of stored carbohydrates, especially root starch, are unknown for 'Concord' grapevines grown in the northeastern United States.

A series of studies on 'Chenin blanc' vines in South Africa demonstrated the seasonal pattern of nitrogen uptake and use in an early-ripening variety in a long-season growing area. These 'Chenin blanc' studies showed a decrease in total root nitrogen from budbreak to the end of rapid shoot elongation (Conradie, 1988), while total plant nitrogen increased during the same period (Conradie, 1980). Therefore, new vine growth was supported by both stored root nitrogen and new nitrogen uptake. Postharvest nitrogen uptake in the long-season growing area of South Africa comprised from 27% to 34% of total nitrogen taken up during the season and represented 60% of the stored nitrogen for the next season (Conradie, 1980, 1986, 1992). A study of seasonal growth and nitrogen uptake and use with 'Concord' grapevines in Michigan showed a similar pattern of root growth and total root nitrogen uptake from bud swell to harvest (Hanson and Howell, 1995). However, 'Concord' roots lost both dry weight and nitrogen during the short postharvest period.

The amount of root-stored nitrogen used for new grapevine shoot growth in the spring has been found to vary from 15% to 70% (Conradie, 1980; Williams, 1987). In one study with 'Thompson seedless' grapevines, 14% to 26% of the stored nitrogen needed for spring growth came from permanent structures other than roots (Araujo and Williams, 1988). In the aforementioned studies with young-potted grapevines, the root system was treated as a whole without delineation between root size or age. Conversely, in field-grown grapevines, thin and fine roots were often lost during vine excavation. There is little information on the seasonal pattern of fine-root flushes in the vineyard and their role in nutrient and water uptake. Studies with 'Colombard' grapevines in South Africa show two periods of fine-root growth: the first flush peaks at anthesis and the second flush peaks after harvest (vanZyl, 1988; Williams and Matthews, 1990). Initial studies of fine-root growth in cool-climate 'Concord' vineyards do not appear to follow the above pattern (D. Eissenstat and A. Lakso, personal communication).

This study focuses on the dry weight, carbohydrate, and nutrient distribution of 'Concord' grapevines in a short-season growing area. Specific attention is given to grapevine root growth in 3-year-old, field-grown vines.

Materials and Methods

Own-rooted 'Concord' grapevines were planted in 1996 on Chenango gravelly loam soil at the Cornell Vineyard Laboratory in Fredonia, N.Y. Vine spacing was 2.44 m in the row and 2.74 m between rows. During the third growing season, vines were trained to a single, 1.83-m-high wire bilateral cordon and pruned to 40 buds. In a plot of 150 vines, five vines were randomly selected and destructively harvested on each of eight dates during 1998 (Table 1). A mechanical excavator was used to dig a trench 1.2 m deep in the row middles, ≈0.75 m on either side of the vine. A pitchfork was used to manually excavate the root system of each vine. The root system from each vine was excavated from a soil volume of 8.78 m^3; however, the young root systems rarely filled the entire soil volume.

Excavated vines were separated into fine roots, thin roots, thick roots, aerial wood (trunk + cordons), shoots, and clusters (Table 2). Separated tissues were dried for 4 weeks in a forced-air drying oven at 55 °C and then

Table 1. Time of plant excavations during the 1998 season.

Harvest no.	Date	Vine stage	Days from bloom
1	30 Mar.	Dormancy	–67
2	22 Apr.	Bud swell	–44
3	21 May	10-inch shoots	–15
4	5 June	Bloom	0
5	7 July	32 days postbloom	32
6	20 Aug.	Veraison	76
7	15 Sept.	Harvest	102
8	2 Nov.	Leaf fall/ dormancy	150

Received for publication 23 Jan. 2001. Accepted for publication 27 June 2001. We thank Mike Vercant, Ted Taft, Christine Cummings, and Eileen Eacker for their viticulture assistance. We thank Alan Taylor and his laboratory staff for their help in tissue starch analysis. This research was supported by the New York Wine and Grape Foundation and the Eastern Viticulture Consortium.

Table 2. 'Concord' grapevine categories used for dry weight, starch, and nutrient analysis.

Tissue identification	Tissue description
Fine roots	Fine roots (< 2 mm diameter)
Thin roots	Woody roots (2–5 mm diameter)
Thick roots	Woody roots (>5 mm diameter)
Aerial wood	1- and 2-year-old trunks and cordons
Shoots	New aerial growth in 1998 (shoots, leaves, and canes)
Clusters	Flower clusters or fruit

weighed. Random tissue subsamples were ground in a Wiley mill (Fisher Scientific, Swedesboro, N.J.) with a 40-mesh screen for carbohydrate and tissue analysis. Tissue starch concentration of each sample was quantified by a Model 2700 Biochemistry Analyzer (Yellow Springs Instrument Co., Yellow Springs, Ohio). In this method, starch within the tissue sample was digested with amylase enzyme into its glucose subunits; then D-glucose was metabolized with enzymes to produce hydrogen peroxide, and the electrical current produced by the hydrogen peroxide was measured by the analyzer (Lee et al., 1995). Free glucose in each tissue sample was determined in a separate sample prior to starch digestion. For nutrient analysis, ground tissue was sent to The Pennsylvania State Univ. Agricultural Analytical Services Laboratory (University Park). Total nitrogen concentration of each sample was determined by combustion (Campbell, 1991), and other nutrient concentrations were determined through dry ash analysis (Dahlquist and Knoll, 1978).

Results and Discussion

Dormant vines. Comparison of above- and belowground woody tissue 67 d before bloom (30 Mar.) showed that in the dormant vine, roots were the dominant storage organ for starch and some nutrients. After winter cane pruning, the root system comprised 59% of the total vine dry weight; however, the roots contained 84% of the total starch, 75% of the nitrogen, and 77% of the phosphorus stored in the vine because of higher tissue concentrations of these components. Other nutrients having greater amounts in the roots than in shoots were aluminum, iron, copper, and zinc, which made up 96%, 90%, 73%, and 69% of the vine's total, respectively. Relative to *Vitis vinifera*, 'Concord' grapevines are tolerant of acid soils, and the accumulation of toxic metal ions such as aluminum in 'Concord' roots may be a part of that variety's low pH tolerance (soil pH in this study was 5.2–5.5). Potassium, sodium, and manganese preferentially accumulated in trunks and cordons, while calcium, magnesium, copper, and boron were equally distributed into above- and belowground tissue.

Bud swell to bloom. By bloom, net dry weight increased 185 g/vine (only 5% of the total dry-weight gain for the season; Fig. 1). In the same period, new shoot growth gained 216 g/vine dry weight, and an early-season root flush added another 98 g/vine during the prebloom period (Fig. 2). Trunks, cordons, and thick woody roots lost weight during the same period, which accounts for early shoot and fine-root dry-weight gain being larger than net vine dry-weight gain at bloom.

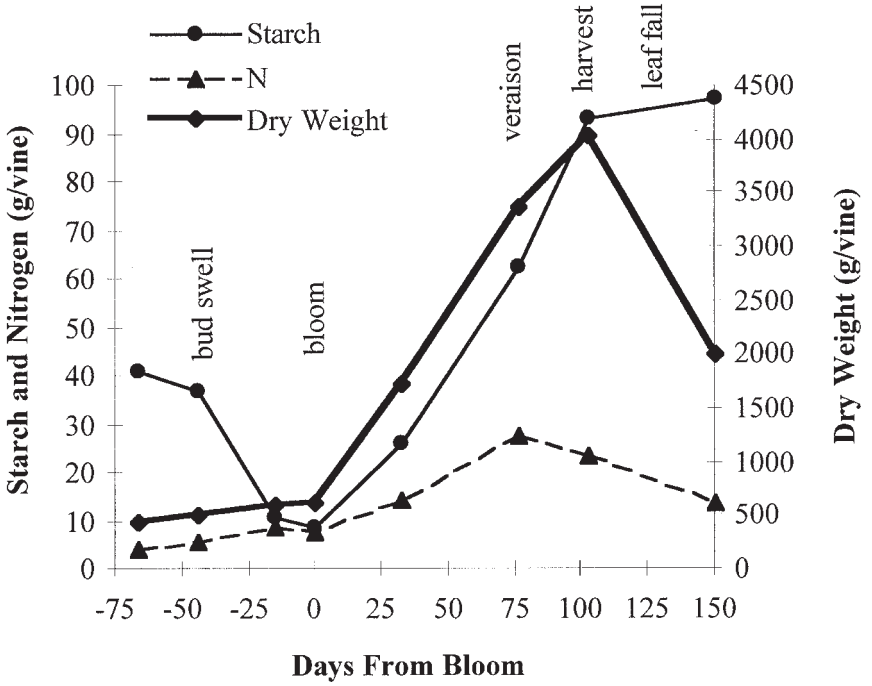

Fig. 1. Seasonal changes in total dry matter, starch, and nitrogen in 3-year-old field-grown 'Concord' grapevines in 1998 at the Cornell Vineyard Laboratory. Each point is the mean of five vines.

Starch decreased in all permanent vine structures from dormancy to bloom. At the beginning of the season, both starch concentration and total starch per vine were greater in woody roots than in woody shoots. Woody roots stored 12% to 14% starch and woody shoots stored 3.5% to 4.5% starch. By bloom, all woody structures contained 1% to 2% starch. Although all woody tissue lost starch during the prebloom period, starch loss was initially greatest in the thickest roots from dormancy to bud swell, then greatest in other woody roots from bud swell to bloom. The greatest rate of starch decline was measured in the fine roots at a time that coincided with the first fine-root flush during the prebloom period. Since new photosynthates were most likely transported to expanding leaf area and shoot tips prior to bloom (Yang and Hori, 1980b), the early-season root flush was most likely completely dependent on carbohydrate reserves for respiration and growth.

Nitrogen patterns in the prebloom period were more dynamic because the nitrogen source for new growth came from both stored reserves and new uptake (Table 3). From dormancy to 10-inch shoots, the thick roots, trunks, and cordons lost nitrogen while the growing roots and shoots gained nitrogen. A whole vine net increase in nitrogen during this period also shows that 84% of vine nitrogen came from spring uptake. From 10-inch shoots until a month after bloom, all roots lost nitrogen and all aboveground organs gained nitrogen. It is difficult to determine the relative nitrogen sources during this period because the thin and fine roots that accumulated nitrogen during the early-season root flush became a stored nitrogen source as well as an uptake nitrogen source during the immediate prebloom period. In addition, it has been shown that stored nitrogen can be used by the grapevine throughout the season and not just in prebloom growth (Conradie, 1992). Fine-root death from the spring root flush presumably returned nitrogen to the soil and accounted for a proportion of nitrogen loss in that organ just prior to bloom.

Bloom to harvest. The period from bloom to harvest was characterized by rapid vegetative and reproductive dry-weight growth, carbohydrate accumulation, and nutrient uptake. Of the total growth and nutrient uptake during the season, ≈95% vine biomass, 96% starch, 85% nitrogen, and 80% phosphorus and potassium were accumulated during this period.

Trunk, cordon, and root dry weight increased from bloom to veraison; however, starch concentration remained at a minimum in those tissues from bloom to 32 d after bloom. This suggests that new photosynthates were used exclusively for new tissue growth in the month following bloom and were not used to replenish lost reserves. About 1 month after bloom, 'Concord' vines reach full shoot development and maximum potential canopy photosynthesis in 80-node vines (Lakso et al., 1996). Total starch and starch concentration increased from 32 d after bloom to veraison in perennial tissue.

From veraison to harvest, starch concentration did not increase in shoot tissue (maturing canes). Fruit maturation may have competed with cane maturation during this period. In contrast, starch concentration of all other woody structures as well as that of fine roots continued to increase from veraison to harvest.

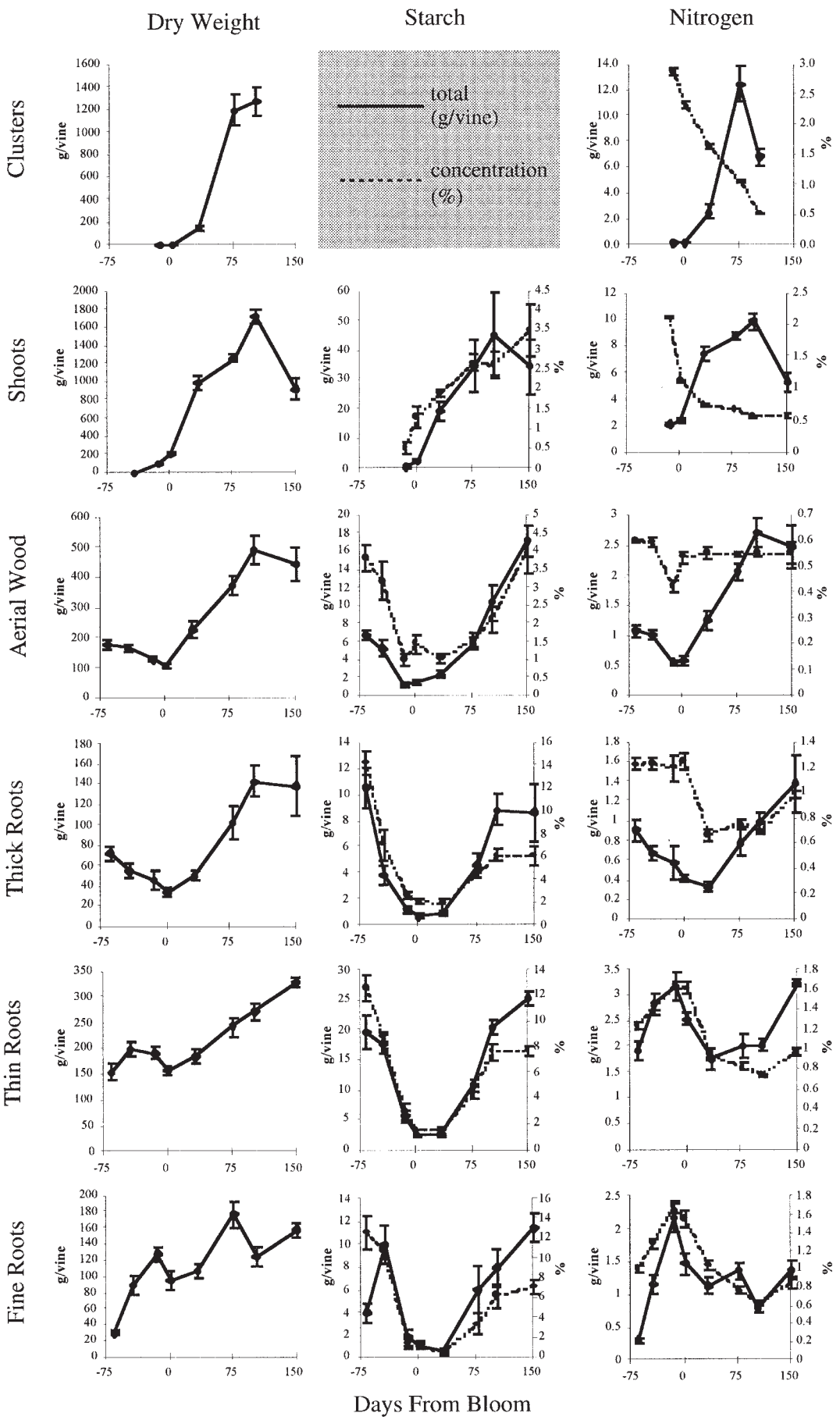

Fig. 2. Seasonal pattern of dry matter, starch, and nitrogen in 'Concord' grapevine tissue in 1998 at the Cornell Vineyard Laboratory. Data are the means of five vines. Bars = ±standard error.

Table 3. Total vine nitrogen and tissue nitrogen change between excavations in 3-year-old field-grown 'Concord' grapevines in 1998 at the Cornell Vineyard Laboratory. Each point is the mean of five measurements.

Total vine N (g/vine)	Dormant 4.23	Bud swell 5.70	10-inch shoots 8.84	Bloom 7.69	32 DPB 14.59	Veraison 27.51	Harvest 23.34	Leaf fall 13.89
N change (g)								
Clusters			0.16	0.03	2.41	9.90	–5.64	–6.86
Shoots			2.17	0.27	5.01	1.29	1.18	–4.54
Trunks + cordons		–0.07	–0.46	0.04	0.67	0.80	0.65	–0.23
Thick roots		–0.23	–0.10	–0.17	–0.07	0.44	0.22	0.39
Thin roots		0.92	0.35	–0.64	–0.77	0.25	0.00	1.22
Fine roots		0.86	1.02	–0.69	–0.35	0.24	–0.58	0.58
Whole vine net		1.47	3.14	–1.15	6.90	12.92	–4.17	–9.45

While most of the total nitrogen, potassium, and phosphorus needed by the vine was taken up during the period from bloom to harvest, the concentration of these mineral nutrients in vine tissues except trunks and cordons decreased during this period. The growth of dry matter exceeded the rate of nutrient uptake from the soil and therefore diluted the tissue nutrient concentration.

Harvest to leaf fall. The short duration from harvest to leaf fall can be one of the viticulture limitations in cool climates. Depending on the weather conditions in western New York, 'Concord' harvest can take place a full month before leaf fall or it can take place with the first killing frost. In addition, potential photosynthesis decreases with decreasing day length and available radiation in late September and early October. Therefore, postharvest photosynthesis benefits can be limited in cool climates.

In 1998, leaf fall was ≈2 weeks after harvest. The concentration of starch continued to increase in aboveground tissue postharvest, but it remained constant in belowground tissue. Although the root system was larger at the end of the season than at the beginning, the starch concentration was lower (13% beginning, 8% end). The high starch concentration at the beginning of the third season may have been a result of defruiting second-year vines to increase vine capacity.

In contrast to starch, nitrogen concentration increased in belowground tissue but not in aboveground tissue from harvest to leaf fall. 'Concord' roots in our study reached a minimum nitrogen concentration of 0.7% at harvest, although they recovered to ≈1% by leaf fall. A longer postharvest period may have led to greater nutrient uptake for tissue reserves.

Fine-root growth. There were three fine-root growth periods during 1998: prebloom, midseason, and postharvest. The first and last root flushes occurred at times when the vine was not rapidly growing and when the functional leaf area was either small (prebloom) or declining (postharvest). These root flushes increased the nitrogen, phosphorus, and potassium concentrations of the fine and thin-root tissue. Interestingly, the midseason fine-root flush did not increase tissue nutrient concentration and did not have a measurable effect on the total nutrient accumulation rate in the vine. It is possible that the rate of vine growth and nutrient uptake during the middle of the season was great enough to mask any additional nutrient uptake benefit by the midseason root flush.

This study supports the role of 'Concord' roots as the major storage organ for carbohydrates and some mineral nutrients that are needed to support early-season shoot and root growth. The carbohydrates and nitrogen lost from root tissues did not begin to be replenished until after the period of rapid shoot growth, ≈1 month after bloom, and root nitrogen concentration did not increase until after the fruit was harvested. This study shows the benefit of postharvest photosynthesis and nutrient uptake in vine recovery, which becomes increasingly important where crop levels are large and/or growing seasons are short.

Literature Cited

Araujo, F.J. and L.E. Williams. 1988. Dry matter and nitrogen partitioning and root growth of young field-grown Thompson Seedless grapevines. Vitis 27:21–32.

Campbell, C.R. 1991. Determination of total nitrogen in plant tissue by combustion, p. 21–23. In: C.O. Plank (ed.). Plant analysis reference procedures for the southern region of the United States. Southern Coop. Ser. Bul. 368. Univ. of Georgia, Athens.

Conradie, W.J. 1980. Seasonal uptake of nutrients by Chenin blanc in sand culture: I. Nitrogen. So. African J. for Enol. and Viticult. 1:59–65.

Conradie, W.J. 1986. Utilization of nitrogen by the grape-vine as affected by time of application and soil type. So. African J. for Enol. and Viticult. 7(2):76–83.

Conradie, W.J. 1988. Effect of soil acidity on grapevine root growth and the role of roots as a source of nutrient reserves, p. 16–29. In: J.L. vanZyl (ed.). The grapevine root and its environment. Republic of So. Africa Dept. Agr. and Water Supply, Stellenbosch, So. Africa.

Conradie, W.J. 1992. Partitioning of nitrogen in grapevines during autumn and the utilization of nitrogen reserves during the following growing season. So. African J. for Enol. and Viticult. 13:45–51.

Dahlquist, R.L. and J.W. Knoll. 1978. Inductively coupled plasma atomic emission spectrometer: analysis of biological materials and major, trace and ultra-trace elements. Appl. Spectroscopy 32(1):1–29.

Hanson, E.J. and G.S. Howell. 1995. Nitrogen accumulation and fertilizer use efficiency by grapevines in short-season growing areas. HortScience 30(3):504–507.

Lakso, A.N., S.S. Denning, R. Dunst, A. Fendinger, and R.M. Pool. 1996. Comparisons of growth and gas exchange of conventionally- and minimally-pruned 'Concord' grapevines. Fourth Intl. Symp. on Cool Climate Viticult. and Enol. IV11–IV12.

Lee, S.S., A.G. Taylor, M.M. Beresniewicz, and D.H. Paine. 1995. Sugar leakage from aged leek, onion, and cabbage seeds. Plant Var. and Seeds 8:81–86.

Loescher, W.H., T. McCamant, and J.D. Keller. 1990. Carbohydrate reserves, translocation, and storage in woody plant roots. HortScience 25(3):274–281.

Mullins, M.G., A. Bouquet and L.E. Williams. 1992. Biology of the grapevine. Cambridge Univ. Press, Cambridge, U.K.

Roper, T.R. and L.E. Williams. 1989. Net CO_2 assimilation and carbohydrate partitioning of grapevine leaves in response to trunk girdling and gibberellic acid application. Plant Physiol. 89:1136–1140.

vanZyl, J.L. 1988. Response of grapevine roots to soil water regimes and irrigation systems, p. 30–43. In: vanZyl, J.L. (ed.). The grapevine root and its environment. Republic of So. Africa Dept. Agr. and Water Supply, Stellenbosch, So. Africa.

Williams, L.E. 1987. Growth of 'Thompson seedless' grapevines: I. Leaf area development and dry weight distribution. J. Amer. Soc. Hort. Sci. 112:325–330.

Williams, L.E. 1987. Growth of 'Thompson seedless' grapevines: II. Nitrogen distribution. J. Amer. Soc. Hort. Sci. 112:330–333.

Williams, L.E. and M.A. Matthews. 1990. Grapevine, p. 1019–1055. In: B.J. Stewart and D.R. Nielsen (eds.). Irrigation of agricultural crops. Agron. Monogr. No. 30. ASA–CSSA–SSSA, Madison, Wis.

Yang, Y.S. and Y. Hori. 1979. Studies on retranslocation of accumulated assimilates in 'Delaware' grapevines. I. Retranslocating of ^{14}C-assimilates in the following spring after ^{14}C feeding in summer and autumn. Tohoku J. Agr. Res. 30(2):43–56.

Yang, Y.S. and Y. Hori. 1980a. Studies on retranslocation of accumulated assimilates in 'Delaware' grapevines. II. Retranslocation of assimilates accumulated during the previous growing season. Tohoku J. Agr. Res. 31(2):109–119.

Yang, Y.S. and Y. Hori. 1980b. Studies on retranslocation of accumulated assimilates in 'Delaware' grapevines. III. Early growth of new shoots as dependent on accumulated and current year assimilates. Tohoku J. Agr. Res. 31(2):120–129.