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Cranberry nutrients, phenology, and N-P-K fertilization.

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CRANBERRY NUTRIENTS, PHENOLOGY, AND N-P-K FERTILIZATION

A Dissertation Presented

by

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ABSTRACT

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The objective of this study was to compile and interpret nutritional and developmental data for cranberry (*Vaccinium macrocarpon* Ait.) as the basis for standardizing experimental techniques (particularly data collection) and tissue analysis, including tissue to sample, time of sampling, and normal element concentrations for 'Early Black'. Seasonal nutrient levels were determined in tissues of 'Early Black' cranberry under 10N-8.7P-8.3K fertilization (0, 170, 335, and 505 kg/ha). After three years, N, P, and K concentrations in new shoot tissues were positively affected by N-P-K supply. The N-P-K supply had no effect on Ca and Mg concentrations in new shoot tissue but B concentrations were lowest in unfertilized plants. N, P, K, and Cu concentrations in new shoots declined during the season, whereas those of Ca, Mg, B, and Mn rose. Element concentrations in the tissues indicated that mobilization of elements into new shoots from old leaf and woody stem tissues occurred. In an average crop (17 Mg/ha), 8.5 kg N/ha and 14.7 kg K/ha were removed from the cranberry bog.

Vegetative growth (dry weight, upright length) was positively correlated with N-P-K supply, but the highest yields were associated with 335 kg N-P-K/ha. Upright density, percent of uprights flowering, and fruit set were the important determinants of yield. These variables were proposed as standards for data collection. Growing degree day (GDD) accumulations were recorded during this study using a base temperature of 6.5C (lower than previously recommended). Based on GDD accumulations at the canopy level, the correct base temperature for cranberries is most likely 4.5C or lower. However, for a single location over several years, day number was superior to GDD as a predictor of developmental and nutritional status.

A period of stable element concentration in new shoot tissue (10 August to 15 September) was identified and recommended as the time to collect cranberry tissue samples for analysis. Mixed vegetative and flowering new upright tips were recommended as the tissue to sample, and standards for 'Early Black' were proposed. Element concentrations in 'Howes', 'Stevens', 'Pilgrim', 'Bergman', and 'Franklin' were determined and compared to the 'Early Black' standard values.

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CHAPTER 1

INTRODUCTION TO THE STUDY: BACKGROUND AND OBJECTIVES

1.1 Background of the Problem

During the 1980s, the need for research pertaining to cranberry field nutrition and fertilization increased. Technological advances in sprinkler irrigation, frost protection, water harvest techniques, and pest control during the previous 30 years led to an increase in average cranberry yields of more than 150% in Massachusetts (Peterson et al., 1968; Anonymous, 1991). With this increase came the need for more fertilizer use. Production of the cranberry yields common before these technological advances was possible with the use of little or no fertilizer. Nutrition was not the factor limiting yield. For this reason, no field research regarding Massachusetts cranberry nutrition and fertilizer was reported between 1962 and 1980. The work reported prior to that time was performed on bogs yielding less than 100 bbl/A -- 11.2 Mg/ha (Chandler, 1961). Research regarding the nutritional requirements of high productivity cranberry bogs was needed. Further, a need existed for basic knowledge regarding cranberry development, nutrition, and response to environment so that fertilizer experiments could be conducted in a way that made the best use of dwindling research resources. The perennial nature of cranberries was an additional factor to be taken into consideration as the potential existed for nutrient cycling or remobilization. Single season field experiments were seldom informative (DeMoranville, 1989), with no differences among treatments until at least the second year.

The demand existed for tissue analysis standards on which to base fertilization for cranberry production. Soil tests seldom have been useful for anything more than assessing cation balance and monitoring soil pH on cranberry bogs. Soil test results did not correlate well with growth and yield of perennial fruit crops nor did soil nutrient levels predict tissue nutrient concentrations (Hanson, 1987). In cranberry samples analyzed at the University of Massachusetts, the values of soil nitrate and ammonium never have correlated well with yield or amount of fertilizer applied to the bogs. Additionally, Dana (1989a) found that the correlations between soil P and K and tissue values for P and K (June sample) were poor ($r=0.19$ and $r=0.24$, respectively). These poor correlations left tissue analysis as the analytical tool with the most promise for use by cranberry growers. This agreed with the conclusion by Hanson (1987) that soil tests were useful for determining fertilizer needs of *Vaccinium corymbosum* L. only at the time of planting and establishment.

Many modern publications regarding cranberry nutrients have concentrated on greenhouse studies with rooted cuttings (Rosen et al., 1990; Medappa and Dana, 1970; Doughty, 1970; Stieber and Peterson, 1987; Dana and Steinmann, 1989b; Torio and Eck, 1969). Information generated in such studies may be minimally applicable to a commercial field situation, except possibly for newly planted bogs.

Cranberry plants are perennial and eventually cover the entire surface of a bog. Because bud development for the following season occurs concurrently with development of the present season's fruit, fertilizer treatments often have substantial carry-over. This

potential for carry-over means that even the most basic field trials must be carried out for multiple years (DeMoranville, 1989). Further, the method of planting a bog, by discing-in cuttings which are spread on the soil surface, leads to vine stands of non-uniform density. This lack of uniformity leads to the need for higher numbers of replicates than are required for laboratory or greenhouse experiments and for a method to standardize the results of sampling. The best method for sample standardization appears to be converting the data collected so that they are compared on the basis of a standard vine density. The preceding factors increase the labor intensity of an experiment: a high replication factor coupled with the need to document the vine density for each sampling area. All of these factors highlighted the need for enough basic information so that the most efficient experiments could be designed.

In addition to the interest of growers and researchers in basic information regarding cranberry nutrition, interest was great for determining the fate of fertilizer materials applied to cranberries. Information regarding the elemental levels in various tissues on a seasonal basis, coupled with information on seasonal growth patterns, would allow construction of a basic balance sheet for nutrient remobilization in the perennial cranberry. This information could provide a background for the interpretation of environmental analyses.

1.2 Description of the Problem

In order to address questions regarding cranberry nutrition, a general knowledge about cranberries grown in commercial settings was

needed. This knowledge should include, but not be limited to: seasonal levels of essential nutrients in various plant tissues; best time and tissue to collect for mineral analysis; cultivar differences in nutrient status and growth pattern when environment and management are kept constant; biomass accumulation patterns; general developmental patterns for the plant, including relationship to weather; and developmental patterns for fruit of different commercial cultivars.

Some of this information was gathered from 1930 to 1970. However, several innovations in commercial cranberry culture since that time have changed the growing conditions on commercial plantings to the extent that much of the previous information is outdated and of little value as the basis for conducting an appropriate fertility experiment today. For example, the Massachusetts average state crop in 1950 was 41.2 barrels per acre (4.6 Mg/ha) (Peterson et al., 1968). In 1989, that figure was 147.6 barrels per acre (16.5 Mg/ha) (Anonymous, 1991). Densities of approximately 3,000 uprights/m^2 which were recommended in 1968 (Dana, 1968) are about half the standard figure for this parameter in today's commercial fields. Further, optimum stand density varies with cultivar. The advent of sprinklers (for irrigation, frost protection, and application of farm chemicals), the introduction of water-harvest technology, and increased availability of pest control strategies, account for much of the change in production levels. It seemed likely that these changes have altered the field habits of cranberries. If data regarding the development and nutrition of cranberries in modern field settings were available, fertilizer programs might be designed to increase the

productivity of marginal bogs and support high productivity levels when they occur.

The general objectives to be addressed in this work were the compilation and interpretation of nutritional and developmental data to be used as the basis for the future design of efficient cranberry fertilizer field experiments and the compilation of grower-usable information regarding cranberry tissue nutrient analysis: timing of collection, tissue to collect, cultivar differences and interpretation. To research the general questions, specific questions were formulated. These specific objectives follow.

1.2.1 Nutrient Levels in New Shoot Tissue of 'Early Black' Cranberry Receiving Four Rates of N-P-K Fertilizer

Currently, commercial cranberry plantings in Massachusetts are fertilized with 'complete' nitrogen, phosphorus, and potassium (N-P-K) mixtures. The dose of N-P-K applied is based on the amount of N to be delivered; the average planting receives between 20 and 35 kg N/ha per season. The most commonly used N-P-K materials have a nutrient ratio of 1:2:1 ($N:P_2O_5:K_2O$). 'Early Black' is the most widely planted cultivar in Massachusetts.

In order to understand the results of 'Early Black' cranberry tissue analyses for N, P, and K, the effect of fertilizing with N-P-K on the concentrations of those elements and others in the plant should be assessed. Did under- or over-fertilization affect the percent of N, P, and K found in cranberry tissue samples? Were the amounts of other elements in the tissue affected?

1.2.2 Biomass Accumulation Patterns in a Commercial 'Early Black' Cranberry Planting

Levels of some nutrient elements in cranberry tissue decline as the season progresses. To determine whether this decline is due to dilution by growth, simultaneous determinations of biomass accumulation and nutrient data were necessary. Fertilizer addition to cranberry bogs could be expected to affect biomass accumulation. Data were collected to document these effects. After combining data for nutrient levels with those for biomass accumulation, a balance sheet approach to following the movement of nutrients in cranberry bogs was attempted.

Because information regarding patterns in fruit development could form the basis for deciding when to add nutritional supplements or irrigation to a cranberry bog to achieve maximum fruit size (weight), data were compiled regarding fruit development (fresh and dry weight) under 4 levels of N-P-K fertilizer.

1.2.3 Seasonal and Tissue Changes in Nutrient Element Levels of 'Early Black' Cranberry

By documenting changes in nutrient element levels for tissue of 'Early Black', standards would be available for comparison to tissue samples taken to diagnose mineral deficiencies at any time during the growing season. Once patterns of change for nutrient element levels in the cranberry tissue were established, times of stability in nutrient content could be selected as the most appropriate time to

collect tissue samples for monitoring nutrient status of the plants. Knowledge of nutrient level patterns also could be used as a starting point for fertilizer timing experiments, based on periods with minimum nutrient levels or times when nutrient levels change significantly over short time periods.

Combining the information on nutrient level changes with measured values for change in biomass over time, movement and cycling of nutrients in the cranberry plant could be estimated. Amounts of elements accounted for in biomass accumulated was one of the components needed to construct an environmental balance sheet for cranberry bogs. An incomplete nutrient balance sheet for 'Early Black' was developed.

1.2.4 'Early Black' Cranberry Development and Temperature Interactions

Documenting the timing of developmental stages and comparing the timing to the corresponding nutrient levels would make the nutritional information gathered in this study more adaptable to cranberry bogs throughout the growing region. If certain nutritional conditions corresponded to specific developmental stages, the occurrence of the developmental stage would become a predictor for nutritional status. If developmental events were going to be used as predictors for nutritional status changes, then information for predicting developmental events would be useful. Predictions would be based on calendar date or growing degree day accumulation.

1.2.5 Developmental Patterns and Nutrient Levels for Six Commercial Cranberry Cultivars

Large plantings of 6 commercial cultivars were available at the experiment site in East Wareham, Massachusetts. In order to compare cultivars under a single management plan (including fertilizer dose), nutrient levels over time in the new shoot and fruit tissue were determined. Times of stable nutrient levels were compared among cultivars. Fruit development patterns were investigated for the 6 cultivars to document differences between 'large fruited' and 'small fruited' cultivars (3 of each in this study).

1.2.6 Determination of Cranberry Nutrient Status: Time to Sample, Tissue to Sample, Standard Values for Ten Elements

In order to use tissue testing for planning fertilizer decisions in cranberry production, there was a need to develop standard values for N, P, K, Ca, Mg, Zn, B, Mn, Cu, and Fe in cranberry tissue based on specific tissue collected at a specific time during the growing season. Current season growth was an obvious choice, but there was a need to determine whether new shoots (leaves and stems) or new leaves were preferable for sampling. Further, new upright shoots may be purely vegetative or mixed reproductive and vegetative, bearing flowers and fruit. Any differences that existed in nutrient levels among these different types of new growth needed to be determined. The time of sampling would be determined by stable periods in the concentrations of the 10 elements in cranberry tissues.

Once time and tissue to sample were selected, standard values for the 10 elements were set based on average values and ranges. Standards based on correlation of yield with tissue nutrient element values were attempted but the results were confounded by the fact that the maximum yields predicted by the resulting model were well below the maximum cranberry crops achieved in Massachusetts. The proposed standard values were compared to available cranberry tissue test standards.

CHAPTER 2

LITERATURE REVIEW

2.1 Cranberry Growth Habit and Productivity

Cranberry (*Vaccinium macrocarpon* Ait. family Ericaceae) is a low-growing, woody, evergreen perennial. Horizontal stems (runners) lie on the surface of the soil. These runners produce roots and vertical stems (uprights) at the nodes. In addition, uprights may arise from the terminal or axillary buds of other uprights (Dana and Klingbeil, 1966). Uprights may be produced from either vegetative or mixed buds. The crop is borne on uprights which arise from these mixed buds. Bergman (1954) categorized uprights as "old" - having a flower bud or arising from the terminal bud of another upright, or "new" - from a runner or upright axillary bud; "new" uprights did not flower. This terminology did not distinguish between "old" uprights which did and did not flower. Modern terminology distinguishes between flowering and nonflowering or vegetative uprights regardless of origin.

Upright density varied with cultivar (Bergman, 1954) but this was not always (Tallman and Eaton, 1976). The total number of uprights did not consistently correlate with yield, but the numbers or percents of flowering uprights could be very important in determining yield (Bain, 1946). Filmer (1955) defined 5380 uprights/m^2 with at least 30% of those flowering as ideal for 'Early Black' in New Jersey. However, 2150 to 3200 uprights/m^2 were considered ideal for 'Searles' in Wisconsin (Roberts and Struckmeyer, 1942). The lengths of the

uprights were correlated with upright density for 'Searles' cranberry (Roberts and Struckmeyer, 1942). However, 'Bergman' and 'McFarlin' cranberries had similar upright densities whereas 'McFarlin' uprights were significantly longer and less productive (Tallman and Eaton, 1976). Upright density and upright length were negatively correlated for 'Early Black' and 'Howes' (Bergman, 1954).

Yield component analyses (stepwise multiple regressions) were performed on data collected from cranberry bogs in British Columbia (Eaton and MacPherson, 1978; Eaton and Kyte, 1978) and in Washington (Shawa et al., 1981) for the cultivars 'Bergman', 'McFarlin' and 'Ben Lear'. The two most important components of yield in those studies were floral induction (flowering upright percent) and fruit set. Vegetative properties, length of upright, and number of leaves also had effects on yield (Eaton et al., 1983).

In common with other perennial fruit crops, the flower buds for the cranberry are formed in the year prior to flower opening and fruit set. Bud development begins in late July and ceases in September (Lacroix, 1926). The dormant buds overwinter and in the spring floral development is completed and flowers begin to open in June. Cranberry requires vernalizing conditions followed by long days to induce flowering (Rigby and Dana, 1972). Because buds are forming on uprights which in some cases (the flowering uprights) already bear fruit, competition for resources exists. Flowering uprights of 'Searles' flowered in successive years but the intensity of return bloom depended on the productivity level of the bog (Roberts and Struckmeyer, 1942). Areas of average yield had 35% return bloom while only 15-20% of flowering uprights on highly productive bogs bloomed in

successive years. Strik et al. (1991) found from 16 to 74% return bloom in seven cultivars in four states. Return bloom was lowest in Massachusetts and for 'Early Black'. Vegetative uprights were more likely than flowering uprights to bloom in the following year. Lenhardt and Eaton (1977) found 37% flower bud production in flowering uprights and 61% in vegetative uprights of 'McFarlin'. Eaton (1978) found that whereas non-flowering uprights produced 80% mixed buds in the cultivar 'Bergman', flowering uprights produced only 25%. The difference was attributed to inhibition of floral induction by flowers and fruit.

The number of flowers formed on a flowering upright varies with cultivar: 'Searles' averages 2.45 flowers (Bain, 1948), 'Early Black' averages 3.24 flowers in New Jersey (Filmer, 1955), and 3.37 flowers in Massachusetts (Bergman, 1950), and 'Howes' averages 3.15 flowers per flowering upright (Bergman, 1950). Cranberry fruit set in June and July and achieve maximum size by mid- to late September (Chandler, 1952; Demoranville, 1960). The fruits form following fertilization of multiple ovules in an inferior ovary. Cranberry is pollinated by bees (Eck, 1986). The cranberry fruit mature in 60 to 90 days after pollination (Darrow et al., 1924). The weight (Hall and Aalders, 1965) and volume (Rigby and Dana, 1971) of the fruit are correlated with seed number. In a study of fruit size vs. seed number in cranberry, Filmer et al. (1958) found only one out of approximately 8,000 berries with no seeds. Fruit set varied from 25% for 'Early Black' and 29% for 'Howes' in Massachusetts (Bergman, 1950) to 40% for 'Early Black' in New Jersey (Filmer, 1955). The average fruit set over several years for 'Searles' in Wisconsin was 37% (Bain, 1948).

Most cranberry bogs in Massachusetts are constructed on a peat base overlaid with sand. If a peat base is not present, some other impervious layer (clay or hardpan) must be present to allow water retention for cultural flooding (Deubert and Caruso, 1989). The cranberry bog soil is essentially a man-made substrate consisting of layers of sand alternating with organic layers made up of fallen cranberry leaves and old roots. Growers add layers of sand periodically to anchor runners, bury old upright wood, and provide aeration and drainage. In addition, burying the organic layer limits the nitrogen available from mineralization and limits the incidence of over-vegetative growth (Colby, 1947).

Commercial cranberry bog soil is mainly sand, 1 to 2% organic matter, 2% silt and clay (<0.5% clay), with a low (<10 meq/100g) CEC and a pH of 4.5 to 5 (Deubert and Caruso, 1989). The content of P and K in cranberry soil does not correlate well with the P and K concentrations in cranberry foliage (Dana, 1981a). When soil and tissue tests for P and K from Wisconsin bogs were plotted against one another (Roper and Coombs, 1992), the plot consisted of a straight horizontal line (no correlation). Low soil organic matter levels (2-4%) are acceptable for the growth of *Vaccinium* species (Korcak, 1987).

Cranberries are adapted to low soil pH and a weak correlation exists between low soil pH and high cranberry yields (Chandler and Demoranville, 1961). In solution cultures, cranberries grown at pH 4.5 had fewer branch roots with many quiescent root initials compared to those grown at pH 6.5 (Finn, et al., 1990). This difference may have been due to greater root efficiency at low pH with less need for high root mass. At low pH, metals such as Fe and Mn are more

available to the plant while P availability is low, in part due to fixation by Fe and Al at the root surface (Korcak, 1987; Rosen et al., 1990). Despite problems with fixation of P, high soil Fe content is associated with good cranberry yields (Fisher, 1951).

In solution culture experiments with rooted cuttings, cranberry plants showed high tolerance to Mn, Fe, and Al excesses in the medium (Medappa and Dana, 1970). The tolerance mechanism seemed to be via accumulation for Mn and avoidance for Fe and Al, based on the content of those elements in shoots of cranberries exposed to excesses. Rosen et al. (1990) analyzed cranberry roots from plants grown in solution culture and found high levels of Mn and extremely high levels of Fe. Microscopic analysis showed particles precipitated on the root surface, most likely made up of P and Fe and Mn.

Cranberry plants have a dense, matted, fibrous root system with no root hairs (Medappa and Dana, 1970). Roots occurr mainly at the soil surface (Darrow et al., 1924) and arise from runners on the surface or just below the surface (buried by resanding). New roots are produced each year beginning soon after the winter flood is withdrawn (Franklin, 1915) and tend to be confined to the top 2 to 10 cm due to saturation of lower soil layers and stratification due to resanding. It has been suggested (Darrow et al., 1924) that root growth is greatest in late summer and fall. Franklin (1915) found little or no root growth prior to bloom (late June).

Cranberry is a mycorrhizal plant. Fungal hyphae have been found in all tissues (Addoms and Mounce, 1931) and the amount of mycorrhizae present has been correlated positively with plant vigor (Addoms and Mounce, 1932). However, cranberry plants were capable of growth in

peat media and in solution culture with nitrate or ammonium nitrogen even if mycorrhizae were not detected in the tissues (Dirr, 1974). When cranberry plants were infected with mycorrhizae, the root/shoot ratio was adjusted downward to compensate for more efficient N uptake and maintain constant internal N concentrations (Hunt, et al., 1975).

In ^{15}N enrichment studies, the presence of mycorrhizae appeared to allow cranberry plants to acquire N sources from the organic component in soil which were unavailable to non-mycorrhizal cranberry plants (Stribley and Read, 1974). The mycorrhizal cranberry plants also could grow more efficiently at low ammonium levels and use amino acids as an N source (stribley and Read, 1976 and 1980). The ability to utilize amino acids as an N source meant that mycorrhizal cranberries could use N from partially decomposed organic matter without the need for complete mineralization. This ability was an advantage under heathland conditions where mineralization is slow.

2.2 Cranberry Tissue Nutrients and Response to N-P-K Fertilization

Tissue nutrient and yield response has been assessed in fertility experiments on field-grown cranberry. Eaton (1971) working with 'McFarlin' in British Columbia found that the addition of P or K gave a dose-dependent increase of that element in leaf tissue. Nitrogen addition in the field increased %N in leaf tissue compared to samples from untreated plots, but the response was equal for all concentrations of N used (Eaton, 1971). Only nitrogen additions had a positive effect on yield. No deficiency symptoms were seen. In further experiments with 'McFarlin', Eaton and Meehan (1976) found no

response in yield or tissue %N to the addition of 20 kg N/ha in field studies. Addition of 70 kg K/ha increased leaf K from 0.27 to 0.4% (dry weight) with no effect on yield. Evidently tissue N and K were not limiting yields in those plots.

The addition of nitrogen encouraged vegetative growth of new cranberry plantings (Eck, 1976) or established bogs (Eck, 1971). The addition of between 17 and 51 kg N/ha did not change the %N (0.77-0.79) in dry leaf tissue collected in October (Eck, 1976). However, leaf tissue sampled in August showed a positive correlation between N dose (18-72 kg/ha) and %N in dry leaf (0.92-1.09) (Eck, 1971).

The addition of phosphorus (11-112 kg/ha) improved growth of 'Stevens' cranberry on peat soil (Greidanus and Dana, 1972). Leaf tissue P (0.05-0.12%) also increased with increased P fertilization. At leaf P of 0.08% or less, deficiency symptoms were apparent.

Attempts have been made to determine sufficiency levels for mineral elements in cranberry. Torio and Eck (1969), using sand cultures of 'Early Black' in the greenhouse, found that yield was unaffected when the leaf tissue ranges of N (0.78-0.98%), P (0.08-0.09%), K (0.59-0.74%) and S (0.11-0.13%) were varied by differential fertilizer applications. Eaton and Meehan (1973) found maximum yield and no visible deficiency in N-P-K factorial experiments associated with the following leaf levels: N 1.0%, P 0.1%, K 0.34-0.4%, Ca 0.6-0.7%, Mg 0.27%, Fe <50 ppm, Mn <150 ppm.

Using solution cultures and rooted cuttings, researchers at the University of Wisconsin have studied critical nutrient levels in cranberry. Dana (1981c) observed deficiency symptoms for 'Stevens' at 0.17% K, 0.05% Ca, 0.02% Mg, 26 ppm Fe, <1 ppm B, 3.1 ppm Cu, or 3.8

ppm In. Dana and Steinmann (1989a) showed that maximum shoot growth of 'McFarlin' was achieved at 0.1% Ca in leaf tissue with deficiency apparent below 0.07% Ca. 'Stevens' showed deficiency at leaf K below 0.27% (Dana and Steinmann. 1989b) during rapid growth. Stieber and Peterson (1987) observed deficiency symptoms in 'McFarlin' when %N was at or below 0.8% in shoot tissue. However, shoot growth did not cease at tissue N levels as low as 0.55%.

Nutrient ranges in cranberry leaf tissue have been surveyed in field samples exhibiting no apparent deficiencies: 'Ben Lear', 'McFarlin', 'Searles' and 'Howes' in Nova Scotia for August-September (Townsend and Hall, 1971); June levels in Wisconsin, cultivars not published (Dana, 1981a); seasonal levels in Oregon, cultivar not stated (Chaplin and Martin, 1979); and seasonal levels for 'Howes' in Massachusetts (DeMoranville and Deubert, 1986). The seasonal patterns differed in the different surveys but the August values (time of greatest stability) were in rough agreement between the Massachusetts and Oregon studies. The published ranges tended to overlap but often only at the extreme high or low values. In all samples, the nutrient levels were well above the deficiency levels found for solution cultured rooted cuttings. The differences between Ca, Mg, B, and Zn concentrations at deficiency and those found in field samples were extreme. This may have been an indication that those elements were not needed in cranberry fertilizers. The concentrations found in rooted cuttings may have reflected those found in a newly planted cranberry bog where only vegetative structures were produced. However, the needs of reproductive plants could be expected to be substantially higher, perhaps explaining the discrepancy between

nutrient concentrations found in cuttings and those found in field surveys of cranberry bogs. Presumably, the sufficiency range for cranberry nutrition lies between these sets of values.

2.3 Cranberry Response to Weather

The range for commercial cranberry growing has long been considered to be limited to areas with moderate summer temperatures, no warmer than those of New Jersey (Darrow et al., 1924). However, cool summer temperatures could lead to an extended bloom period (Darrow et al., 1924), which along with daylength constraints may determine the northern limit for cranberry production. Pilcher (1985) showed that the commercial cranberry growing areas of North America were defined by the isotherm for a July daily average maximum temperature of 85F.

2.2.1 Monthly Temperature, Sunlight, and Rainfall

The relationship of temperature, sunlight, and rainfall to cranberry development was examined in Massachusetts (Franklin, 1943; Franklin, 1946; Franklin and Cross, 1948) and in New Jersey (Degaetano and Shulman, 1987). Franklin (1943) found that fruit size was correlated positively with August rainfall. This relationship may no longer be as important since the advent of sprinkler irrigation. Warm springs promoted early ripening whereas high temperature in August inhibited color development. It appeared that while anthocyanin production in the fruit was triggered by a change in photoperiod

(Hawker and Stang, 1985), cool temperatures were also a factor in anthocyanin production (Franklin, 1943).

Yield in Massachusetts was correlated with monthly temperature, rainfall, and sunshine in the crop year and in the preceding year (Franklin, 1946; Franklin and Cross, 1948). Crop size was correlated positively with sunshine for each month from April through September in the year prior to the crop year (Franklin, 1946) and in February of the crop year (Franklin and Cross, 1948). The prior-year relationship was explained in terms of photosynthetic activity whereas the February relationship was judged to involve amelioration of winter kill (oxygen deficiency) conditions during the winter flood (Bergman, 1943). Crop size correlated with temperature only for the crop year. Crop yield was correlated negatively with high temperatures in March, July, and September (Franklin, 1946). The reasons proposed were increased frost susceptibility, heat injury to blossoms, and loss of fruit quality (scald), respectively. Precipitation in the crop year was a factor determining crop size. Ideal rainfall from May through August was 2 to 4 inches/month (Franklin, 1946). This relationship is less likely to hold in modern times due to the use of sprinkler irrigation. However, excess rainfall may still be a problem.

Degaetano and Shulman (1987) examined the size of the New Jersey cranberry crops since 1906 in relation to temperature, rainfall, sunlight hours, and several other weather factors. They examined a 19-month year beginning in April of the year prior to the crop. Yield had the strongest correlation with temperature and sunlight. Crop size was correlated positively with temperature for May through June in the year prior to the crop (vegetative upright production - such

uprights usually flower in the second year) and October through November (bud development, which extends later in the year in New Jersey than in Massachusetts). The importance of warm temperatures in the year prior to the crop is supported by the survey data reported by Lacroix (1926) in Massachusetts. The May-June finding (Degaetano and Shulman, 1987) complements the finding of Franklin (1946) for the need for sunshine in the year prior to crop to promote strong vegetative uprights. High temperature in May and June of the crop year had a negative effect on yield (increased frost susceptibility, heat stress to new growth). This positive or negative impact of spring temperature provided a paradox which could explain the tendency towards biennial bearing in cranberry, which is especially strong in New Jersey. High temperatures in the summer of the crop year also had negative effects (blossom blast, scald). The negative temperature correlations agreed with those found by Franklin (1946) in Massachusetts. In the crop year, sunshine hours in May and June (photosynthesis, pollination) were correlated positively with crop yield. Low temperature in February and March had a positive effect, probably due to lessening of oxygen deficiency injury during the winter flood. This low temperature effect complemented the findings of Franklin and Cross (1948) regarding the positive effect of February sunshine in preventing winter injury.

2.2.2 Chilling Hours

Cranberry flower buds are initiated in the year before the crop. The end of the floral induction period was determined by removal of

mature leaves (source of floral promotion) to occur on July 8 in Wisconsin (Roberts and Struckmeyer, 1943) and on July 4 in British Columbia (Eaton, 1978). Floral primordia were observed by August (Lacroix, 1926; Roberts and Struckmeyer, 1943) and visible changes in the developing buds ceased in October (Lacroix, 1926). Floral buds remained dormant until after the withdrawal of the winter flood in the spring (Lacroix, 1926).

During the dormant period, chilling units accumulated. Chandler and Demoranville (1964) proposed that 2,500 hours below 45F were required as a rest period for cranberries prior to bud break and normal flowering. At greater than 1,500 hours (but less than 2500) some abnormal flowering was observed. However, the chilling hours were supplied at continuous low temperature in the dark with subsequent bud break in a greenhouse with no light supplement (Chandler and Demoranville, 1964). When chilling conditions were applied to cranberries under an 8- or 9-hour daylength (Eady and Eaton, 1969; Rigby and Dana, 1972) approximately 1,000 hours of chilling below 45F was sufficient for subsequent flowering. However, longer chilling periods reduced the subsequent time to flowering (Eady and Eaton, 1972). It appears that chilling units alone do not account for optimum flowering response. A daily period above 45F combined with daily hours below 45F and a 9 hour day length allowed a flowering response after 1,000 hours of chilling, whereas at constant temperatures below 45F, 2,500 hours of chilling were required to get the same response (Eady and Eaton, 1972). Rigby and Dana (1972) confirmed the importance of heat units accumulated along with chilling hours. In addition, rapid transition to flowering after chilling

required long days. If day length was limited to 8 hours after the completion of chilling, flowering was abnormal (Rigby and Dana, 1972).

Pilcher (1985) developed a model for chilling units based on the data of Eady and Eaton (1972). The model was based on accumulation of daily chilling units based on minimum daily temperatures between 51 and 30F. Chill unit accumulation began when daylength was 14.5 hours (Wisconsin) or when minimum daily temperature fell to 51F (lower latitudes) and continued until daylength was again 14.5 hours or minimum daily temperature rose to 30F. Applying this model to Wisconsin conditions, the required number of chilling units was 477 (Pilcher, 1985).

2.2.3 Growing Degree Days

At the end of the period during which chilling units accumulate, events leading to bud break and flowering may begin. Pilcher (1985) developed equations to determine the "growth units" needed for the plant to go from the end of the chilling period to bloom. The same equations were used to determine the growth units needed for the completion of fruit development. Growth unit accumulation began at the beginning of May (14.5 hour daylength, see chilling above) using 45F and 85F as the low and high cutoff temperatures. From that date until the date of full bloom, 472 growth units accumulated under Wisconsin conditions (Pilcher, 1985). Another 1,028 units accumulated from the time of bloom until the completion of fruit development.

Hawker and Stang (1985) compared cranberry development to the accumulation of growing degree days (GDD) from the end of April at

three location in Wisconsin with varying GDD accumulation profiles. High and low cutoff temperatures were 32C (90F) and 9C (48F). They found that vegetative growth and flowering occurred at the same number of GDD at all locations (1,000 GDD to complete shoot elongation, 510 GDD to open bloom). However, fruit maturity as determined by ethylene evolution or anthocyanin production, did not correlate well with GDD, occurring any time after 1,500 or 1,650 GDD, respectively. Involvement of other environmental cues, specifically daylength, was proposed (Hawker and Stang, 1985). The "growth units" calculated by Pilcher (1985) to go from bud break to flowering (472) or fruit maturity (1,500 total) were in agreement with the observations of Hawker and Stang (1985) of flowering at 510 GDD and fruit maturity at >1,500 GDD.

CHAPTER 3

APPROACH FOR INVESTIGATING THE PROBLEM

3.1 'Early Black' Cranberry Seasonal and Tissue Nutrient Levels, Biomass Accumulation, Development, and N-P-K Fertilizer

A field experiment was established on a commercial 'Early Black' cranberry planting in East Wareham, Massachusetts, in 1986. The experimental design consisted of 10 pairs of 4.5 by 4.5-m plots: one of each pair received no fertilizer, the other received 10N-8.7P-8.3K fertilizer at 335 kg/ha (33.5 kg N/ha, 29 kg P/ha, 28 kg K/ha). In order to observe the effect of under- and over-fertilizing cranberries on subsequent tissue analysis values and biomass accumulation, the experiment was modified beginning in 1987. At that time, plots were established with 5 replicates and 4 levels of N-P-K treatment (0, 170, 335, and 505 kg N-P-K/ha -- 10N-11.6P-12K). The nutrient sources in the fertilizer were ammonium phosphate, ammonium sulfate, ammoniated super phosphate, and muriate of potash. The fertilizer was delivered to the plots by hand in split applications: 20% at the end of May, 70% at the end of June, and 10% in early August. The application timing was based on University of Massachusetts Cranberry Experiment Station recommendations which were developed based on nutrient patterns observed on 'Howes' cranberries from 1980-84 (DeMoranville and Deubert, 1986). The plots were each 4.5 by 4.5-m, laid out in a randomized complete block design. These plots were treated and evaluated through 1989.

3.1.1 Sample Collection

Tissue samples from each plot were collected biweekly for each of the 4 seasons (1986-89), beginning in April and continuing until harvest (late September), with the exception of weekly collections during rapid vegetative growth (late May through June). Developmental stages were observed and recorded at each sampling. Sampling intervals were based on previously observed nutrient change patterns in leaves of 'Howes' cranberry (DeMoranville and Deubert, 1986). Each sample was selected by dropping a 15 by 15-cm wire template at random within a plot. All above-ground tissue was cut from within the template, then a 5 by 5 by 5-cm cube of soil was removed from the resulting cleared area in order to collect root tissue. Samples were brought to the laboratory and kept below 4C for no longer than 48 h. For each sample of above-ground tissue, the numbers of current-season and previous-season uprights were counted, separated, and weighed; and fruit were counted, removed from the uprights, and weighed. Above-ground tissues (old leaves, woody stems, new shoots, and fruit) were then separated and dried at 60C for 24 h (or until the dry weight was stable). Roots were separated from the soil cubes by washing under running tap water, weighed, then dried at 60C. After dry weights were recorded, the dried tissues were ground with a Wiley mill to pass a 20-mesh screen and stored below -15C until analyzed.

Soil samples (top 15 cm) were collected from each plot at the beginning of each season and late in each season. Soil was air-dried, then passed through a 2-mm sieve. Sheltered daily minimum and maximum air temperatures were recorded at the experiment site. Growing degree

day accumulations were calculated for base temperatures 4.5, 6.5, 7, 8, 9, and 10C. The actual base temperature for cranberries was unknown.

3.1.2 Analytical Procedures

Dried, ground tissue samples were analyzed for 10 elements: N, P, K, Ca, Mg, Zn, B, Mn, Cu, and Fe. Analyses for all elements but N were run on a dry-ashed portion of each sample at the University of Massachusetts Soil and Plant Testing Laboratory using inductively coupled plasma spectrometry.

Total N in dry tissue was determined. Portions (250 mg) of dried tissue were digested in a 40 sample block digestor using a modification of the method of Isaac and Johnson (1976). A digestion mixture (7 ml of H_2SO_4-H_2SeO_3 reagent -- 97g H_2SeO_3 in 100 ml water added to 2.5 L concentrated H_2SO_4) and 2 boiling chips (Hengar granules) were added to the sample, followed by 3 ml of 30% H_2O_2. When the initial reaction slowed, the samples were placed in the digestor which had been preheated to 400C. The samples were not cooled before placement in the block digestor. After 45 min, the tubes were removed, cooled for at least 1 hour and the volume adjusted to 50 ml with deionized water. The extract was analyzed for ammonium N using an automated analyzer (Technicon Industrial Method, 1978). The method is based on the reaction of ammonium with salicylate in the presence of nitroprusside and chlorine in an alkaline environment to form a blue complex. The color intensity was determined by a colorimeter set at 660 nm.

Soil samples were analyzed by A & L Mid West Laboratories, Inc., Omaha, Nebraska. Soil P was determined by the Bray method (Dickman and Bray, 1941; Bray and Kurtz, 1945). The concentrations of K, Mg, Ca in the soil were determined in ammonium acetate extracts. Values for pH and % organic matter were reported.

3.1.3 Data Processing

This experiment is a repeated measures or split plot in time (Littell, 1989) with replication achieved in randomized complete blocks. Analysis of variance (ANOVA) by N-P-K level and by sampling date was performed on the data for the concentrations of each of the 10 elements in new shoots. ANOVA by sampling date was followed by profile analysis to determine if significant differences in mineral content of new shoots existed between adjacent dates. A further ANOVA for repeated measures design grouped by N-P-K level was performed on the new shoot nutrient data to determine significance of N-P-K level and treatment date interactions. All statistical analyses for the project were run on SYSTAT (Wilkinson, 1989).

New shoot dry weight and fruit fresh and dry weight accumulation data were subjected to regression analysis. In addition, an analysis of day number vs. log-transformed shoot dry weight data was run in an attempt to fit an exponential model. The regression analyses were repeated using growing degree days in place of date. Date and growing degree days were compared as to suitability as a predictor for developmental events (the two were compared for each of 4 years). The

effects of N-P-K on biomass accumulation, upright density, fruit production, and other components of yield were evaluated by ANOVA.

For each tissue (new shoots, old leaves, woody stems, roots, and fruit) ANOVA for repeated measures with N-P-K level as a grouping factor was performed to determine the effect of fertilizer on tissue element levels. Next, ANOVA by date for the elements in each tissue was run, followed by a profile analysis to determine differences between adjacent dates.

The biomass and nutrient analysis data were combined so that each nutrition data point was expressed as the amount of that element (in kg) present in that tissue per hectare of bog. These transformed data were used to construct an incomplete balance sheet for nutrients in a cranberry bog.

3.2 Developmental Patterns and Nutrient Levels for Six Commercial Cranberry Cultivars

For 3 seasons (1989-1991), weekly samples of above-ground tissue were collected from commercial plantings of 6 cultivars at a site in East Wareham, Massachusetts. Sampling began at first bloom and continued through September. The cultivars were Early Black, Howes, Stevens, Pilgrim, Bergman, and Franklin. Development was documented: percent flowering uprights, flowers per flowering upright, percent fruit set (developed fruit), fresh weight per fruit, and dry weight per fruit (1989 and 1990 only) were determined. Fruit development data were subjected to regression analysis and the cultivars were compared. Distribution and development of fruit size classes with

time were investigated in 1991. Fruit samples (180 cm^2 area, 4 replicates) were collected weekly beginning after fruit set (second week of July). Fruit were sorted by passing them through 6 stacked sieves (5.66 to 19.0 mm). Total weight, number, and weight per fruit were determined for fruit in each size class.

On two dates in September of 1991, samples (four replicates) for yield analysis (180 cm^2) were collected. Upright density, percent fruit set, weight per fruit, percent flowering uprights, number of flowers per flowering upright, and yield (kg/ha) were determined. Stepwise regression analyses on logarithmically transformed data (Jolliffe, et al., 1982) were performed to determine which developmental parameters were major determinants of yield.

In 1989 and 1990, portions of new shoot and fruit tissue were dried and ground for elemental analyses (see 3.1.1 and 3.1.2). ANOVA was run for each element in new shoot tissue for each cultivar, followed by contrast analyses of adjacent dates to determine periods of nutrient level stability. Contrast analyses of cultivars determined what differences existed. Based on fruit nutrient content and fruit dry weight data, nutrient removal in a cranberry crop of 100 barrels per acre (11.2 Mg/ha) was calculated.

3.3 Time to Sample, Tissue to Sample, and Standard Values for Ten Elements

The best time to collect samples for assessment of cranberry nutrient status was determined by examining the patterns of nutrient concentrations in the new shoot tissue with time. The best time to

sample would be a period when nutrient element content is stable for at least 3 weeks. ANOVA by date was performed on the nutrient data from the N-P-K study followed by profile analysis to determine differences in nutrient levels between adjacent sampling dates. Nutrient data from the 6 cultivar study were also evaluated by ANOVA followed by contrast analysis by date.

New shoot tissue, which was collected for comparison of the 6 cultivars (see 3.2), was separated into different tissue types for nutrient analysis. The tissue types were: mixed vegetative and reproductive upright tissue (whole shoot tips -- top 5 cm), new uprights -- leaves only, shoot tips from vegetative uprights, and shoot tips from reproductive (flowering) uprights. ANOVA by tissue was performed on the nutrient-content data followed by contrast analysis to determine differences among the tissue types sampled.

Regression analysis of yield at collection sites with nutrient content in the samples at the time of stable values was run using data from the N-P-K study and the 6 cultivar study. The resulting predictive model did not account for the high yields often found in Massachusetts cranberry bogs. Therefore, on the basis of mean values and ranges, standard values for N, P, K, Mg, Ca, Zn, B, Mn, Cu, and Fe in cranberry shoot tissue were proposed.

CHAPTER 4

NUTRIENT LEVELS IN NEW SHOOT TISSUE OF 'EARLY BLACK' CRANBERRY RECEIVING FOUR RATES OF N-P-K FERTILIZER

4.1 Effect of N-P-K Rate on Cranberry Bog Soil Tests

Soil samples were collected from each plot at the beginning of each season (1987-1989) and after the last fertilizer applications in 1989. Nitrogen analyses were not performed. The results of the soil tests for P and the major cations are shown in Table 4.1. The levels of P, K, Mg, and Ca in the soil were similar for all plots at the beginning of the study (Apr. 1987) and showed no effect of the N-P-K treatments after one season (Apr. 1988). However, after two seasons of N-P-K treatments (May 1989), K levels in the soil were lower in the plots receiving the lower rates of N-P-K. After three seasons of fertilizer applications (July 1989), 0 or 170 kg N-P-K/ha continued to be related to low soil K levels, with the effect greater than that after two seasons. Regression analysis of the 1989 soil test data showed that K levels at the second (July) sampling date were significantly different from those at the first 1989 sampling ($p<0.001$). The high rates of N-P-K did not result in increases in soil K over time (compare 1987 to 1989). This result may be due to an interactive effect of the elements in the N-P-K fertilizer. Cummings (1978) found that the addition of N or P to blueberry soils with pH similar to that in these cranberry plots caused lower soil test K, while the addition of K increased soil test K. The addition of the

three elements in combination in this study may have led to one effect cancelling the other for no net change in soil K over time.

The addition of P in the N-P-K treatments had no effect on the P levels in the soil. However, the P levels in the soil in these plots at the beginning of the study were higher than the proposed normal P value for cranberry soil (Greidanus and Dana, 1972). There were no differences in Ca and Mg soil levels among treatments at any sampling period. Soil pH (4.1) was unaffected by N-P-K treatments.

Table 4.1 Soil tests of N-P-K treated plots. Values are the mean (standard deviation) of 5 replicates. Significance of F from ANOVA.

N-P-K (kg/ha)	Apr. 1987	Apr. 1988	May 1989	July 1989
ppm P				
0 (0 kg P)	89 (6)	91 (13)	86 (14)	81 (12)
170 (15 kg P)	88 (11)	90 (17)	92 (20)	78 (18)
335 (29 kg P)	87 (14)	96 (14)	87 (25)	84 (13)
505 (44 kg P)	91 (6)	102 (11)	86 (16)	99 (12)
ppm K				
0 (0 kg K)	13 (1)	13 (1)	12 (2)	7 (1)
170 (14 kg K)	13 (2)	14 (2)	12 (2)	11 (3)
335 (28 kg K)	14 (1)	13 (3)	15 (3)	12 (2)
505 (42 kg K)	14 (2)	15 (1)	16 (3)	14 (2)
sig. of F	p>0.05	p>0.05	p=0.04	p<0.001
ppm Mg				
0	17 (1)	18 (2)	18 (1)	15 (2)
170	19 (2)	19 (2)	18 (3)	18 (3)
335	21 (4)	19 (3)	19 (3)	17 (3)
505	21 (3)	20 (5)	21 (4)	20 (5)
ppm Ca				
0	64 (6)	80 (43)	65 (6)	54 (8)
170	74 (16)	103 (72)	72 (24)	75 (21)
335	82 (26)	90 (39)	74 (14)	76 (22)
505	82 (22)	82 (22)	86 (33)	82 (25)

4.2 Effect of N-P-K Rate on N, P, K, Ca, and Mg in New Shoot Tissue

In 1986, a preliminary study of the response of cranberry tissue nutrient levels to two rates of N-P-K (0 and 335 kg/ha) was conducted. Table 4.2 shows the tissue analysis results for N, P, and K in new shoot samples collected in mid-August after expansion of new shoots had ceased. The plants receiving N-P-K fertilizer had higher levels of N, P, and K in the new shoot tissue than did the unfertilized plants. This response was similar to that found by Torio and Eck (1969) when they added N, P, and K to cuttings of 'Early Black' cranberry rooted in sand. Strawberry leaf tissue N and K (but not P) also increased after a single season of N-P-K application (Albregts and Howard, 1986). Foliar N, P, and K in highbush blueberry increased in response to one season of application of the respective elements (Cummings, 1978).

Table 4.2 N, P, and K levels (percent dry weight) in new shoot tissue of 'Early Black' cranberry receiving 2 rates of N-P-K fertilizer. Samples collected in mid-August; values represent the mean of 10 replicates. Significance of F from ANOVA.

N-P-K (kg/ha)	N	P	K
0	0.93	0.11	0.41
335	0.96	0.14	0.51
sig. of F	P=0.008	P=0.005	P=0.004

4.2.1 Three Years of N-P-K Treatment: Effect on Late-season Tissue Nutrients

In 1987, a new set of plots was established for treatment with four levels of N-P-K (0, 170, 335, or 505 kg/ha). The plots were treated each season for three seasons. The results of tissue analyses for major elements on samples collected late in August of each season are shown in Table 4.3. At the end of one season of treatment, N, P, and K levels in new shoots were significantly higher in plants receiving the highest rate of N-P-K than in those receiving no fertilizer (Figures 4.1 to 4.3, p. 42-43). After three years, N, P, and K levels in plants receiving no fertilizer or the lowest N-P-K rate were lower than those in plants receiving the highest N-P-K rate. The differences in N with N-P-K treatment were contrary to the results of Eck (1976), who found no differences in N content of cranberries treated with 17, 34, or 51 kg N/ha (the same amounts of N provided in the N-P-K treatments in this study). He found N values between 0.77 and 0.79%, similar to those of the plants receiving the 170 kg N-P-K/ha rate (17 kg N) in the present study. The increase of N, P, and K in 'Early Black' cranberry shoot tissue with increasing N-P-K fertilizer rate confirms findings for 'Ben Lear' cranberry (Eaton and Meehan, 1973) and 'McFarlin' cranberry (Eaton, 1971). In the 'Ben Lear' study N, P, and K were added separately in a factorial design. The addition of each element increased its level in the leaves but no statistically significant interaction occurred among the effects of the elements (Eaton and Meehan, 1973). This makes it likely that each element in the N-P-K fertilizer is acting independently on the tissue

Table 4.3 N, P, K, Ca, and Mg levels (percent dry weight) in new shoot tissue of 'Early Black' cranberry receiving 4 rates of N-P-K fertilizer. Samples collected in late August, values represent the mean of 5 replicates. Significance of F from regression analyses (n=20).

N-P-K (kg/ha)	1987	1988	1989
	Percent N		
0 (0 kg N)	0.95	0.89	0.72
170 (17 kg N)	1.06	0.99	0.79
335 (34 kg N)	1.15	1.03	0.90
505 (51 kg N)	1.36	1.03	0.97
Sig. of F	p<0.001	p=0.012	p<0.001
	Percent P		
0 (0 kg P)	0.13	0.11	0.09
170 (15 kg P)	0.14	0.12	0.11
335 (29 kg P)	0.15	0.12	0.13
505 (44 kg P)	0.18	0.12	0.13
Sig. of F	p<0.001	p>0.05	p<0.001
	Percent K		
0 (0 kg K)	0.57	0.42	0.35
170 (14 kg K)	0.62	0.46	0.43
335 (28 kg K)	0.72	0.43	0.47
505 (42 kg K)	0.80	0.46	0.53
Sig. of F	p<0.001	p>0.05	p<0.001
	Percent Ca		
0	0.67	0.89	0.69
170	0.74	0.79	0.70
335	0.69	0.87	0.74
505	0.66	0.79	0.59
Sig. of F	p>0.05	p>0.05	p>0.05
	Percent Mg		
0	0.27	0.25	0.21
170	0.27	0.23	0.21
335	0.26	0.25	0.21
505	0.25	0.24	0.22
Sig. of F	p>0.05	p>0.05	p>0.05

content of N, P, and K in 'Early Black'. The effect of adding N-P-K to the soil was similar for cranberries as that for other *Vaccinium* species. The addition of increasing rates of N-P-K fertilizer to rabbiteye blueberries (Spiers, 1987) increased tissue N content but did not affect P and K levels. Adding N, P, and K to highbush blueberry plantings resulted in increases of all three elements in the foliage, with greater effect of dose becoming apparent in later treatment years (Cummings, 1978).

N-P-K fertilizer treatments had no effect on the levels of Ca or Mg in late-season new shoot tissue samples (Table 4.3). A decrease in one or both of these elements would be expected with increasing N-P-K dose due to the addition of K (Eaton and Meehan, 1973 and 1976; Eaton, 1971). However, in those studies, the addition of K led to an increase of foliar K levels concomitant with the decline in Mg and Ca. In the present work, K levels were maintained with the higher rates of N-P-K fertilizer, and decreased with the lower rates. This lack of increase in foliar K may explain the lack of effect of N-P-K on Ca and Mg. Spiers (1987) found that the highest foliar Mg levels in rabbiteye blueberry were associated with bushes receiving no N-P-K fertilizer. This was not true for cranberries in this study. Lack of N-P-K fertilizer was associated with low foliar K but had no effect on foliar Mg.

4.2.2 Three Years of N-P-K Treatments: Effects on Seasonal Nutrient Levels in New Shoots

Samples of new shoot tissue from N-P-K treated 'Early Black' cranberry plots were collected throughout each season. The results of the analyses for N, P, and K in plots treated with 0 or 335 kg N-P-K/ha in 1986 are shown in Figures 4.4, 4.5, and 4.6 (p. 43-44). The analytical values were significantly different by treatment for N, P, and K ($p=0.01$ for N, $p=0.005$ for P, $p=0.005$ for K) over the season. However, date by treatment interactions were not significant.

When the numbers of N-P-K levels were increased to four in 1987, the effect of treatment on N, P, and K in new shoot tissue were again significant ($p=0.02$ for N, $p=0.02$ for P, $p=0.002$ for K). The seasonal levels for N, P, and K are shown in Figures 4.7, 4.8, and 4.9 (p. 45-46). Univariate analysis for repeated measures indicated a significant date by treatment interaction for the effects on N, P, and K. However, when the sampling dates cover such an extensive period of time (here the entire growing season), it is likely that the measurements do not have the same variance, a condition required for a valid univariate analysis of interactions involving time (Littell, 1989). A multivariate analysis, which does not require equal variances, failed to confirm the date by treatment interaction.

In the third year of N-P-K applications, the seasonal effect of N-P-K level on N, P, and K continued to be apparent (Figures 4.10, 4.11, and 4.12; p. 46-47). The treatment effect was significant ($p<0.001$ for N, $p=0.03$ for P, $p=0.02$ for K). In addition, a significant date by treatment interaction for N and P concentration in

new shoot tissue occurred ($p<0.001$), confirmed by both univariate and multivariate repeated measures analyses. The effects of N-P-K on new shoot N and P became more pronounced as the season progressed.

4.3 Effects of N-P-K Treatment on B, Cu, Fe, Mn, and Zn in New Shoot Tissue

Cranberries which received N-P-K at 335 kg/ha had higher Mn levels in new shoot tissue during the season than did those receiving no fertilizer (Figure 4.13, p. 48). The effect of treatment for the whole season was significant ($p<0.005$), but the interaction between date of sampling and treatment was not significant. For the samples collected in mid-August, at the end of the growing period, a difference occurred between Mn levels for the two treatments ($p=0.06$). The seasonal increase of cranberry tissue Mn in response to N-P-K is in agreement with the increase of foliar Mn in highbush blueberry fertilized with N (Townsend, 1973). However, Eaton and Meehan (1973) found that 'Ben Lear' cranberries responded to N fertilizer with decreased foliar Mn levels. Further, tissue Mn levels responded to the addition of N-P-K in only one year of the three-year study (Table 4.4). Mn levels in cranberry shoot tissue are normally high and variable, tending to obscure any effect of fertilizer treatments.

4.3.1 Three years of N-P-K: Effects on Late-season Tissue Nutrients

The levels of five minor elements in new shoot tissue late in the season for cranberries treated with N-P-K are shown in Table 4.4.

Table 4.4 B, Cu, Fe, Mn, and Zn levels (ppm dry weight) in new shoot tissue of 'Early Black' cranberry receiving 4 rates of N-P-K fertilizer. Samples collected in late August, values represent the mean of 5 replicates. Significance of F from regression analyses (n=20).

N-P-K (kg/ha)	1987	1988	1989
ppm B			
0	85	53	45
170	58	42	32
335	61	52	29
505	53	34	25
Sig. of F	p>0.05	p>0.05	p<0.001
ppm Cu			
0	5	4	3
170	5	5	5
335	5	5	6
505	5	5	6
Sig. of F	p>0.05	p=0.033	p=0.005
ppm Fe			
0	32	53	84
170	29	65	76
335	42	63	65
505	34	66	66
Sig. of F	p>0.05	p>0.05	p>0.05
ppm Mn			
0	116	205	278
170	122	192	248
335	136	245	231
505	172	222	242
Sig. of F	p=0.029	p>0.05	p>0.05
ppm Zn			
0	18	23	22
170	20	23	23
335	20	27	22
505	18	25	22
Sig. of F	p>0.05	p>0.05	p>0.05

If rabbiteye blueberries were treated with N-P-K (Spiers, 1987), the 0 treatment level was associated with the highest foliar Zn content. Treatment with N-P-K had no effect on Zn or Fe in cranberry tissue. N-P-K had an effect on late-season tissue Mn in 1987 (Figure 4.14, p. 48). If N-P-K fertilizer was withheld, lower levels of Cu occurred in the new shoots (Figure 4.15, p. 49). Conversely, B levels were lower with increased levels of N-P-K (Figure 4.16, p. 49). The effect of N-P-K on Cu is opposite that found when highbush blueberries were fertilized with N but the effect on B is similar to that found when highbush blueberries were fertilized with N or K (Cummings, 1978). Cummings (1978) postulated that the effects of N fertilizer on minor element foliar levels were related to changes in soil pH and organic matter content caused by the addition of the fertilizer, and leading to changes in minor element availability. However, in these cranberry plots, N-P-K treatments had no effect on soil pH or organic matter content after three seasons. High B concentrations in unfertilized plants were most likely due to reduced biomass production in response to three years of that treatment.

4.3.2 Three Years of N-P-K Treatment: Effects on Seasonal Nutrient Levels in New Shoots

The effect of N-P-K treatments on new shoot tissue B levels were significant across the entire season ($p=0.02$ for 1987, $p<0.001$ for 1988 and 1989). The negative effect of N-P-K on new shoot B became more apparent late in the season (Figures 4.17, 4.18, and 4.19, p. 50-51). The date by treatment interaction was significant in univariate

analysis for all three years, but could be confirmed only by multivariate repeated measures analysis for 1989 ($p<0.001$).

The positive effect of N-P-K treatment on new shoot Cu levels (Figure 4.20, p. 51) was significant over the whole season in 1989 ($p=0.007$). No significant date by treatment interaction occurred.

4.4 Summary and Implications

Treatment of 'Early Black' cranberries with N-P-K fertilizer led to changes in the soil and in new shoot nutrient content. Cropping with no fertilizer or underfertilization led to a decline in soil K. However, N-P-K level had no effect on other measured soil properties. Fertilizing with N-P-K led to an increase in N, P, and K in cranberry new shoot tissue, but Mg and Ca in the new shoots were not affected, probably because N-P-K treatments did not change soil Ca or Mg levels.

N-P-K treatment had some effect on the minor element content of cranberry new shoot tissue. Decreasing N-P-K led to higher B in the new shoot tissue. This may have been due to concentration in the smaller underfertilized plants. Lack of N-P-K fertilizer was associated with low tissue Cu and Mn levels.

The results of this study have implications for fertilizer practices in cranberry production and for the use of tissue analysis for determining the nutritional status of cranberries. Use of N-P-K fertilizers has effects on the minor element content of the cranberry plants. This means that tissue testing for minor elements should be routine for cranberry production in order to monitor for deficiencies or excesses which might be induced by the use of N-P-K fertilizer.

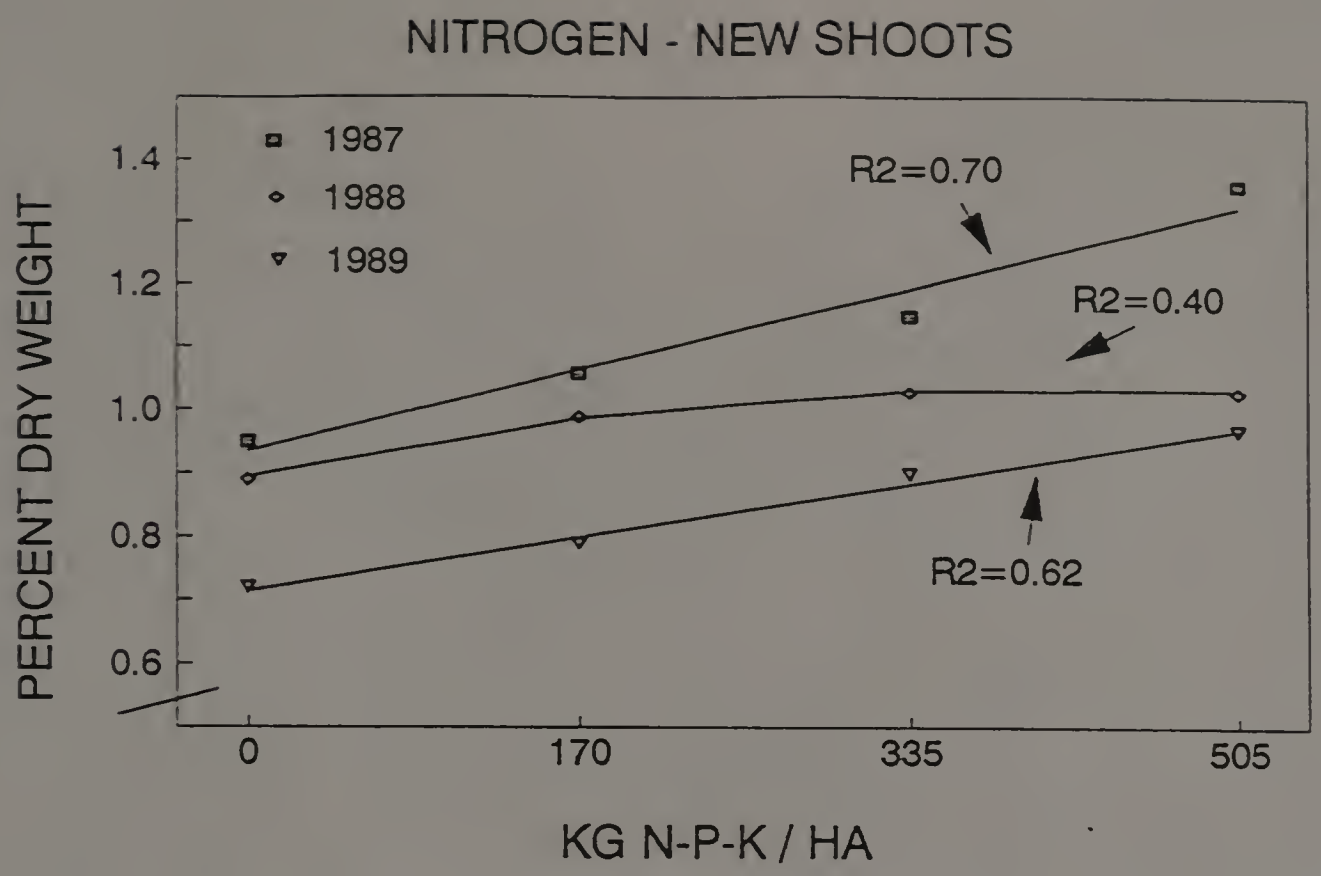


Figure 4.1 Effect of N-P-K treatment on N in cranberry new shoot tissue, August sample.

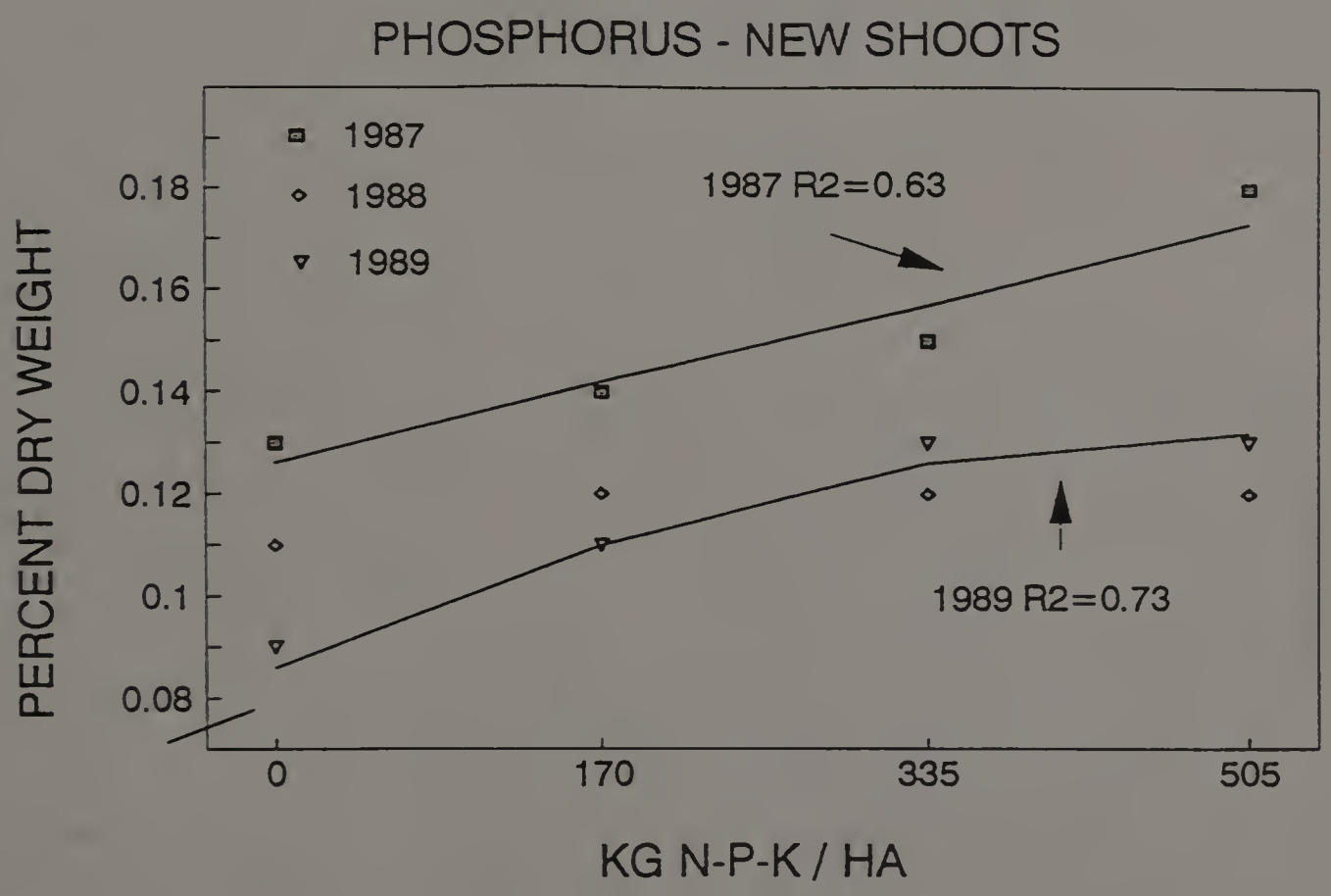


Figure 4.2 Effect of N-P-K treatment on P in cranberry new shoot tissue, August sample. Regression analysis not significant in 1988.

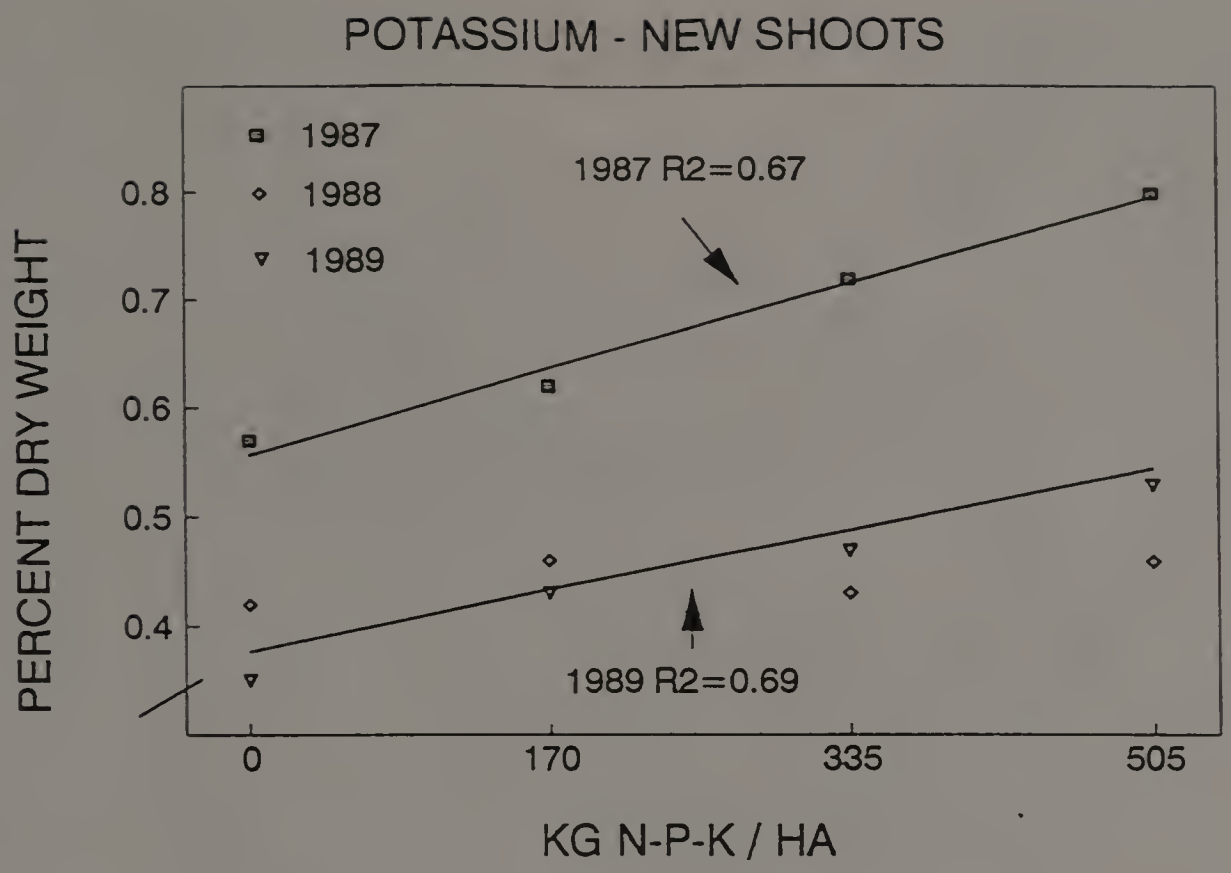


Figure 4.3 Effect of N-P-K treatment on K in cranberry new shoot tissue, August sample. Regression analysis not significant in 1988.

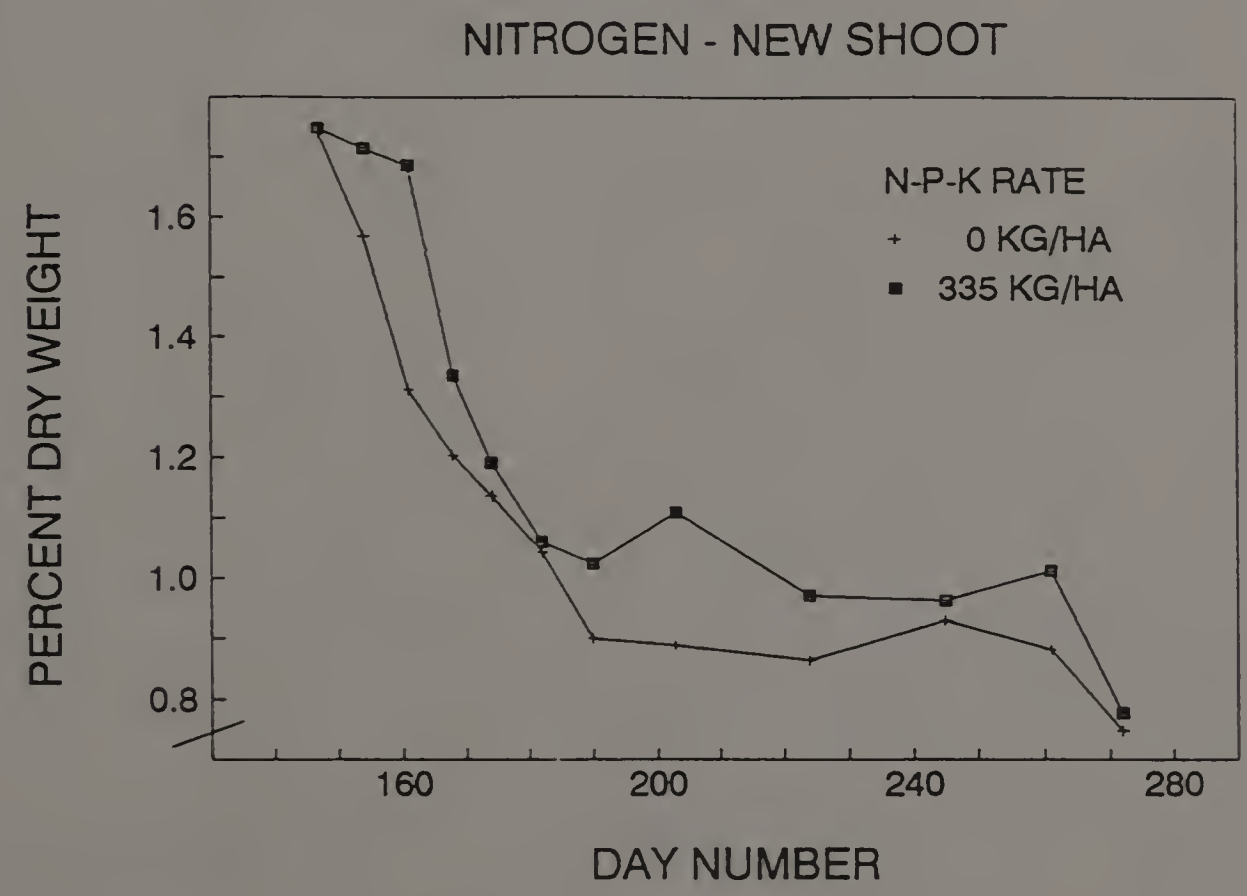


Figure 4.4 Effect of N-P-K treatment on N in cranberry new shoot tissue - one year of treatment - 1986.

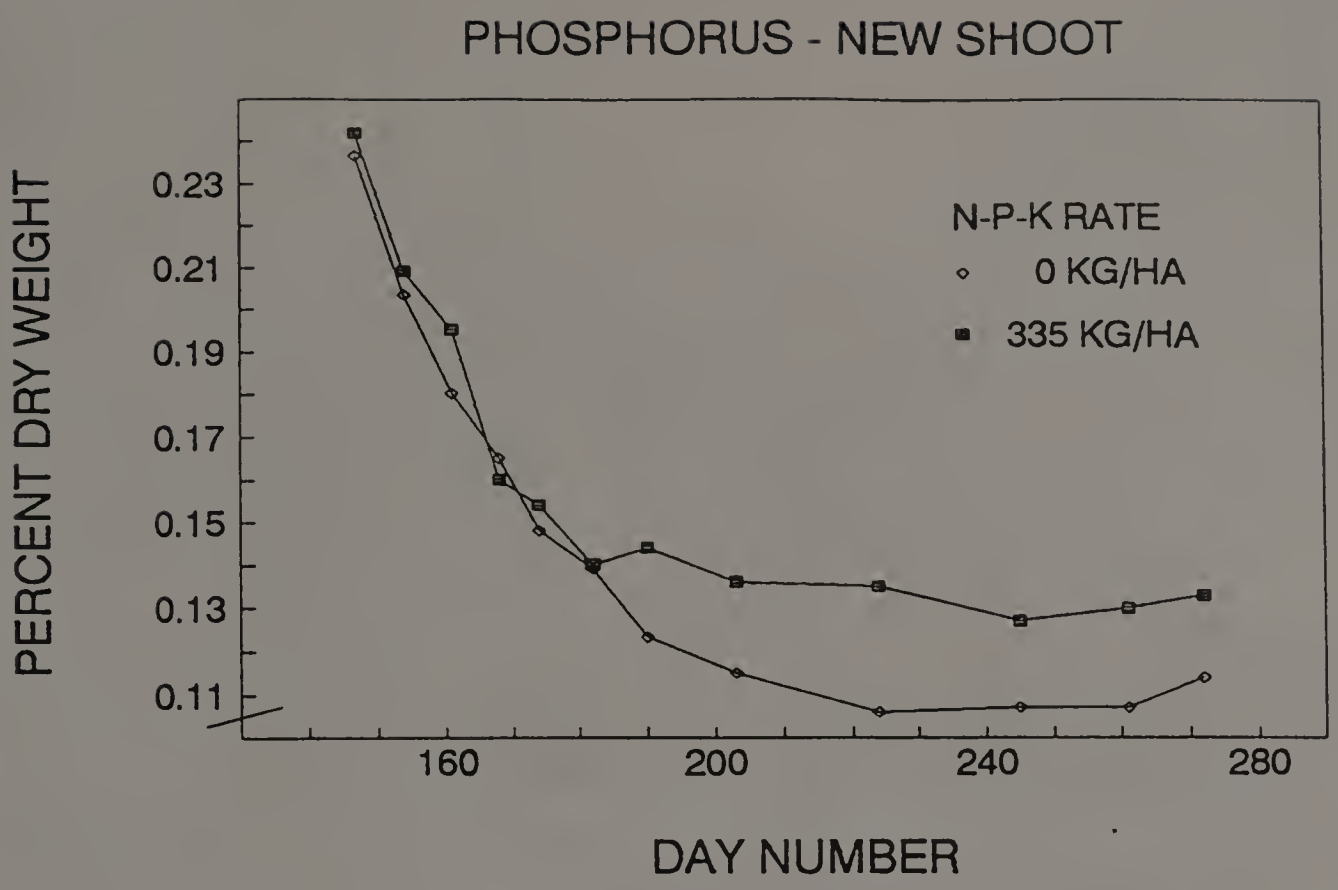


Figure 4.5 Effect of N-P-K treatment on P in cranberry new shoot tissue - one year of treatment - 1986.

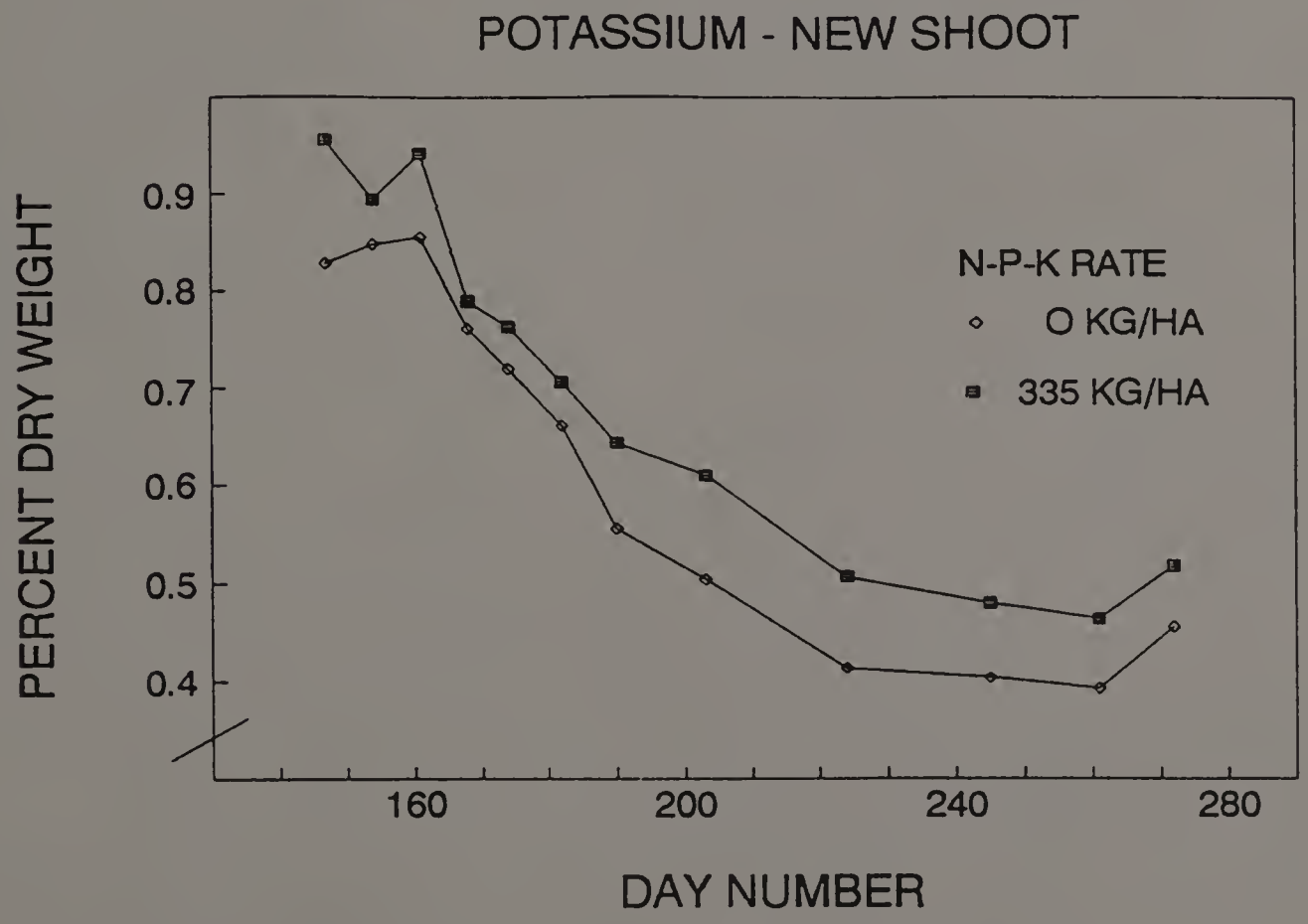


Figure 4.6 Effect of N-P-K treatment on K in cranberry new shoot tissue - one year of treatment - 1986.

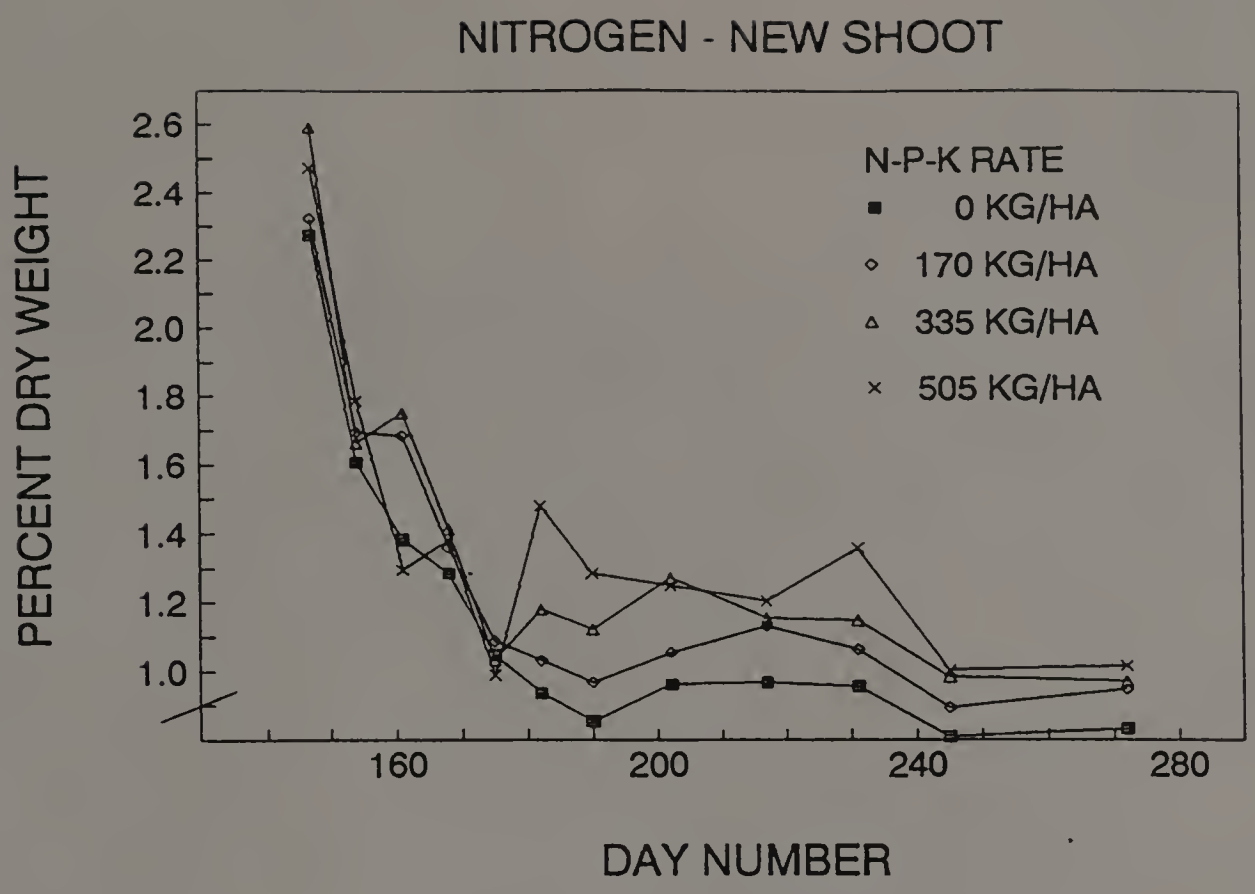


Figure 4.7 Effect of N-P-K treatment on N in cranberry new shoot tissue in the first year of treatment - 1987.

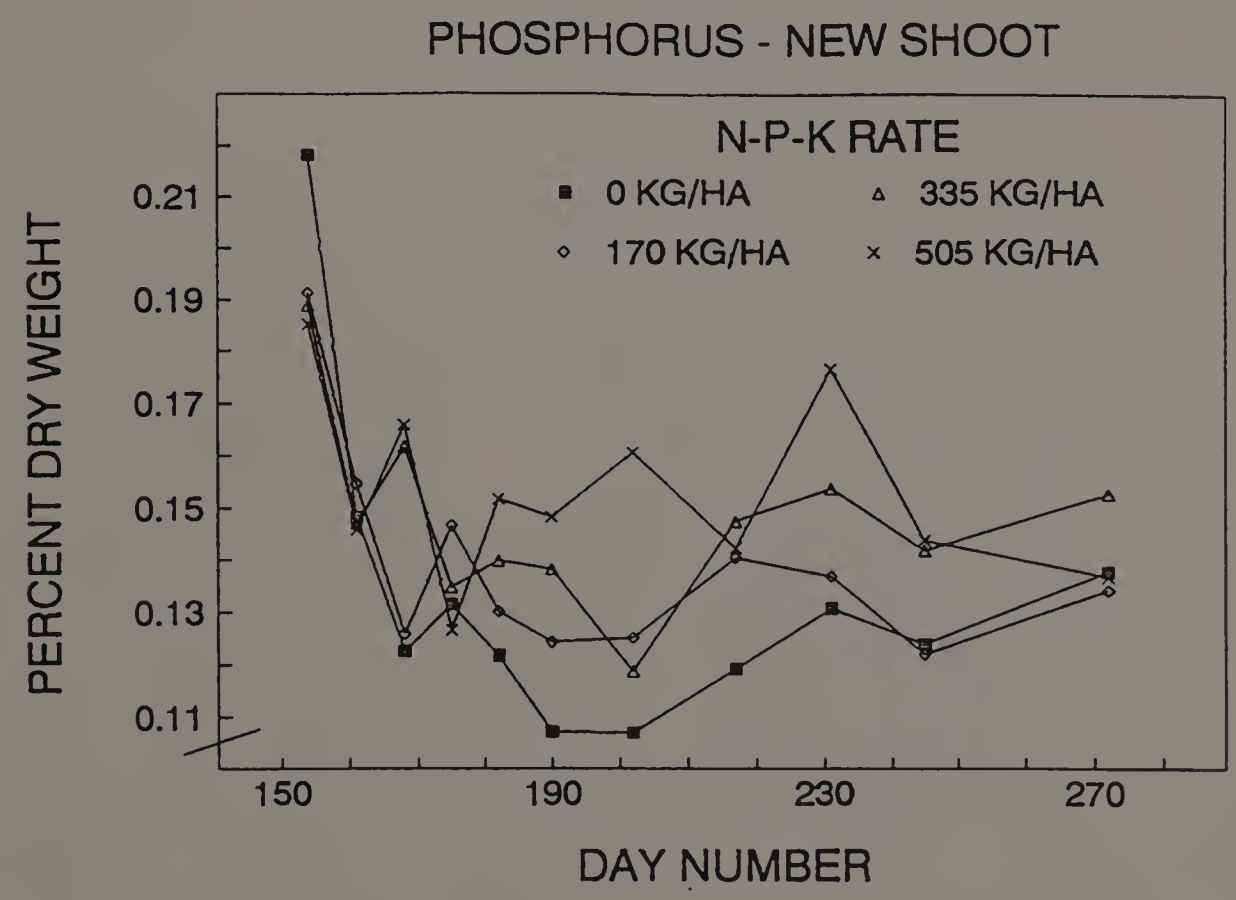


Figure 4.8 Effect of N-P-K treatment on P in cranberry new shoot tissue in the first year of treatment - 1987.

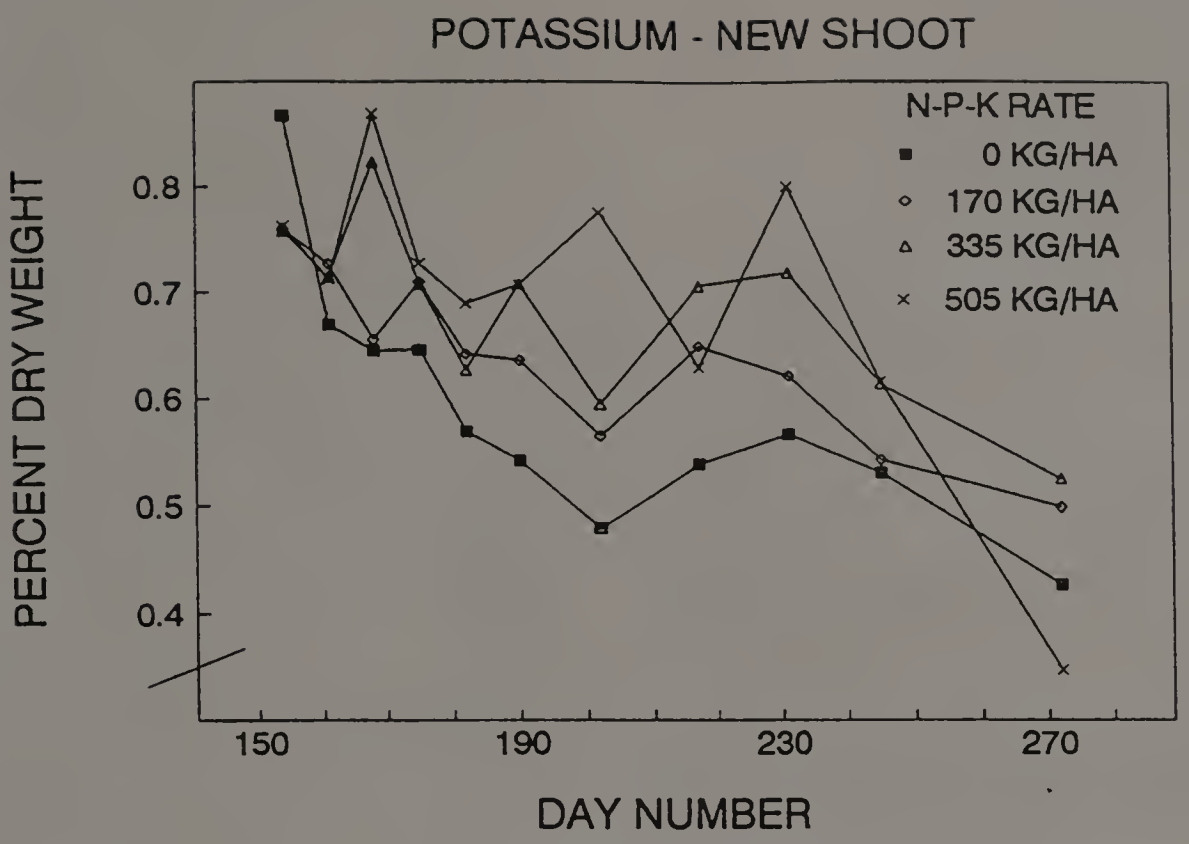


Figure 4.9 Effect of N-P-K treatment on K in cranberry new shoot tissue in the first year of treatment - 1987.

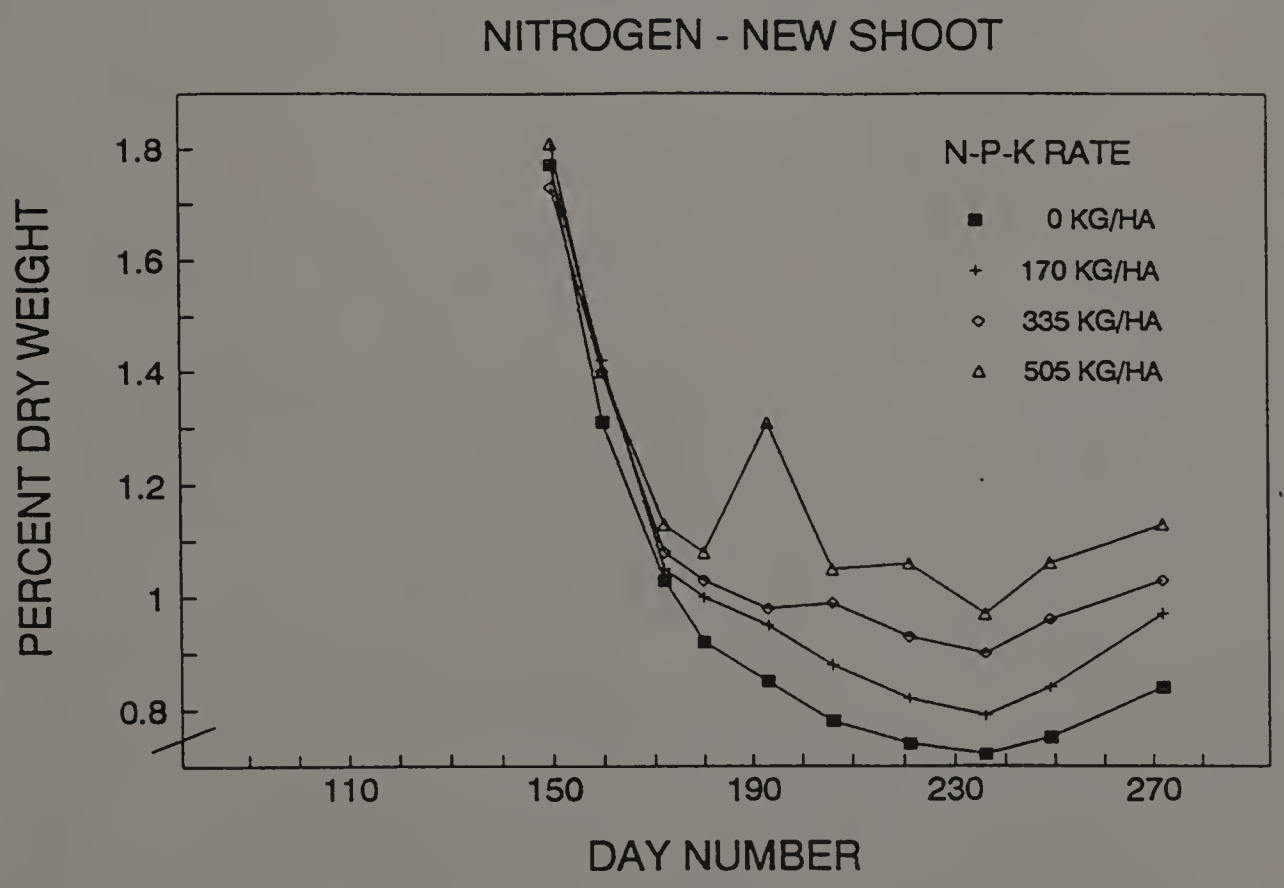


Figure 4.10 Effect of N-P-K treatment on N in cranberry new shoot tissue in the third year of treatment - 1989.

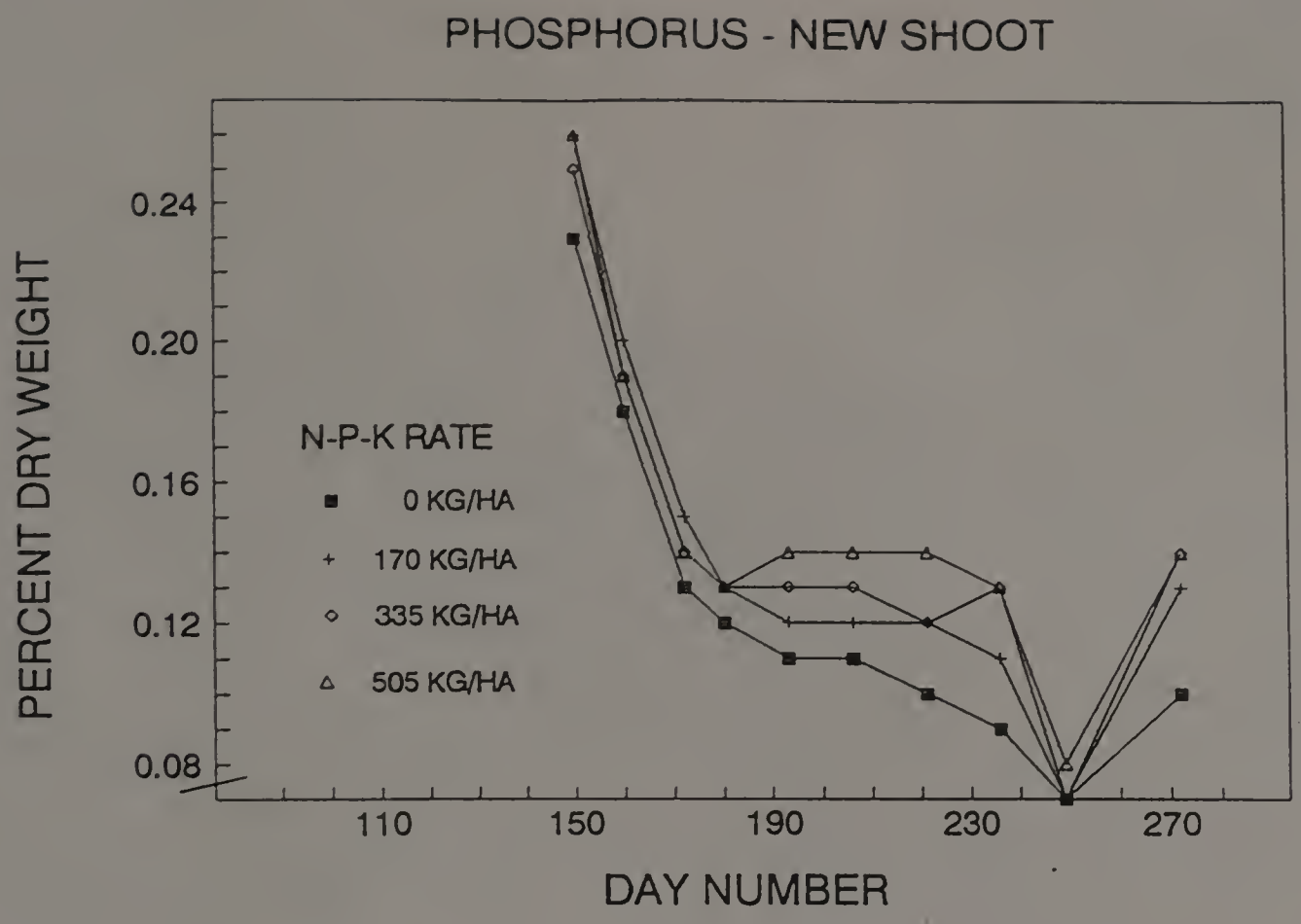


Figure 4.11 Effect of N-P-K treatment on P in cranberry new shoot tissue in the third year of treatment - 1989.

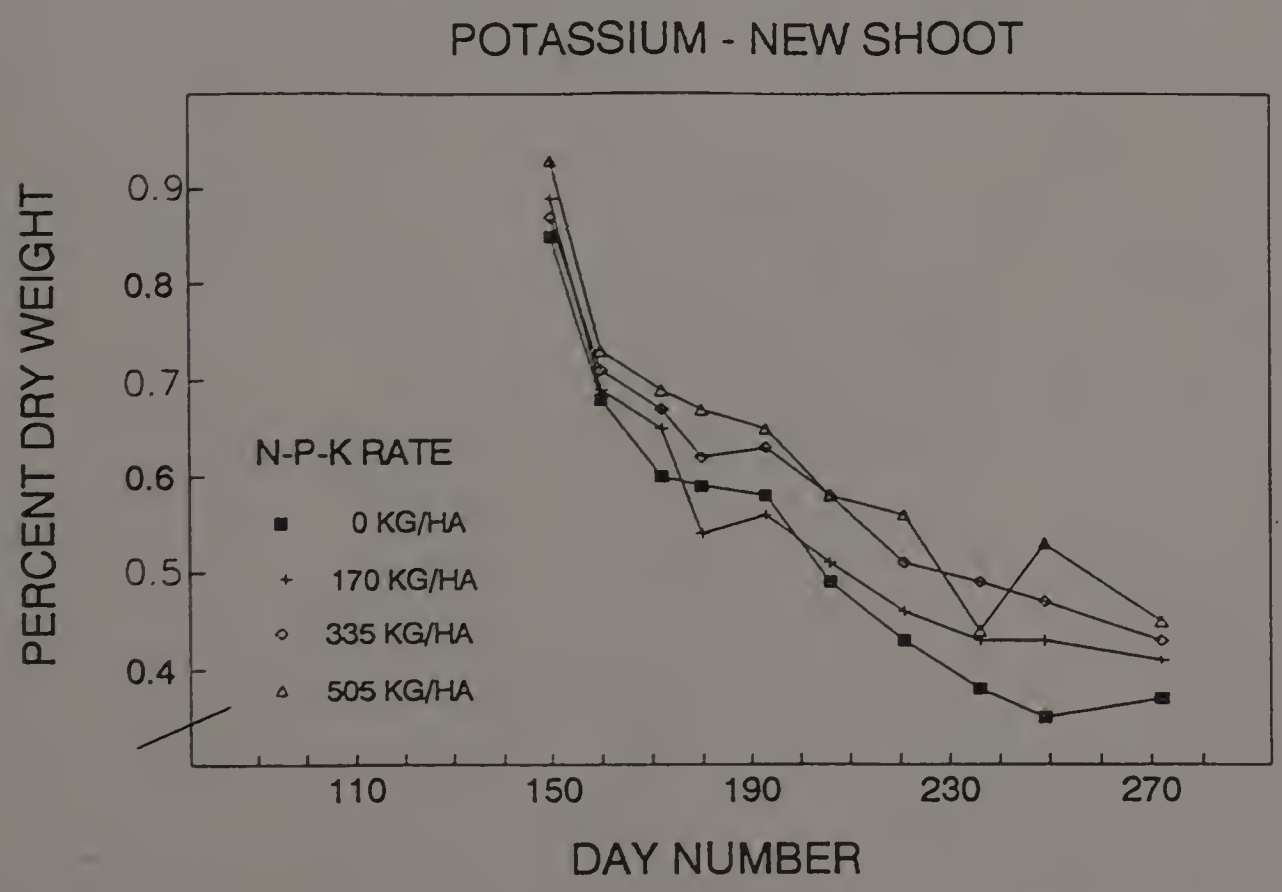


Figure 4.12 Effect of N-P-K treatment on K in cranberry new shoot tissue in the third year of treatment - 1989.

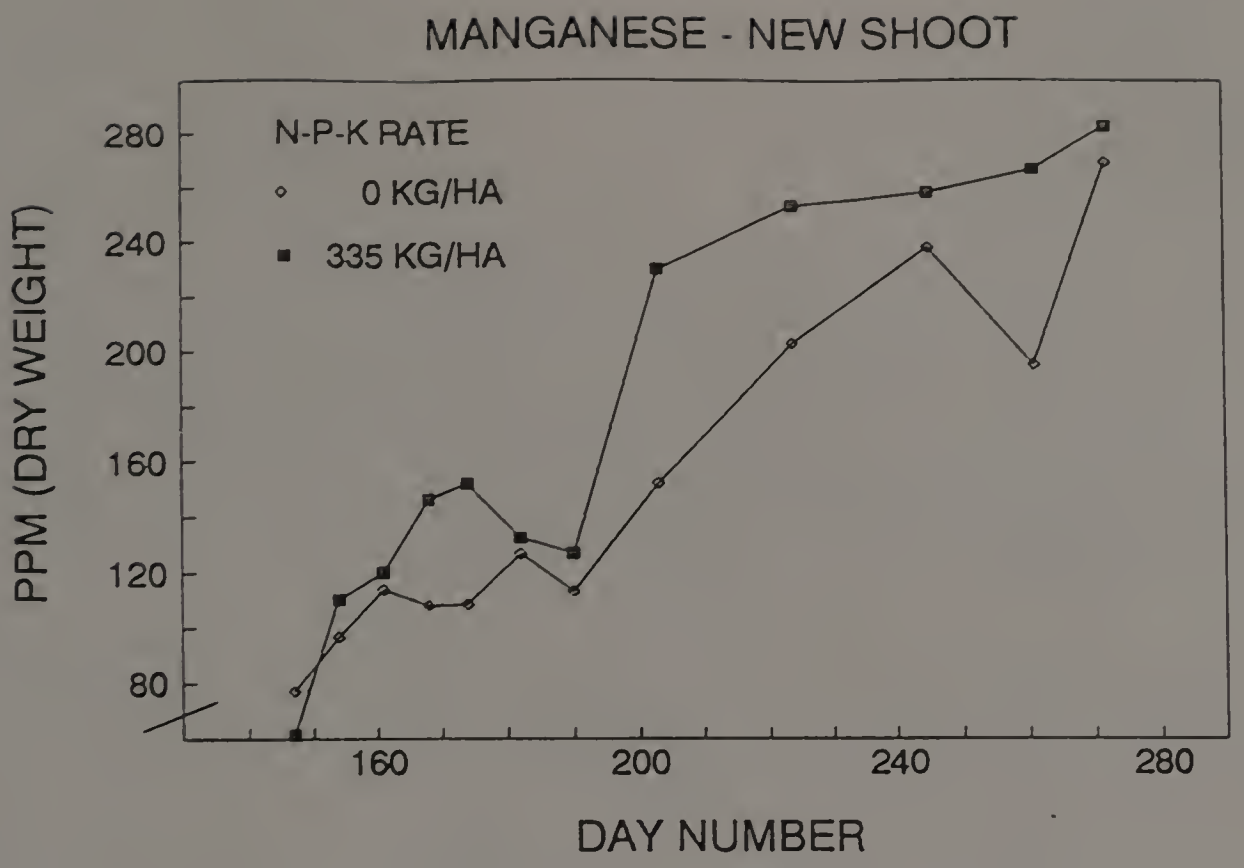


Figure 4.13 Effect of N-P-K treatment on Mn in cranberry new shoot tissue - one year of treatment - 1986.

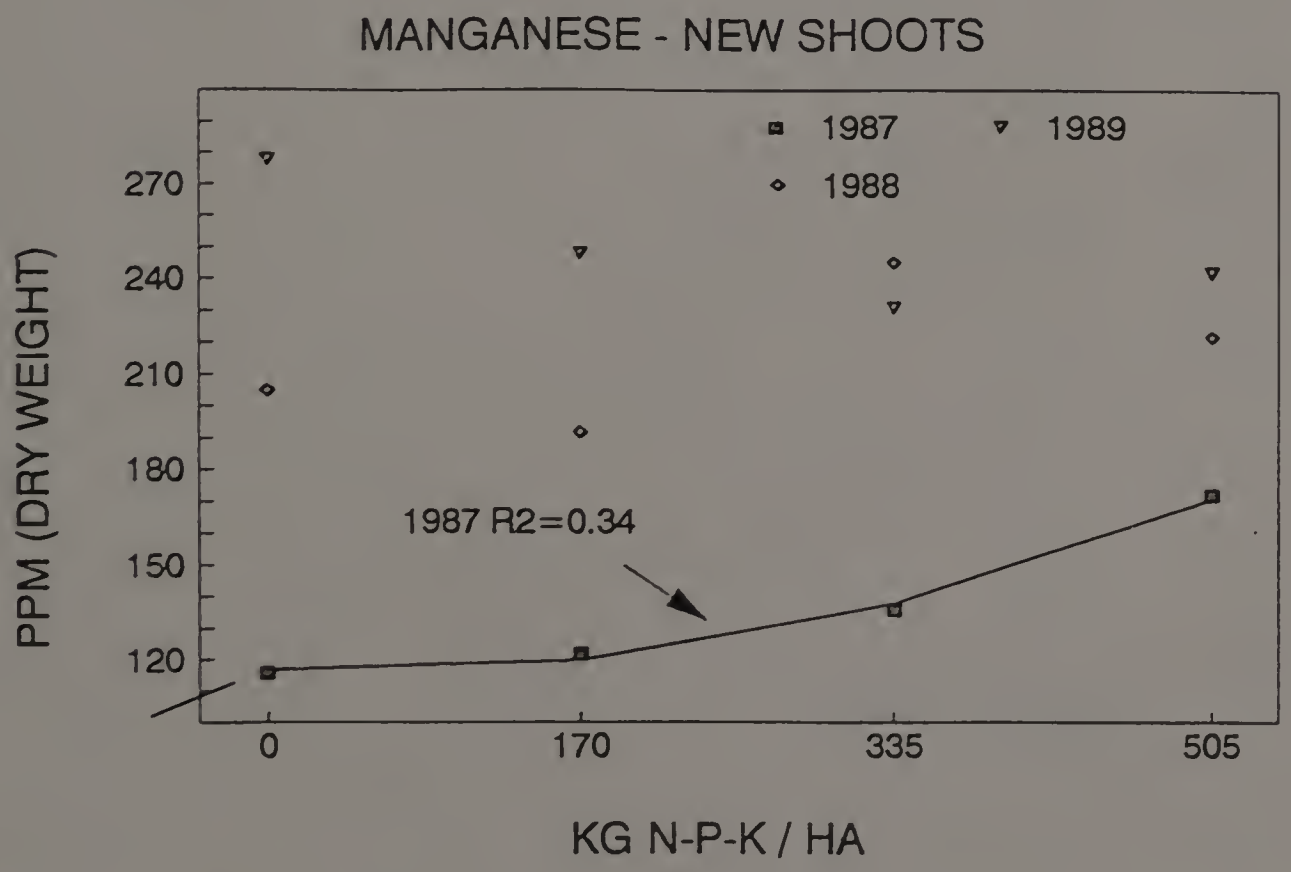


Figure 4.14 Effect of N-P-K treatment on Mn in cranberry new shoot tissue, August sample. Regression analysis was not statistically significant in 1988 and 1989.

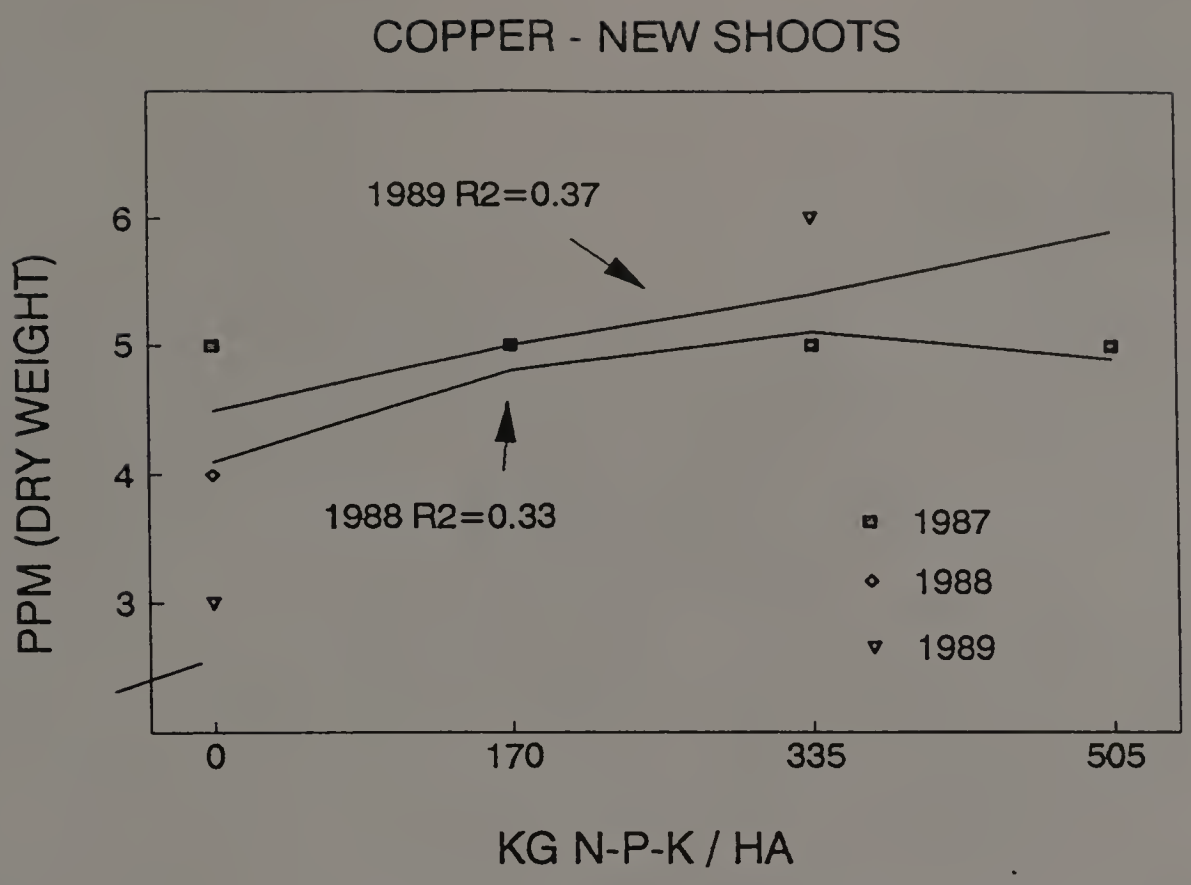


Figure 4.15 Effect of N-P-K treatment on Cu in cranberry new shoot tissue, August sample. Regression analysis was not statistically significant in 1987.

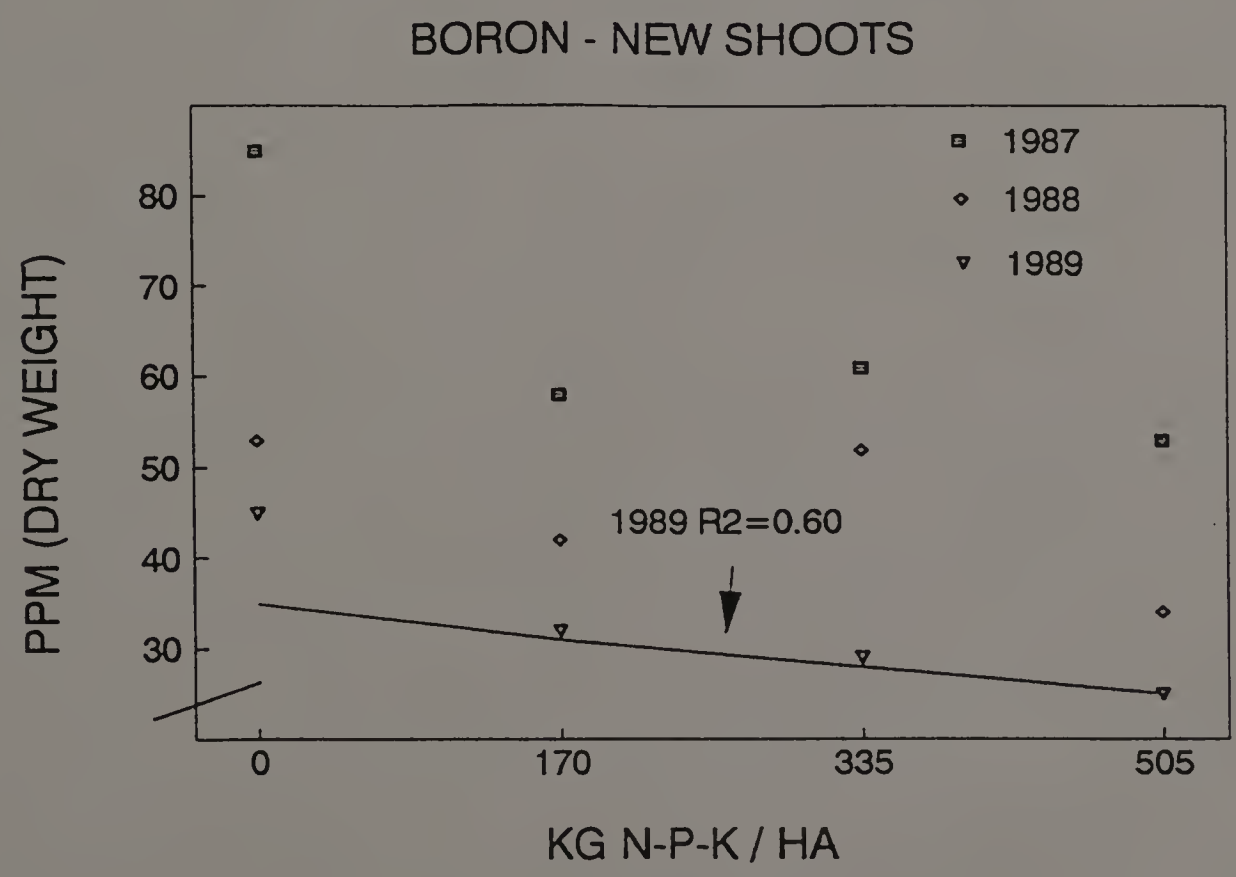


Figure 4.16 Effect of N-P-K treatment on B in cranberry new shoot tissue, August sample. Regression analysis was not statistically significant in 1987 and 1988.

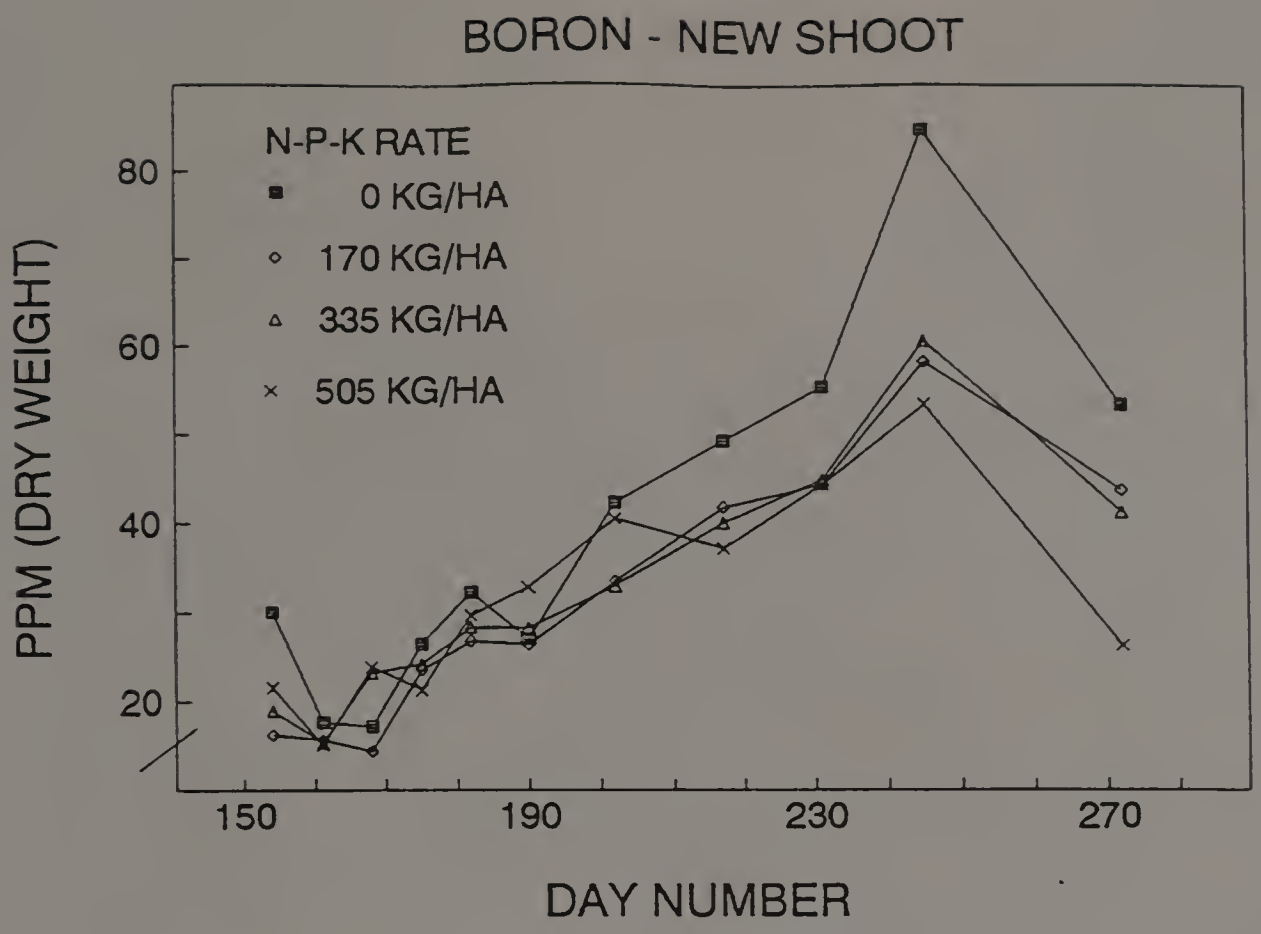


Figure 4.17 Effect of N-P-K treatment on B in cranberry new shoot tissue in the first year of treatment - 1987.

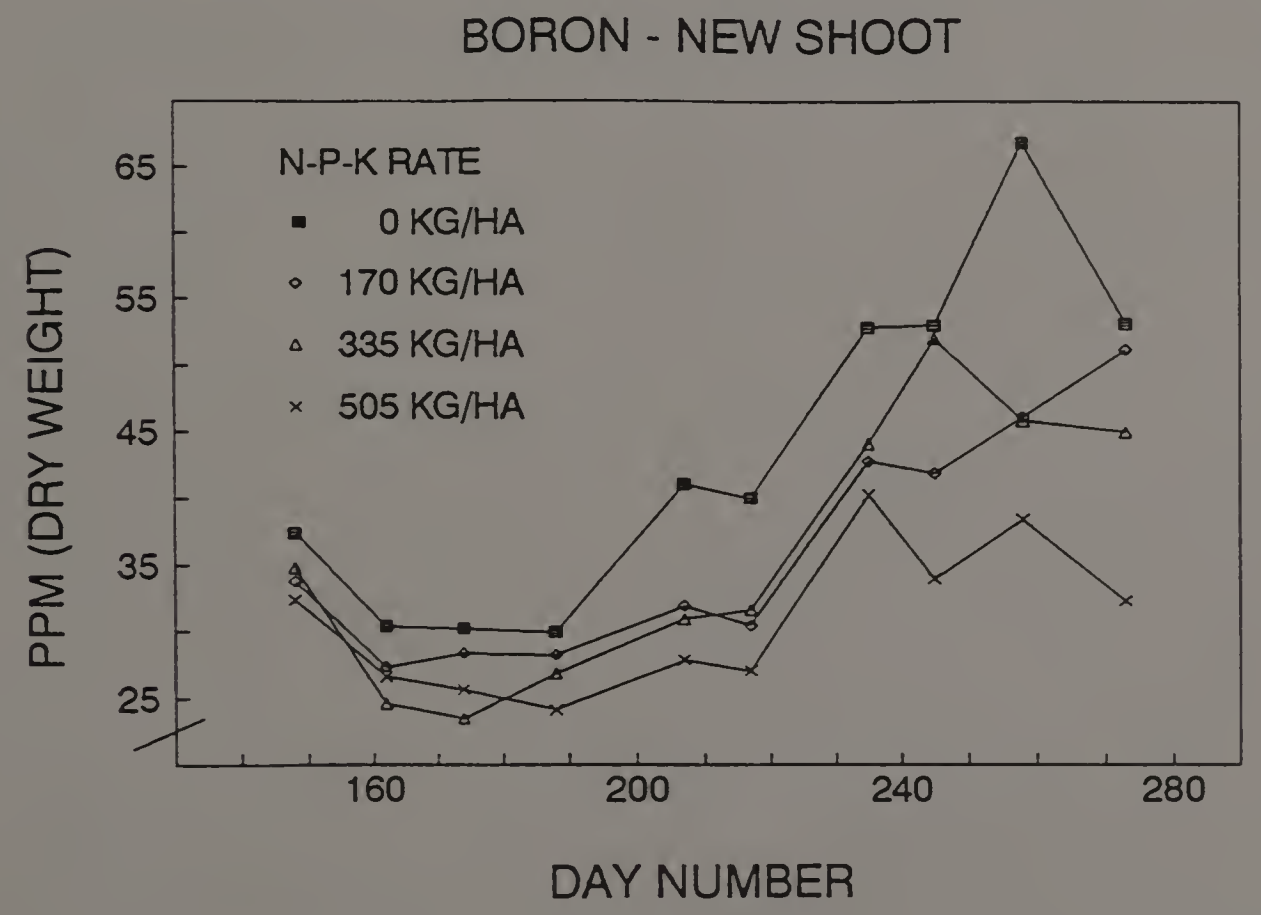


Figure 4.18 Effect of N-P-K treatment on B in cranberry new shoot tissue in the second year of treatment - 1988.

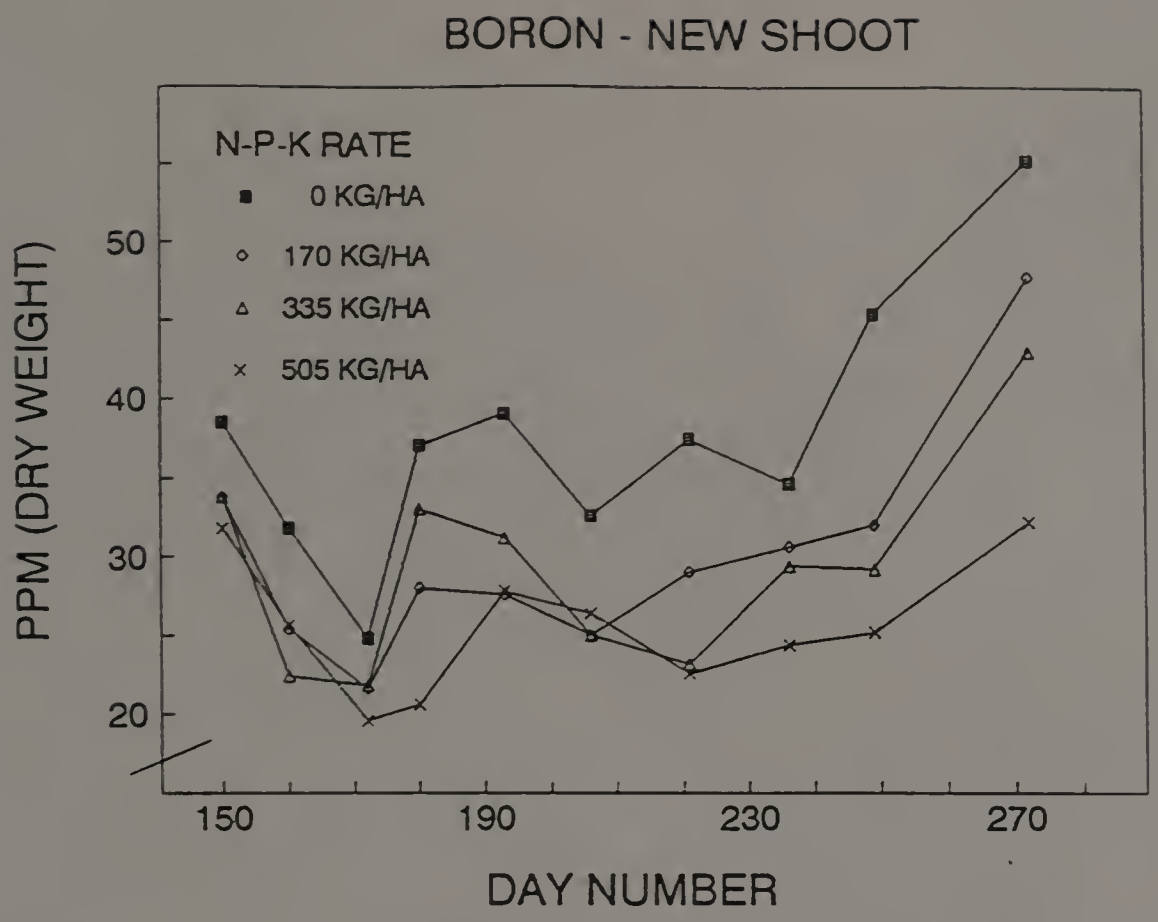


Figure 4.19 Effect of N-P-K treatment on B in cranberry new shoot tissue in the third year of treatment - 1989.

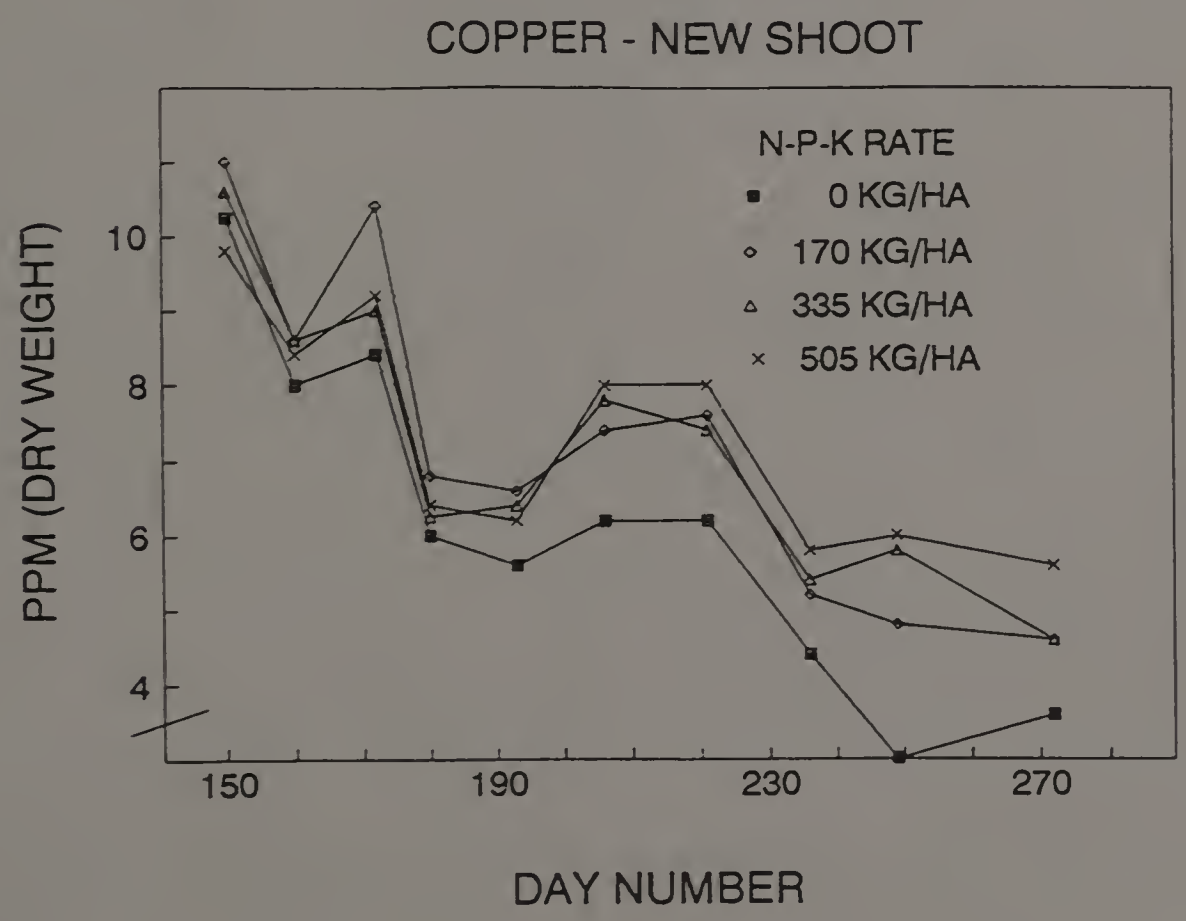


Figure 4.20 Effect of N-P-K treatment on Cu in cranberry new shoot tissue in the third year of treatment - 1989.

CHAPTER 5

BIOMASS ACCUMULATION PATTERNS IN A COMMERCIAL 'EARLY BLACK' CRANBERRY PLANTING

5.1 Vegetative and Reproductive Growth of Cranberry Plants

Growth (dry weight accumulation) of all cranberry plant parts was assessed in the N-P-K experimental plots from 1987 to 1989, beginning in April and ending in September. The accumulation patterns varied during the season, but generally were similar from season to season.

5.1.1 Roots and Shoots

The patterns for root growth are shown in Figure 5.1 (p.70). The data were highly variable due to the difficulties inherent in cleaning the soil from cranberry roots, which formed a dense fibrous mat in the upper 5 cm of the soil. Repeated measures analyses (ANOVA) of the root data showed that the changes in root biomass by date in 1987 and 1989 were not statistically significant. Root biomass could not be described by any regression equation on a seasonal basis.

New shoot development patterns were much more regular than those for roots (Figure 5.2, p.70). New shoot tissue accumulated at a rapid rate from late May until late July, then continued to accumulate at a lower rate. A steeper rise in new shoot biomass late in the summer was most likely due to the stem of the new shoot portion becoming lignified. As was expected, repeated measures univariate analysis of

new shoot growth showed that the effect of date was significant. Sequential regression analyses correlating new growth biomass accumulation with day number were performed to describe the relationship between growth and sampling date for several years. The generated regression equations (Table 5.1) were plotted (Figure 5.3A, p.71). The theoretical curves plotted from the regression equations fit the actual data fairly well, especially during early season rapid growth., Shoot growth in other plants has been assessed by correlation with growing degree day accumulation (Johnson and Lasko, 1985). Using a base temperature of 6.5C, growing degree days were calculated from sheltered temperatures (daily maximum and minimum) at the experimental site. The same polynomial types which were used to compare growth and day number were used to repeat the regression analyses for new shoot growth, correlated with accumulated growing

Table 5.1 Calculated regression equations for new shoot biomass development (kg/ha) of cranberry based on day number or growing degree days (cumulative, base 6.5C).

Year	Regression equation		R^2
	Day Number		
1986	$-31\ D^2 + 14374\ D - 1379117$	(n=233)	0.59
1987	$3230\ D - 449859$	(n=220)	0.74
1988	$-21\ D^2 + 11106\ D - 1134841$	(n=200)	0.56
1989	$-34\ D^2 + 16234\ D - 1578021$	(n=176)	0.49
	Growing Degree Days		
1986	$-0.07\ G^2 + 309.7\ G - 52744$	(n=233)	0.59
1987	$129\ G - 21747$	(n=220)	0.74
1988	$-0.04\ G^2 + 230.4\ G - 11288$	(n=200)	0.54
1989	$-0.06\ G^2 + 300.3\ G - 36050$	(n=176)	0.49

degree days. The theoretical equations (Table 5.1) were plotted (Figure 5.3B, p.71).

The equations based on day number differed from those based on growing degree day. However, the coefficients of determination were not significantly improved by the change to growing degree days (Table 5.1, compare R^2 values). The differences between the two sets of plots were slight (Figures 5.3A and 5.3B, p.71). Based on these regression relationships, using growing degree days to predict cranberry vegetative growth was not enough of an improvement over using calendar dates to justify the time and expense involved in collecting the growing degree day data.

Quadratic equations of log-transformed variables vs. date of sampling have been used to describe an exponential model for growth of cowpea (Fernandez and Miller, 1987). In an attempt to describe a relationship between new shoot growth and date with improved correlation for cranberries, regression equations (same types as before) correlating day number with log-transformed dry weight data were calculated. The resulting equations were plotted (Figures 5.4A, 5.4B, 5.4C, 5.4D, p.72-73). The log-transformed data gave much improved correlation compared to the original dry weights. However, the growth trends described by either set of equations were similar except for the 1987 data and season's end values in 1986 and 1988.

5.1.2 Fruit

Several parameters describing fruit growth were studied in the same plots where vegetative growth was assessed. The changes in fresh

and dry weight of individual fruit, as well as those for fruit on an area (30x30 cm) basis, were recorded. The seasonal changes in fresh weight and dry weight per fruit are shown in Figures 5.5 and 5.6 (p.74). The patterns were similar, with weight gain rate somewhat more rapid (steeper slope) for fresh weight than for dry weight accumulation. There was remarkable agreement among the data for the three years of the study. In all three years, dry weight accumulation rate declined after 20 Aug., although in 1987 the rate did rise again in September. Repeated measures ANOVA on the dry weight per fruit data showed that the changes by date were significant, so regression analyses were performed (Table 5.2). The theoretical relationships (quadratic for 1986 and 1988, linear for 1987 and 1989 data) were plotted (Figure 5.7, p.75), and showed fair agreement with the actual data, although the change in growth rate was not as apparent. The fit of the equations, based on coefficient of determination, was much better than that for vegetative growth vs. date.

As was attempted for vegetative growth data, dry weight accumulation per fruit was correlated with growing degree days (Table 5.2 and Figure 5.8, p.75). The relationship between fruit dry weight and growing degree days was the same as the relationship of weight with date for all years (similar R^2).

The fruit dry weight accumulation on a bog area basis was determined (Figure 5.9, p.76). Demoranville (1960) found that fresh weight accumulation rate in 'Early Black' cranberry slowed dramatically by mid-September. In this study, fresh and dry weight accumulation had slowed by early September (Figures 5.5 and 5.6, p.74), with the exception of 1987 dry weight. The temperatures

Table 5.2 Calculated regression equations for fruit development (dry weight each fruit x 10^5) of cranberry based on day number or growing degree days (cumulative, base 6.5C).

Year	Regression equation		R^2
	Day Number		
1986	$-1.998\ D^2 + 1063.5\ D - 132375$	(n=92)	0.91
1987	$132.2\ D - 24330$	(n=119)	0.91
1988	$-1.679\ D^2 + 92296\ D - 117273$	(n=120)	0.91
1989	$129.9\ D - 23172$	(n=138)	0.91
	Growing Degree Days		
1986	$-0.003\ G^2 + 20.02\ G - 23434$	(n=92)	0.91
1987	$5.66\ G - 7498$	(n=119)	0.91
1988	$-0.001\ G^2 + 12.19\ G - 14848$	(n=120)	0.91
1989	$5.22\ G - 6034$	(n=138)	0.92

(growing degree day accumulations) in 1987 were normal and could not account for the continued fruit growth of 'Early Black' cranberries in that year. The sharp drop in fruit biomass per unit bog late in 1989 was mostly accounted for by loss of fruit to fungal and insect infestations, individual fruit did not lose biomass.

5.1.3 Seasonal Biomass Change and Partitioning in 'Early Black' Cranberry

Biomass accumulation in all plant parts of cranberry fertilized with 335 kg N-P-K/ha was documented for 4 years (Figures 5.10, 5.11, 5.12, and 15.13, p.76-78). Biomass in old leaves and woody stems tended to decline during the season, with the exception of the two weeks prior to bud break (beginning of new shoot growth). At that

time, biomass in old stem and leaf tissue increased transiently. This may have been due to accumulation of carbohydrate which would then be used for the production of the new tissues when rapid vegetative growth began. New shoot growth began late in May and continued at a rapid rate through June. The growth rate of vegetation slowed in July and August as fruit began to develop (fruit set at the beginning of July). By mid-August, as biomass accumulation rate in fruit declined, new shoot biomass rose, perhaps due to tissue lignification. Root biomass was variable early in the season from year to year but tended to decline in April, then rise some in May. Later in the season, root biomass declined in June and July, rose in late July and August, declined in early September, and finally rose again at harvest (late September). Apparently, cranberry roots were short-lived. When roots were sampled at low biomass times, many decayed roots were washed away during sample preparation. It should be noted that the tissue classified as roots in this study was limited to the fibrous mat of root tissue and did not include larger woody underground structures which are properly classified as underground stems. Many of these underground stems actually originated as aerial parts which were buried during resanding operations (a cultural practice in which a layer of sand was periodically added to the surface of the cranberry bog).

The pattern of biomass accumulation in roots was opposite that for vegetation, root biomass rose when shoot growth rate was low and declined during rapid increases in shoot biomass. Head (1967) found a similar pattern for apple trees, with roots produced around bloom (before vegetative growth) and after the cessation of shoot elongation

in the fall. New root growth associated with the onset of fruit production was also seen in this study of cranberries. Most likely new roots were produced at that time in response to hormonal signals from the developing fruit. The opposing patterns of shoot and root growth have also been documented in peach (Williamson and Coston, 1989). The authors of that study noted that while root growth ceased during rapid shoot growth, the subsequently produced new roots would then supply the new vegetation with water and nutrients. In the present study, it was shown that cranberry root biomass increased after the first flush of new growth and again late in the season after the cessation of new shoot growth.

The ratio of shoots (new and old) to roots (S/R) varied during the season from 0.12 to 0.55. The greatest S/R corresponded with the end of the first flush of new vegetative growth, just prior to fruit set. Pritts and Hancock (1983) found similar changes in S/R in goldenrod (*Solidago pauciflosculasa* Michaux.), a woody perennial, with S/R maximum in the summer as new shoots were made and root biomass declined, most likely due to carbohydrate depletion. Goldenrod S/R declined after fruit production due to increased root production at that time.

At all times of the season more biomass was accounted for in the root tissue of cranberry plants than in any other tissue, although the percent declined as the season progressed. In May 12% of 'Early Black' cranberry biomass was old leaves, 14% was old stems, 1% was new shoots, and 73% was root tissue. In July the proportions were 10%, 16%, 9%, and 65%, and in September the proportions were 7%, 4%, 14%, and 64%, respectively. In September, fruit made up 10% of standing

biomass. Kappel (1991) claimed that new vegetation was a stronger sink for carbohydrates than fruit in sweet cherry, based on the finding that of new biomass produced in a season, only 16% was fruit, while 41% was leaf and 43% new stems. In comparison, it was found in this study that of the new top growth in cranberry, 42% was fruit and 58% new shoot. Cranberry plants, while woody, did not require large amounts of biomass to produce wood when compared to fruit trees. Further, cranberry plants are evergreen and do not replace all leaf biomass annually.

5.2 Effects of N-P-K Fertilizer on Cranberry Growth

The growth data for this study were collected from plots receiving four rates of N-P-K fertilizer. Growth of vegetation, roots, and fruit was assessed periodically during the season. Using N-P-K level as a grouping factor, ANOVA by date (repeated measures analysis) was performed on the data. There was no effect of N-P-K level on the growth of roots. The growth patterns for that tissue were discussed in Section 5.1.1. In none of the analyses (roots, new shoots, fruit dry weight by bog area, individual fruit dry weight) was there a significant date by treatment interaction.

In the second and third years of treatment with N-P-K fertilizer, biomass accumulation in new vegetation and fruit were affected by N-P-K level (Table 5.3). Overfertilized (505 kg N-P-K/ha) cranberries had significantly more new growth (Figures 5.14 and 5.15, p.78-79) than did those receiving no fertilizer or a less than optimum dose (170 kg N-P-K/ha). However, large amounts of biomass in new

Table 5.3 Effect of N-P-K fertilizer on the average seasonal growth of 'Early Black' cranberry. Biomass in g/30x30 cm, 5 replicates. Only plant parts and years with significant effects of fertilizer are shown. Significance of F from regression analyses (linear for new shoots, quadratic for fruit).

New shoots (g/30x30 cm)		
N-P-K (kg/ha)	1988	1989
0	19.9	18.0
170	26.4	27.3
335	28.0	33.3
505	35.8	37.4
Sig. of F	p<0.001 r2=0.14, n=200	p<0.001 r2=0.24, n=176
Fruit (g/30x30 cm)		
	1988	1989
0	16.0	5.86
170	18.0	9.41
335	22.8	11 23
505	17.8	9.27
Sig. of F	p=0.01 r2=0.07, n=120	p=0.003 r2=0.08, n=138

vegetation did not mean good productivity (Figures 5.17 and 5.18, p.80). In 1988, a high crop year generally, cranberries receiving the highest dose and those receiving no fertilizer had the poorest crops. Beckwith (1919) found that 45 kg N/ha led to too much vine growth in New Jersey cranberries, while 33 kg N/ha gave more crop than 22 kg N/ha. The N doses in the current study were 17, 33, and 50 kg N/ha, with the largest crops associated with the 33 kg rate, and the most vegetation with 50 kg N/ha. The effect of N-P-K on fruit production was not due to an effect on dry weight of individual fruit (Figure 5.16, p.79), but to an effect on fruit number per area.

5.3 Yield Component Relationships

Yield components were documented along with biomass data. These included, on a 30x30 cm area basis, upright density (U_T), number of vegetative uprights (U_N), number of flowering uprights (U_F), percent U_F, dry weight per upright, length of U_N and U_T, number of flowers, number of flowers per U_F, number of fruit, fruit per flower (% fruit set), fresh weight of fruit, fresh weight per fruit, and yield (kg/ha).

5.3.1 Effects of N-P-K Treatment on Yield Components of Cranberry

The effects of N-P-K on growth and yield components were assessed separately for each year of the experiment. Because cranberry is a woody perennial, carryover and cumulative effects were expected to make the results different by year. N-P-K fertilizer treatments had no *significant* effects on yield due to high variability in the plots. However, yield components were affected (Table 5.4, 5.5, 5.6). The effects were more apparent over time.

The data from 1988 (second year) showed increased effect of N-P-K on yield components (Table 5.5). As had been found on a seasonal basis, the season's end dry weight in new growth was greatest at the highest rate of N-P-K, as was the length and weight of the individual uprights. The length of the uprights in the 170 and 335 kg treatments were within the range previously recommended for cranberries (Roberts and Struckmeyer, 1942; Dana, 1968), while that in the 505 kg treatments was higher and that in the 0 kg treatments was lower.

Table 5.4 Effects of N-P-K fertilizer on yield components of 'Early Black' cranberry, one year of treatment, 5 replicates. Upright counts and dry weights were based on 30x30 cm bog area sampled in September. Significance of F from regression analyses (n=20).

N-P-K level	Dry wt old shoot	Dry wt new shoot	Dry wt root	Flowers (number)	Fruit (number)
0 kg/ha	38.4	26.7	236.6	337	74
170 kg/ha	35.7	36.3	221.8	303	96
335 kg/ha	30.2	35.6	221.8	414	122
505 kg/ha	38.0	44.4	239.7	538	175
Sig. of F	p>0.05	p=0.025 r2=0.25	p>0.05	p=0.048 r2=0.20	p=0.004 r2=0.38

	U_T (number)	U_N (number)	U_F (number)	dry wt/U	U_F/U_T
0 kg/ha	630	498	132	0.041	0.21
170 kg/ha	688	560	128	0.053	0.18
335 kg/ha	694	533	161	0.052	0.22
505 kg/ha	809	600	209	0.056	0.25
Sig. of F	p>0.05	p>0.05	p>0.05	p=0.039 r2=0.22	p>0.05

	Flower/ U_F	fruit/ flower	Fresh wt fruit	Yield kg/ha	Wt (g)/ fruit
0 kg/ha	2.55	0.22	48.0	15,352	0.63
170 kg/ha	2.39	0.29	75.0	15,524	0.79
335 kg/ha	2.56	0.33	86.5	15,924	0.73
505 kg/ha	2.67	0.34	118.6	20,992	0.67
Sig. of F	p>0.05	p=0.049 r2=0.20	p=0.005 r2=0.37	p>0.05	p>0.05

Upright densities in these 'Early Black' plots were much higher in all treatments than those recommended for 'Searles' in Wisconsin (Roberts and Struckmeyer, 1942). Increasing N-P-K dose had positive effects on the production of vegetative uprights and fruit set, but the proportion of uprights flowering was negatively affected. The upright effects were related to the promotion of vegetative over reproductive growth by high fertilizer doses. The effect on fruit set may have been related to lack of essential nutrient elements in unfertilized

Table 5.5 Effects of N-P-K fertilizer on yield components of 'Early Black' cranberry, two years of treatment, 5 replicates. Upright counts and dry weights were based on 30x30 cm bog area sampled in September. Upright lengths were mean of 25 per replicate. Significance of F from regression analyses (n=20).

N-P-K level	Dry wt old shoot	Dry wt new shoot	Dry wt root	Flowers (number)	Fruit (number)
0 kg/ha	18.1	26.7	190.4	1004	261
170 kg/ha	20.7	35.1	197.9	1043	271
335 kg/ha	23.7	38.0	158.8	1234	372
505 kg/ha	19.8	55.3	127.5	830	262
Sig. of F	p>0.05	p<0.001 r2=0.58	p>0.05	p>0.05	p>0.05

	U_T (number)	U_N (number)	U_F (number)	dry wt/U	U_F/U_T
0 kg/ha	785	486	299	0.034	0.38
170 kg/ha	915	584	331	0.038	0.36
335 kg/ha	921	555	366	0.041	0.40
505 kg/ha	996	741	255	0.056	0.25
Sig. of F	p>0.05	p=0.013 r2=0.30	p>0.05	p<0.001 r2=0.65	p=0.04 r2=0.21

	Flower/ U_F	Length U_N mm	Length U_F mm	Fresh wt fruit	Fruit/ flower
0 kg/ha	3.32	50.9	44.3	204.3	0.27
170 kg/ha	3.15	61.1	48.4	209.4	0.26
335 kg/ha	3.42	69.7	55.3	282.3	0.30
505 kg/ha	3.30	89.9	62.4	218.6	0.32
Sig. of F	p>0.05	p<0.001 r2=0.79	p<0.001 r2=0.72	p>0.05	p=0.002 r2=0.41

	Yield kg/ha	Wt (g)/ fruit
0 kg/ha	19,708	0.77
170 kg/ha	22,029	0.78
335 kg/ha	30,076	0.76
505 kg/ha	27,385	0.83
Sig. of F	p>0.05	p>0.05

and underfertilized plants. Even when not statistically significant, most of the important yield components (e.g. flowers, flowering uprights, flowers/upright) were greatest in the highest yielding

Table 5.6 Effects of N-P-K fertilizer on yield components of 'Early Black' cranberry, three years of treatment, 5 replicates. Upright counts and dry weights were based on 30x30 cm bog area sampled in September. Upright lengths were mean of 25 per replicate. Significance of F from regression analyses (n=20).

N-P-K level	Dry wt old shoot	Dry wt new shoot	Dry wt root	Flowers (number)	Fruit (number)
0 kg/ha	28.2	20.2	129.5	272	106
170 kg/ha	33.0	35.5	146.1	435	204
335 kg/ha	36.9	48.2	142.3	441	212
505 kg/ha	33.3	59.6	163.1	382	196
Sig. of F	p>0.05	p<0.001 r2=0.85	p>0.05	p>0.05	p>0.05

	U_T (number)	U_N (number)	U_F (number)	dry wt/U	U_F/U_T
0 kg/ha	607	514	93	0.033	0.16
170 kg/ha	942	767	174	0.038	0.19
335 kg/ha	977	819	158	0.049	0.16
505 kg/ha	1053	930	122	0.057	0.12
Sig. of F	p<0.001 r2=0.55	p<0.001 r2=0.59	p=0.019 r2=0.37	p<0.001 r2=0.78	p>0.05

	Flower/ U_F	Length U_N mm	Length U_F mm	Fresh wt fruit	Fruit/ flower
0 kg/ha	2.89	50.7	40.2	87.1	0.40
170 kg/ha	2.62	55.9	45.3	178.2	0.47
335 kg/ha	2.81	68.1	53.8	195.6	0.48
505 kg/ha	3.00	76.2	59.3	176.7	0.53
Sig. of F	p>0.05	p<0.001 r2=0.71	p<0.001 r2=0.72	p>0.05	p=0.017 r2=0.28

	Yield kg/ha	Wt (g)/ fruit
0 kg/ha	5,599	0.82
170 kg/ha	10,006	0.87
335 kg/ha	11,780	0.92
505 kg/ha	10,677	0.91
Sig. of F	p>0.05	p=0.044 r2=0.21

treatment (335 kg N-P-K/ha). The yield data shown here were for a single sampling early in September. At that time the differences

among the treatments were not statistically significant, although over the season the yield differences were significant (Table 5.3).

The effects of N-P-K in the third year of treatment were similar to those in the second year. In 1989, total upright density as well as that for each type of upright was positively affected by any fertilizer treatment compared to no fertilizer. The positive effect on flowering uprights as well as vegetative uprights explained the lack of an effect on percent flowering uprights in 1989.

As in the second year, weight of new shoot, upright weight and upright length were all affected positively by N-P-K treatment in 1989. Eck (1976) also found positive effects of increasing N dose on length of both upright types in cranberry. After three years of no fertilizer, uprights were quite stunted. Limitation on photosynthate production due to limited leaf area was likely responsible for reduced fruit set, size, and yield in that treatment (Roper, et al., 1992).

Underfertilization had negative effects on yield and yield components. However, overfertilization was equally negative, promoting vegetative growth over fruit production. The ideal dose for balanced reproductive and vegetative growth at the experimental 'Early Black' site was 335 kg N-P-K/ha.

5.3.2 Correlations Among Yield Components in Cranberry

Correlation coefficients could be calculated across treatments for vegetative and reproductive components within each year (Archbold, et al., 1989). This would allow assessment of the effects of the yield components on each other and on yield. In both 1988 and 1989,

Table 5.7 Correlation coefficients among vegetative and reproductive variables of 'Early Black' cranberry, 1987.

Variable	1	2	3	4	5	6
1) U_T						
2) Dry wt new	0.811**[Z]					
3) %U_F	0.494	0.102				
4) Flower/U_F	-0.165	-0.232	-0.013			
5) Fruit/flower	0.146	0.432	-0.096	-0.190		
6) g/fruit	-0.114	0.240	-0.304	-0.246	0.593	
7) kg fruit/ha	0.340	0.262	0.342	0.110	0.308	0.062

[Z] Values significant at **p<0.01

dry weight of new shoots were positively correlated with upright weight, number, and length (data not shown). Correlations among components considered to be most important in determining yield (Archbold, et al., 1989; Eaton and Kyte, 1978) were tabulated (Tables 5.7 and 5.8). All of the selected variables were positively

Table 5.8 Correlation coefficients among vegetative and reproductive variables of 'Early Black' cranberry, 1989.

Variable	1	2	3	4	5	6
1) U_T						
2) Dry wt new	0.854**[Z]					
3) %U_F	-0.267	-0.335				
4) Flower/U_F	0.071	0.082	-0.303			
5) Fruit/flower	0.419	0.535	-0.372	0.012		
6) g/fruit	0.541	0.627	-0.095	-0.244	0.412	
7) kg fruit/ha	0.472	0.511	0.299	0.028	0.211	0.523

[Z] Values significant at **p<0.01

correlated with yield, however, none of the correlation coefficients were significant. The only significant correlation among the selected variables was that of upright density with dry weight of new shoots (positive). The correlation method of determining important contributors to yield was not very effective for cranberries.

5.3.3 Stepwise Regression of Cranberry Yield Components

Certain components of yield were selected as serially important in determining yield (Eaton and Kyte, 1978). The variables were log-transformed and then subjected to stepwise regression on yield (Table 5.9). The components selected for a model without a constant were upright density (all years) and percent flowering uprights (1989). If a constant was added to the model, percent fruit set was selected in addition to the other two components (1987 and 1988). However, the models containing a constant had much lower correlation coefficients

Table 5.9 Stepwise regression models for yield component data. Variables chosen from: U_T, $\%U_F$, flower/U_F, %set, g/fruit, yield.

Year	Model regression equation	r
	No constant	
1987	Yield = 1.479 U_T	0.999
1988	Yield = 1.483 U_T	0.999
1989	Yield = 1.549 U_T + 0.749 $\%U_F$	0.999
	With constant	
1987	Yield = 11.266 + 0.556 $\%U_F$ + 0.569 %set	0.70
1988	Yield = 8.538 + 0.587 U_T + 0.0554 $\%U_F$ + 1.476 %set	0.67
1989	Yield = 1.001 + 1.398 U_T + 0.74 $\%U_F$	0.77

than did those with no constant. Based on this type of analysis, the most important factors determining yield in cranberry were upright density and the proportion of those uprights which were reproductive. In studies on other cranberry cultivars, percent flowering uprights and percent fruit set alone (Eaton and Kyte, 1978) or with upright density (Shawa, et al., 1981) were found to be major determinants of yield based on stepwise regression analyses.

Eaton and Kyte (1978) also compiled the successive contributions of each component to the coefficient of determination in the yield model as they were forced into the model in succession. This analysis was performed on the data in the current study (Table 5.10). In 1987 and 1988, the important determinants of yield were upright density and percent fruit set. All selected components were significant in 1989. The selection of fruit set in this analysis confirmed the findings of

Table 5.10 Yield components, logarithmic scale. Independent contribution to yield (100 x R^2) of each yield component taken in succession (%).

Year	U_T	$\%U_F$	Flower/U_F	%Set	g/fruit	Yield
1987	37.1*[z]	11.0	1.5	49.9*	0	99.5*
1988	40.5*	6.6	7.8	44.8*	0	99.7
1989	53.7**	36.8**	1.1**	0.9**	7.5**	100**

[z] Values significant at **p<0.01, or *p<0.05

Eaton and Kyte (1978). However, they found that percent flowering uprights was the other important determinant in their model.

When regression analyses were run using each successive log-transformed component as the dependent variable with the other variables independent, certain significant correlations between variables were found in 1987 and 1989. In 1987, upright density was positively correlated with percent flowering uprights and fruit set was positively correlated with weight per fruit. In 1989, upright density and weight per fruit were positively correlated. Most likely the positive correlation between variables was due to some factor or factors which had a common effect on those variables. For example, fruit set and weight per fruit could both be affected by pollinator activity or pollen viability (Shawa, et al., 1981). Fruit weight has been found to be correlated with seed number (Hall and Aalders, 1965), which was dependent on pollination. When yield was used as the dependent variable in the regression analyses, the significant positive correlations were with fruit set (1987 and 1988) and with upright density and percent flowering uprights (1989).

Based on all of the yield analyses attempted in this study, upright density, percent flowering uprights, and fruit set would have to be considered the most important determinants of yield in 'Early Black' cranberry.

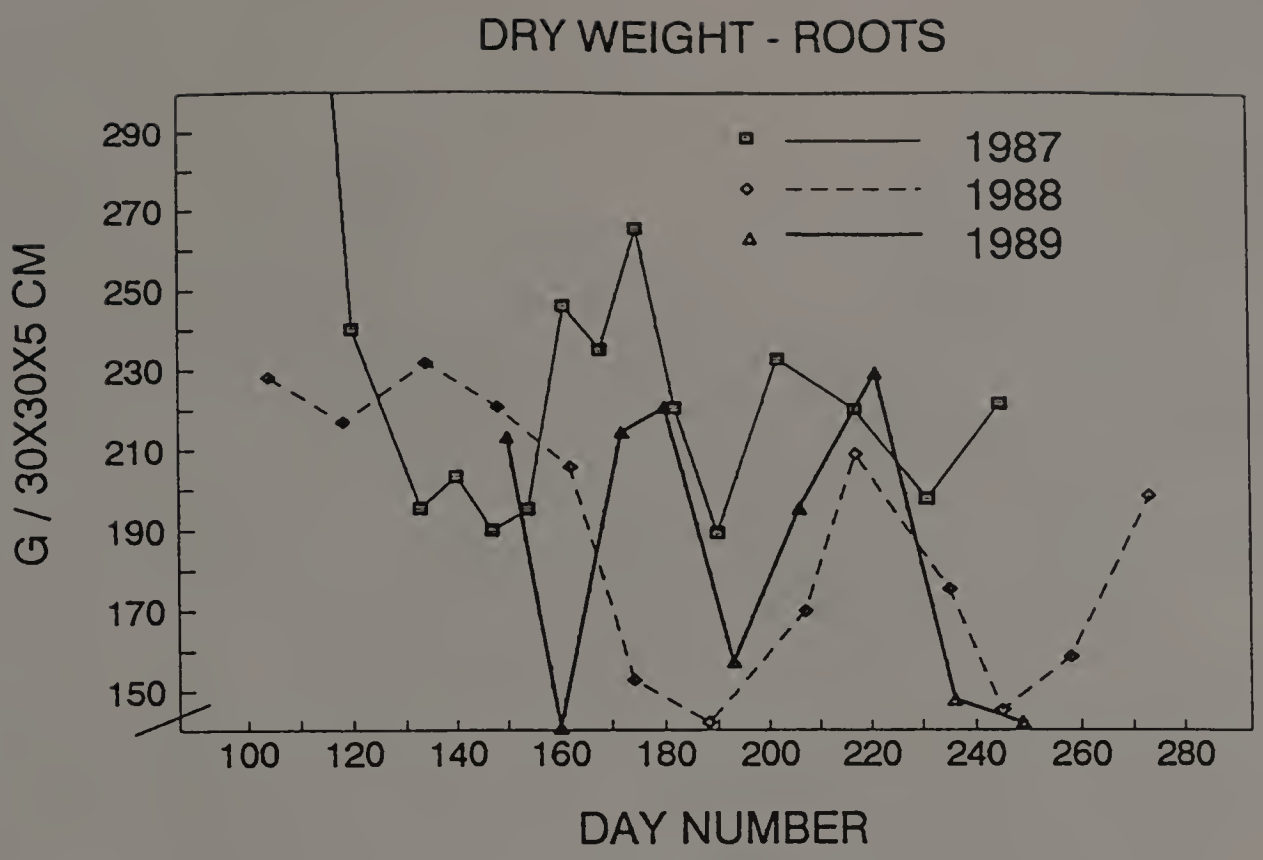


Figure 5.1 Seasonal changes in biomass of roots of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data points are means of 5 replicates.

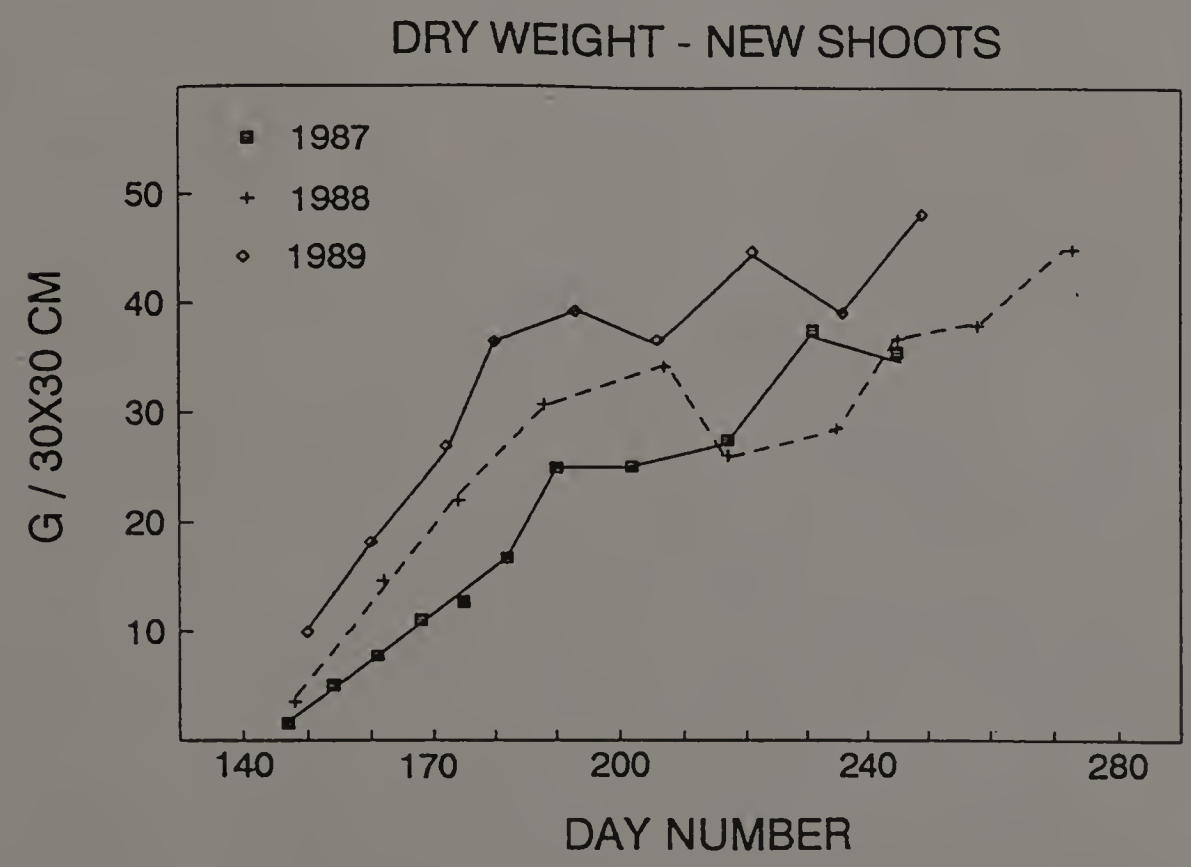


Figure 5.2 Seasonal changes in biomass of new shoots of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates.

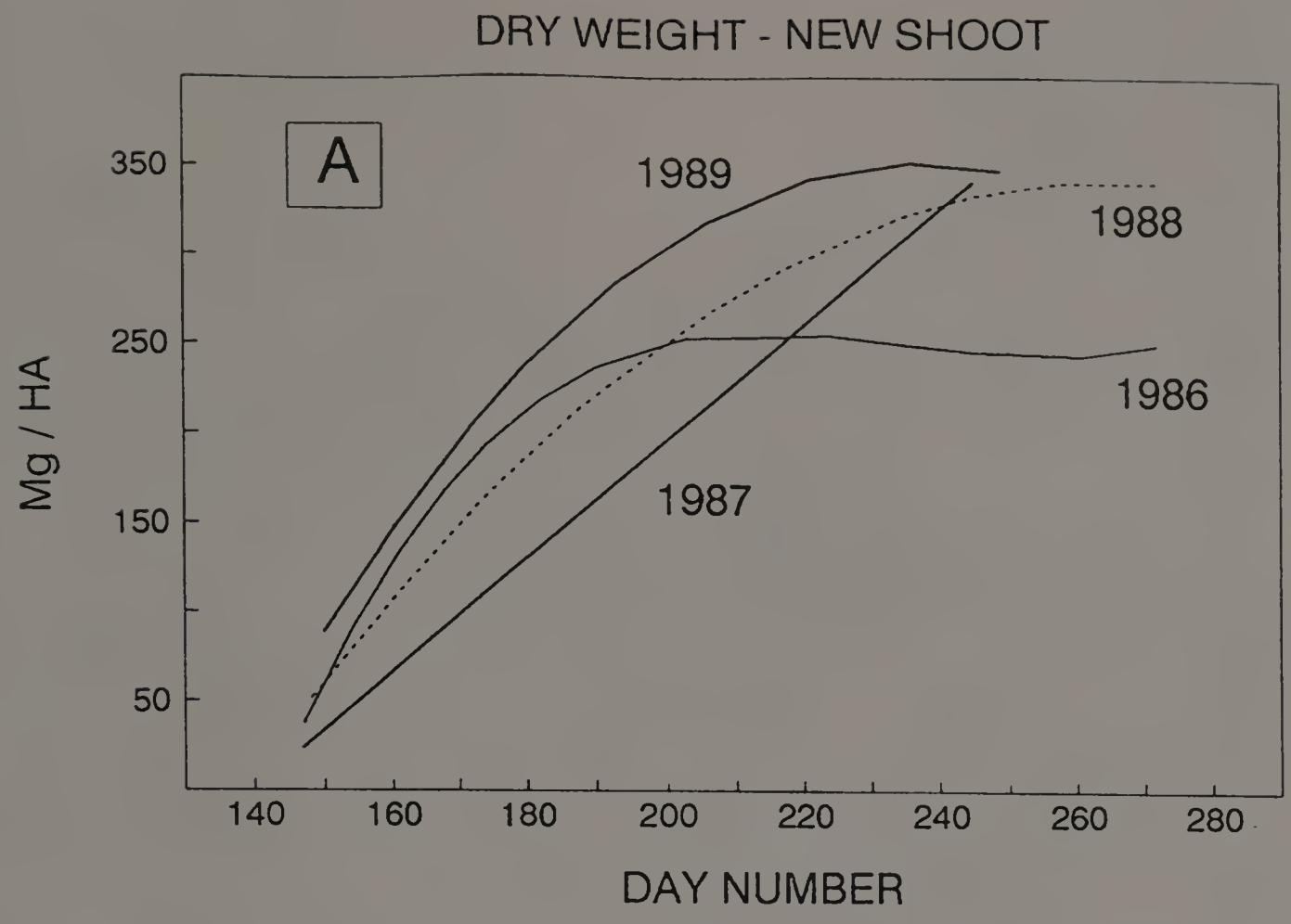


Figure 5.3 Seasonal change in biomass of new shoots of 'Early Black' cranberry, estimated regression lines. Equations shown in Table 5.1. A: biomass vs day number; B: biomass vs cumulative growing degree days.

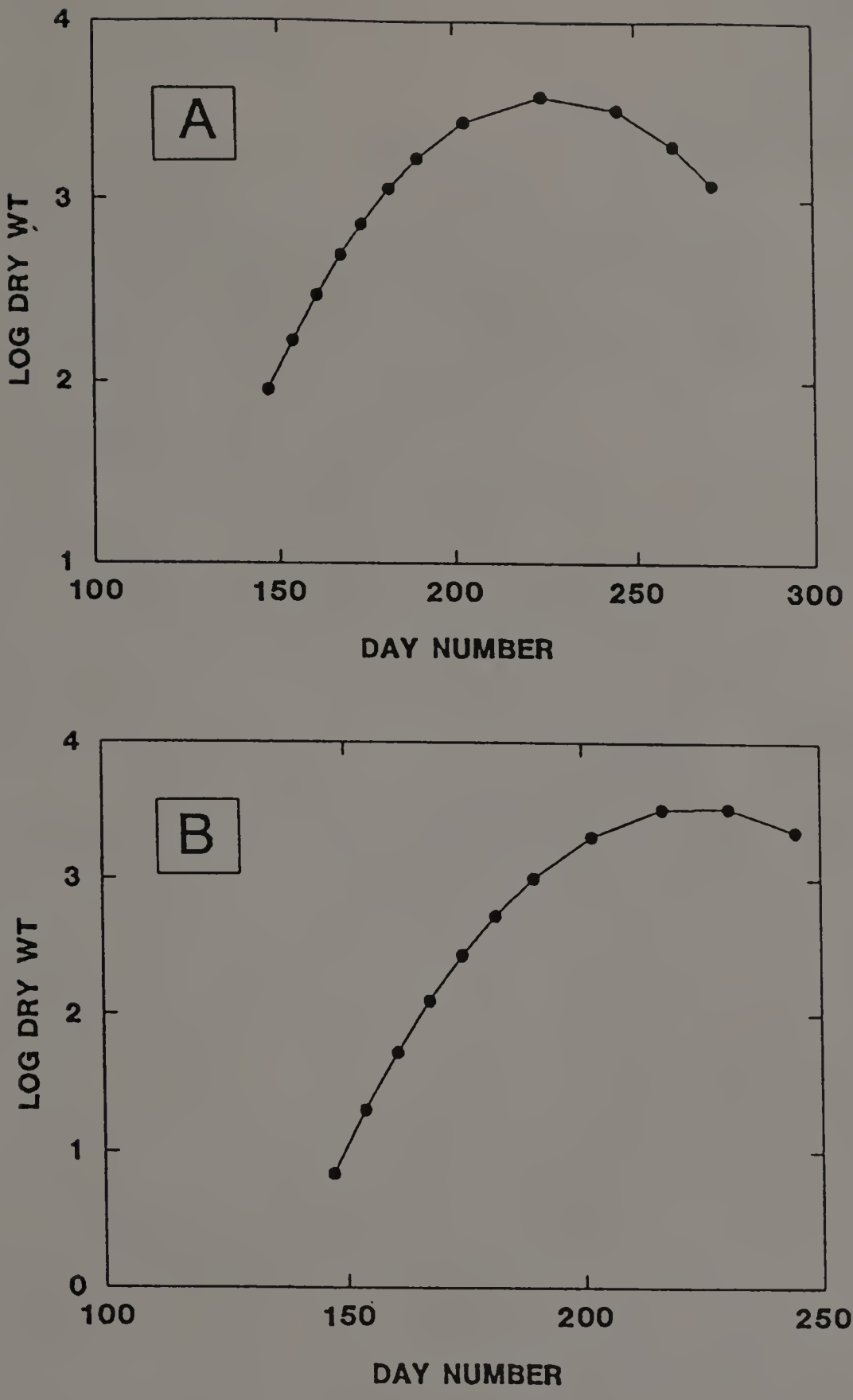
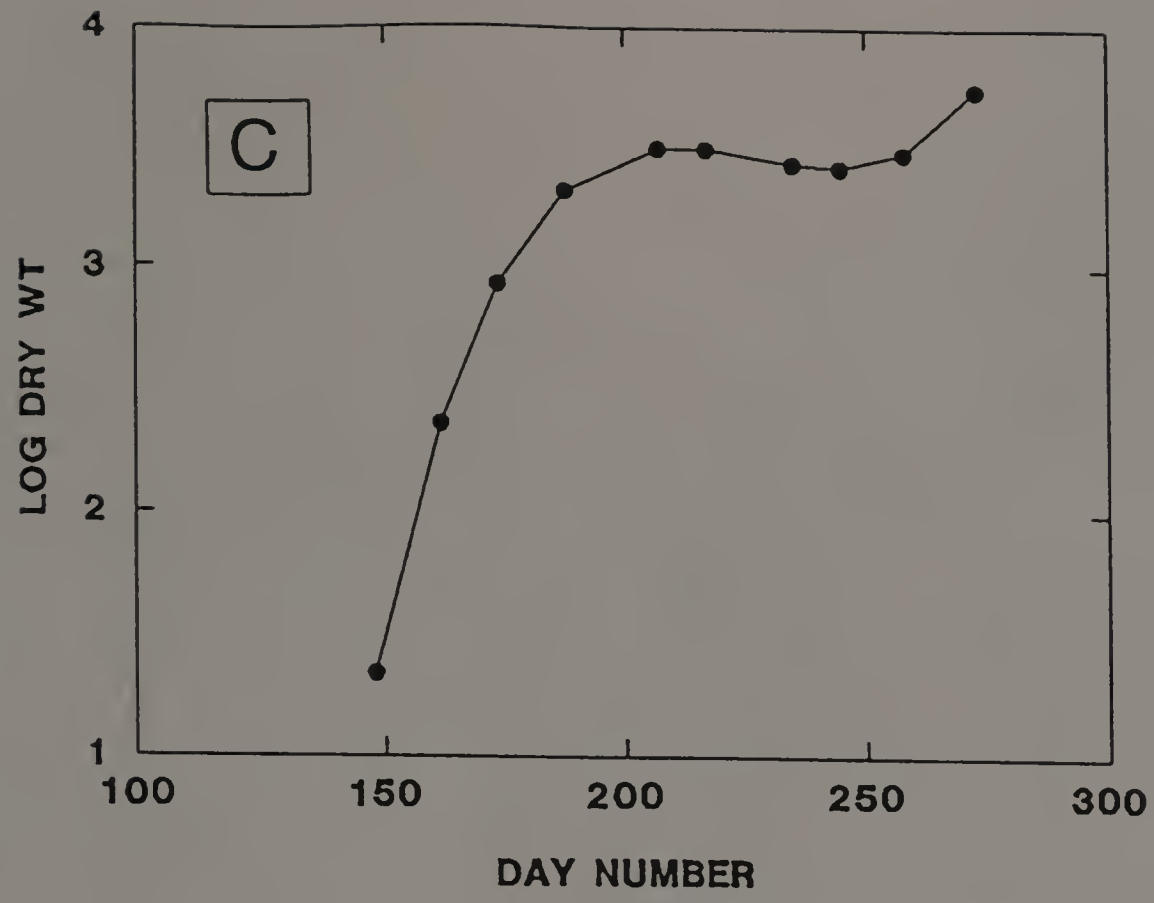


Figure 5.4 Regression of log-transformed cranberry shoot dry weight (30x30 cm area) data, D=day number. A: 1986; prediction equation: log dry weight = $-0.000\ D^2 + 0.114\ D - 9.389$ ($r=0.83$). B: 1987; prediction equation: log dry weight = $-0.000\ D^2 + 0.202\ D - 19.132$ ($r=0.92$).



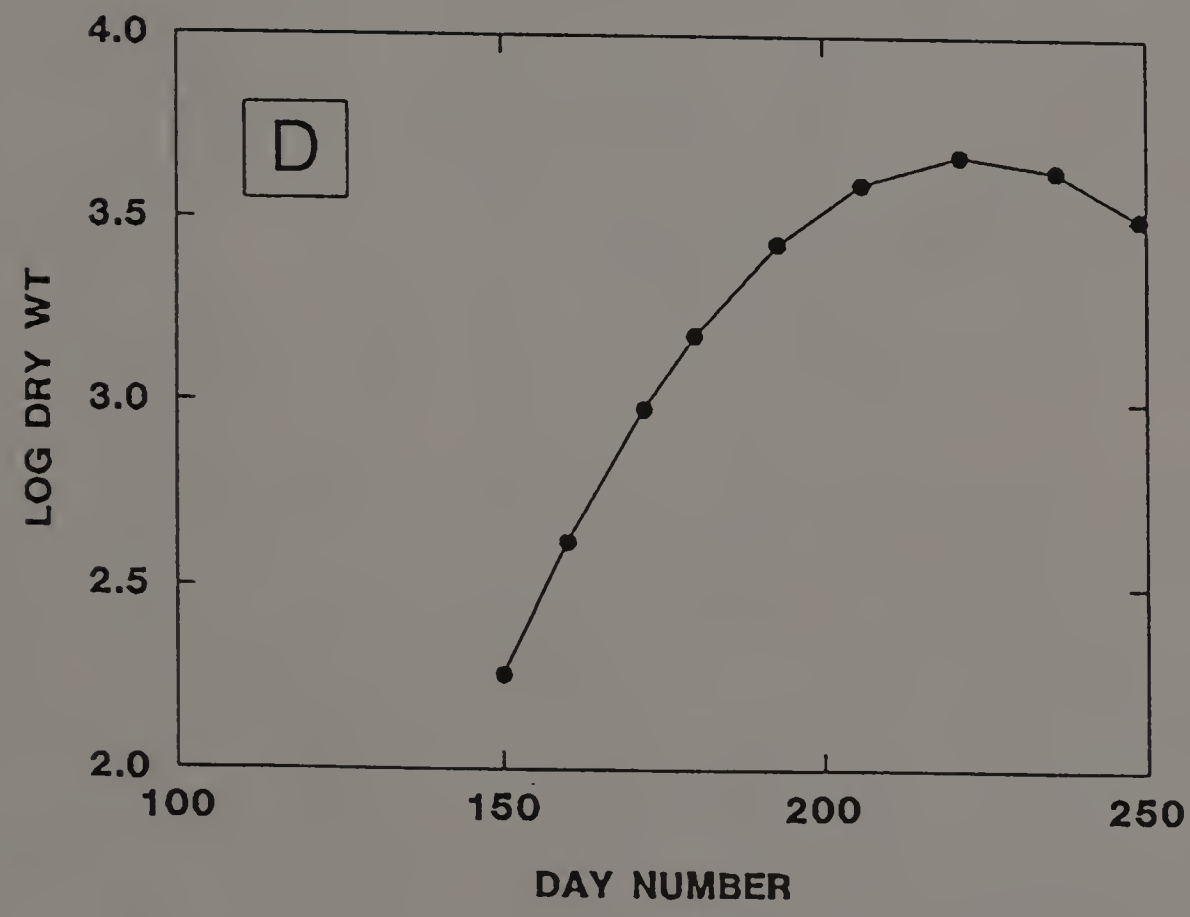


Figure 5.4 Continued. C: 1988; prediction equation: log dry weight = 0.000 D3 -0.003 D^2 + 0.754 D - 53.068 (r^2=0.83). D: 1989; prediction equation: log dry weight = -0.000 D^2 + 0.118 D - 9.476 (r^2=0.59).

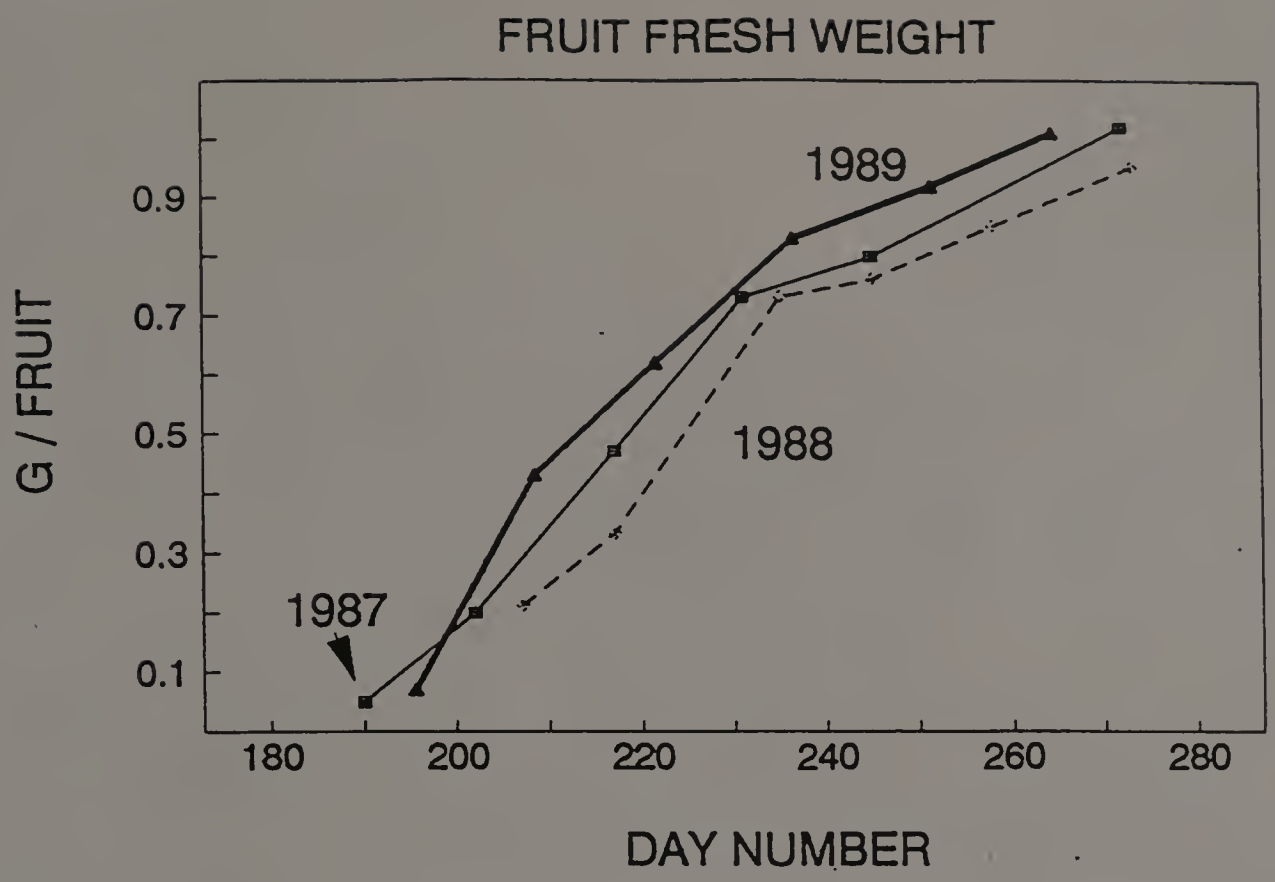


Figure 5.5 Seasonal changes in biomass of individual fruit (fresh weight) of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates.

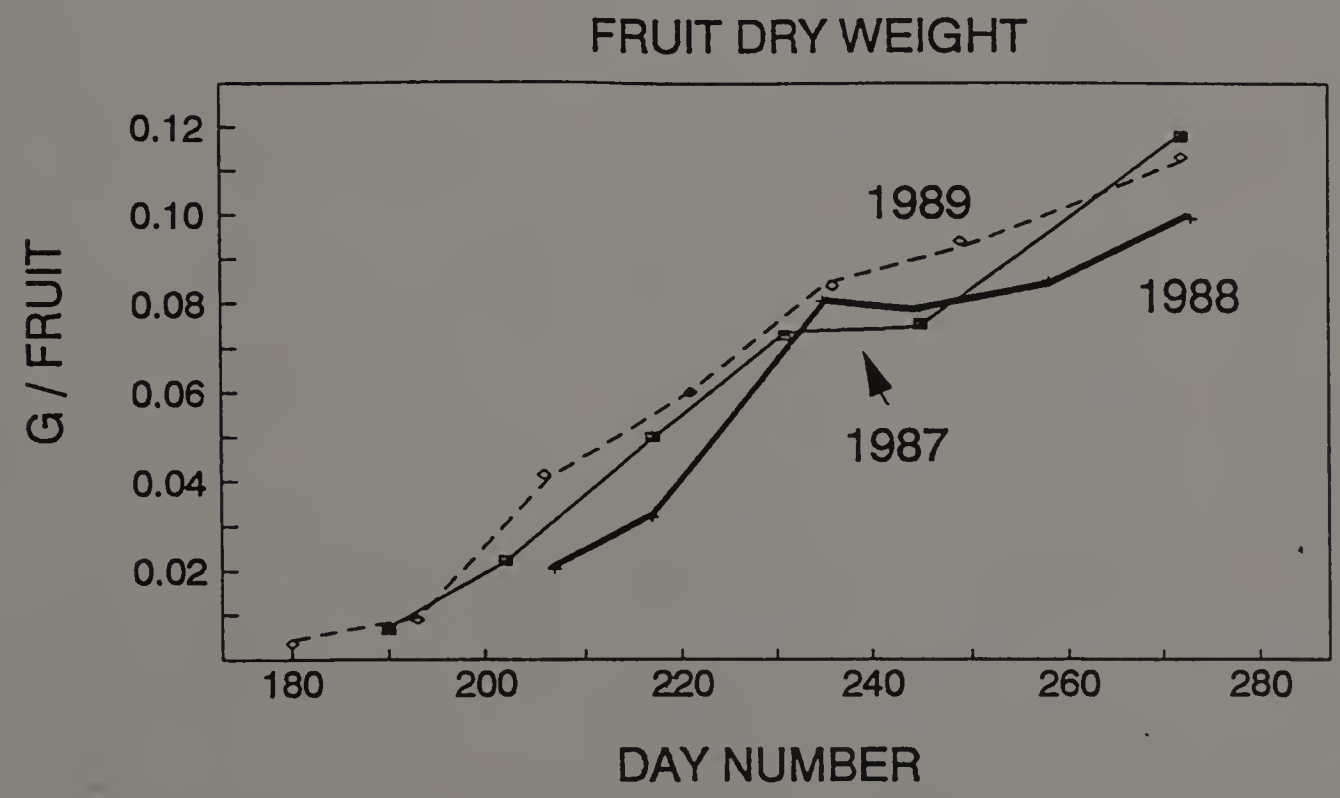


Figure 5.6 Seasonal changes in biomass of individual fruit (dry weight) of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates.

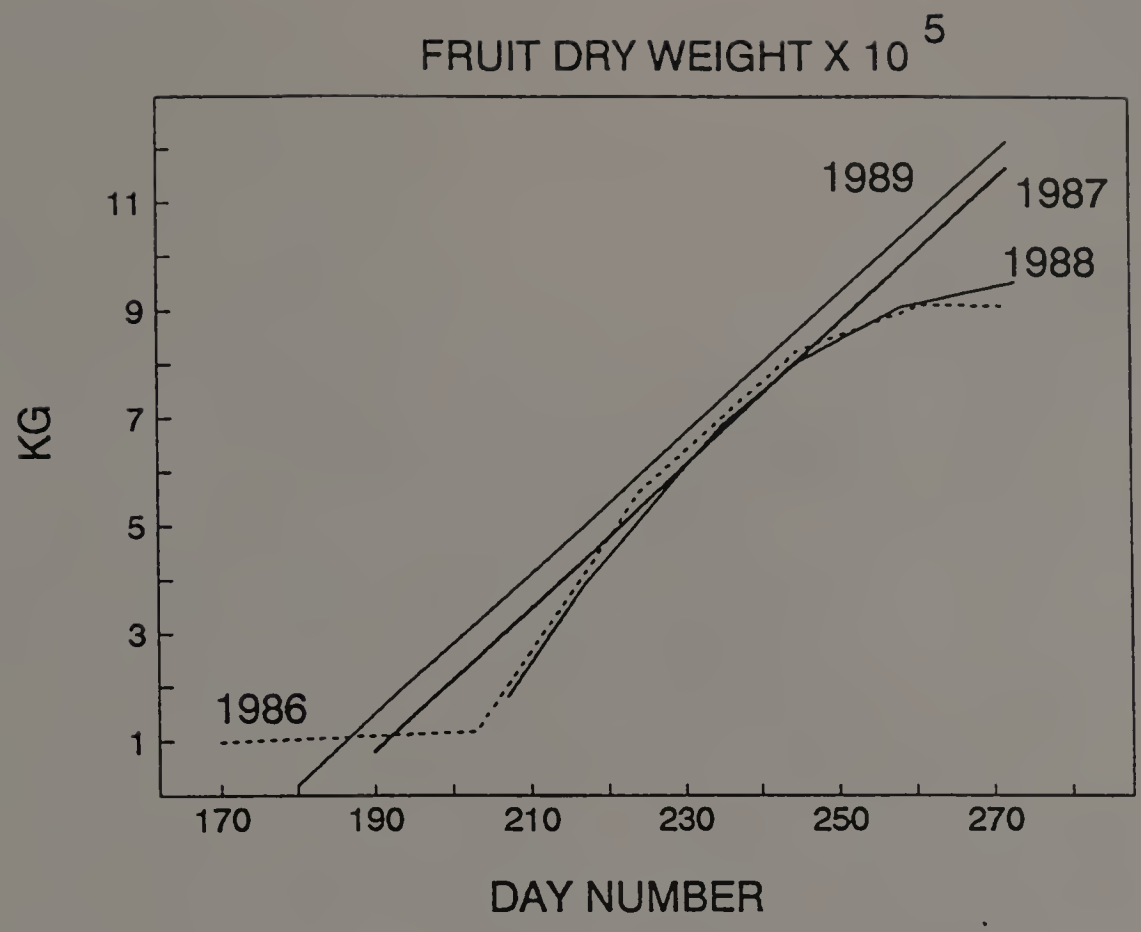


Figure 5.7 Seasonal changes in biomass of individual fruit of 'Early Black' cranberry, calculated regression lines correlating biomass and day number. Equations shown in Table 5.2.

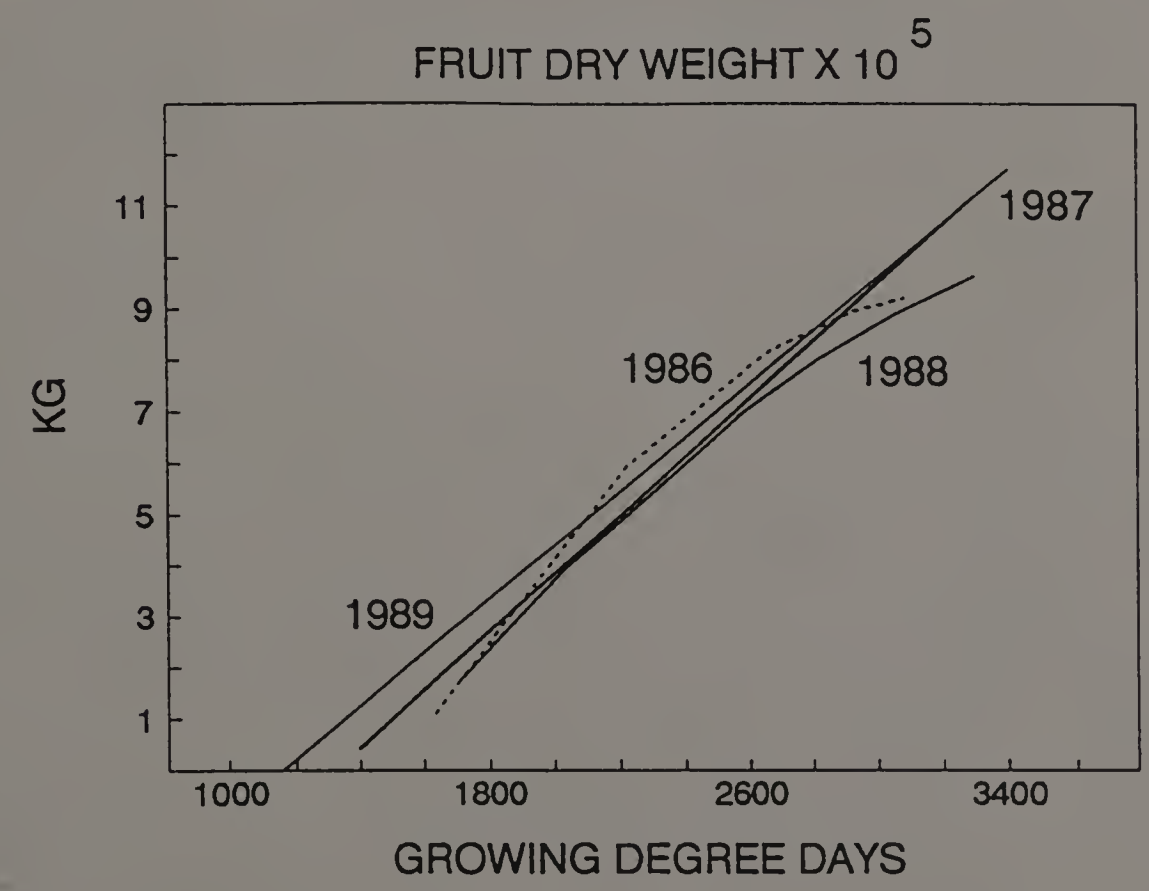


Figure 5.8 Seasonal changes in biomass of individual fruit of 'Early Black' cranberry, calculated regression lines correlating biomass and cumulative growing degree days. Equations shown in Table 5.2.

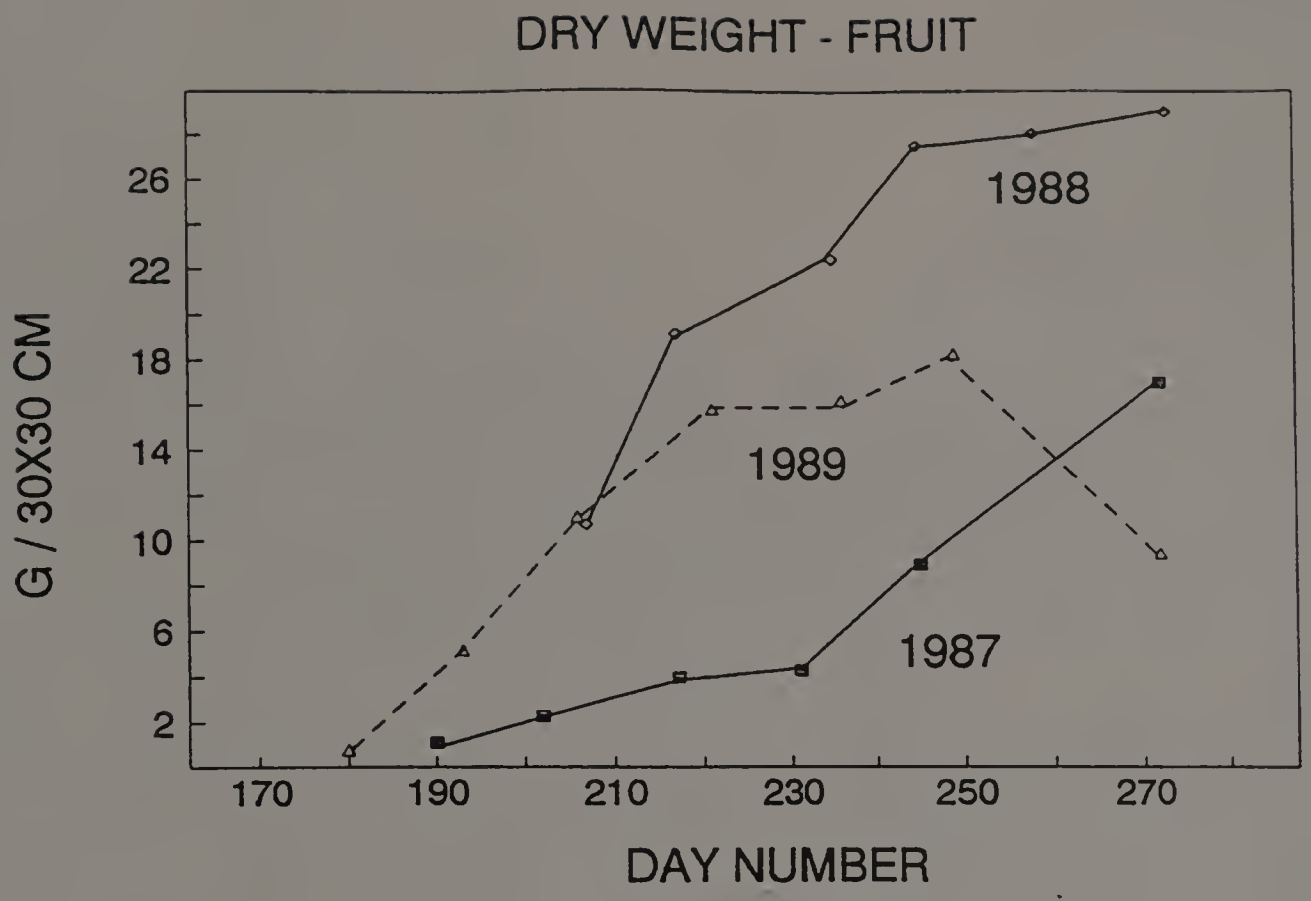


Figure 5.9 Seasonal changes in biomass of total fruit of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates.

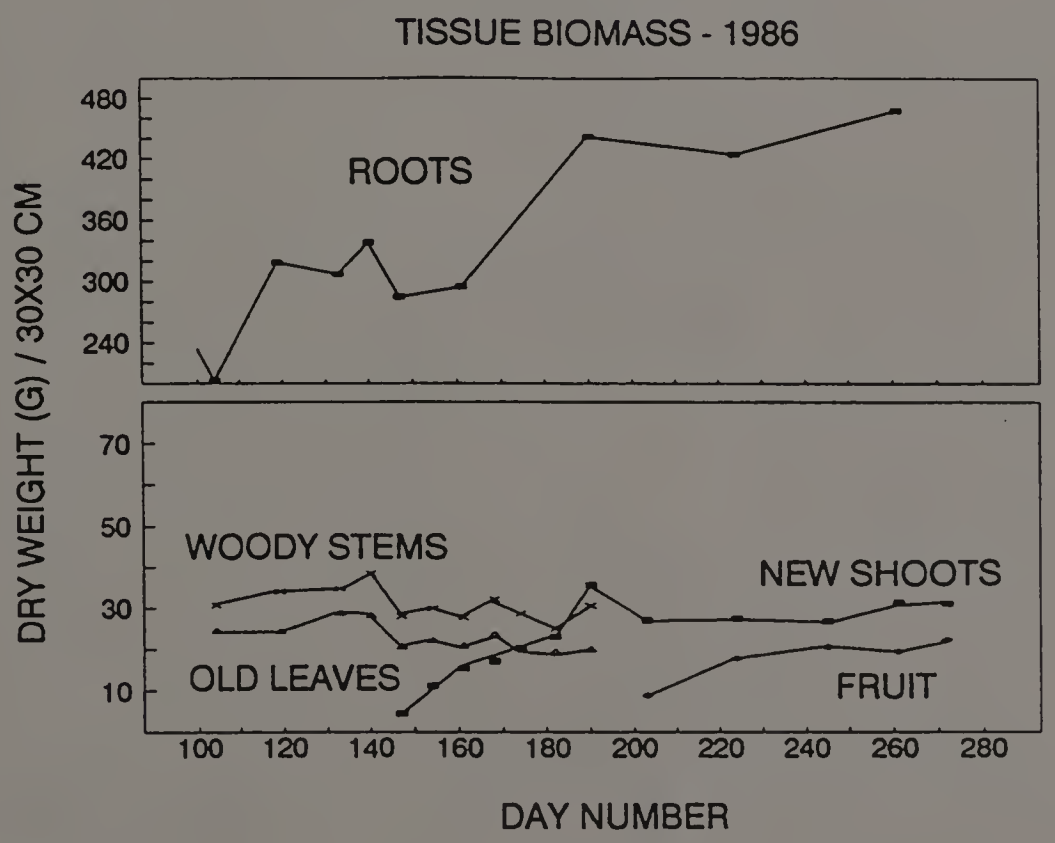


Figure 5.10 Seasonal changes in tissue biomass of 'Early Black' cranberry plantings receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates, data collected in 1986.

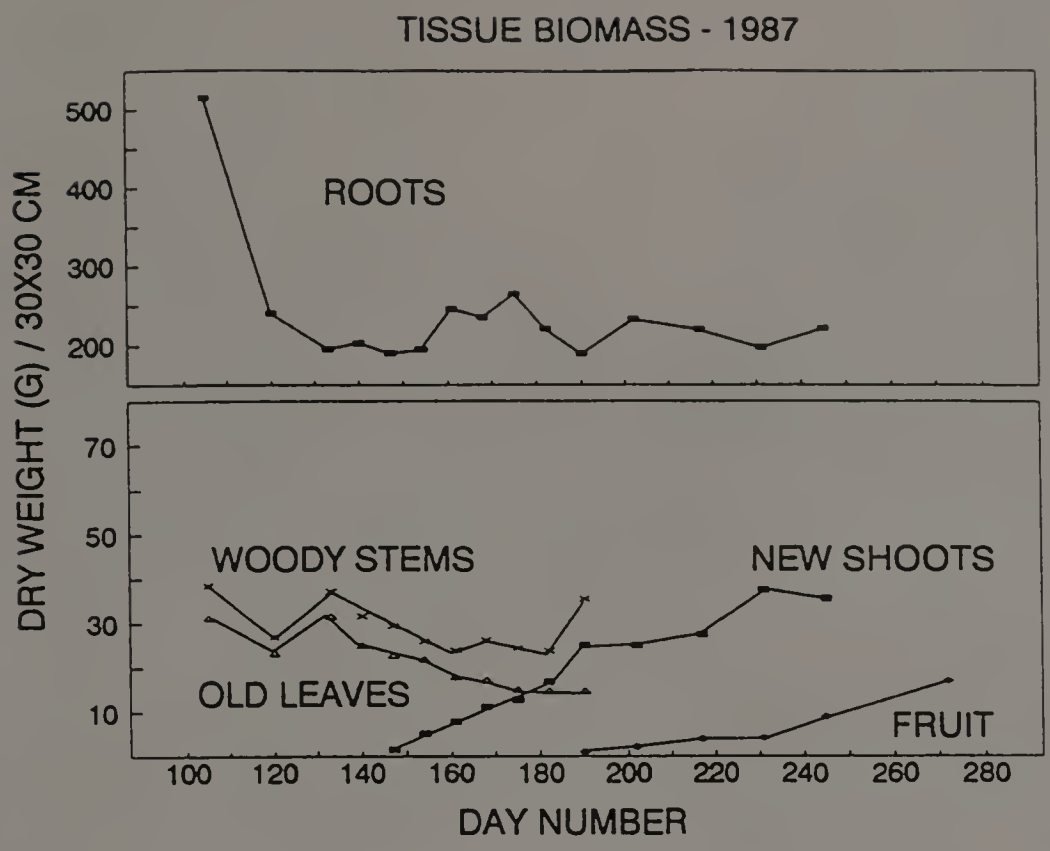


Figure 5.11 Seasonal changes in tissue biomass of 'Early Black' cranberry plantings receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates, data collected in 1987.

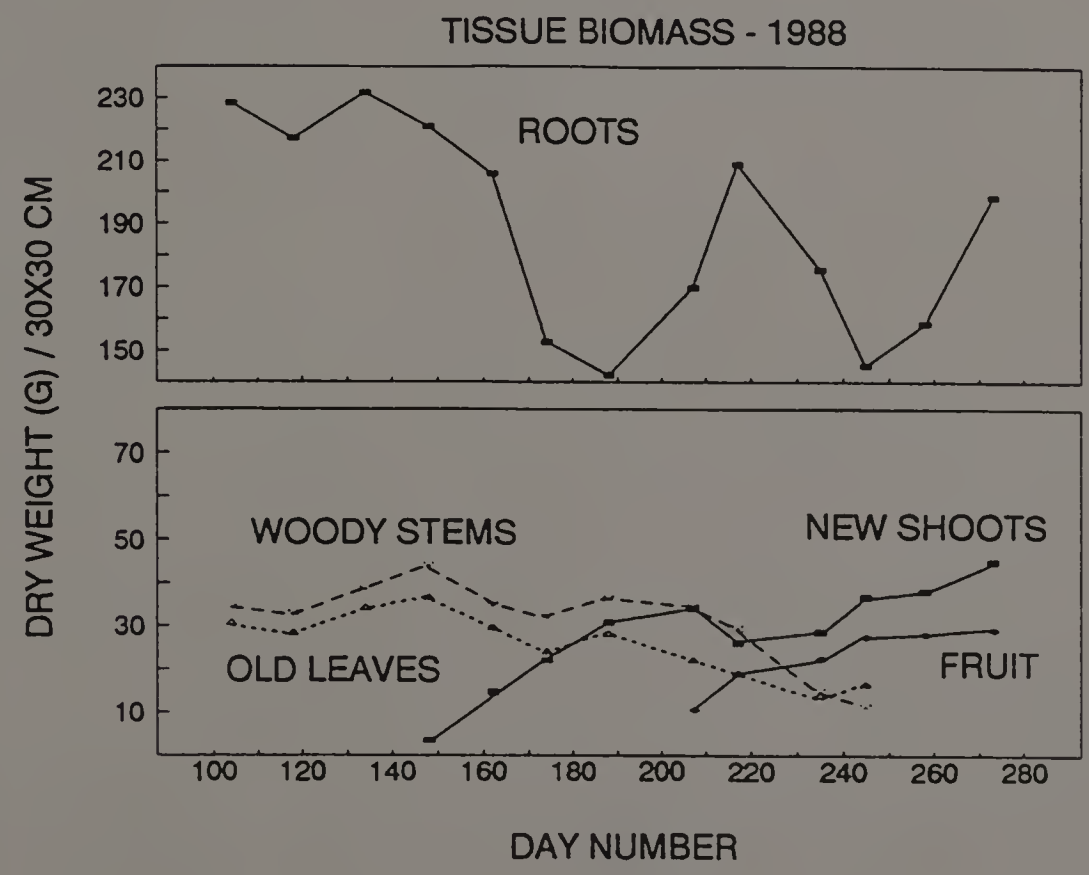


Figure 5.12 Seasonal changes in tissue biomass of 'Early Black' cranberry plantings receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates, data collected in 1988.

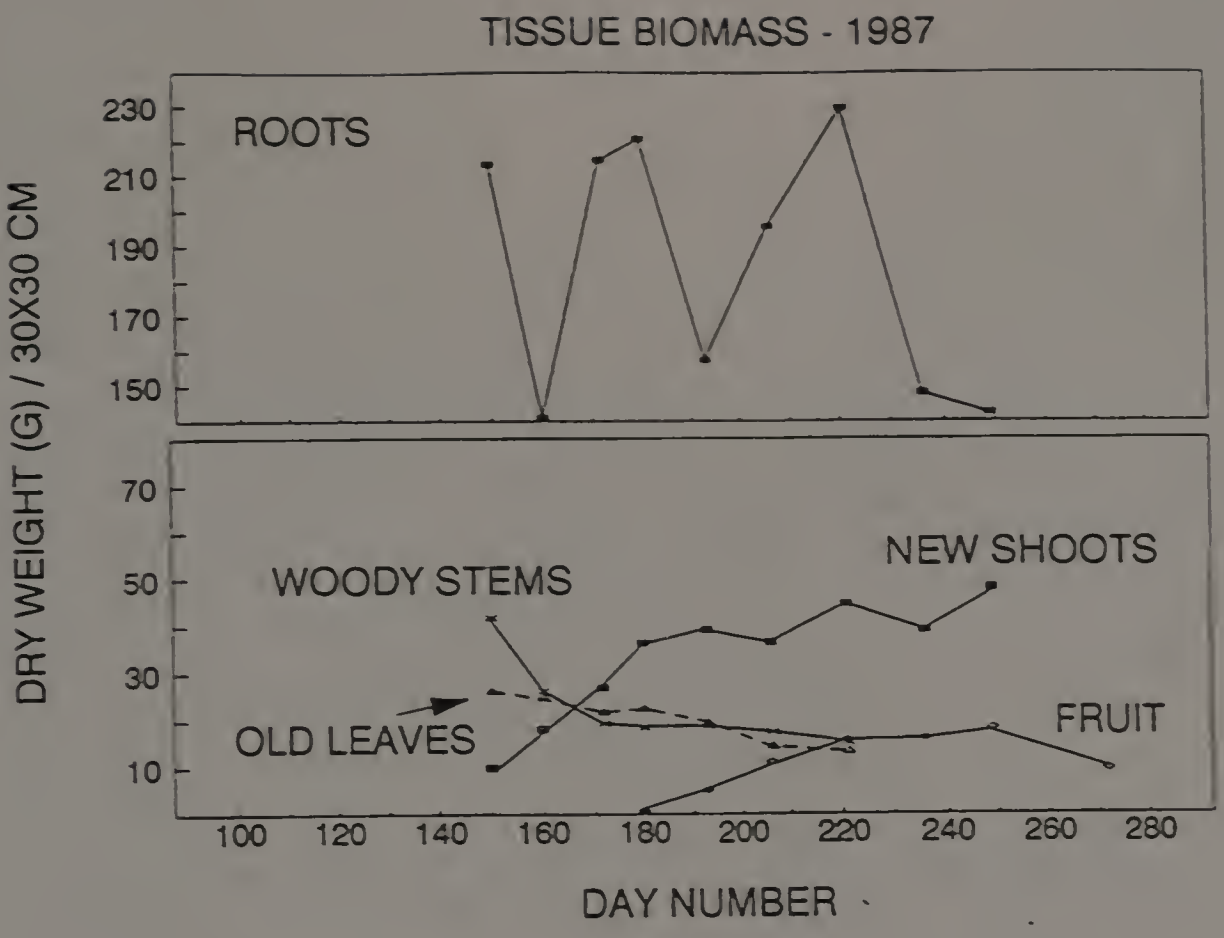


Figure 5.13 Seasonal changes in tissue biomass of 'Early Black' cranberry plantings receiving 335 kg N-P-K/ha. Data points are the means of 5 replicates, data collected in 1989.

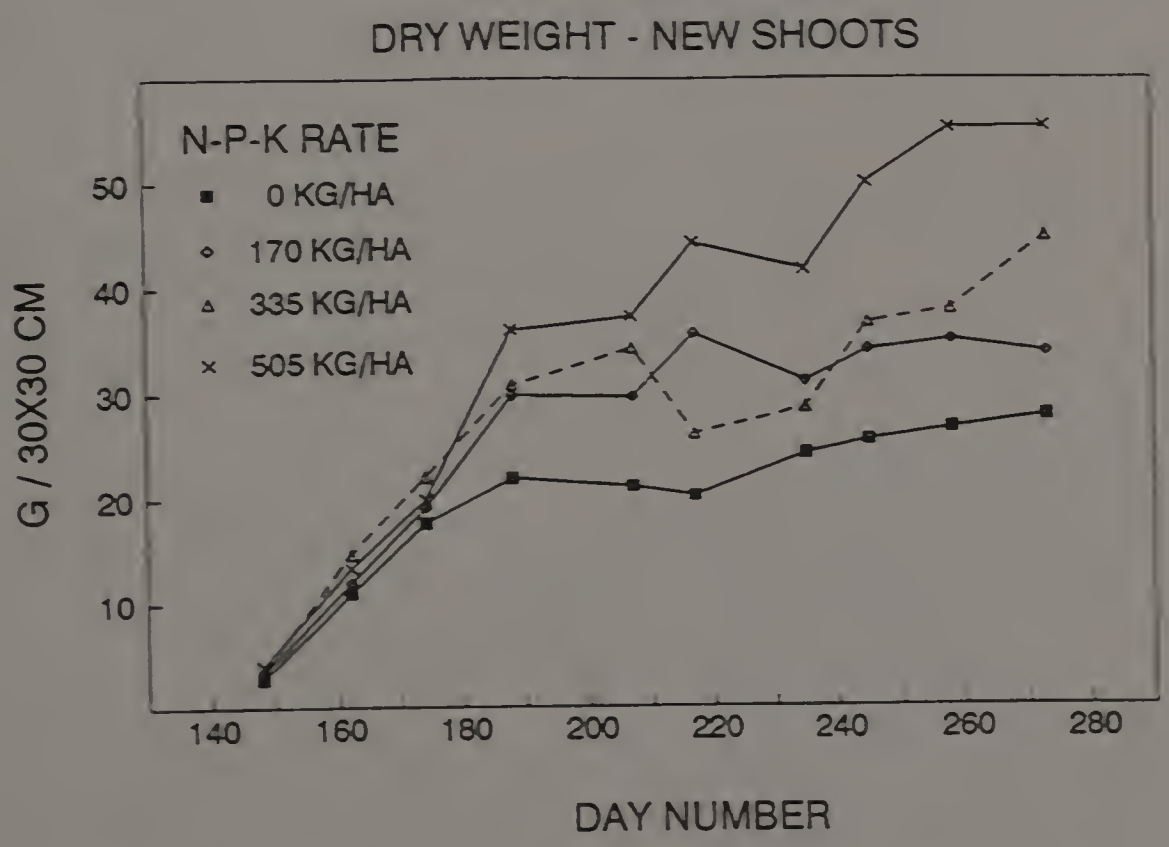


Figure 5.14 Effects of N-P-K fertilizer on accumulation of new shoot biomass in 'Early Black' cranberry. Data points are the means of 5 replicates, data collected in 1988, second year of treatment.

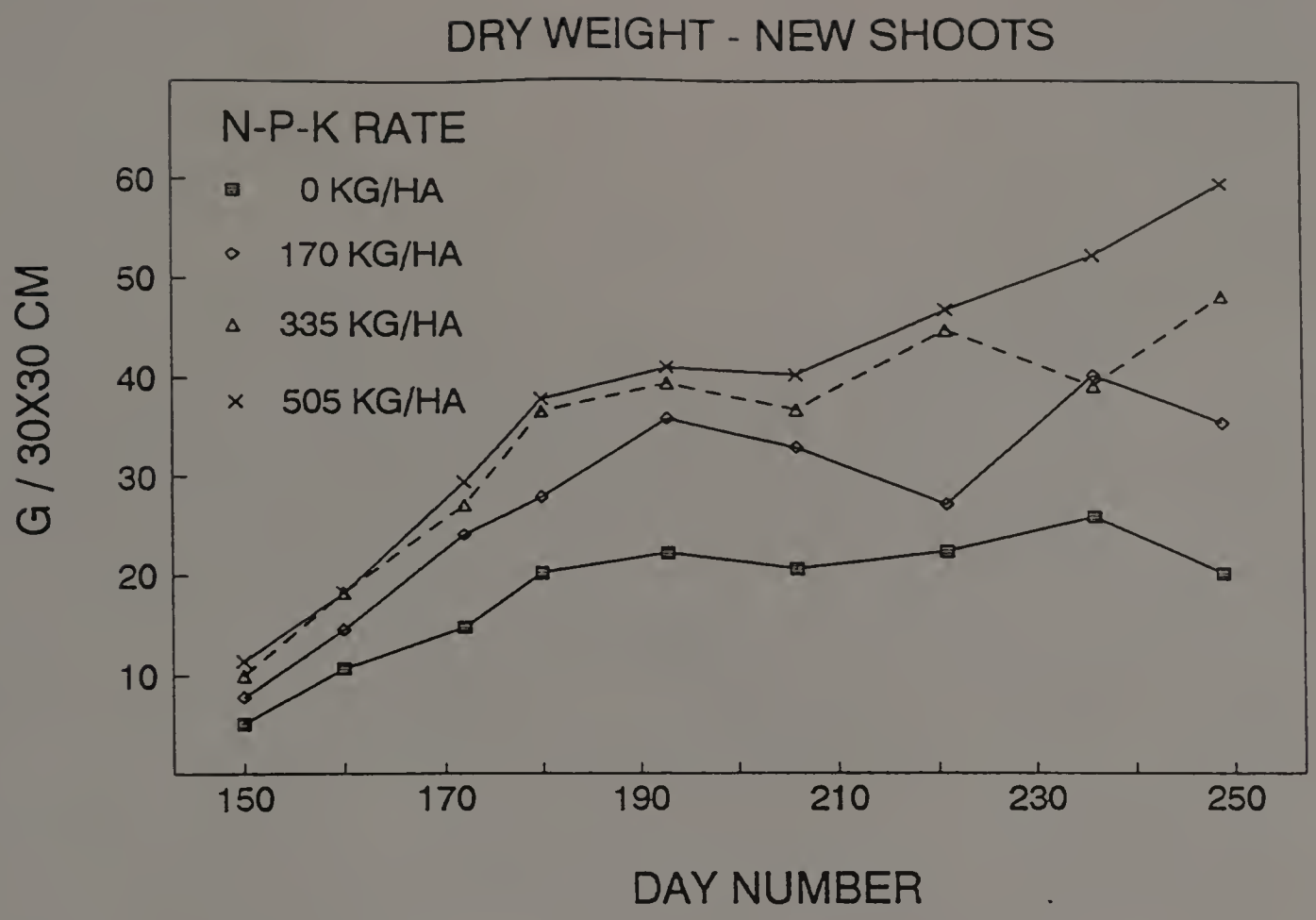


Figure 5.15 Effects of N-P-K fertilizer on accumulation of new shoot biomass in 'Early Black' cranberry. Data points are the means of 5 replicates, data collected in 1989, third year of treatment.

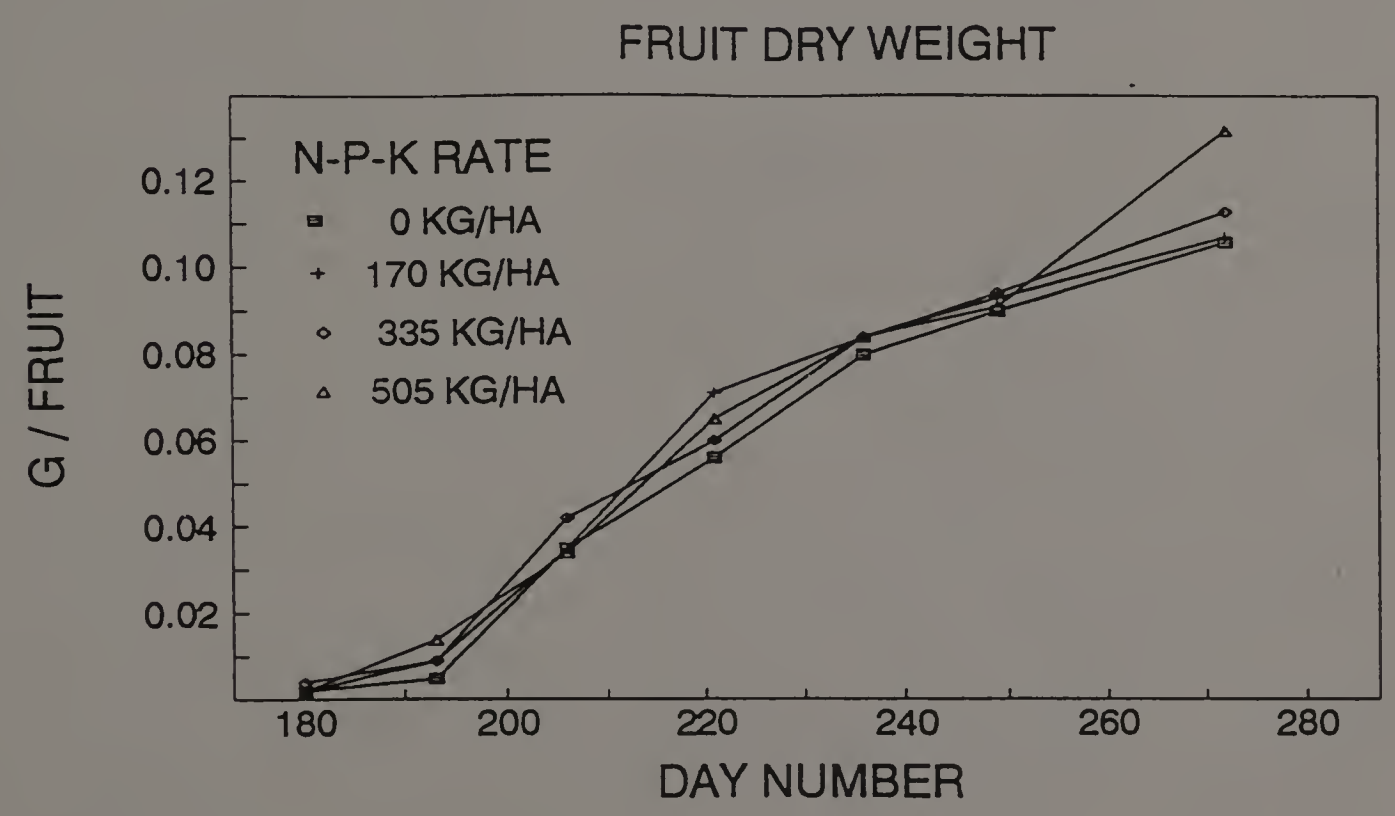


Figure 5.16 Effects of N-P-K fertilizer on dry weight accumulation in individual fruit of 'Early Black' cranberry. Data points are the means of 5 replicates, third year of treatment.

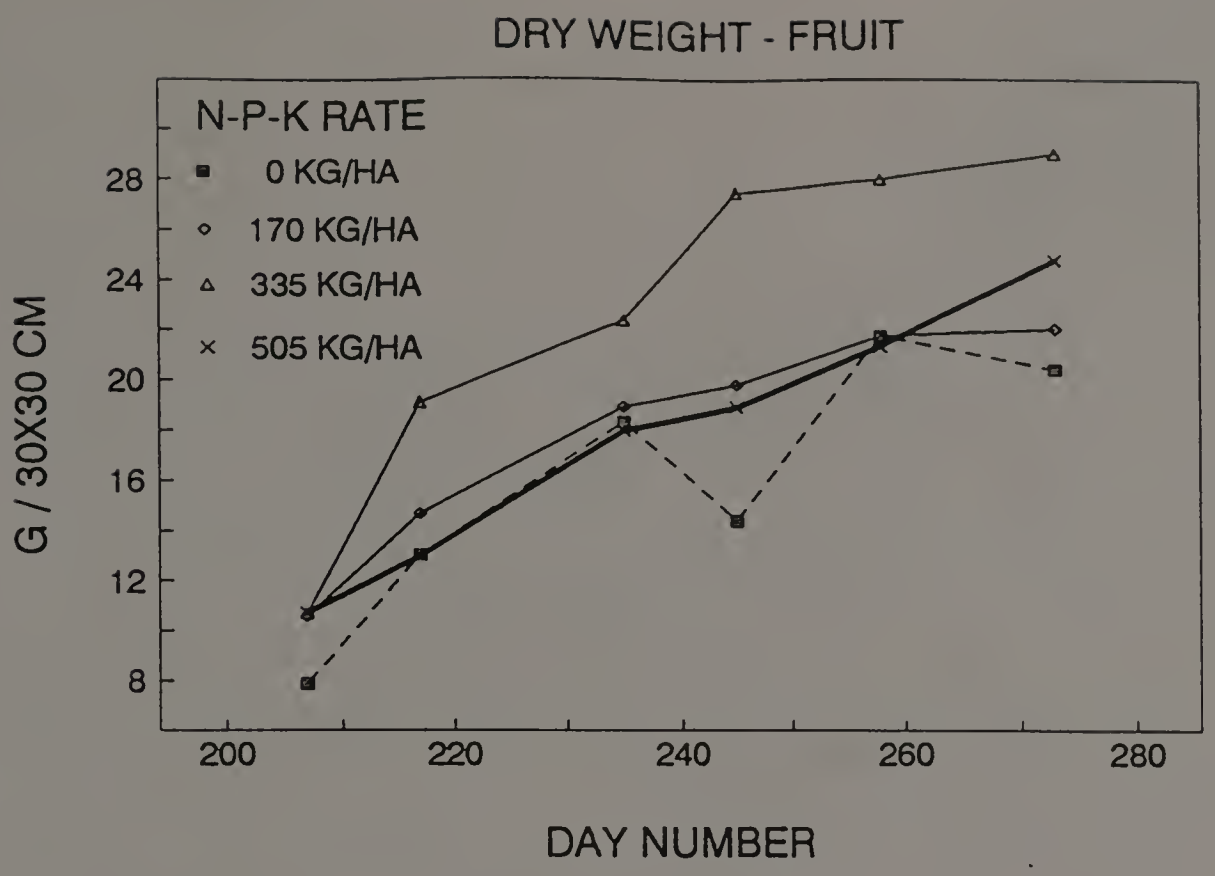


Figure 5.17 Effects of N-P-K fertilizer on accumulation of total fruit biomass in 'Early Black' cranberry. Data points are the means of 5 replicates, data collected in 1988, second year of treatment.

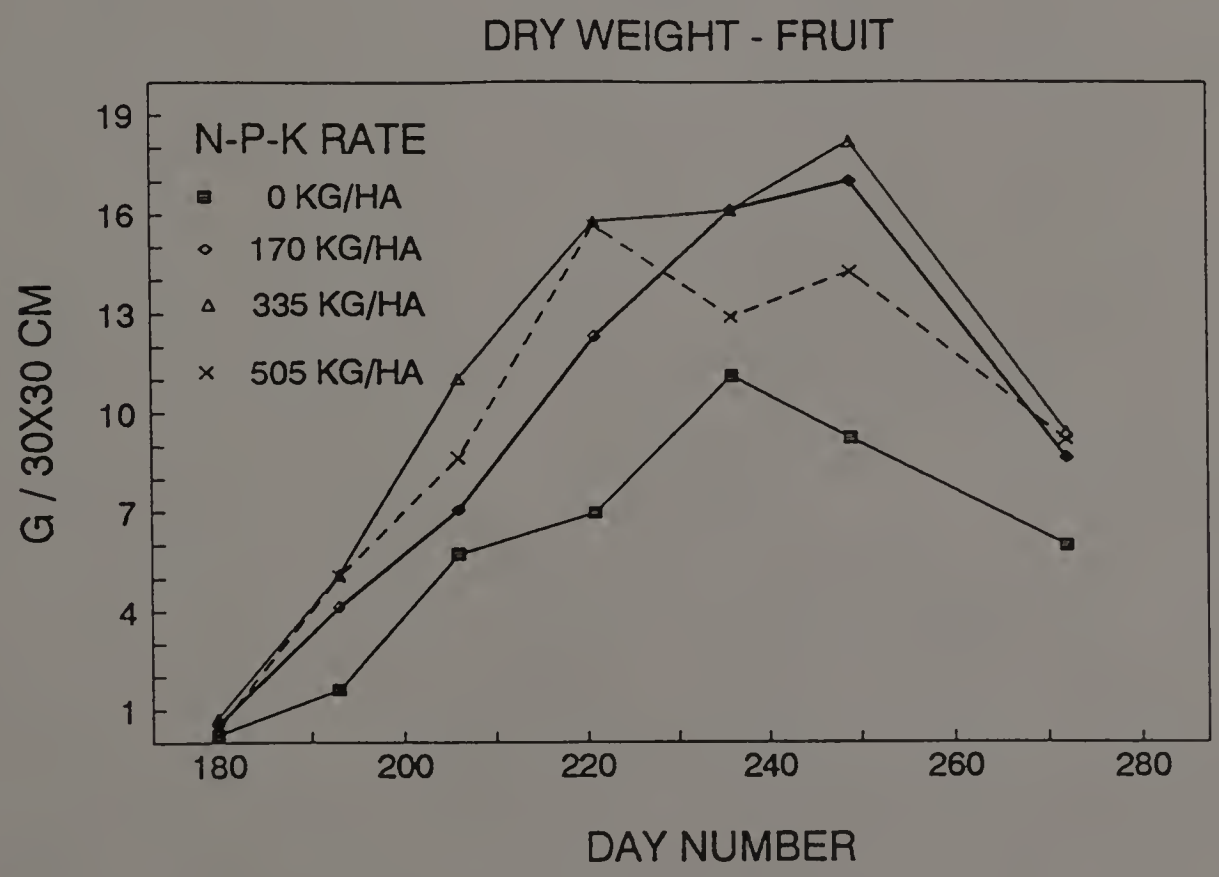


Figure 5.18 Effects of N-P-K fertilizer on accumulation of total fruit biomass in 'Early Black' cranberry. Data points are the means of 5 replicates, data collected in 1989, third year of treatment.

CHAPTER 6

SEASONAL AND TISSUE CHANGES IN NUTRIENT ELEMENT CONTENT OF 'EARLY BLACK' CRANBERRY

6.1 Seasonal Patterns for Nutrient Elements in Cranberry Tissues

The concentrations of mineral elements in tissues of cranberry plants changed during the growing season. The patterns for three years (1987 to 1989), ten elements (N, P, K, Ca, Mg, B, Cu, Fe, Mn, Zn), and five tissues (new shoots, old leaves, woody stems, roots, fruit) are shown in Figures 6.1 to 6.50 (p. 114-138). Those figures were based on results from plots receiving 335 kg N-P-K/ha combined with those from other treatments which did not differ significantly from the 335 kg/ha plots (see figure legends). Element concentrations in root tissue were the most stable, while the seasonal differences in new shoot tissue were all statistically significant. By using ANOVA and profile analysis, periods of element concentration stability during the season were identified for the five tissues.

6.1.1 Seasonal Trends in Element Content of 'Early Black' Cranberry Tissues

Nitrogen: In all three years, N concentration in new shoot tissue declined rapidly (Figure 6.1, p. 114) during the first month of new growth (June). The content of N in new shoots then was stable with a slight decline associated with the early stages of fruit development. The N content of old leaves (those produced in previous

seasons) began to decline rapidly at about the same time that new growth emerges (Figure 6.2, p. 114). The N pattern for woody stems was more variable, with some indication of transient increases which may be associated with N movement between other plant parts via the stems (Figure 6.3, p. 115). One such transient occurred in 1987 at the time of new growth emergence, and another occurred in 1989 at the beginning of fruit development. The N content of roots was variable (Figure 6.4, p. 115) with minima roughly associated with early development of new shoots and fruit. In 1987 there was no significant effect of date on the N concentration of roots. The N concentration pattern in fruit was similar to that in new shoots, with an initial high concentration declining to a stable lower value (Figure 6.5, p. 116). That type of pattern is most likely due to dilution of N during the rapid growth of shoot and fruit, which occur after bud break and after fruit set, respectively. A decline in N concentration in foliage during the season has been shown for peaches (Batjer and Westwood, 1958), grapes (Cummings, 1977), lowbush blueberries (Trevett et al., 1968; Townsend and Hall, 1970), plums (Sanchez-Alonso and Lachica, 1987b), blackberries (Clark et al., 1988), rabbiteye blueberries (Spiers, 1982), apples (Chuntanaparb and Cummings, 1980), sweet cherries (Sanchez-Alonso and Lachica, 1987a), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b). As for lowbush blueberry leaves (Townsend and Hall, 1970), the general pattern of N change in 'Early Black' cranberry tissues held from year to year.

Phosphorus: As for N, the general patterns for P change in 'Early Black' cranberry tissue held over the three years of the study,

although root P concentrations were variable. The pattern of change in P concentration in new shoots and fruit (Figures 6.6, p. 116 and 6.10, p. 118) was similar to that for N, showing dilution by growth. The P levels in old leaves (Figure 6.7, p. 117) declined slightly over the season, with no apparent change in pattern associated with any developmental event with the exception of a slightly greater decline in 1987 and 1988 at the time of bud break (new growth emergence). A decline in P concentration in foliage during the season also has been shown in peaches (Batjer and Westwood, 1958), lowbush blueberries (Trevett et al., 1968; Townsend and Hall, 1970), plums (Sanchez-Alonso and Lachica, 1987b), blackberries (Clark et al., 1988), grapes (Cummings, 1977), rabbiteye blueberries (Spiers, 1982), apples (Chuntanaparb and Cummings, 1980), sweet cherries (Sanchez-Alonso and Lachica, 1987a), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b). The P concentration in woody stems (Figure 6.8, p. 117) declined until about 10 days after bud break and then rose for the rest of the season. Increases in P concentration in root tissue (Figure 6.9, p. 118) were associated with times of root tissue production (June and August), with an overall pattern of increase. However, date had no statistically significant effect on P concentration in roots in 1988 or 1989.

Potassium: As for N and P, K concentrations in new shoots and fruit of 'Early Black' cranberry declined during the season (Figures 6.11, p. 119 and 6.15, p. 121). However, the slope of the function was smaller for K, with the decline in fruit especially being very slight. Cranberry, in common with other fruit such as apple, accumulate K in fruit tissue so that the concentration in the fruit is

greater than that in the leaves. A declining pattern of K in foliage during the season also has been shown associated with fruit production for peaches (Batjer and Westwood, 1958), lowbush blueberries (Trevett et al., 1968), blackberries (Clark et al., 1988), grapes (Cummings, 1977), sweet cherries (Sanchez-Alonso and Lachica, 1987a), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b). The K content in old leaves (Figure 6.12, p. 119) of cranberry declined steeply beginning about 15 days prior to bud break. Most likely, K (a mobile element) was recycled to newly produced tissues. The pattern of K concentration in woody stems (Figure 6.13, p. 120) during the season was variable, with no significant effect of date on K concentration in 1988. The K content in roots (Figure 6.14, p. 120) rose early in the season, declined during rapid new shoot growth, and rose again just prior to fruit set. The period of declining K concentration in roots occurred during the June period of root production, and the decline in K may have been due to dilution by growth.

Calcium: The Ca concentration in 'Early Black' cranberry foliage increased during the season (Figures 6.16, p. 121 and 6.17, p. 122). The most rapid increase in Ca in new shoots occurred during fruit development. Seasonal accumulation of Ca in foliage also occurred in peaches (Batjer and Westwood, 1958), lowbush blueberries (Trevett et al., 1968; Townsend and Hall, 1970), plums (Sanchez-Alonso and Lachica, 1987b), blackberries (Clark et al., 1988), grapes (Cummings, 1977), apples (Chuntanaparb and Cummings, 1980), sweet cherries (Sanchez-Alonso and Lachica, 1987a), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b; DeMoranville and Deubert,

1986). Little of the Ca which accumulated in the cranberry foliage was mobilized into the developing fruit. The Ca concentration in the fruit (Figure 6.20, p. 123) was much lower than that in the new shoots and declined rapidly during fruit development. The Ca concentrations in woody stems (Figure 6.18, p. 122) varied within a narrow range. The date had no effect on Ca concentration in stems in 1989. The Ca concentration in roots (Figure 6.19, p. 123) declined early in the season to a stable level. The effect of date on Ca concentration in roots was not significant in 1988 or 1989.

Magnesium: The pattern of Mg concentration in new shoots of 'Early Black' cranberry (Figure 6.21, p. 124) was similar to that for Ca. This same pattern of seasonal accumulation of Mg was shown for peaches (Batjer and Westwood, 1958), lowbush blueberries (Trevett et al., 1968), plums (Sanchez-Alonso and Lachica, 1987b), apples (Chuntanaparb and Cummings, 1980), sweet cherries (Sanchez-Alonso and Lachica, 1987a), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b; DeMoranville and Deubert, 1986). The Mg concentration in old leaves increased at a much lower rate (Figure 6.22, p. 124) than Mg in new shoots, and the date effect on Mg in old leaves in 1989 was not significant. The Mg content in woody stems (Figure 6.23, p. 125) rose just prior to bud break, then declined as new shoots developed. This pattern may indicate recycling of Mg into new growth from the stems or through the stems (Mg in the roots declined during that same period). The Mg levels in the root remained low until the time of fruit development (Figure 6.24, p. 125). The Mg concentration patterns for cranberry fruit (Figure 6.25, p. 126) were similar to those for N, P, K, and Ca.

Boron: B concentration in new or old foliage (Figures 6.26, p. 126 and 6.27, p. 127) increased during the season. Similar B patterns were found in the foliage of lowbush blueberries (Trevett et al., 1968), grapes (Cummings, 1977), sweet cherries (Sanchez-Alonso and Lachica, 1987a), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b). The B concentration in woody stems (Figure 6.28, p. 127) rose rapidly just prior to fruit set, possibly a recycling response. The B concentration in the roots (Figure 6.29, p. 128) was variable. Fruit B concentration (Figure 6.30, p. 128) declined slightly over time.

Copper: With some variability, Cu levels in new and old cranberry foliage (Figures 6.31 and 6.32, p. 129) declined during the season. Similar patterns were found for blackberries (Clark et al., 1988), grapes (Cummings, 1977), and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b). The Cu concentration in woody stems (Figure 6.33, p. 130) was stable for most of the season. Cranberry roots accumulated Cu at concentrations 100 times that in other tissue (Figure 6.34, p. 130). The lowest Cu concentrations in roots occurred during rapid new shoot growth. The pattern for Cu concentrations in fruit (Figure 6.35, p. 131) was similar to that for the other elements in 'Early Black' cranberry fruit.

Iron: The Fe levels in cranberry new shoot tissue (Figure 6.36, p. 131) were variable, but there was little net change in Fe concentration by the end of the season. The Fe levels in old leaves (Figure 6.37, p. 132) were very stable and higher than those found in new shoots. Variable Fe levels in foliage also have been found in lowbush blueberries (Trevett et al., 1968; Townsend and Hall, 1970)

and grapes (Cummings, 1977). The Fe levels in woody stems (Figure 6.38, p. 132) increased in the later part of the season and were higher than those in the foliage. In addition to accumulating Fe in stem tissue, the cranberry plants seemed to accumulate Fe in roots as well (Figure 6.39, p. 133). Root Fe concentrations declined only during rapid root growth in June. The Fe levels in the fruit (Figure 6.40, p. 133) were variable. However, cranberry fruit seem to exclude Fe, with Fe levels lower than those in any other tissue.

Manganese: The Mn concentration increased during the season in both new shoots and old leaves (Figures 6.41 and 6.42, p. 134), with Mn levels higher in old leaves. Seasonal increase in Mn in foliage also has been shown for plums (Sanchez-Alonso and Lachica, 1987b) and other cranberry cultivars (Chaplin and Martin, 1979; Dana, 1981b). The Mn concentrations in woody stems and roots (Figures 6.43 and 6.44, p. 135) were variable. The effect of date on stem Mn was not significant in 1988 or 1989, and the effect of date on root Mn concentration was not significant in 1987 or 1988. The Mn levels in new tissues (shoots and roots) were lower than those in old leaves and stems. Fruit (Figure 6.45, p. 136) Mn levels declined during development, with apparent exclusion of Mn.

Zinc: Allowing for some variability, Zn concentrations in cranberry foliage and woody stems (Figures 6.46, p. 136 and 6.47 and 6.48, p. 137) remain about the same throughout the season. The seasonal pattern for foliage Zn was similar for grapes (Cummings, 1977). Root Zn concentrations (Figure 6.49, p. 138) were very variable but the trend was towards higher values late in the season. However, the date effect on root Zn was not significant in 1987 or

1988. The concentration of Zn, like those of most of the other elements, declined in cranberry fruit (Figure 6.50, p. 138).

6.1.2 Seasonal Changes in Elemental Content of 'Early Black' Cranberry Tissues: Stable Periods

Following the ANOVA for repeated measures analysis of the seasonal nutrient data, a profile analysis was performed to contrast nutrient values on adjacent dates. The average nutrient values by date with the statistically similar values (stable periods) linked by an underline are shown in Appendix A, Tables A.1-A.50 (pp. 254-278). The common stable periods over the three years of the study also are shown on the graphs of tissue element concentrations (Figures 6.1 to 6.50, p. 114-138). Common stable periods (all elements) for the five tissue studied were as follows: new shoots - 15 August to 15 September, old leaves and woody stems - 15 to 30 June, roots 1 to 31 July, and fruit 1 to 14 September. These stable periods are for 'Early Black' cranberry in Massachusetts and may not hold for other cultivars with different developmental timing or in other growing areas. Chaplin and Martin (1979) determined a stable period for new shoots of Oregon cranberries of 15 August to 1 September for the elements N, P, K, Ca, B, Cu and Zn, but Mg, Mn, and Fe were only stable from 15 June to 15 July in that study. In mixed new and old leaves of 'Howes' cranberry, DeMoranville and Deubert (1986) found that N, K, Ca, and Mg concentrations were stable from 15 August to 15 September, but P concentration was not. The late season stable period

for new shoots and fruit is most likely due in part to slowing and cessation of biomass production.

The nutrient ranges in the five cranberry tissues studied at the late season stable period (three years combined) are shown in Table 6.1. These values for 'Early Black' cranberry are in fair agreement with those published by Dana (1981c) for new shoot tissue of 'Searles' cranberry, by Townsend and Hall (1971) for new shoots of 'Ben Lear', 'Stevens', and 'Howes' cranberry, and by Bear (1949) for cranberry fruit. The values found by Townsend and Hall (1971) were higher for N, Ca, and Mn than those found in this study. The difference in N was most likely due to differences in soil organic content between Massachusetts and Nova Scotia. Mn content is known to vary widely in cranberry plants from different bogs.

Nutrient levels in the leaves and stems of stands of huckleberries (*Vaccinium globulare* Rydb.) have been determined (Stark et al., 1989). Of the ten elements studied for cranberries, the huckleberry leaves had higher concentrations of all elements but Ca (similar) and Zn (lower), whereas the huckleberry stems were higher in N, P, K, Mg, and Mn, but lower in Ca and Fe. Levels of B, Cu, and Zn in stems were similar for huckleberry and cranberry. The generally higher levels of nutrients in huckleberry were interesting, as the huckleberries were not fertilized. It appears that cranberries, like lowbush blueberries (Trevett et al., 1968), are low nutrient plants, even under well fertilized conditions and compared to other *Vaccinium* species.

Table 6.1 Nutrient ranges in cranberry - stable nutrient periods.

Element	New shoot	Old leaves	Woody stems	Roots	Fruit
N %	0.95-1.15	0.65-0.75	0.50-0.65	0.55-0.75	0.35-0.50
P %	0.12-0.15	0.11-0.16	0.09-0.12	0.12-0.16	0.08-0.10
K %	0.45-0.75	0.30-0.50	0.30-0.40	0.12-0.17	0.75-0.95
Ca %	0.65-0.85	0.60-0.90	0.20-0.30	0.08-0.13	0.07-0.08
Mg %	0.22-0.26	0.16-0.22	0.07-0.10	0.06-0.08	0.06-0.07
B ppm	25-42	38-45	14-17	10-20	12-18
Cu ppm	4-6	3-6	11-13	160-300	6-8
Fe ppm	60-70	50-300	300-1000	4000-6000	14-32
Mn ppm	140-240	200-300	500-650	130-180	12-30
Zn ppm	20-25	15-30	20-40	40-70	8-12

6.2 Effect of N-P-K on Seasonal Element Levels in Cranberry Tissues

The addition of N-P-K fertilizer to cranberry plantings led to changes in the mineral element contents of new shoot tissue (see Chapter 4). N-P-K fertilizer use also led to changes in other plant tissue element levels. These will be discussed in the following sections. For some tissues and some elements N-P-K fertilizer had no effect. These unaffected tissue elements are listed in Tables 6.2 and 6.3. Generally, there were few effects on elements other than N, P, and K. Of the minor elements, B was the most affected by the use of N-P-K fertilizer.

Table 6.2 Effects of N-P-K on seasonal major nutrient levels in tissues of 'Early Black' cranberry. For each element below, the level of the element in the tissues listed was *not* affected by N-P-K level.

1987	1988	1989
old leaves woody stems roots fruit	<u>Nitrogen</u> roots new shoots fruit	fruit
woody stems	<u>Phosphorus</u> new shoots fruit	fruit
roots	<u>Potassium</u> roots new shoots	roots
old leaves woody stems new shoots fruit	<u>Calcium</u> roots new shoots fruit	roots new shoots
old leaves woody stems new shoots	<u>Magnesium</u> woody stems new shoots fruit	all tissues

6.2.1 <u>Effect of N-P-K Treatment on Elements in Old Leaves</u>

In the first year of N-P-K treatments, only P, K, Cu, and Fe levels in old leaves were affected by treatment. The levels of P and K were positively correlated with fertilizer treatment (Table 6.4) Because these are leaves produced in previous seasons, little effect of current season treatments is to be expected. However, in the second year, all elements except Cu and Zn were affected by N-P-K (Table 6.4) and in the third year all elements but Mg, Cu, and Mn were

Table 6.3 Effects of N-P-K on seasonal minor nutrient levels in tissues of 'Early Black' cranberry. For each element below, the level of the element in the tissues listed was *not* affected by N-P-K level.

old leaves woody stems roots	<u>Boron</u> roots fruit	roots fruit
woody stems roots fruit	<u>Copper</u> all tissues	old leaves woody stems roots fruit
roots new shoots	<u>Iron</u> woody stems roots new shoots fruit	roots new shoots fruit
old leaves woody stems roots new shoots	<u>Manganese</u> woody stems roots new shoots fruit	old leaves woody stems new shoots
old leaves woody stems roots new shoots	<u>Zinc</u> old leaves roots new shoots fruit	woody stems roots new shoots fruit

affected by N-P-K levels. As was the case for new shoots, N, P, and K in old leaves were positively affected by N-P-K dose. Although N-P-K had no effect on Ca or Mg in new shoots, both elements in old leaves were negatively affected in 1988, as was Ca in 1989. The Mg levels in old leaves of lowbush blueberry also were negatively affected by the addition of N-P-K fertilizer (Trevett et al., 1968). As was the case for new shoots, B concentration in old leaves was lower in all fertilized treatments compared to unfertilized. The old leaves in

Table 6.4 Element levels in old leaves of 'Early Black' cranberry receiving 4 rates of N-P-K fertilizer. Data for tissues and elements with significant treatment effects are shown. Values represent the mean across all sample dates, 5 replicates. Significance of F from linear regression analyses.

1987				
N-P-K level	%P	%K	ppm Cu	ppm Fe
0 kg/ha	0.11	0.38	13	310
170 kg/ha	0.12	0.41	11	317
335 kg/ha	0.12	0.44	4	134
505 kg/ha	0.12	0.45	2	54
Sig. of F	p=0.002	p=0.008	p=0.028	p=0.015
n=280	r2=0.03	r2=0.07	r2=0.02	r2=0.02

1988					
N-P-K level	%N	%P	%K	%Ca	% Mg
0 kg/ha	0.76	0.13	0.40	0.86	0.22
170 kg/ha	0.79	0.14	0.45	0.81	0.22
335 kg/ha	0.80	0.15	0.46	0.80	0.22
505 kg/ha	0.85	0.15	0.47	0.72	0.21
Sig. of F	p=0.002	p<0.001	p=0.003	p<0.001	p<0.001
n=184	r2=0.05	r2=0.16	r2=0.05	r2=0.10	r2=0.07
	ppm B	ppm Fe	ppm Mn		
0 kg/ha	47	124	246		
170 kg/ha	41	135	237		
335 kg/ha	38	145	263		
505 kg/ha	36	171	307		
Sig. of F	p<0.001	p<0.001	p<0.001		
n=184	r2=0.16	r2=0.13	r2=0.08		

1989				
N-P-K level	%N	%P	%K	%Ca
0 kg/ha	0.65	0.09	0.28	0.84
170 kg/ha	0.68	0.11	0.28	0.87
335 kg/ha	0.70	0.13	0.32	0.82
505 kg/ha	0.75	0.13	0.31	0.76
Sig. of F	p<0.001	p<0.001	p=0.001	p=0.018
n=136	r2=0.10	r2=0.43	r2=0.09	r2=0.04
	ppm B	ppm Fe	ppm Zn	
0 kg/ha	54	265	24	
170 kg/ha	45	295	24	
335 kg/ha	41	303	29	
505 kg/ha	40	308	28	
Sig. of F	p<0.001	p=0.008	p=0.014	
n=136	r2=0.21	r2=0.05	r2=0.04	

plots receiving 505 kg N-P-K/ha had the highest Fe and Mn levels (1987 Fe was an exception), although both elements in new shoots were unaffected by N-P-K level.

6.2.2 Effect of N-P-K Treatment on Elements in Woody Stems

The effects of N-P-K treatments on element levels in cranberry woody stems (Table 6.5) were generally similar to those on old leaves. N-P-K treated plants had lower Zn levels in stems than those receiving no fertilizer. In contrast to old leaves, stems of plants receiving N-P-K had less Fe than those which were not fertilized. As expected, effects were less common in the first year of treatment and increased with succeeding seasons.

6.2.3 Effect of N-P-K Treatment on Elements in Roots

Most of the effects of N-P-K treatment on roots were on the concentration of P, which was affected positively in all years (Table 6.6). The concentrations of Ca and Mg were each negatively affected, Ca in one year of three and Mg in two years. The effects on Mn, although statistically significant, showed no sensible trend. The large degree of variability in the root data made it difficult to draw any conclusions. The effects on P were interesting. Cranberry is a mycorrhizal plant. Often the addition of P containing fertilizers to such plants has negative consequences in elemental content and biomass production. No such negative effects were found in this study.

Table 6.5 Element levels in woody stems of 'Early Black' cranberry receiving 4 rates of N-P-K fertilizer. Data for tissues and elements with significant treatment effects are shown. Values represent the mean across all sample dates, 5 replicates. Significance of F from linear regression analyses.

1987		
N-P-K level	%K	ppm Fe
0 kg/ha	0.29	306
170 kg/ha	0.30	293
335 kg/ha	0.30	299
505 kg/ha	0.31	270
Sig. of F	p=0.008	p=0.007
n=220	r2=0.03	r2=0.03

1988				
N-P-K level	%N	%P	%K	%Ca
0 kg/ha	0.52	0.09	0.31	0.28
170 kg/ha	0.54	0.10	0.34	0.27
335 kg/ha	0.56	0.11	0.35	0.26
505 kg/ha	0.57	0.11	0.36	0.24
Sig. of F	p=0.016	p<0.001	p<0.001	p<0.001
n=196	r2=0.03	r2=0.18	r2=0.10	r2=0.06
	ppm B	ppm Zn		
0 kg/ha	17	33		
170 kg/ha	16	31		
335 kg/ha	15	30		
505 kg/ha	16	30		
Sig. of F	p=0.026	p<0.001		
n=196	r2=0.03	r2=0.06		

1989				
N-P-K level	%N	%P	%K	%Ca
0 kg/ha	0.50	0.08	0.29	0.30
170 kg/ha	0.49	0.08	0.30	0.26
335 kg/ha	0.51	0.09	0.34	0.23
505 kg/ha	0.55	0.10	0.37	0.22
Sig. of F	p=0.005	p<0.001	p<0.001	p<0.001
n=133	r2=0.06	r2=0.13	r2=0.12	r2=0.14
	ppm B	ppm Fe		
0 kg/ha	23	1061		
170 kg/ha	21	926		
335 kg/ha	18	846		
505 kg/ha	19	893		
Sig. of F	p=0.026	p=0.012		
n=133	r2=0.04	r2=0.05		

Table 6.6 Element levels in roots of 'Early Black' cranberry receiving 4 rates of N-P-K fertilizer. Data for tissues and elements with significant treatment effects shown. Values represent the mean across all sample dates, 5 replicates. Significance of F from linear regression analyses.

1987			
N-P-K level	%P	%Ca	%Mg
0 kg/ha	0.09	0.12	0.06
170 kg/ha	0.10	0.10	0.05
335 kg/ha	0.11	0.10	0.05
505 kg/ha	0.11	0.08	0.05
Sig. of F	p=0.003	p<0.001	p=0.012
n=299	r2=0.03	r2=0.04	r2=0.02

1988		
N-P-K level	%P	%Mg
0 kg/ha	0.11	0.08
170 kg/ha	0.12	0.07
335 kg/ha	0.13	0.08
505 kg/ha	0.14	0.07
Sig. of	p<0.001	p=0.001
n=260	r2=0.10	r2=0.04

1989			
N-P-K level	%N	%P	ppm Mn
0 kg/ha	0.64	0.11	168
170 kg/ha	0.66	0.12	136
335 kg/ha	0.71	0.14	113
505 kg/ha	0.71	0.14	148
Sig. of	p=0.007	p<0.001	p0.034
n=180	r2=0.04	r2=0.21	r2=0.03

6.2.4 Effect of N-P-K Treatment on Elements in Fruit

The addition of N-P-K fertilizer to cranberry plants led to an increase in fruit K concentration in all years of the study (Table 6.7). This increase was expected due to the fact that cranberry fruit were strong sinks for K. When French prunes were fertilized with high

Table 6.7 Element levels in fruit of 'Early Black' cranberry receiving 4 rates of N-P-K fertilizer. Data for tissues and elements with significant treatment effects shown. Values represent the mean across all sample dates, 5 replicates. Significance of F from linear regression analyses.

1987				
N-P-K level	%P	%K	%Mg	
0 kg/ha	0.06	0.45	0.04	
170 kg/ha	0.09	0.69	0.05	
335 kg/ha	0.10	0.76	0.05	
505 kg/ha	0.10	0.80	0.08	
Sig. of F	p=0.002	p<0.001	p=0.013	
n=59	r2=0.15	r2=0.35	r2=0.10	
	ppm B	ppm Fe	ppm Mn	ppm Zn
0 kg/ha	11	10	8	5
170 kg/ha	15	13	11	9
335 kg/ha	15	16	13	9
505 kg/ha	15	18	13	9
Sig. of F	p=0.045	p<0.001	p=0.004	p=0.004
n=59	r2=0.07	r2=0.20	r2=0.13	r2=0.13

1988	
N-P-K level	%K
0 kg/ha	0.77
170 kg/ha	0.83
335 kg/ha	0.81
505 kg/ha	0.93
Sig. of F	p<0.001
n=110	r2=0.10

1989			
N-P-K level	%K	%Ca	ppm Mn
0 kg/ha	0.70	0.13	34
170 kg/ha	0.78	0.11	28
335 kg/ha	0.82	0.09	25
505 kg/ha	0.85	0.09	24
Sig. of F	p<0.001	p<0.001	p<0.001
n=116	r2=0.26	r2=0.16	r2=0.17

K levels, the K concentration in the fruit did not change (Niederholzer et al., 1991). However, the total K content in fruit

did increase due to greater fruit biomass being produced in those treatments.

By the third year of treatment, there may have been some antagonism of Ca by the K added in the fertilizer. The antagonistic effect may also have been due to the high N levels in the fertilizer. Cummings and Lilly (1980) found that adding N fertilizer to highbush blueberries led to decreased Ca in the fruit. Cranberry fruit tend to be low in Ca and N-P-K treatments led to even lower fruit Ca concentrations. Calcium deficiency may be the cause for fruit quality problems which have been associated with the use of large quantities of N-P-K fertilizers on cranberries. This relationship requires further investigation before any conclusions can be drawn.

The use of N-P-K fertilizer tended to lead to higher levels of minor elements in the fruit. However, this result did not always hold (e.g. 1989 Mn).

6.3 Nutrient Content of the Plants in a Cranberry Bog

Based on measurements of plant biomass and nutrient concentration in 'Early Black' cranberry during the season, the amounts of the elements in the various tissues per unit area (ha) were calculated. The data were collected from plots (5 replicates) receiving 335 kg N-P-K/ha. Three groups of patterns for element content change during the season were found. The data for the 10 elements in 1987 are shown in Figures 6.51 to 6.60 (p. 139-143). The 1988 and 1989 data are shown in Appendix B, Figures B.1 to B.20 (p. 280-289). The late season declines in woody stem element content in

1988 and 1989 were related to the way biomass was assessed in those years. Woody stems were included only if they had leaves attached. This method led to an underestimation of the amount of biomass, and consequently, the amount of element content present.

Group I: This group included N, P, K, and Zn (Figures 6.51 and 6.52, p. 139, 6.53, p. 145, and 6.60, p. 143, respectively). While the concentration of the elements in new shoots declined (N, P, and K) or remained stable (Zn) during the season, the content (kg/ha) of the elements rose throughout the season as biomass accumulated. The elemental content in old leaf and woody stem tissues declined, with transient increases in the element content in woody stems occurring at the time of bud break and fruit set. These increases may have been due to movement of elements to growing tissues via the stems. In comparison to leaves, Zn accumulated in stem tissue to a greater-extent than did N, P, or K. The decline in element content of old cranberry leaves was similar to declines in N and K in peach leaves late in the season, prior to leaf shed (Batjer and Westwood, 1958). Old cranberry leaves were shed during the season rather than all at once at season's end. The element content of roots increased in June and August, times of increased root biomass production. Most likely, new roots were produced at those times in response to hormonal signals from newly produced vegetation (June) and fruit (August). The seasonal increases in root element content were most pronounced for P, which was present at high levels in the soil of these plots. A decline in element content in September was associated with a loss of root biomass at that time. Although the concentration of N, P, and K in root tissue was low, the roots served as a large reservoir for

those elements (kg/ha) due to the large amount of root biomass present in a cranberry bog. The pattern for fruit element content over the season was similar to that for new shoots, with the content increasing despite decreasing element concentration in the fruit. N, P, and K contents per peach fruit also increased during development, while percents of the elements in dry fruit tissue declined (Batjer and Westwood, 1958). K content of cranberry fruit was quite high; in 1988, it was higher than that in new shoots (Figure B.5, pg. 282). The K concentration in cranberry fruit also was higher than that in new shoots (Table 6.1). Late in the season, K content in new shoots leveled out, despite biomass increase. This may be indicative of K being moved from new leaves to developing fruit as fruit accumulated K. A similar pattern for K content in leaves and fruit of French prune was documented by Niederholzer et al. (1991). They postulated that, late in the season, roots might not have the carbohydrate reserves to take up K at high rates, so that K was scavenged from the leaves to accumulate in the fruit.

Group II: This group included Ca, Mg, and B (Figures 6.54, p. 140, 6.55 and 6.56, p. 141, respectively). The basic direction of element movement was the same for this group as for the first group. However, the rate of increase in element content in new shoots was higher for this group, while the rate of loss from old leaves and stems was slower. The steeper increase was due to the combination of biomass increase and element concentration increase during the season. The slow loss in old tissues may have been due to continued deposition of Ca, Mg, and B in old tissues. The contents of these elements in roots showed patterns similar to the first group. The fruit content

pattern differed in that while the concentration declined (as in the first group), the content rose only slightly. Biomass production did not overcome concentration decreases, especially for Ca and B. The slow rate of loss from old tissues and the slow increase of these elements in fruit indicated that Ca and B were not mobile in cranberry plants. Transient increases in stem Mg may indicate that Mg was more mobile than the other elements in the group.

Group III: This group included Cu, Fe, and Mn (Figures 6.57 and 6.58, p. 142, and 6.59, p. 143). The patterns for these elements showed compensation by the cranberry plants for the high minor element availability in acid soils. The concentrations of all three elements were lowest in fruit tissue and low in new shoot tissue. These elements were concentrated in certain tissues; Cu in roots, Fe in roots and somewhat in stems, and Mn in old stems and leaves. The high root Cu and Fe levels may have been due to precipitation on the root surface. Cranberries grown in solution culture by Rosen et al. (1990) also accumulated Fe in root tissue. With x-ray microanalysis, they showed that the Fe appeared to be precipitated on the root surface as iron phosphate. For new shoots and fruit the element content pattern was similar to that for Group I, but with a slower rate of change in fruit.

6.4 Nutrient Movement in a Cranberry Bog

A summary of biomass produced and lost during the season is presented in Table 6.8. Leaves were produced on the new shoot tissue and accounted for half the new shoot biomass by the end of the season.

Table 6.8 Biomass (dry weight) produced or lost during the growing season by 'Early Black' cranberries receiving 335 kg N-P-K/ha.

Leaves (kg/ha)

Produced			Lost	
1987	1988		1987	1988
1937	2421	Shed	1722	1507
		Harvest/winter	215	1452

Notes: 1. Leaf biomass produced is 1/2 of the total new shoot production. 2. Harvest/winter loss is calculated by subtracting the leaf biomass at the beginning of the following season from the sum of old leaves plus leaves produced at season's end.

Fruit

	1987	1988	1989
Percent dry weight	12.2	10.4	11.3
Dry weight of 100 bbl/A (kg/ha)	1367	1166	1267

Note: 100 bbl (barrels) equals 10,000 lb. The bbl is a standard measure for cranberries.

Roots (kg/ha)

	Produced			Lost		
	1987	1988	1989	1987	1988	1989
	70	10	80	50		70
	40	60	70	70	90	80
	20	40		40	50	80
total	130	110	150	160	140	210

Note: Root biomass was produced in June, August, and late September. Root biomass declined in May, mid-July, and early September.

Leaves were lost as old leaves were shed during the season and when some leaves were knocked off and removed in harvest and subsequent 'detrashing' operations. In detrashing, the bog was flooded and agitated by passing machinery over the surface. Detached plant tissue floated to the surface of the water and was removed from the bog.

Approximately 75% of the 'trash' was removed in this operation; the remainder staying on the soil surface.

Fibrous root biomass varied during the season, with increases occurring in June, August, and late September. The first two increases coincided with periods of high demand for nutrients in the production of new shoots and fruit, respectively. The late season root increase may be related to the plants entering dormancy, accompanied by the transfer of carbohydrates to the roots. Apparently root tissue was short-lived, as root biomass declined at three periods during the season: May, mid-July, and early September. These decaying roots remained in the bog system.

6.4.1 Nutrients Used in the Production of Cranberry Biomass

The amount of nutrients required in the production of new shoot tissue was calculated from biomass production and nutrient concentrations in the new shoot tissue. The results are shown in Table 6.9. Biomass production was suppressed in 1987 by frost injury, which accounted for the generally lower amounts of nutrients in new shoots that year.

Root tissue had a high content of nutrients due to the large amount of biomass present as roots. However, only part of that was produced in one season. That fact, coupled with the fact that roots were low in concentrations of most elements, explained the lower amounts of nutrients which were required to make new root tissue (Table 6.10) compared to that needed to make new shoots (Table 6.9).

Table 6.9 Mineral contents (kg/ha) in newly produced shoot tissue of 'Early Black' cranberry receiving 335 kg N-P-K/ha.

Year	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1987	38	5.8	20	27	9.8
1988	52	4.7	18	34	9.5
1989	50	3.8	25	37	11.0
Year	Boron	Copper	Manganese	Iron	Zinc
1987	2.4	0.19	6.9	1.4	0.82
1988	2.0	0.26	10.2	2.5	1.00
1989	1.5	0.30	11.7	3.3	1.15

The combined total N required to make new shoots and roots in a season was approximately 48 kg/ha, much higher than the value of 11 kg N/ha for these tissues proposed by Dana (1968).

Nutrients were used in the production of fruit. To limit variability in the data due to unevenness of fruit production in experimental plots, theoretical nutrient use in fruit production was calculated based on actual percent dry weight of fruit and nutrient analyses and a theoretical crop of 100 bbl/A (10,000 lb, approximately

Table 6.10 Mineral contents in newly produced root tissue of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data for N, P, K, Ca, and Mg are in kg/ha. All other data are in g/ha.

Year	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1987	0.88	0.17	0.18	0.16	0.09
1988	0.75	0.14	0.15	0.13	0.08
1989	1.02	0.20	0.21	0.18	0.11
Year	Boron	Copper	Manganese	Iron	Zinc
1987	2.0	25	20	740	7.5
1988	1.7	21	17	626	6.4
1989	2.3	29	23	854	8.7

Table 6.11 Mineral contents in 100 bbl/A of fruit of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data for N, P, K, Ca, and Mg are in kg/ha. All other data are in g/ha.

Year	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1987	6.97	1.23	10.12	1.09	0.68
1988	6.30	1.17	9.68	0.82	0.70
1989	3.67	0.89	9.63	0.76	0.63
Year	Boron	Copper	Manganese	Iron	Zinc
1987	17.8	8.2	16.4	17.8	12.3
1988	11.7	8.2	21.0	39.6	11.7
1989	21.5	8.9	11.7	19.0	10.1

4535 kg). A 100 bbl/A crop represents low yield, since the actual crop for 'Early Black' cranberry is generally 150 bbl/A (16.8 Mg/ha) or better. The results are shown in Table 6.11. Cranberry fruit production required more K than any other element. The high K levels in fruit supported the contention that cranberry fruit are strong sinks for K. In contrast, the Ca used in fruit production was only one tenth the amount of K needed.

6.4.2 Nutrient Losses in Biomass During the Season

Old leaves were shed during the season, and some new leaves were lost during harvest and over the winter. The nutrient contents in those lost leaves are shown in Table 6.12. N and Ca losses were greatest due to the high concentration of these elements in leaf tissue. In the period from the beginning of one growing season to the beginning of the next, 50% of old leaf biomass was lost. However, the nutrient content lost from old leaves was not always 50% of the

Table 6.12 Mineral contents in leaves lost from 'Early Black' cranberry receiving 335 kg N-P-K/ha. Lost leaves include old leaves shed during the season and new leaves lost during harvest and over the winter. Data for N, P, K, Ca, and Mg are in kg/ha. All other data are in g/ha.

Year	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1987	15.1	2.6	8.4	17.9	4.0
1988	25.8	4.1	10.2	24.5	6.6
Year	Boron	Copper	Manganese	Iron	Zinc
1987	97	8.2	732	218	48
1988	148	14.7	893	254	68

original value. More than 50% of N, P, K, Mg, and Cu was lost from old leaves (60%, 55%, 70%, 55%, and 55%, respectively), whereas less than 50% was lost for B, Fe, and Mn (30%, 40%, and 35%, respectively). Ca and Zn losses were 50%. A loss of greater than 50% could be explained by remobilization of the elements into other tissues prior to leaf shed, whereas losses of less than 50% could have been due to continued accumulation of the elements in the leaves not shed. The immobile nature of Ca in cranberries was supported by these data.

Minerals were lost from cranberry plants as root tissue decayed (Table 6.13). The amounts of nutrients lost were small due to the low concentrations of elements in root tissue. The exception was Fe, which was present in high levels in roots.

While decaying roots remained in the system, leaves which were shed and fruit which was harvested were taken out of the system.

Table 6.13 Minerals lost from decayed root tissue of 'Early Black' cranberry receiving 335 kg N-P-K/ha. Data for N, P, K, Ca, and Mg are in kg/ha. All other data are in g/ha.

Year	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
1987	1.09	0.21	0.22	0.19	0.11
1988	0.95	0.18	0.20	0.17	0.10
1989	1.43	0.27	0.29	0.25	0.15
Year	Boron	Copper	Manganese	Iron	Zinc
1987	2.4	31	25	910	9.3
1988	2.1	27	22	797	8.1
1989	3.2	41	32	1195	12.2

The same amounts of nutrients which were used to produce fruit (Table 6.11) were removed from the system at harvest.

6.4.3 Movement of Nutrients in a Cranberry Bog: An Incomplete Balance Sheet

The calculated amounts of nutrients gained and lost in biomass were used to construct incomplete balance sheets for the 10 elements studied (Tables 6.14 and 6.15). No attempt was made to include inputs from soil nutrients, water nutrients, lightning (nitrogen), or to estimate the actual inputs from organic matter decay. According to these calculations, more than 55 kg N/ha was used to produce the biomass in a cranberry bog in a season. Up to 24 kg/ha of this was removed in crop and 'trash' leaves. A maximum of about 6 kg N/ha could be recovered from decaying biomass. The rest of the N inputs would have had to come from organic matter breakdown (organic matter besides the current season's decaying biomass), lightning fixation,

Table 6.14 Movement of major nutrients (kg/ha) in a cranberry bog - incomplete balance sheet.

	N	P	K	Ca	Mg
BIOMASS PRODUCTION					
new shoots	47.0	4.8	21.0	33.0	10.1
roots	0.88	0.17	0.18	0.16	0.09
fruit (150 bbl)	8.48	1.65	14.72	1.34	1.02
TOTAL	56.36	6.65	35.9	34.5	11.21
BIOMASS REMOVED					
leaves [a]	15.3	2.51	3.83	15.9	3.98
fruit (150 bbl)	8.48	1.65	14.72	1.34	1.02
TOTAL	23.78	4.16	18.55	17.24	5.0
INPUTS [b]					
fertilizer	33.5	29.0	28.0		
decaying leaves [c]	5.1	0.84	1.28	5.3	1.33
decaying roots	1.16	0.22	0.24	0.20	0.12
TOTAL	39.76	30.06	29.52	5.5	1.45

a) Includes old leaves shed during the season and leaves lost during harvest and winter flood. Assumes 75% are removed from the bog in detrashing operations.

b) Assumes inputs from organic matter are all available - maximum possible input.

c) See note a. Assumes 25% of leaves remain on the bog after detrashing operations.

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water, and fertilizer. Dana (1968) estimated N loss in old leaves at 22 kg/ha. This value was similar to the N content in old leaves lost in this study. However, the balance sheet assumption was that only 75% of that was removed from the bog. Colby (1945) estimated that the N, P, and K removed in one ton of dry leaves and 100 bbl of fruit was

26, 5, and 18 kg/ha, respectively. Based on this balance sheet, the same amount of biomass (1 ton leaves, 100 bbl crop) would remove 24 kg N/ha, 4 kg P/ha, and 15 kg K/ha.

The information in these incomplete balance sheets could be used to construct more detailed nutrient budgets for cranberry production. One fact which was apparent is that the amounts of minor elements removed from a bog in crop and leaves is small, much less than one kg/ha for most. This means that minor element supplements should not be necessary in cranberry production. This is especially true for the metals which are very available in acid soils. The balance sheet also showed that N and K fertilizer amounts currently used in cranberry production (33 and 27 kg/ha, respectively) are necessary to maintain production, while P use (29 kg/ha) seems too high.

To accurately estimate nutrient budgets for cranberry bogs two cultural practices, in addition to harvest and detrashing, needed to be taken into account. These were resanding and pruning. Neither pruning nor resanding, the placement of a 2-3 cm layer of sand over the bog surface, was done on the plot areas during the study period. If resanding had been done, trailing woody stems would have been covered, giving rise to increased new shoot production from the covered nodes. Pruning would have removed more biomass from the bog than the amount listed in the incomplete balance sheet. Both practices could have increased the demand for nutrient input (biomass production and removal).

The 'inputs' section of the balance sheet did not include possible remobilization of nutrients from leaves prior to drop. There was some indication that this took place, as discussed in section

Table 6.15 Movement of minor elements (g/ha) in a cranberry bog - incomplete balance sheet.

	B	Cu	Mn	Fe	Zn
BIOMASS PRODUCTION					
new shoots	2000	250	9600	2400	990
roots	2	25	20	740	7.5
fruit (150 bbl)	25.5	12.6	24.6	38.3	17.1
TOTAL	2027.5	287.6	9644.6	3178.3	1014.6
BIOMASS REMOVED					
leaves [a]	92	8.6	609	177	44
fruit (150 bbl)	25.5	12.6	24.6	38.3	17.1
TOTAL	117.5	21.2	633.6	215.3	61.1
INPUTS [b]					
decaying leaves [c]	31	2.9	203	59	15
decaying roots	2.6	33	26	967	9.9
TOTAL	33.6	35.9	229	1026	24.9

a) Includes old leaves shed during the season and leaves lost during harvest and winter flood. Assumes 75% are removed from the bog in detrashing operations.

b) Assumes inputs from organic matter are all available - maximum possible input.

c) See note a. Assumes 25% of leaves remain on the bog after detrashing operations.

6.4.2. However, the remobilization remains unproven at this time, and was left out of the balance sheet for that reason.

6.5 Summary and Implications

The concentrations of the nutrient elements in cranberry plant tissues changed during the season. N, P, K, and Cu concentrations in new shoots decreased, and Ca, Mg, B, and Mn concentrations increased. The trends for old leaves were similar to those for new growth, except for Mg concentrations which were stable in old leaves. Iron and Zn levels in new shoots and in old leaves changed little during the season. Nutrient concentrations in fruit generally declined as the fruit developed. The nutrient concentration trends in woody stems and roots were generally more variable. There was some indication that nutrient concentrations in roots rose at the time of fruit set, perhaps due to increased production of new functional roots in response to fruit hormonal signals. Transient changes in woody stem nutrient concentrations may have been due to transport through that tissue to nutrient sinks.

The changes in concentrations of nutrients in cranberry tissues during the season have implications for the interpretation of tissue sample analyses. Samples need to be collected at times when the tissue concentrations are stable if comparisons to the values established here are to be made. Such stable periods were determined using ANOVA for repeated measures and profile analysis of adjacent date differences (Section 6.1.3, and Appendix A).

The use of N-P-K fertilizer had an effect on the nutrient concentrations in cranberry tissues. The effects on new shoots were covered in Chapter 4. Root element levels were least affected, with the exception of P concentration, which was positively affected in all

three years. In old leaves and woody stems, N, P, and K concentrations were positively correlated with N-P-K dose. In both tissues, effects of N-P-K generally became apparent in the second year of treatment. Ca, Mg, and B concentrations in the old leaves and stems of fertilized plants were generally lower than those in plants receiving no N-P-K fertilizer. K concentration in fruit was most affected (positively) by the use of N-P-K fertilizer. After three years of treatment, Ca concentration in fruit showed a negative response to N-P-K fertilizer. N-P-K fertilizer use tended to increase the levels of minor elements in the fruit.

The use of N-P-K fertilizer increased the concentration of those three elements in cranberry tissues, as was expected. The increases in old tissue N, P, and K concentrations in response to N-P-K fertilizer had implications for carryover effects, particularly if the elements were remobilized in the plants. The results of this study confirm that cranberry fruit are a strong sink for K. Roots accumulated P in response to N-P-K fertilizer. The possible effect of the fertilizer on mycorrhizal relationships was not determined.

The seasonal content (per ha) of elements in cranberry tissues was determined. The elements could be divided into three groups by the patterns of their content in cranberry tissues. Group I (N, P, K, and Zn) content in new growth and fruit increased, in spite of decreasing concentrations due to biomass production. The content of these elements in old leaves and stems declined, with transient increases in stems associated with bud break and fruit set. Root increases in element content for this group were associated with increases in root biomass. Group II (Ca, Mg, and B) was similar to

group one in direction of change. However, the increases in content in new shoots were steeper (associated with concomitant rises in element concentration), and the losses from old tissues were less due to immobility of the element and increased concentrations over time. Accumulation of these elements in fruit was less than that for Group I, again likely due to immobility, especially for Ca and B. Group III (Cu, Fe, and Mn) metals were excluded from fruit and to some extent from new shoots (compared to other tissues). Cu was sequestered in roots, Fe in stems and roots, and Mn in old leaves and stems. Aside from the slow accumulation rate in fruit, the patterns for fruit and new growth were similar to those of Group I.

The amounts of nutrients needed to produce new roots, shoots, and fruit during a cranberry growing season were calculated. In addition, the amounts of nutrients lost in biomass removal of decay were determined. Based on this information, an incomplete balance sheet covering the biomass-based changes in cranberry bog nutrient content was constructed. Based on these data, current industry fertilizer practices with N and K could be justified. Those for P seemed less justifiable. Cranberries appeared to require very little minor element input. The balance sheet data could be used as part of the information needed to construct a nutrient budget for cranberry production.

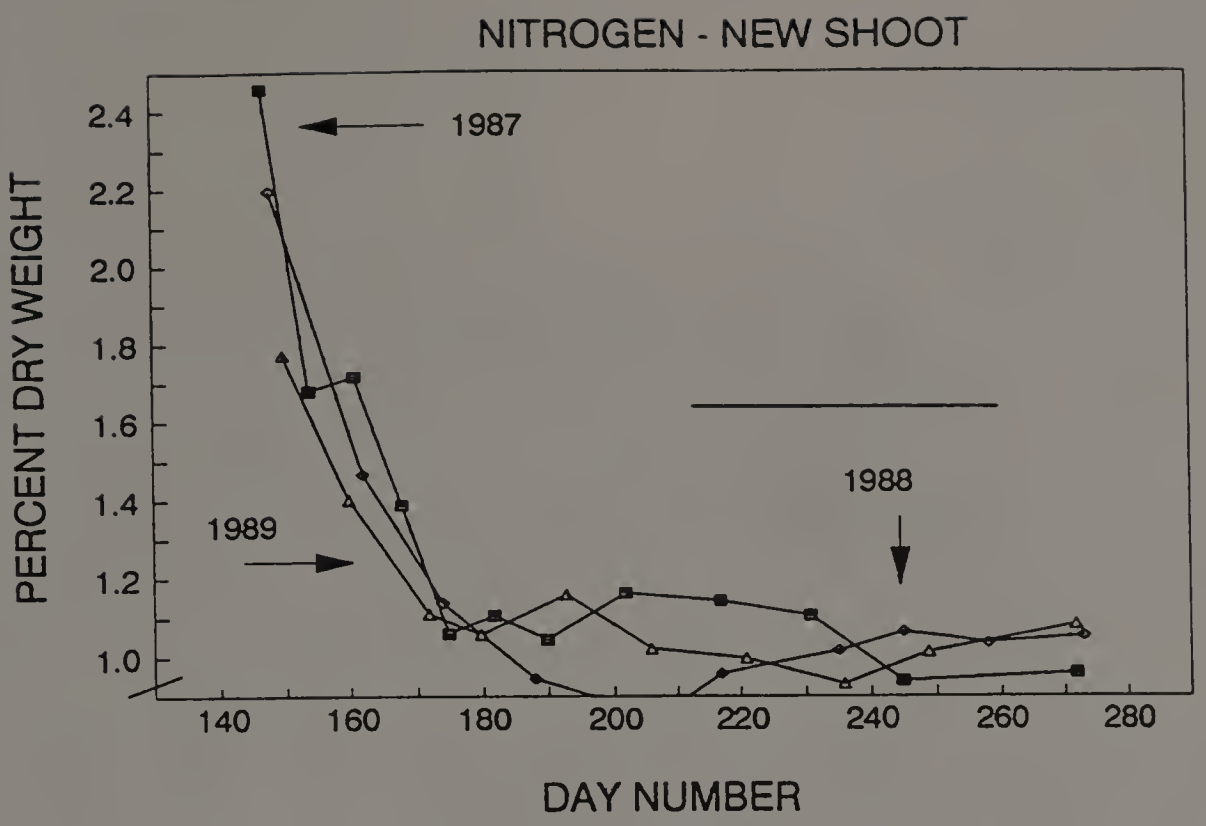

Figure 6.1 Nitrogen (percent dry weight) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 10 (1987 and 1989) or 15 (1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

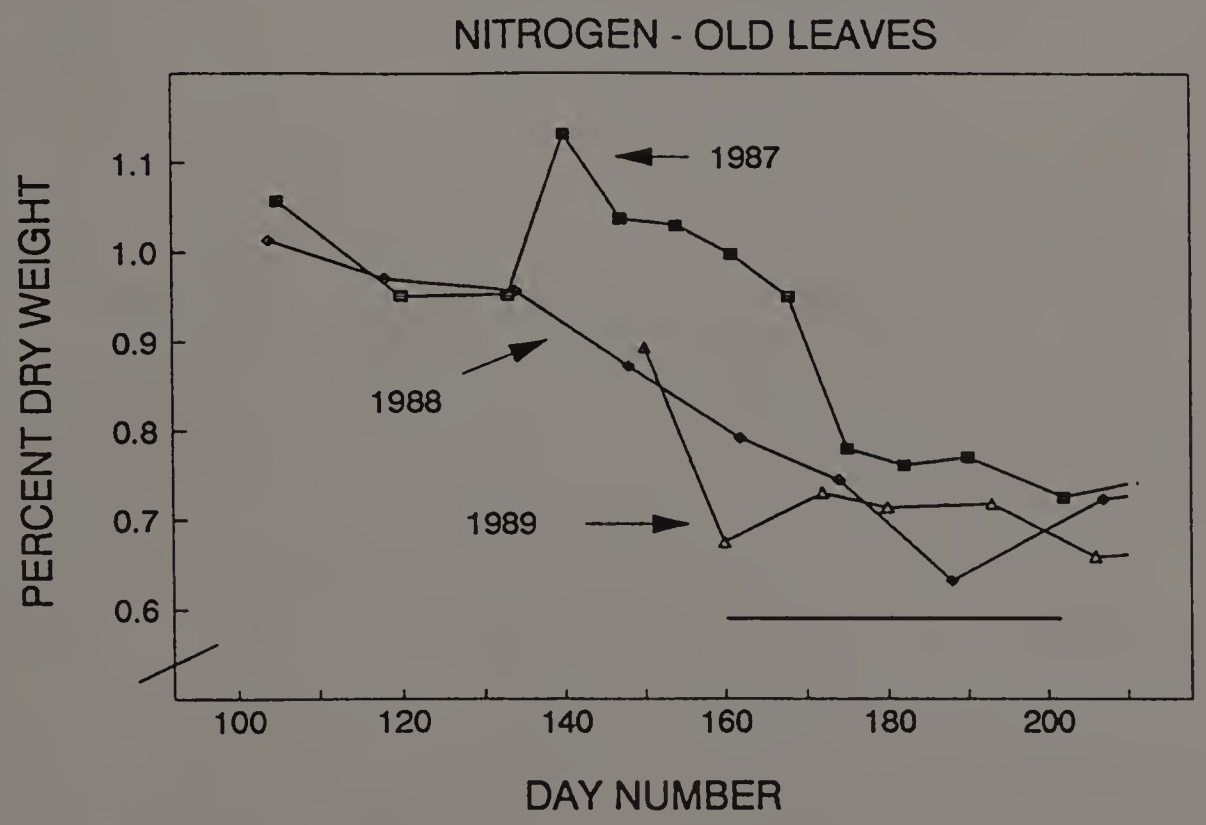

Figure 6.2 Nitrogen (percent dry weight) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987), 15 (1988), or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

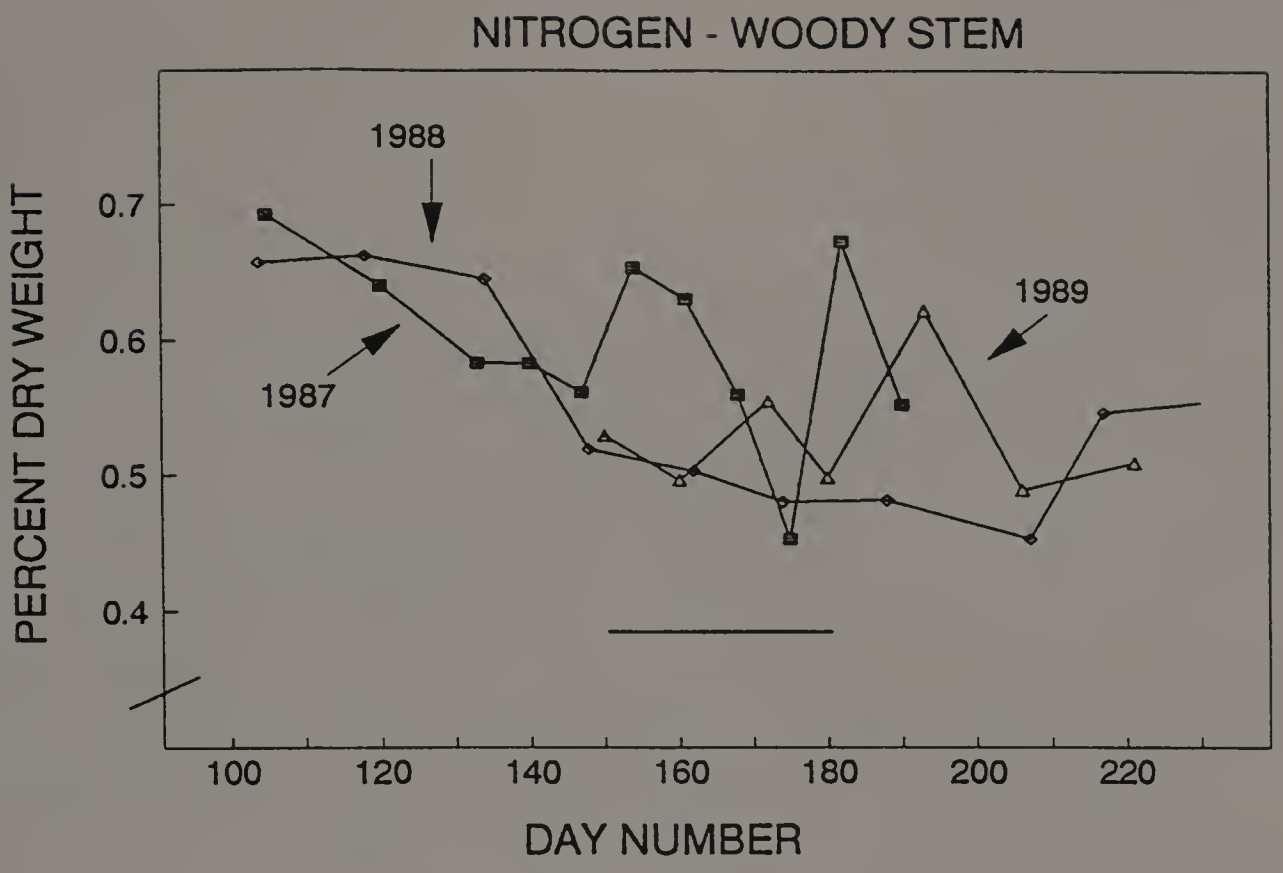

Figure 6.3 Nitrogen (percent dry weight) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987 and 1988) or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

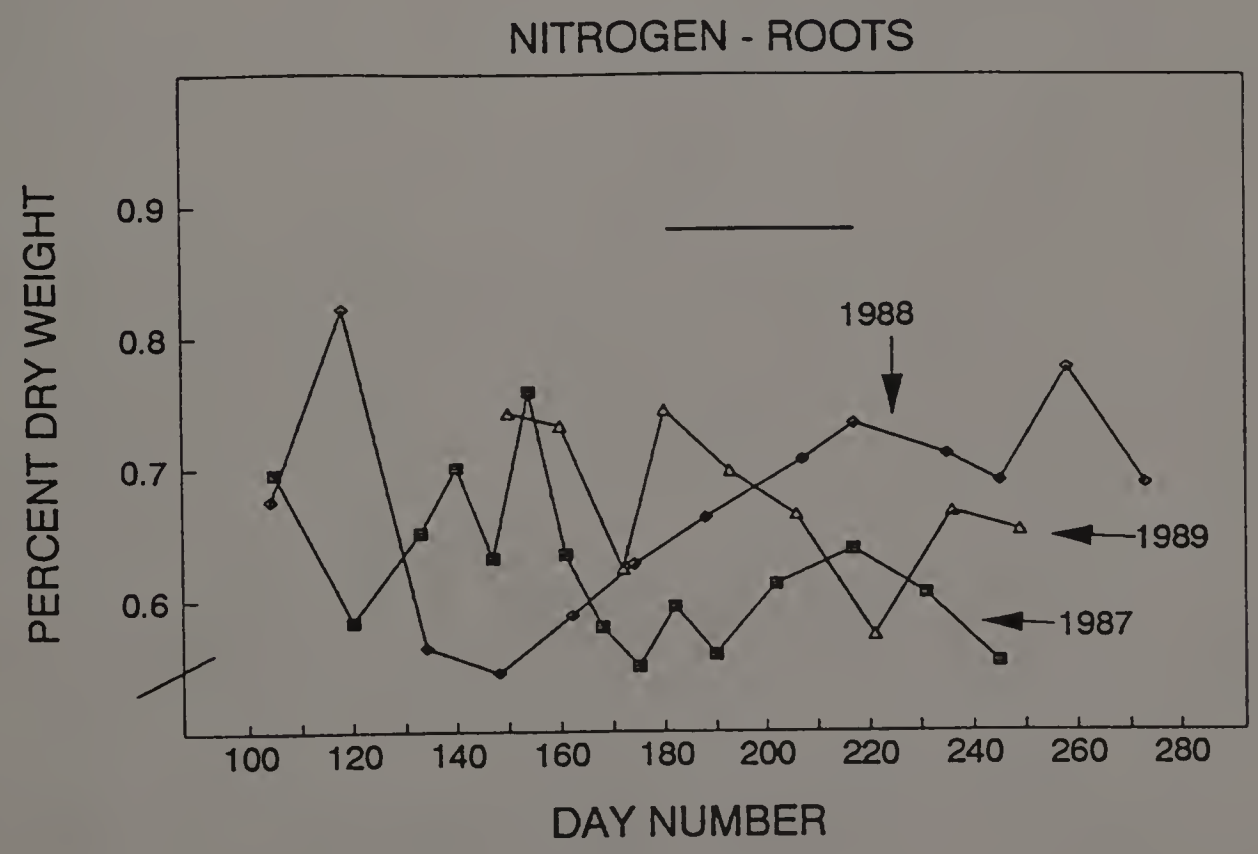

Figure 6.4 Nitrogen (percent dry weight) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

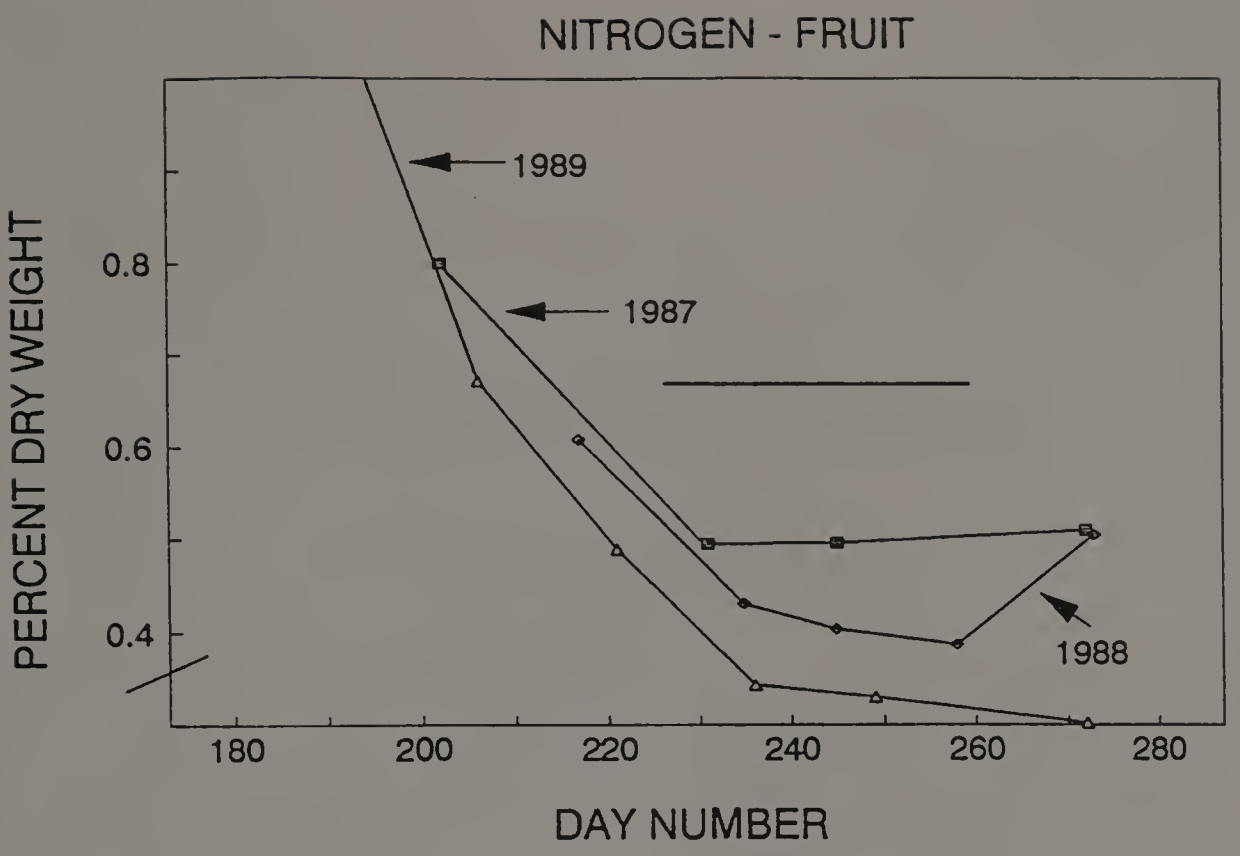

Figure 6.5 Nitrogen (percent dry weight) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

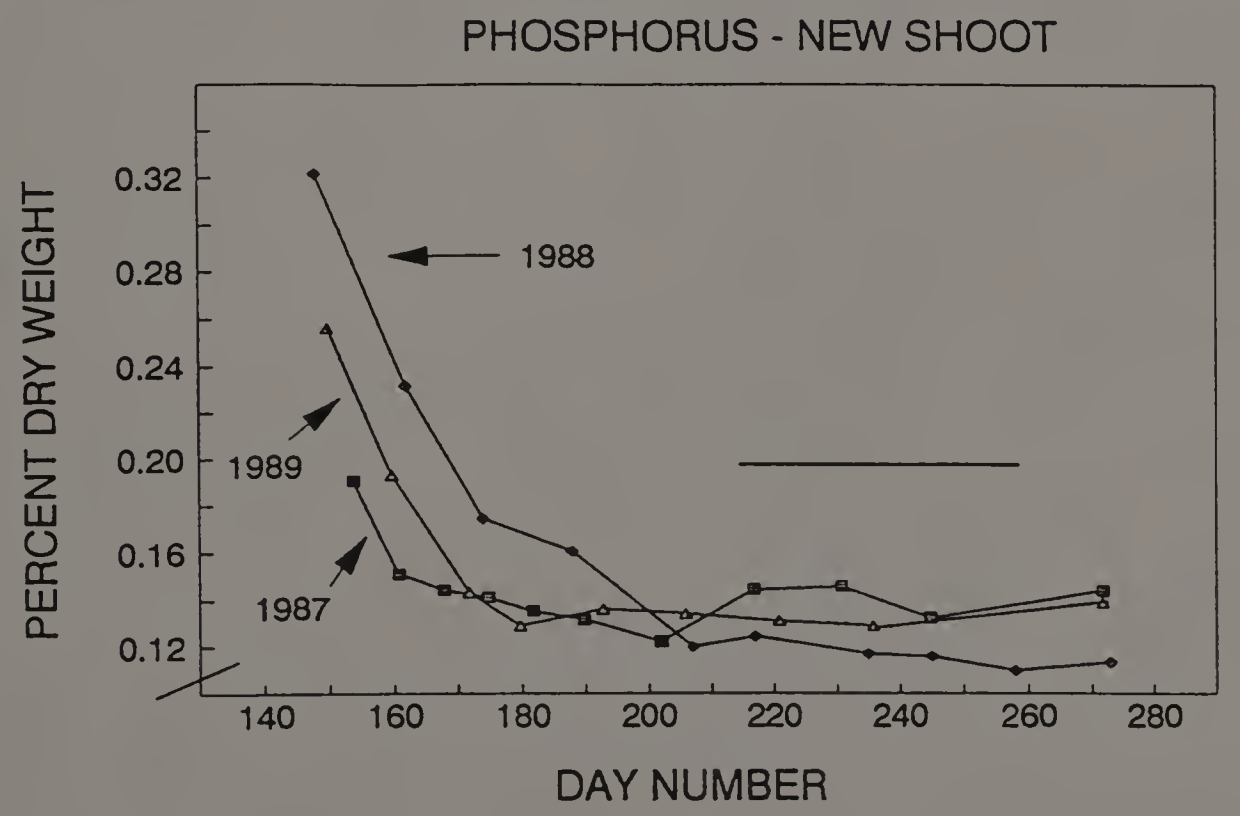

Figure 6.6 Phosphorus (percent dry weight) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1988) or 10 (1987 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

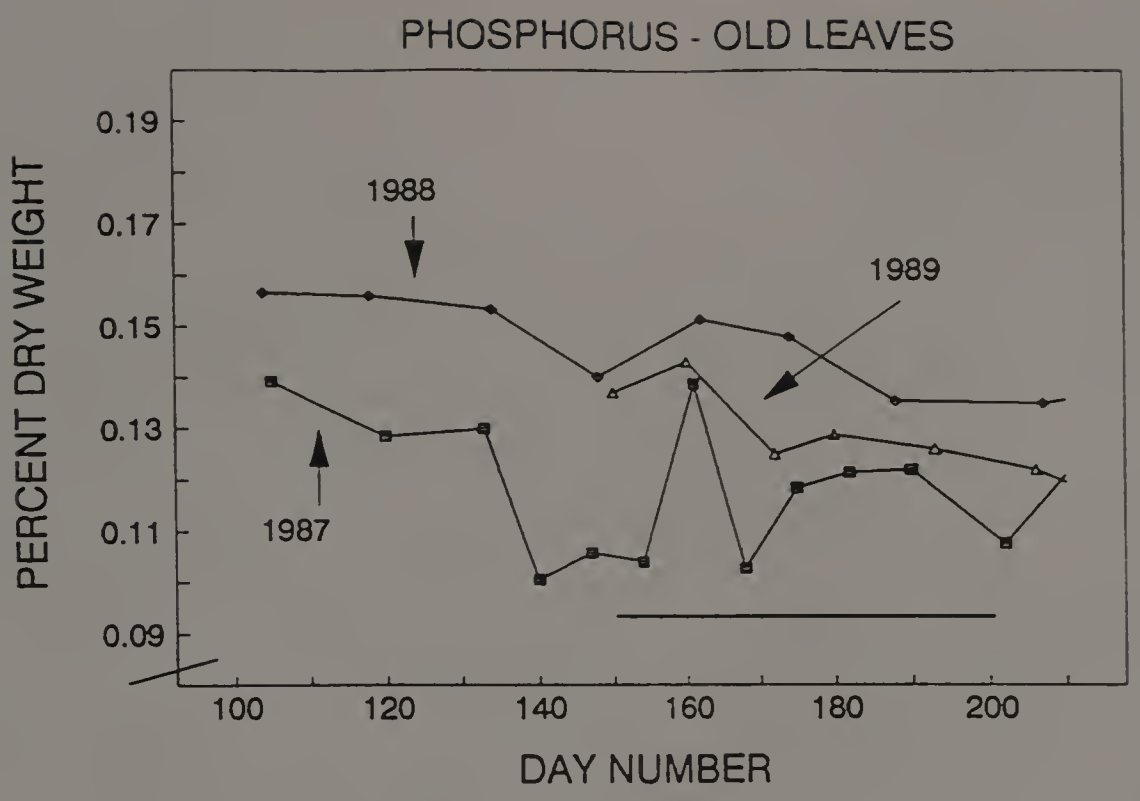

Figure 6.7 Phosphorus (percent dry weight) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1988) or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

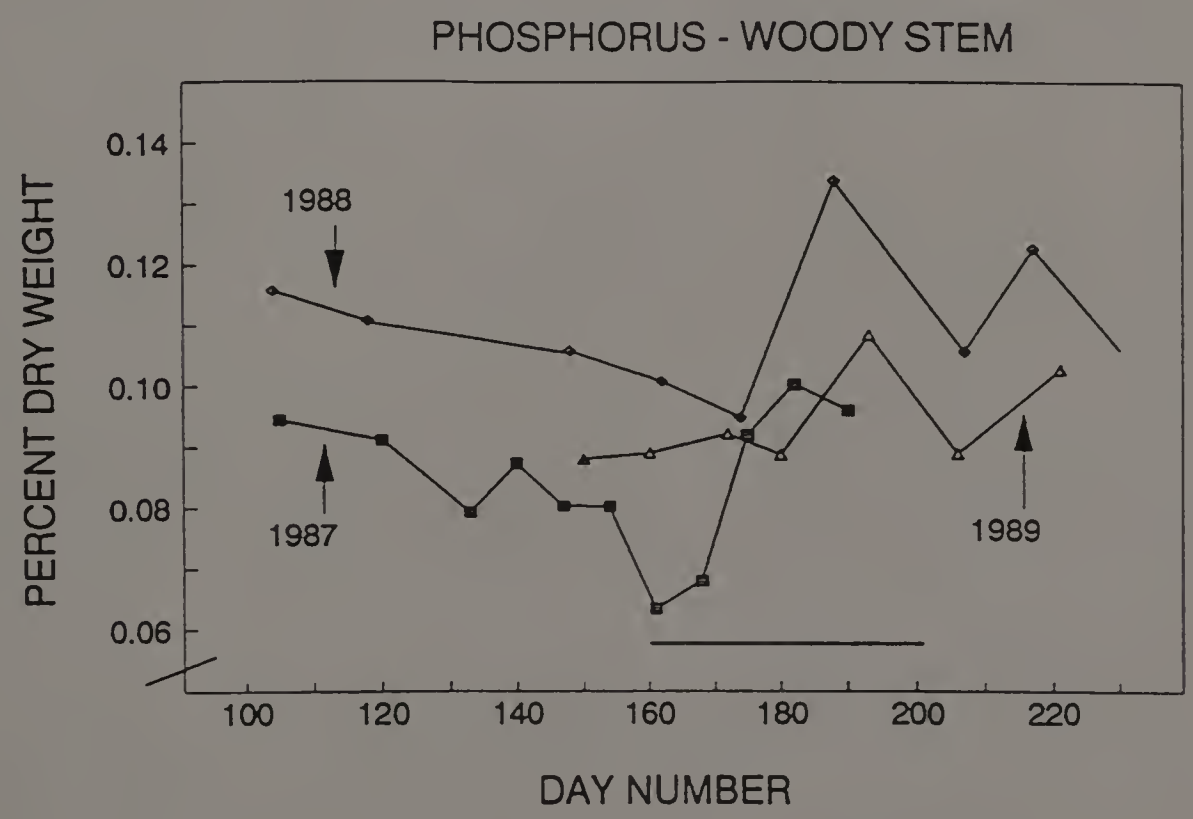

Figure 6.8 Phosphorus (percent dry weight) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987) or 10 (1988 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

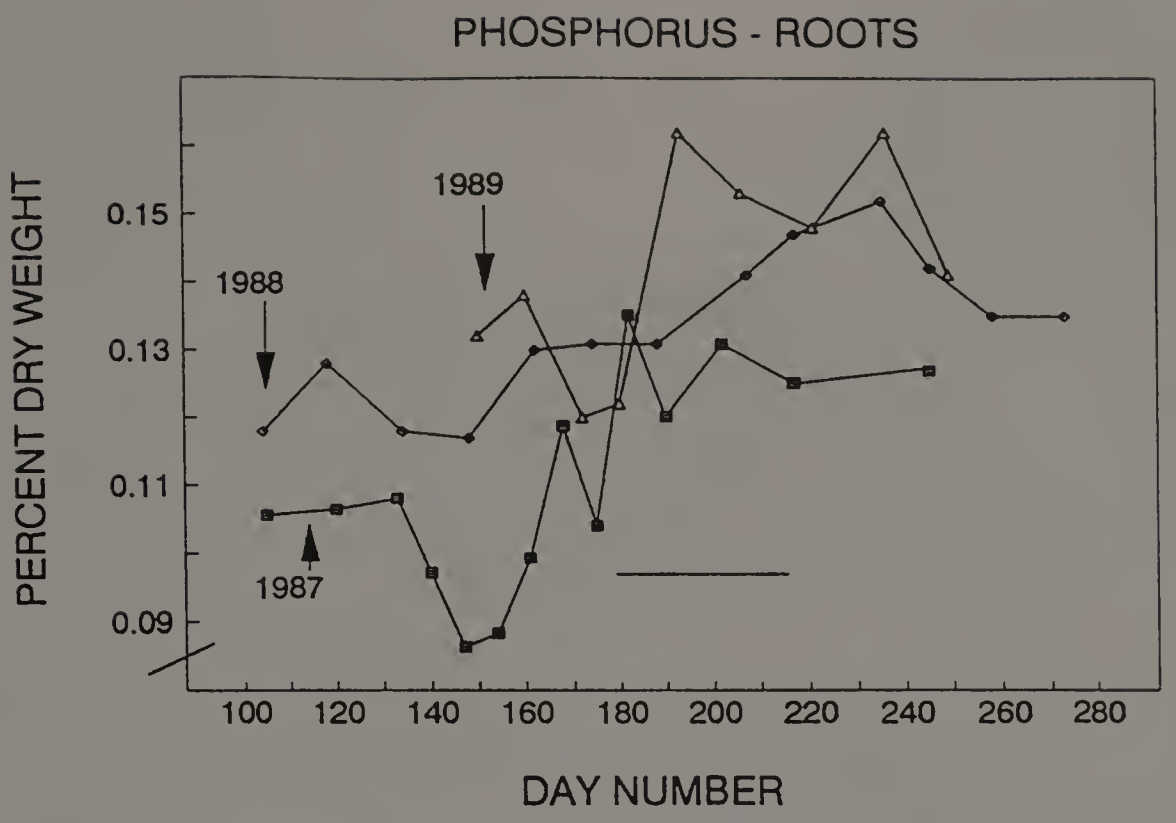

Figure 6.9 Phosphorus (percent dry weight) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987) or 10 (1988 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

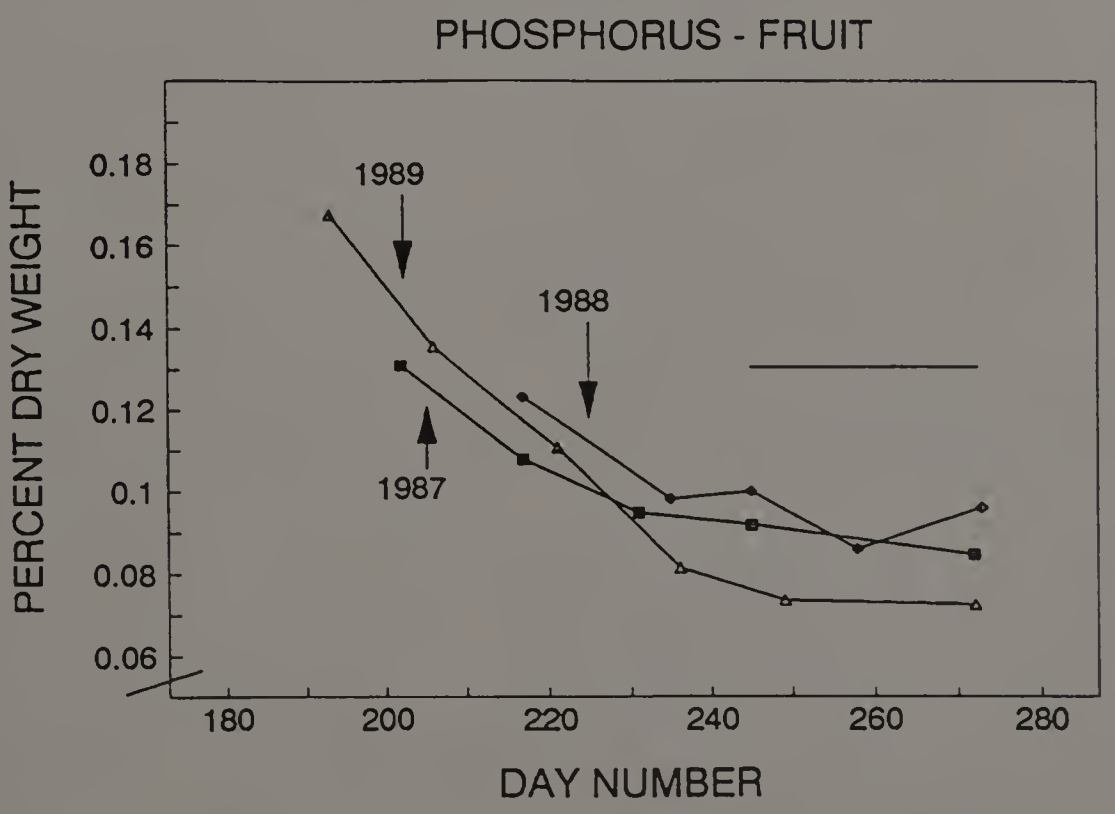

Figure 6.10 Phosphorus (percent dry weight) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1988 and 1989) or 15 (1987) replicates. Horizontal line is the time of statistically determined stability in analytical values.

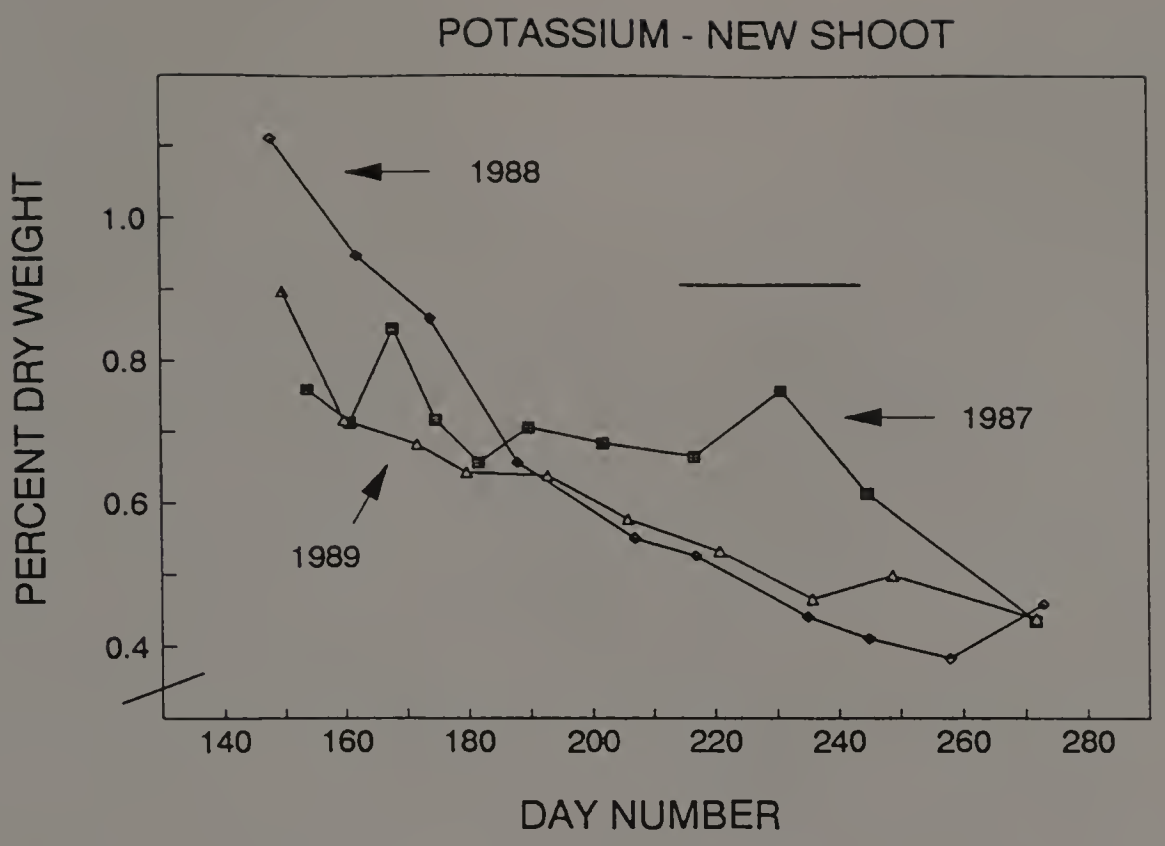

Figure 6.11 Potassium (percent dry weight) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1988) or 10 (1987 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

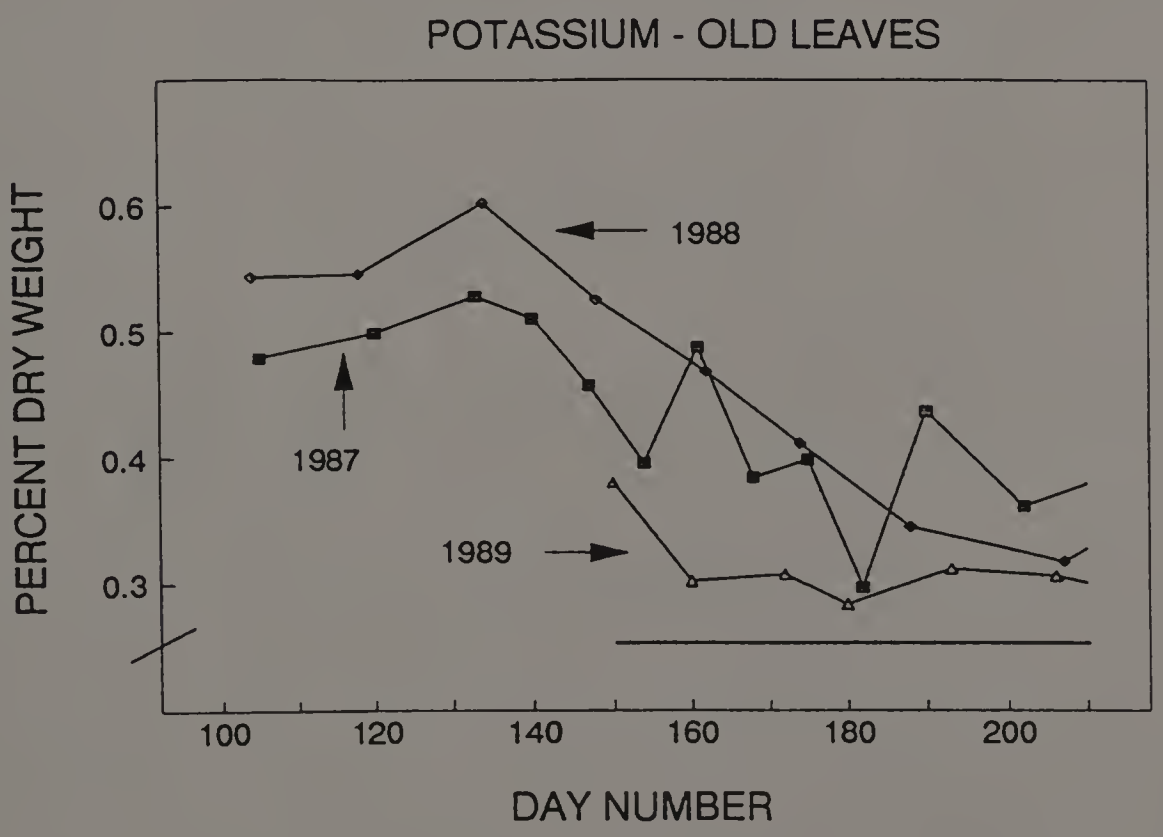

Figure 6.12 Potassium (percent dry weight) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1988) or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

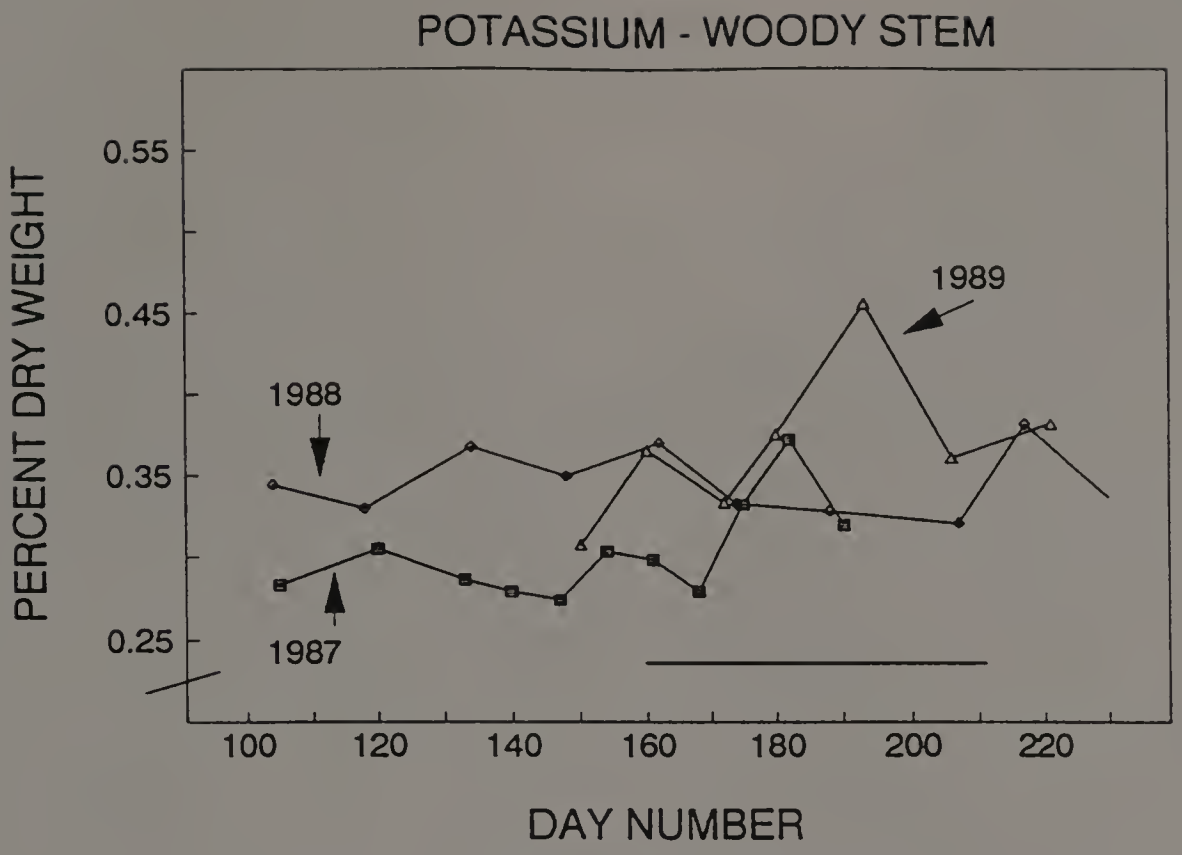

Figure 6.13 Potassium (percent dry weight) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1988) or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

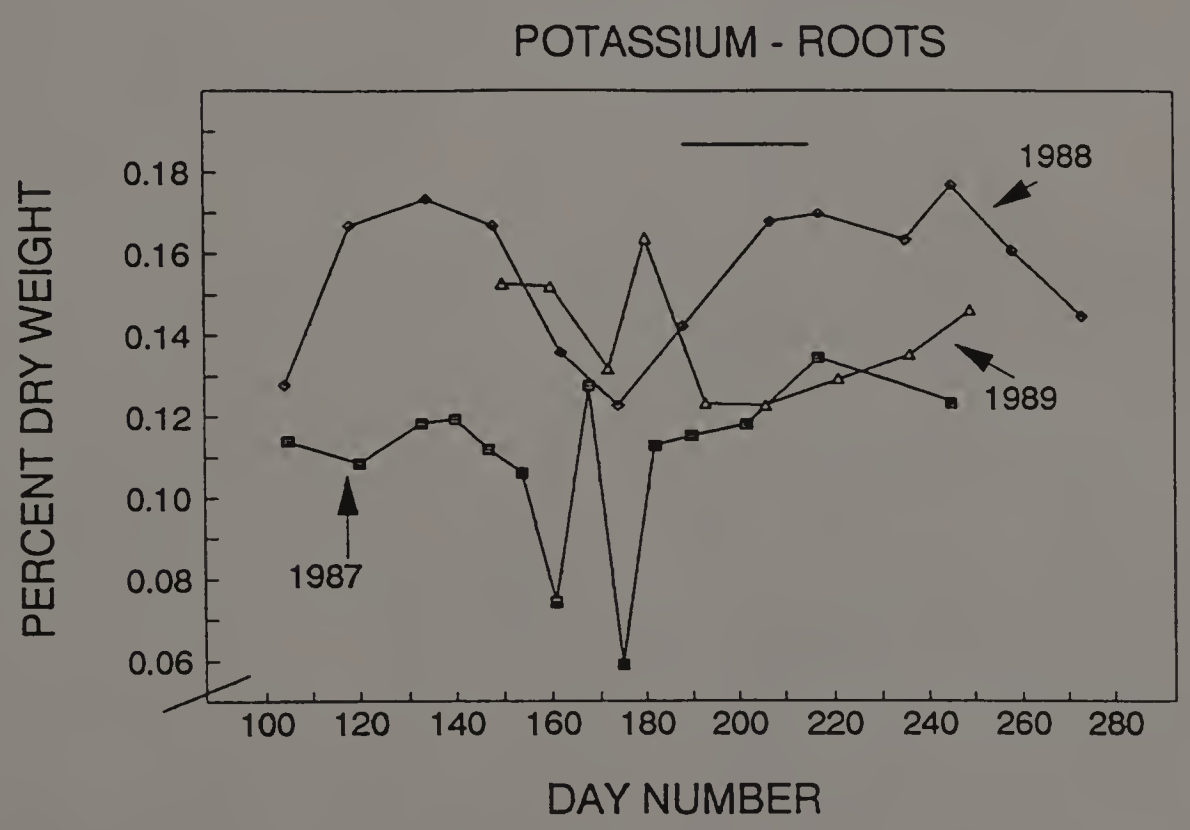

Figure 6.14 Potassium (percent dry weight) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1988 and 1989) or 15 (1987) replicates. Horizontal line is the time of statistically determined stability in analytical values.

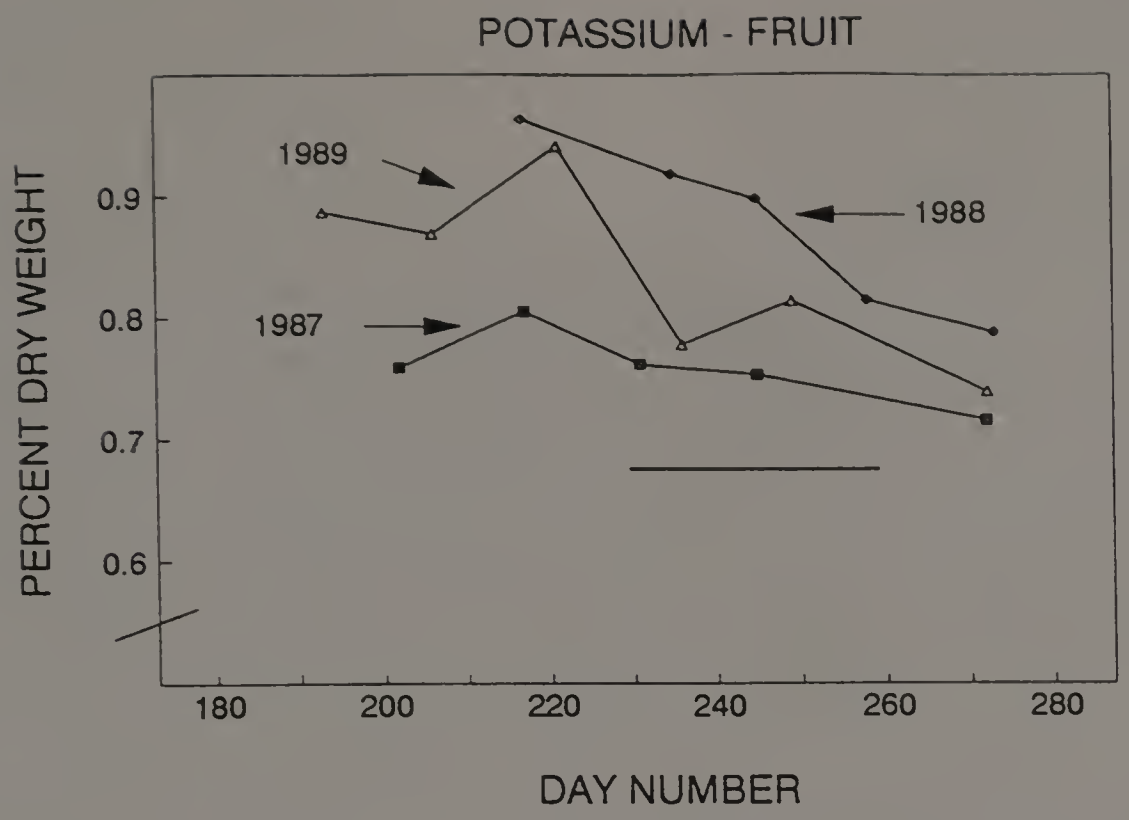

Figure 6.15 Potassium (percent dry weight) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1988) or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

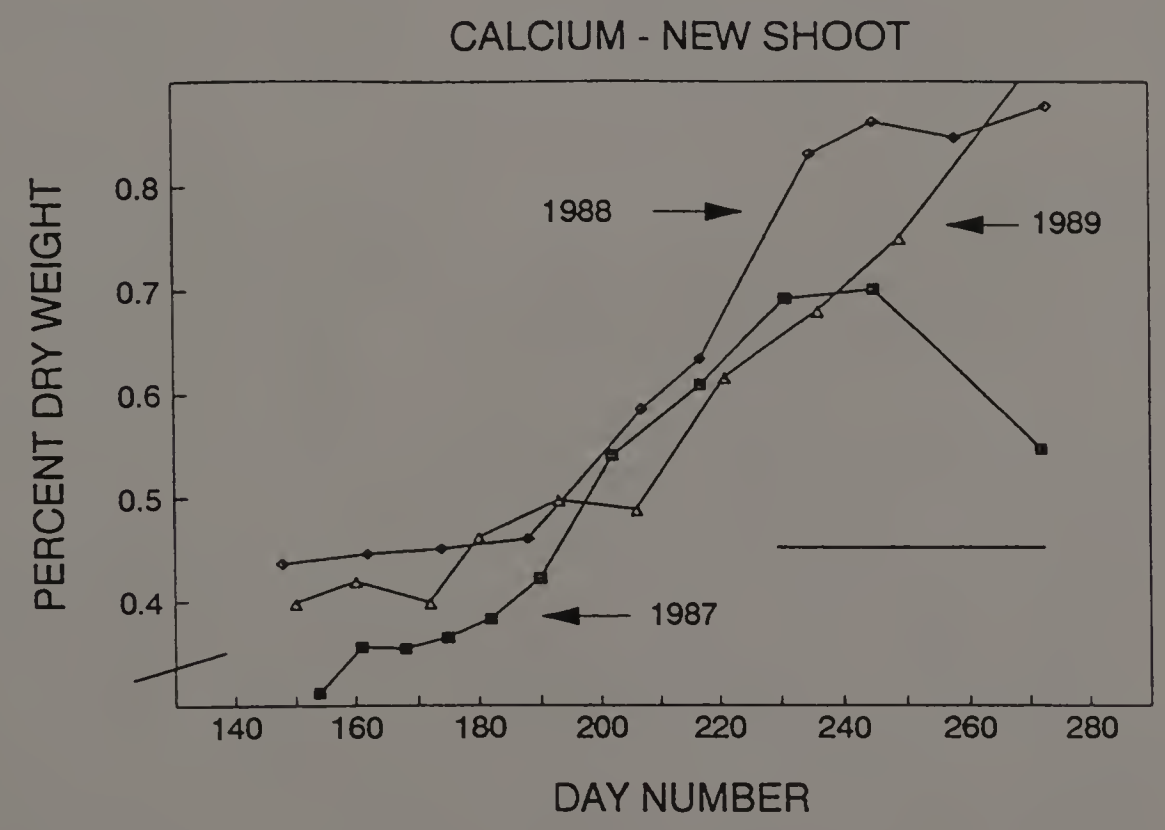

Figure 6.16 Calcium (percent dry weight) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

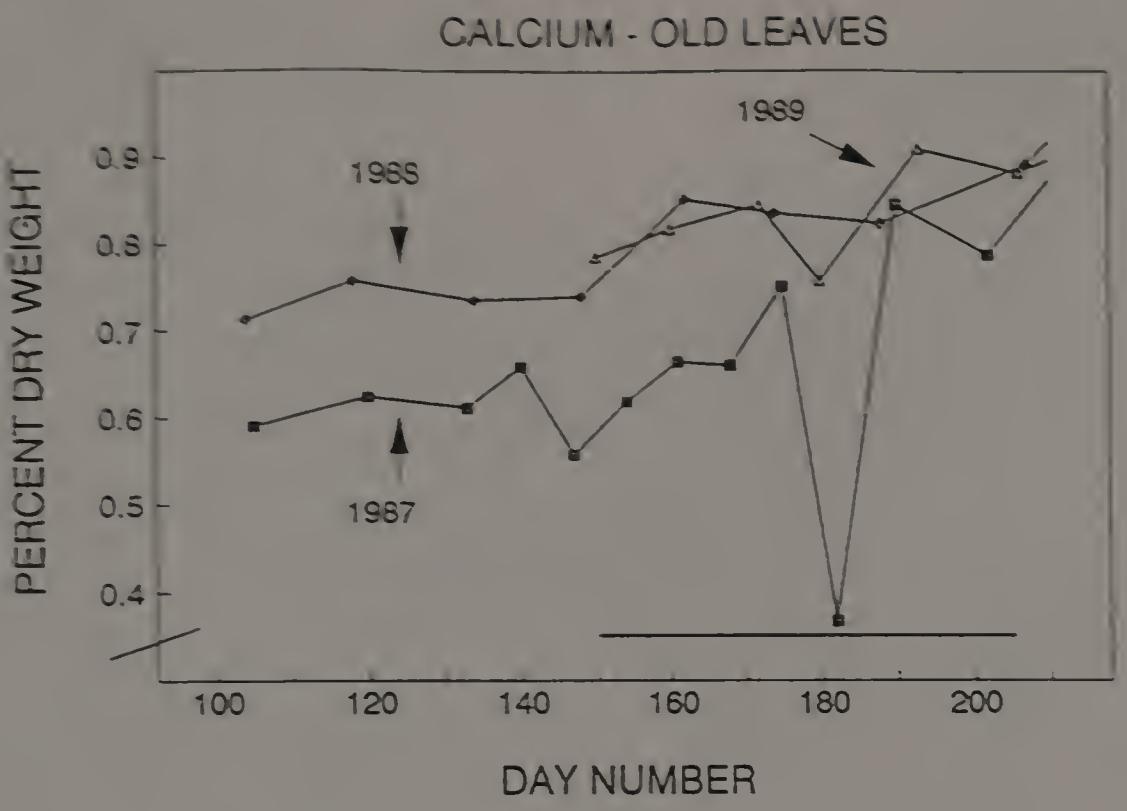

Figure 6.17 Calcium (percent dry weight) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987) or 15 (1988 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

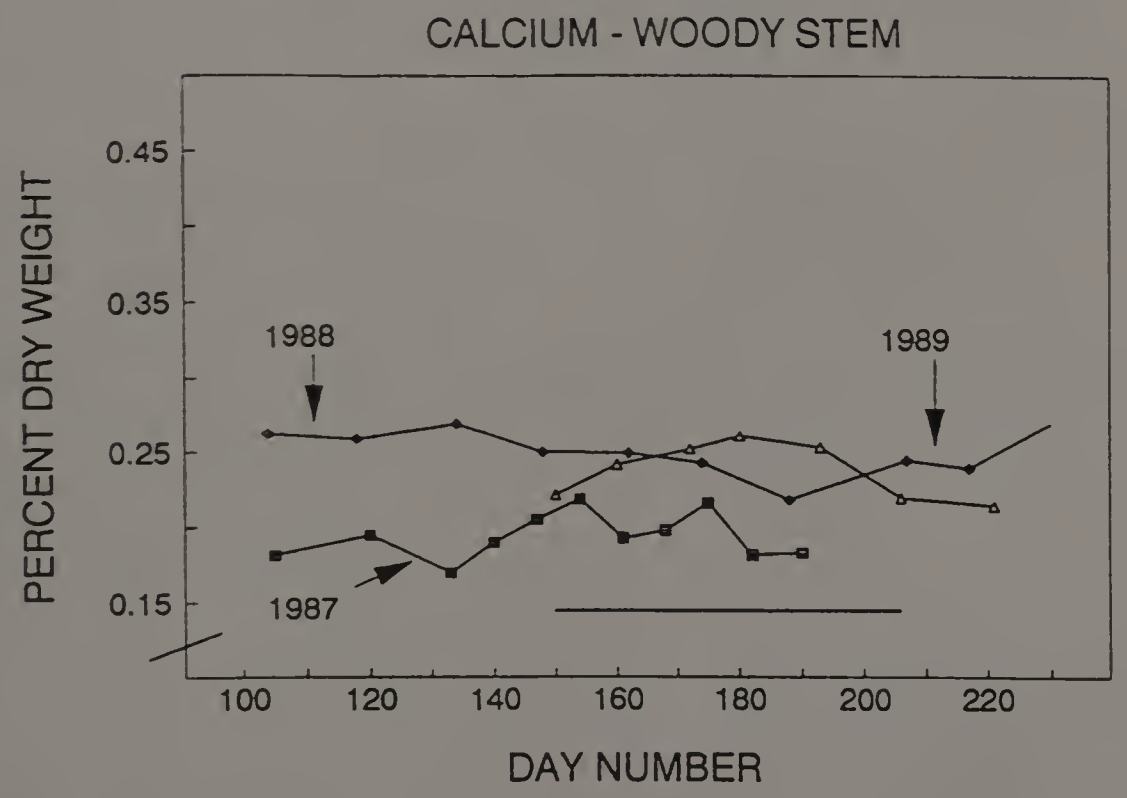

Figure 6.18 Calcium (percent dry weight) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987), 15 (1988), or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

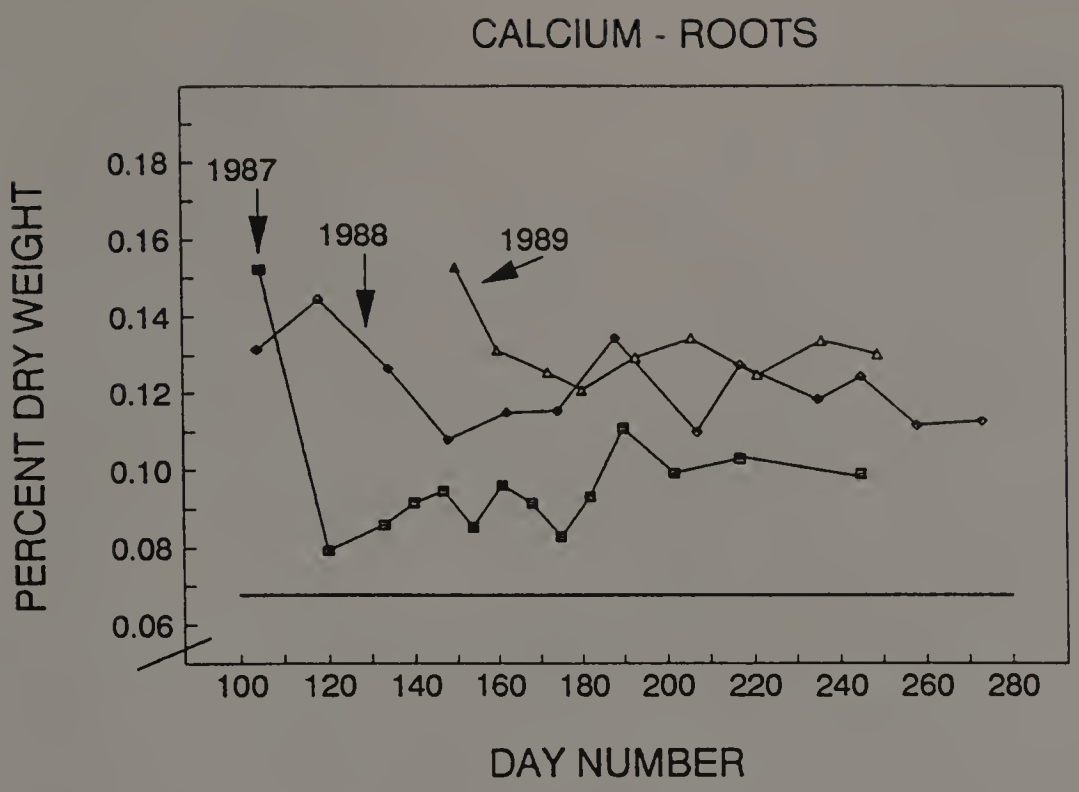

Figure 6.19 Calcium (percent dry weight) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1988 and 1989) or 15 (1987) replicates. Horizontal line is the time of statistically determined stability in analytical values.

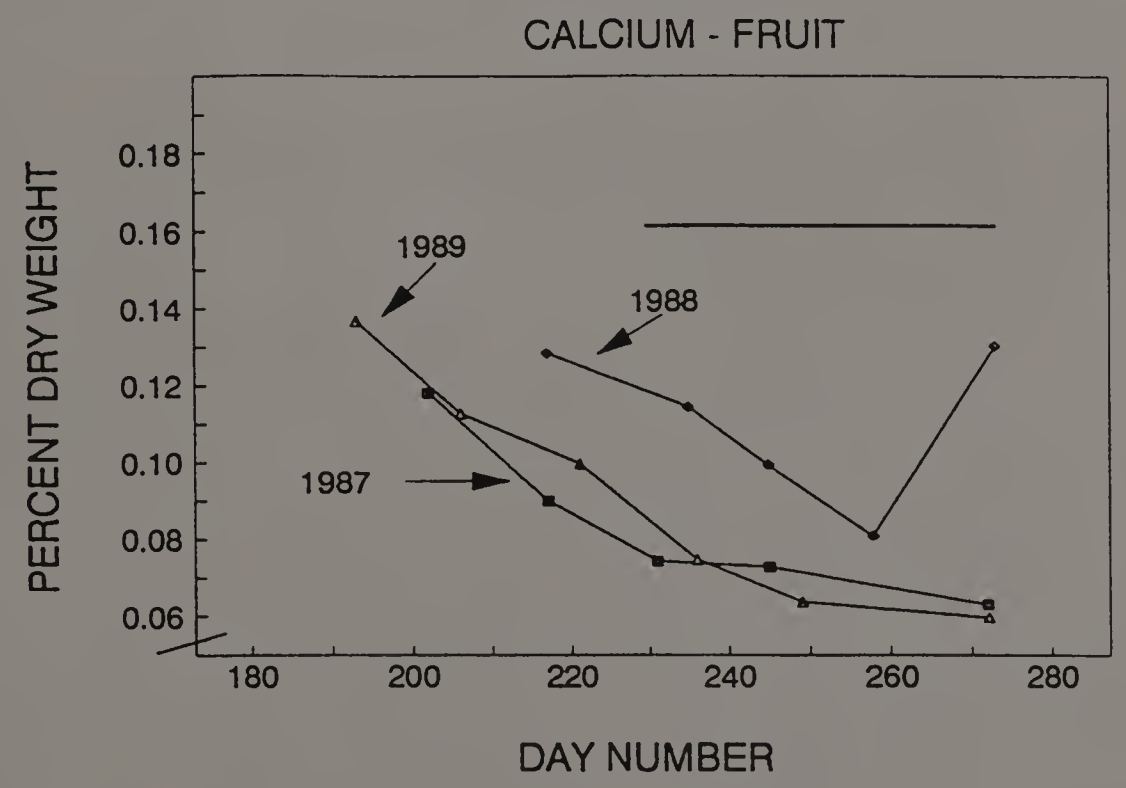

Figure 6.20 Calcium (percent dry weight) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987 and 1988) or 10 (1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

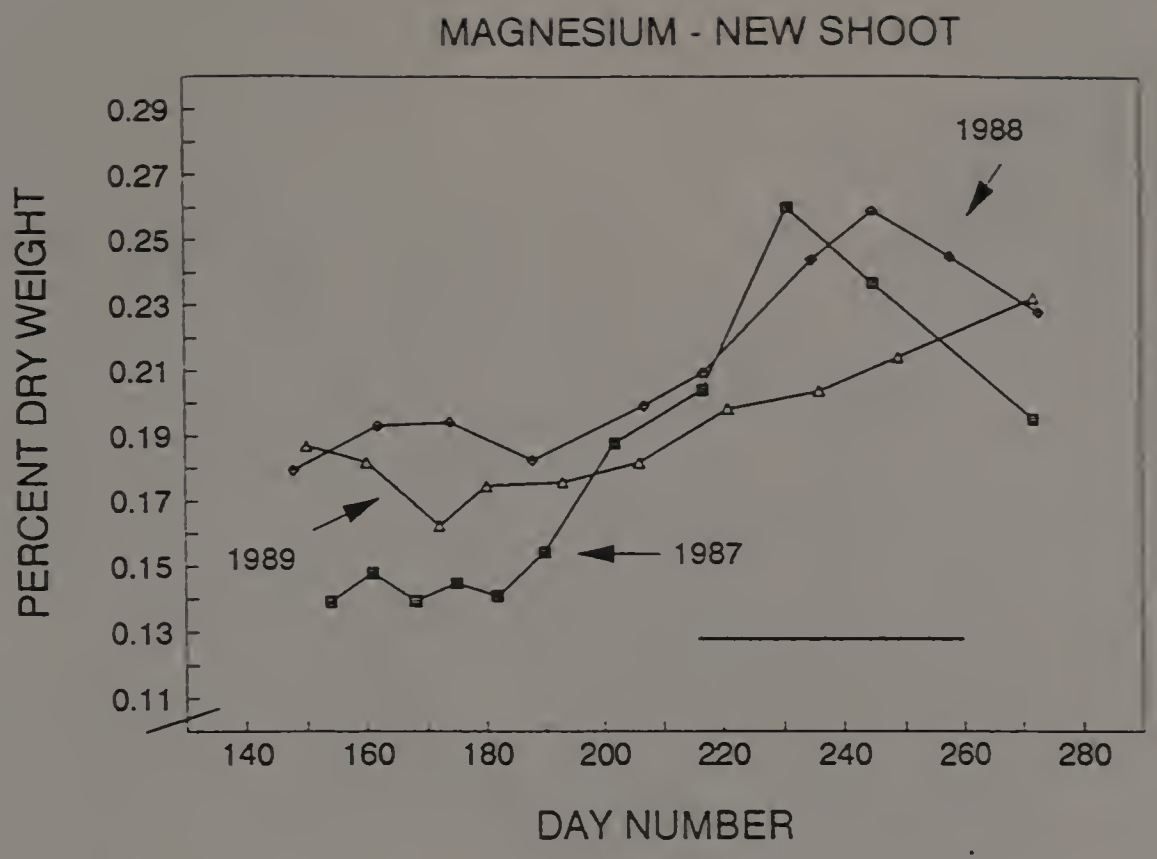

Figure 6.21 Magnesium (percent dry weight) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

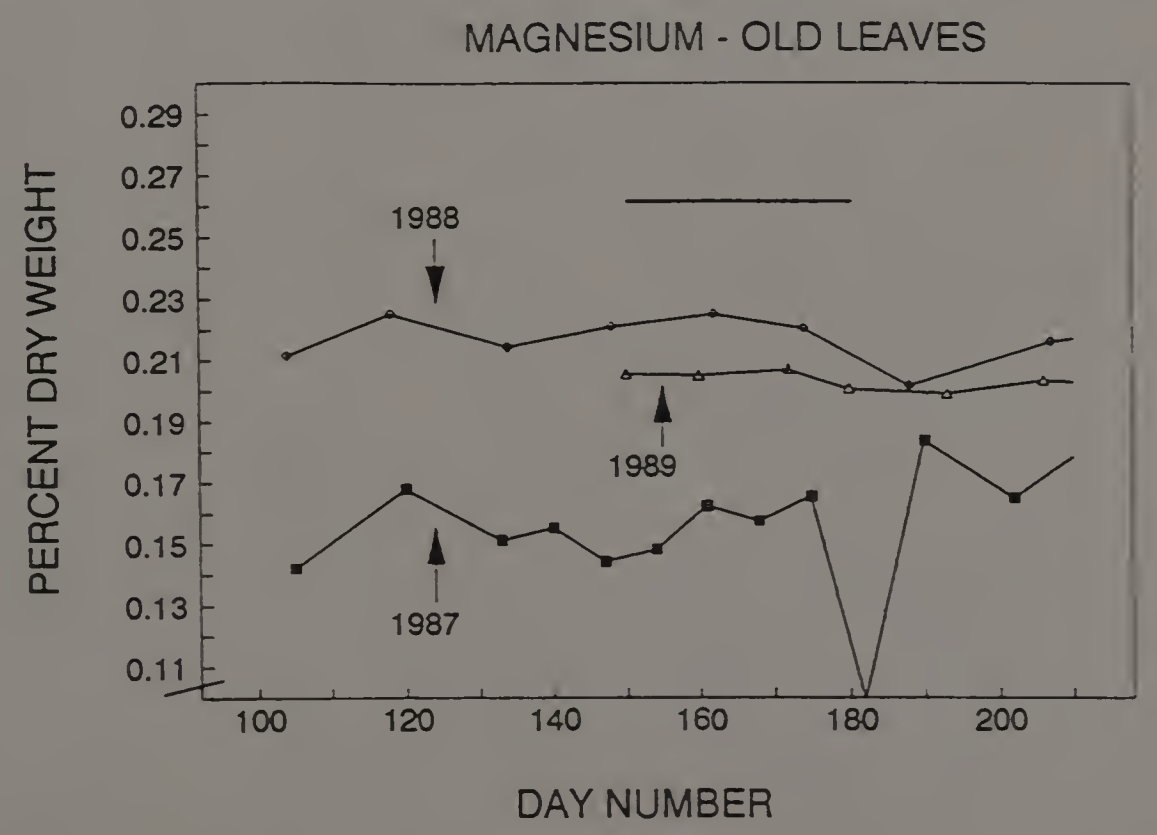

Figure 6.22 Magnesium (percent dry weight) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987 and 1989) or 15 (1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

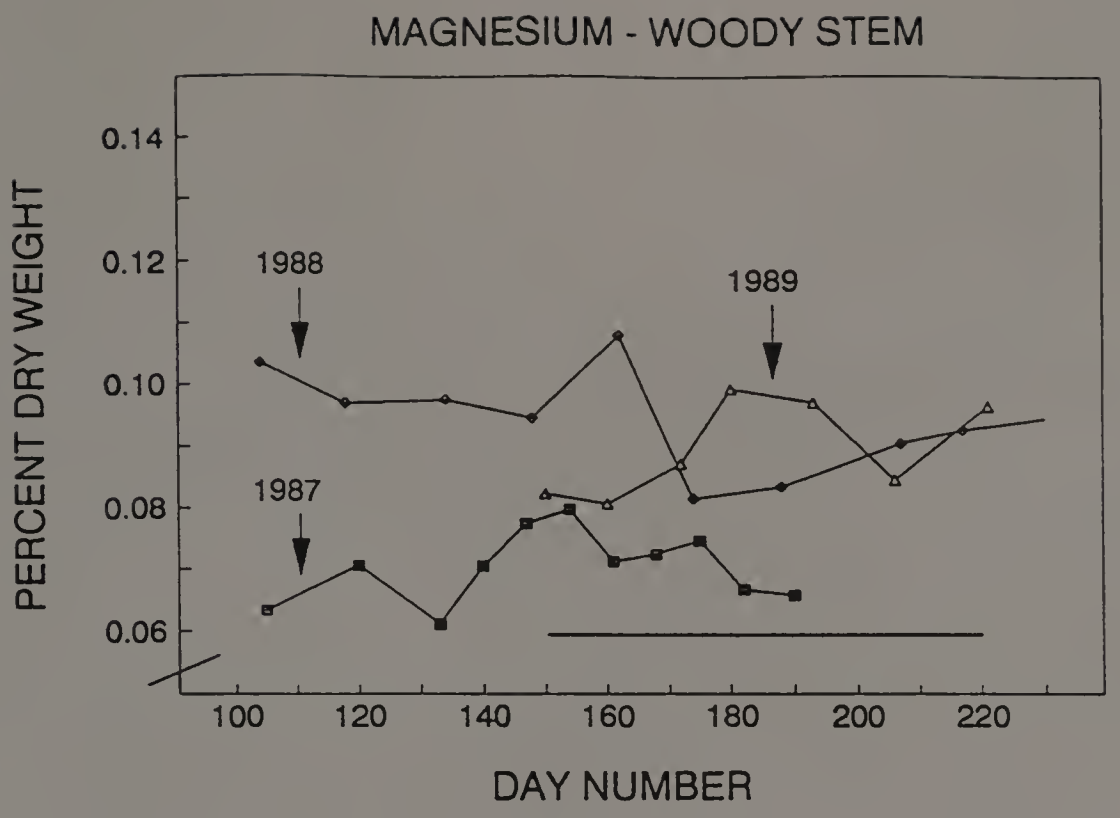

Figure 6.23 Magnesium (percent dry weight) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

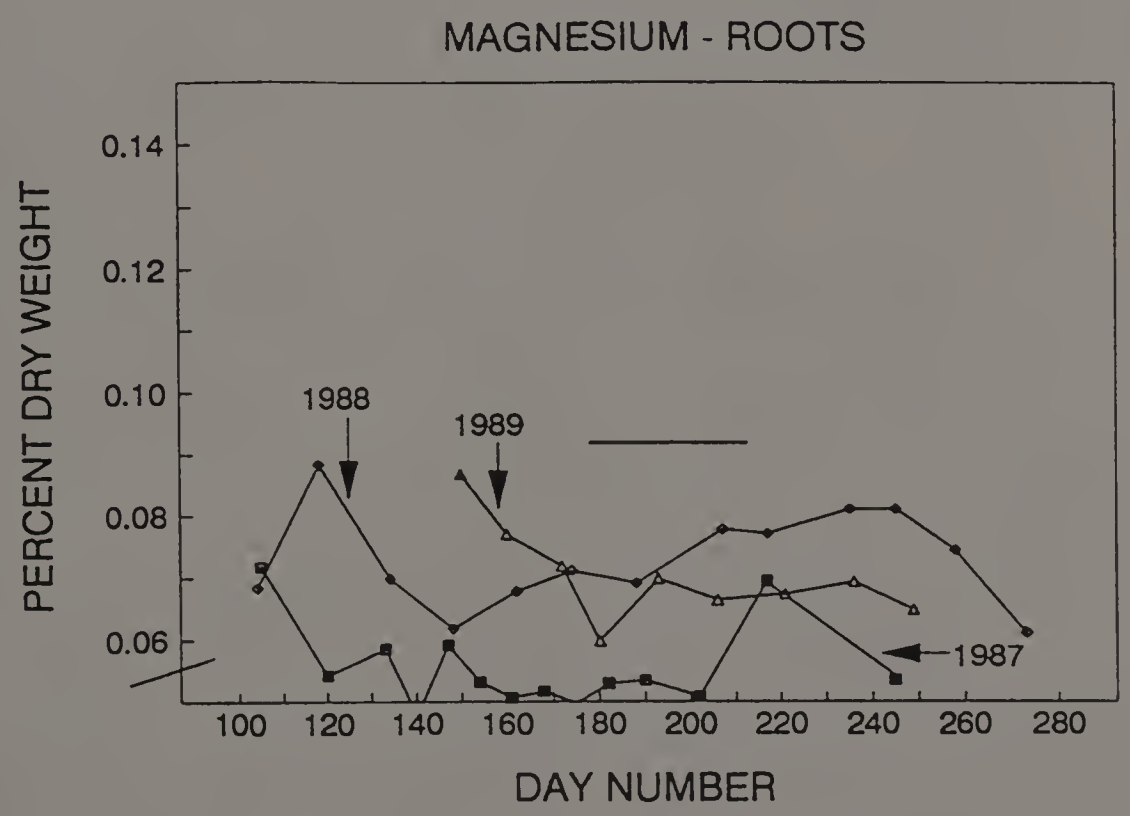

Figure 6.24 Magnesium (percent dry weight) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 (1987 and 1989) or 15 (1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

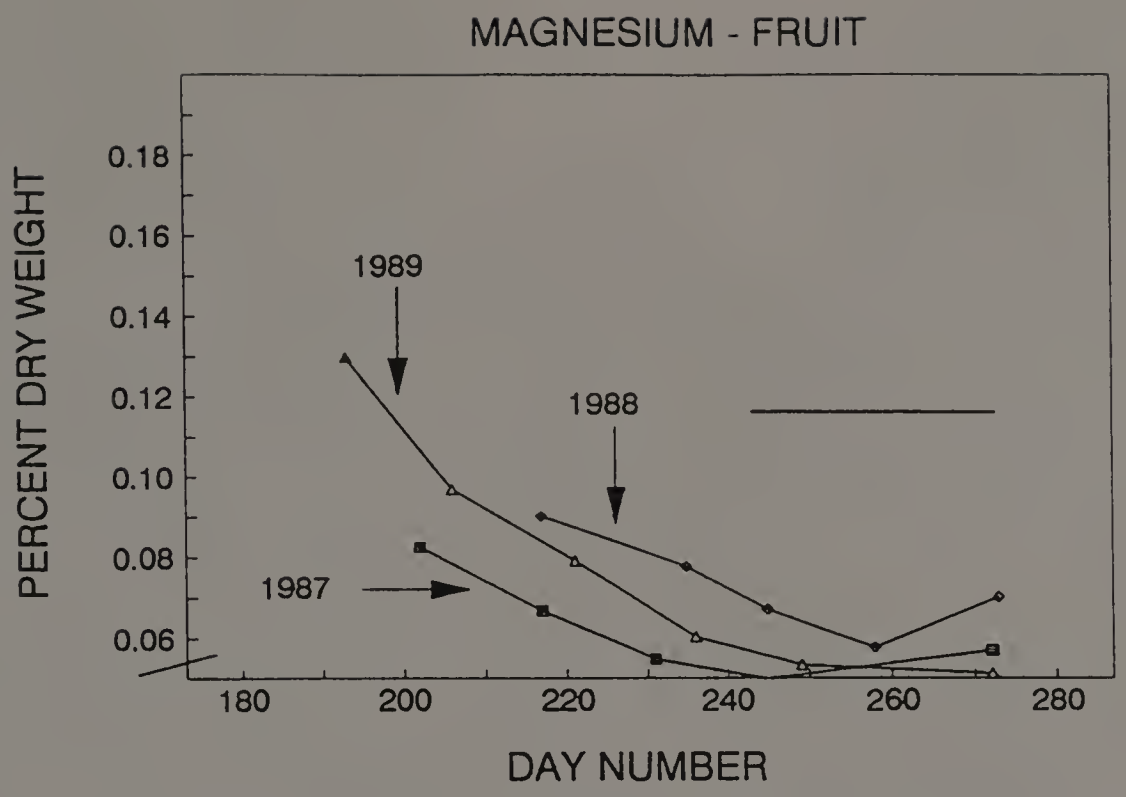

Figure 6.25 Magnesium (percent dry weight) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

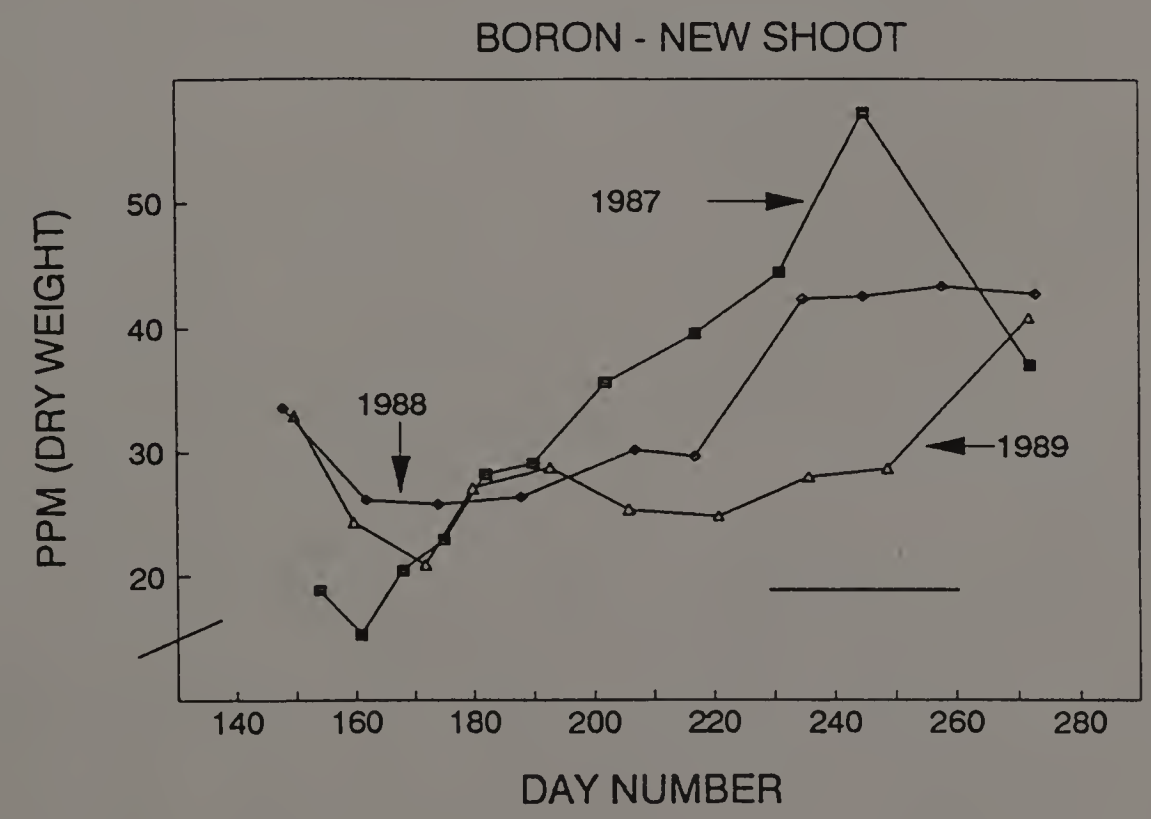

Figure 6.26 Boron (ppm) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 replicates. Horizontal line is the time of statistically determined stability in analytical values.

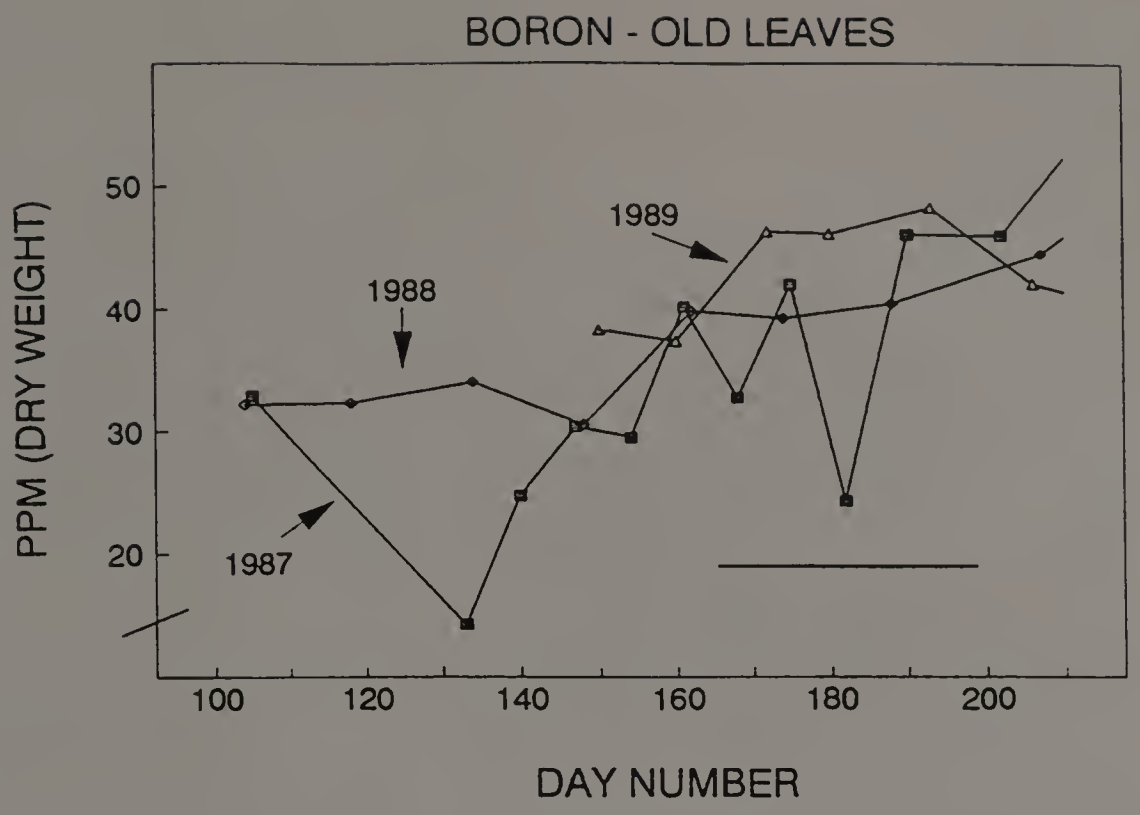

Figure 6.27 Boron (ppm) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1988 and 1989) or 20 (1987) replicates. Horizontal line is the time of statistically determined stability in analytical values.

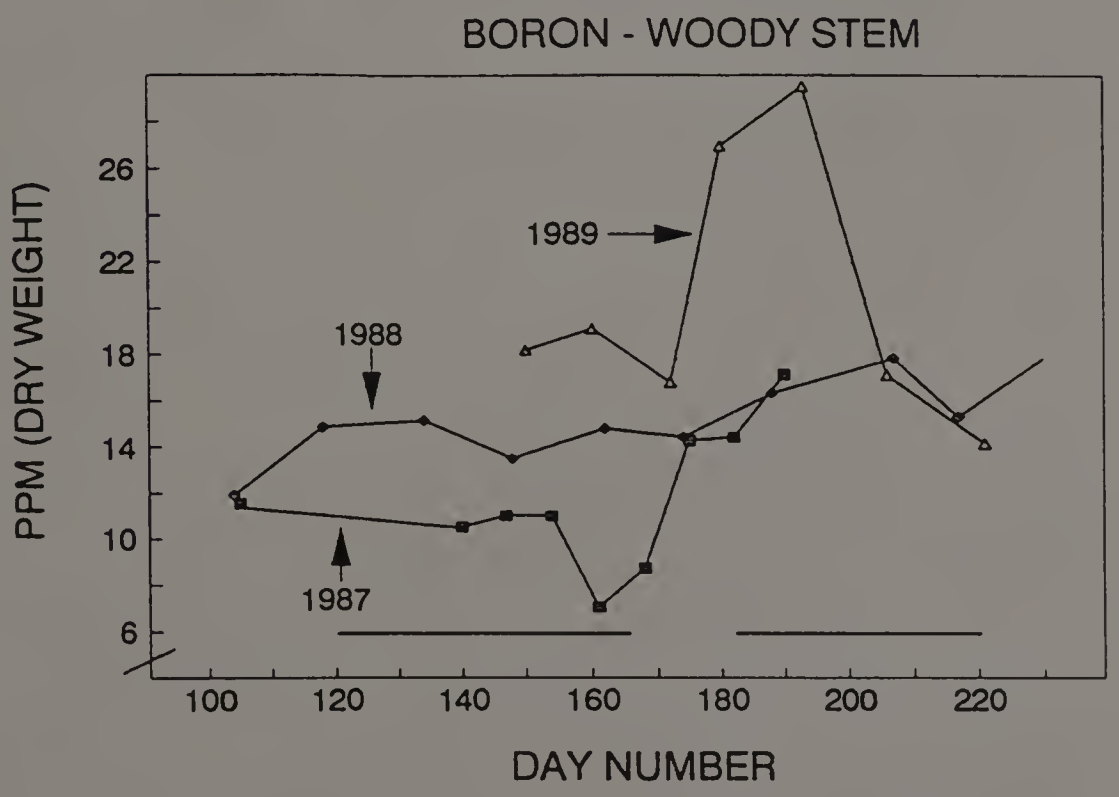

Figure 6.28 Boron (ppm) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1988 and 1989) or 20 (1987) replicates. Horizontal line is the time of statistically determined stability in analytical values.

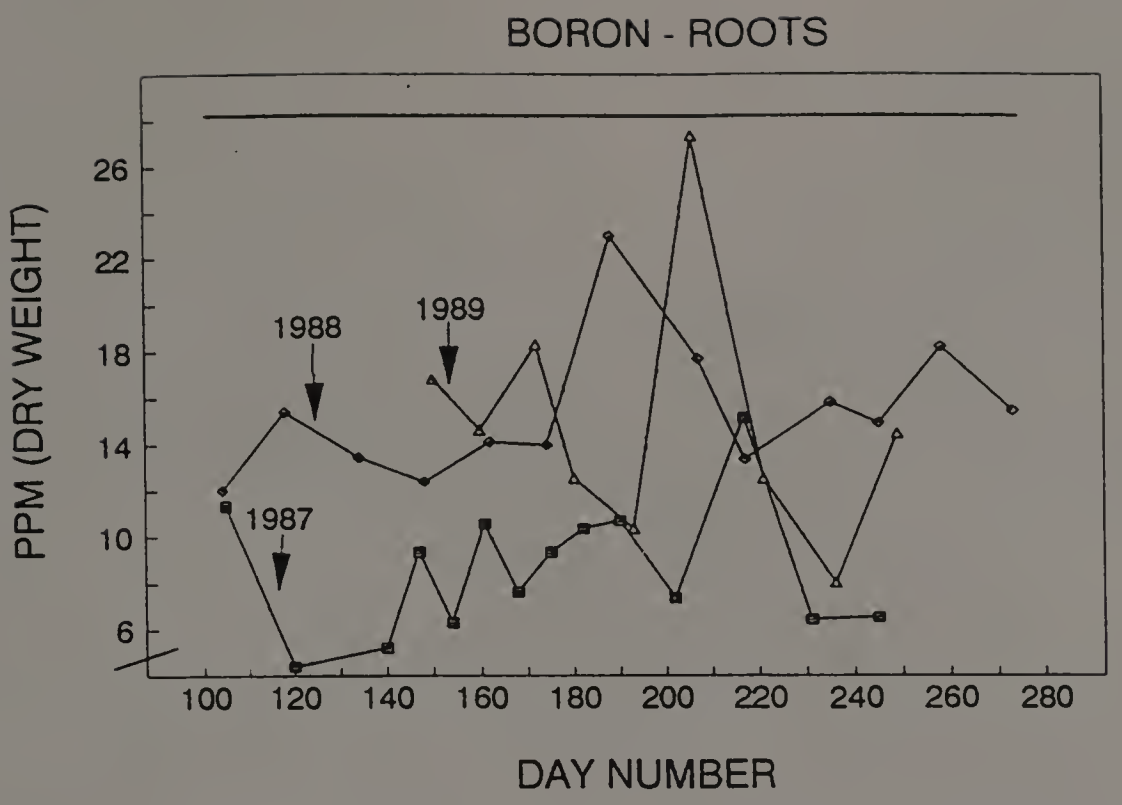

Figure 6.29 Boron (ppm) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

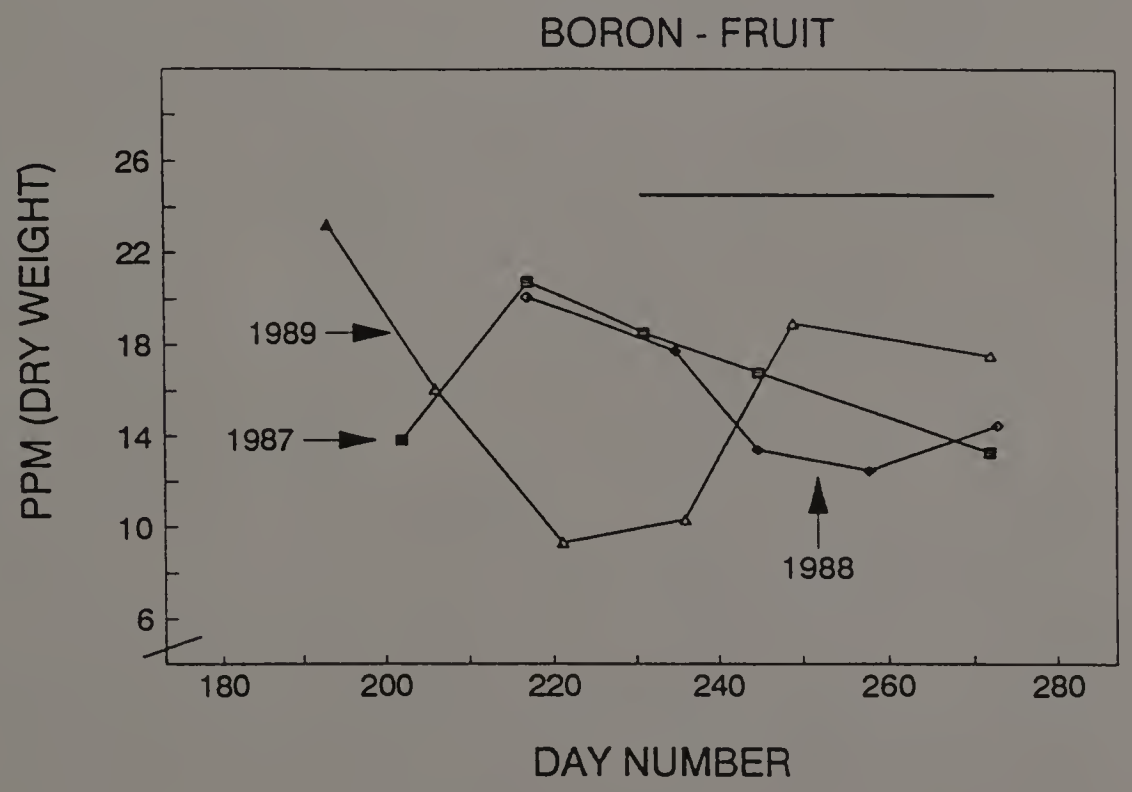

Figure 6.30 Boron (ppm) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1989) or 20 (1987 and 1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

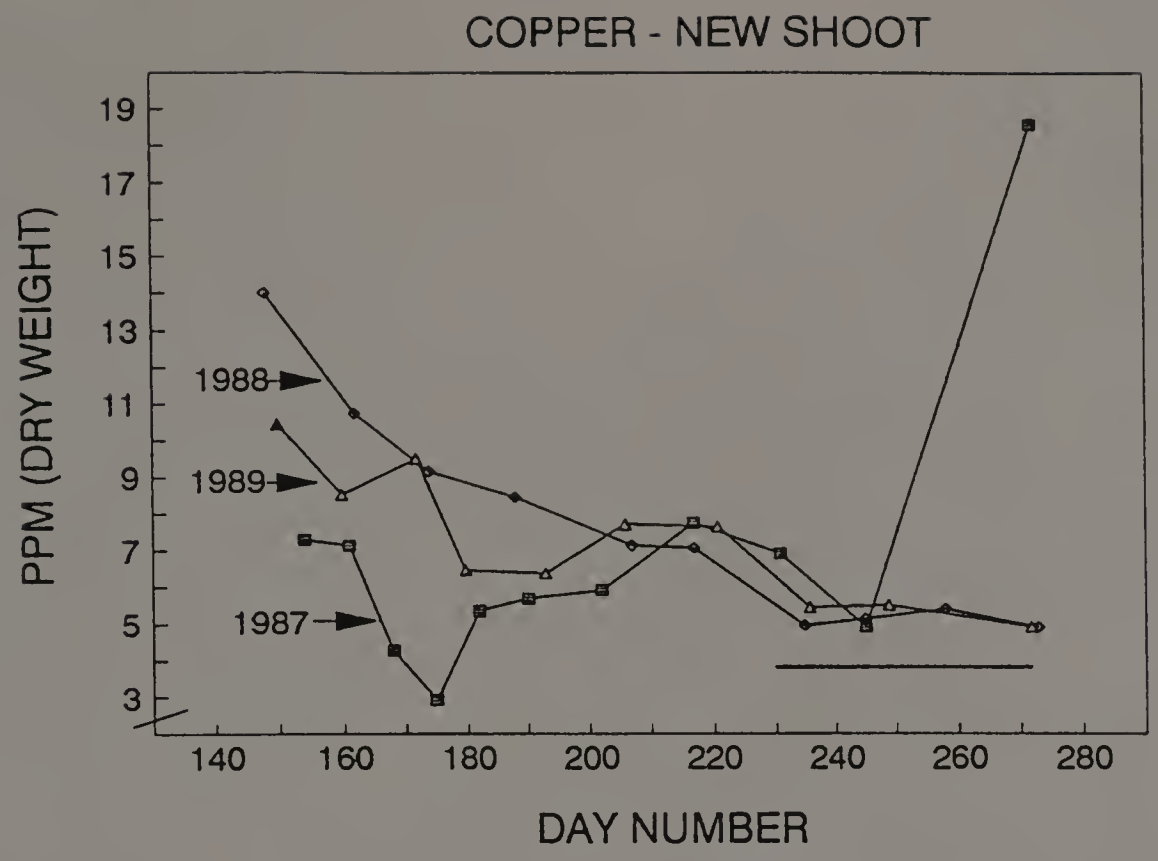

Figure 6.31 Copper (ppm) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 replicates. Horizontal line is the time of statistically determined stability in analytical values.

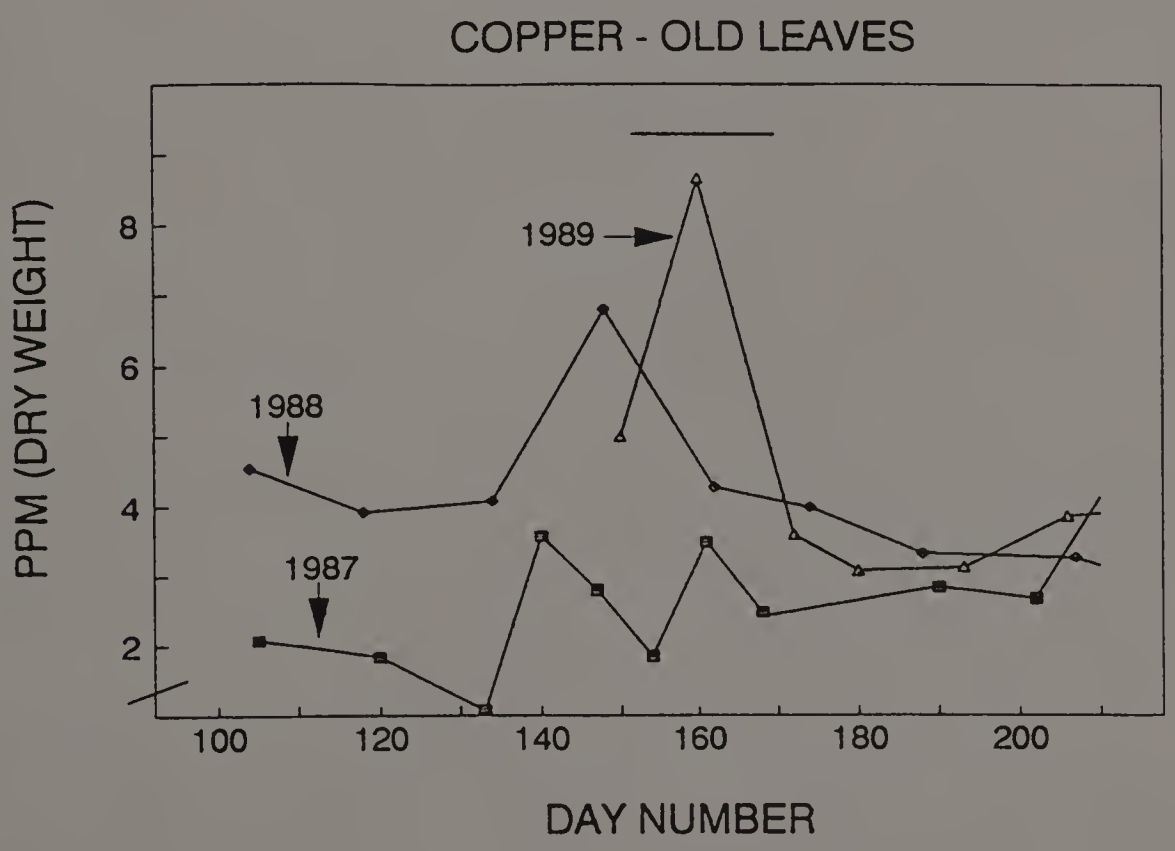

Figure 6.32 Copper (ppm) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1989) or 20 (1987 and 1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

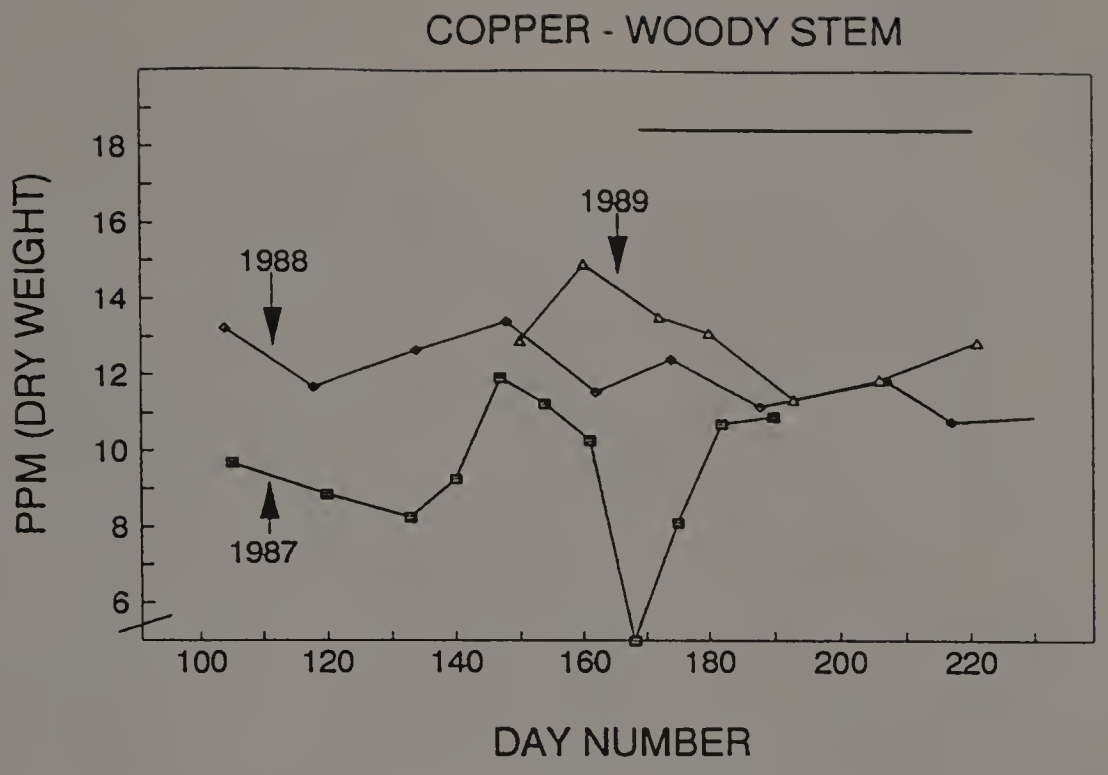

Figure 6.33 Copper (ppm) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

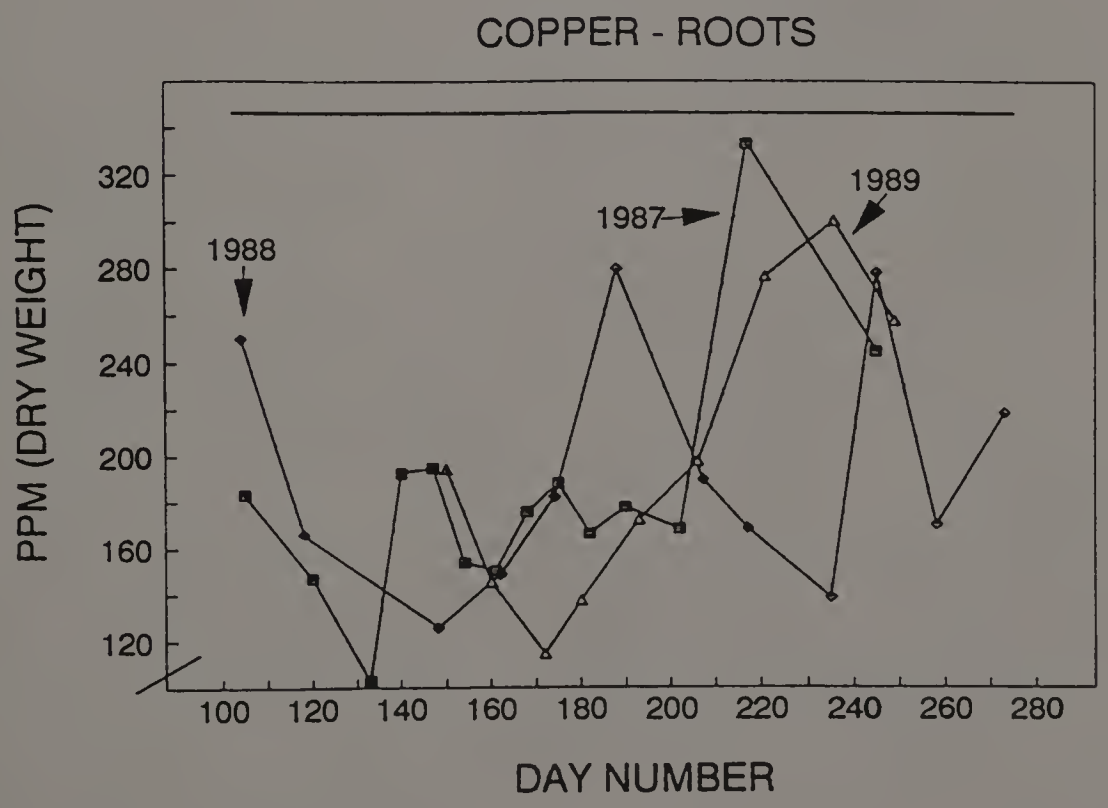

Figure 6.34 Copper (ppm) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

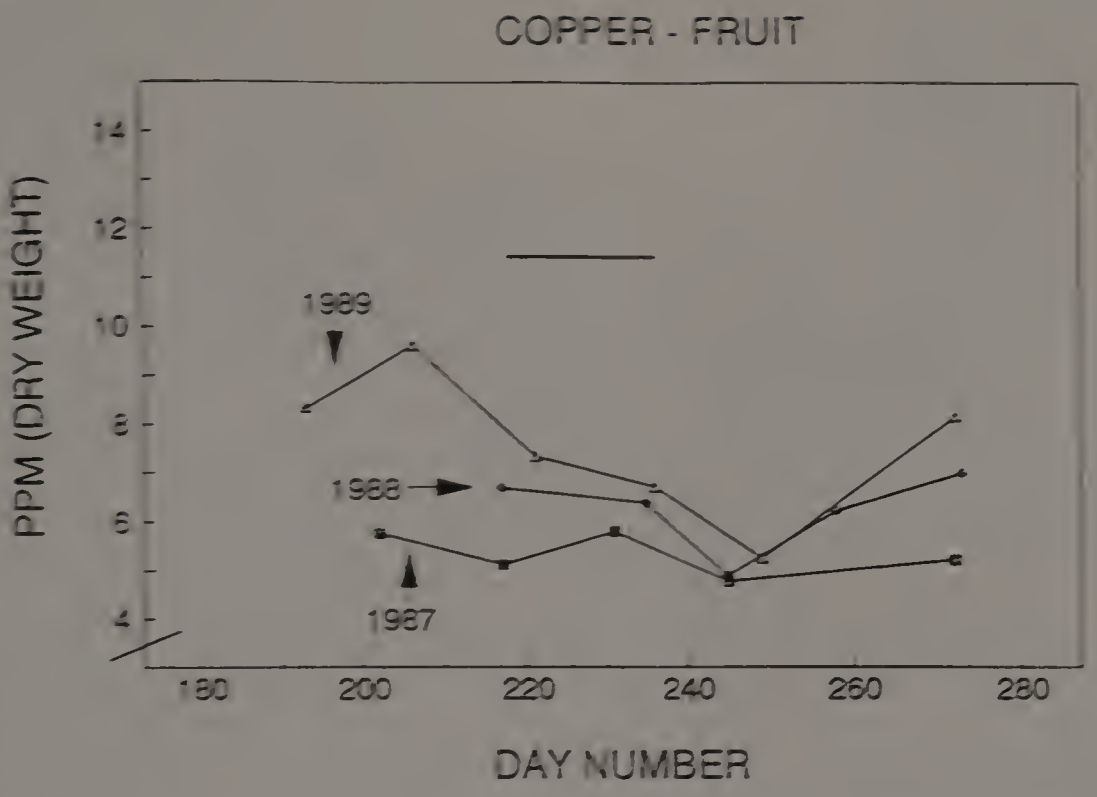

Figure 6.35 Copper (ppm) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987) or 20 (1988 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

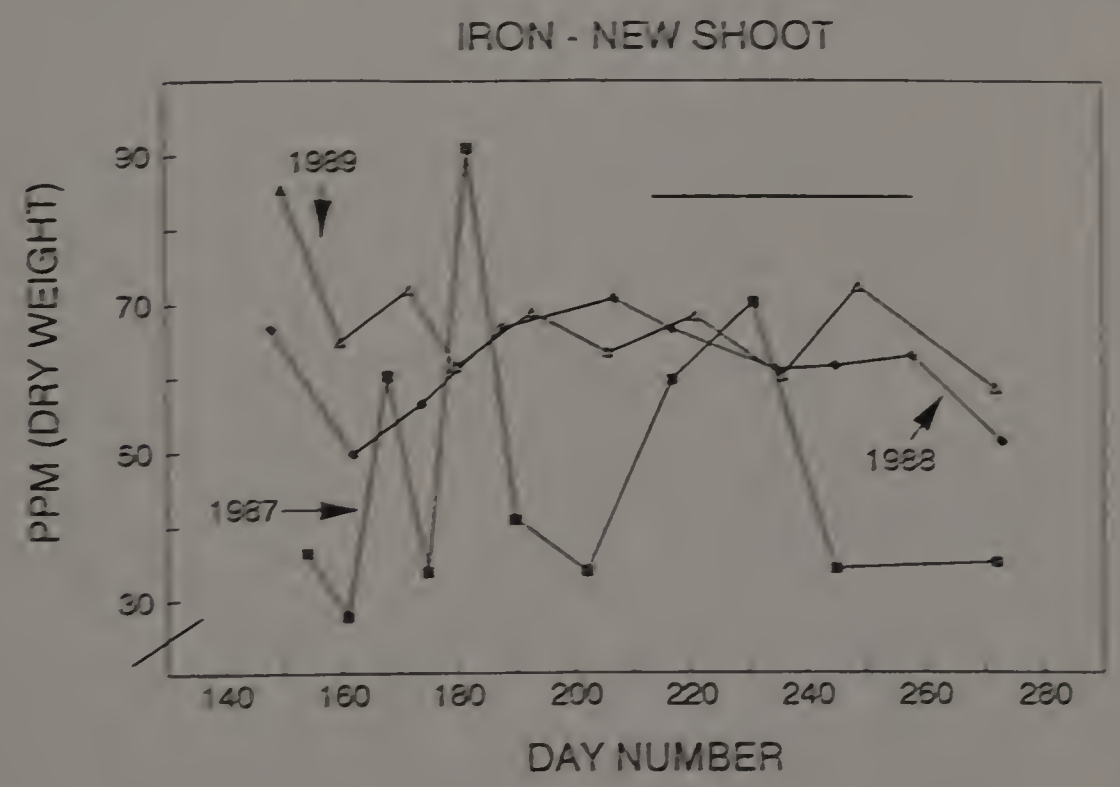

Figure 6.36 Iron (ppm) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

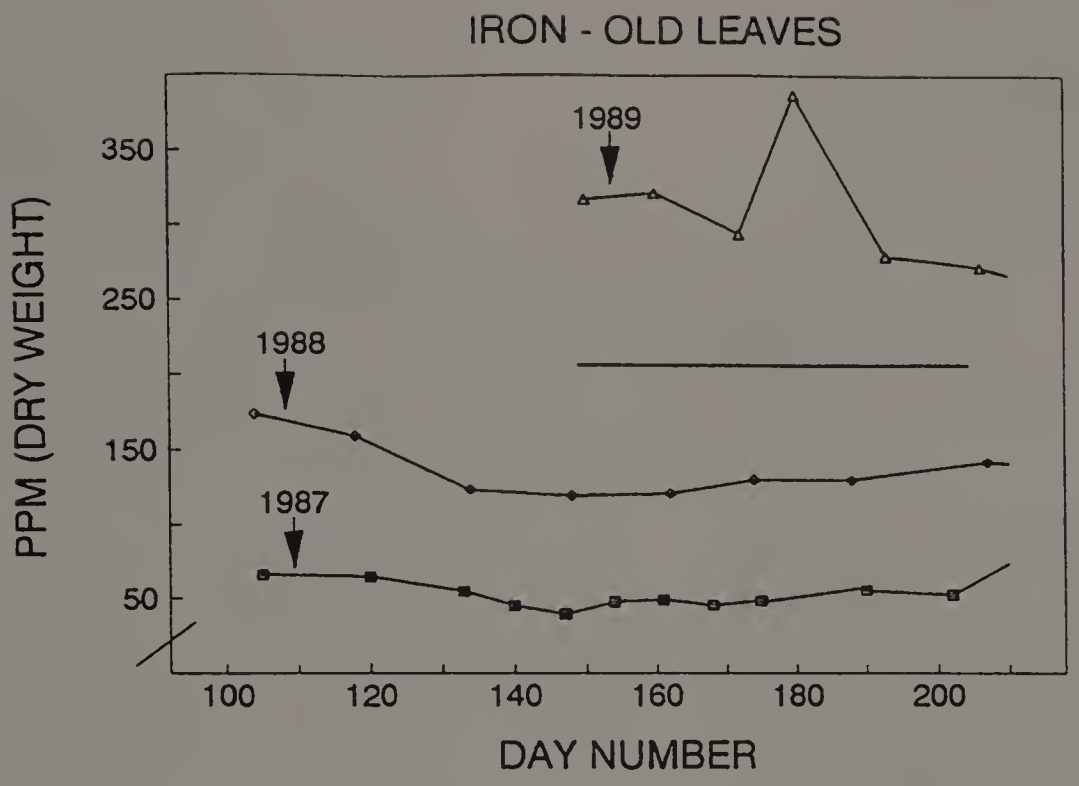

Figure 6.37 Iron (ppm) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1988 and 1989) or 20 (1987) replicates. Horizontal line is the time of statistically determined stability in analytical values.

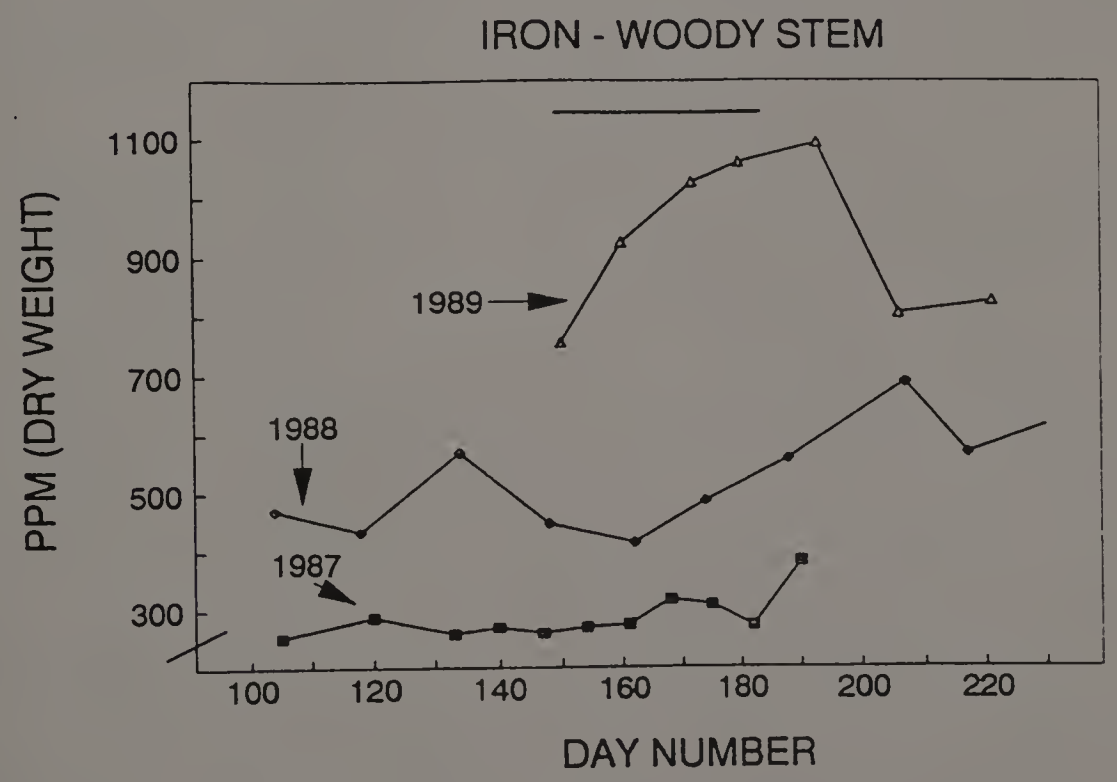

Figure 6.38 Iron (ppm) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1989) or 20 (1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

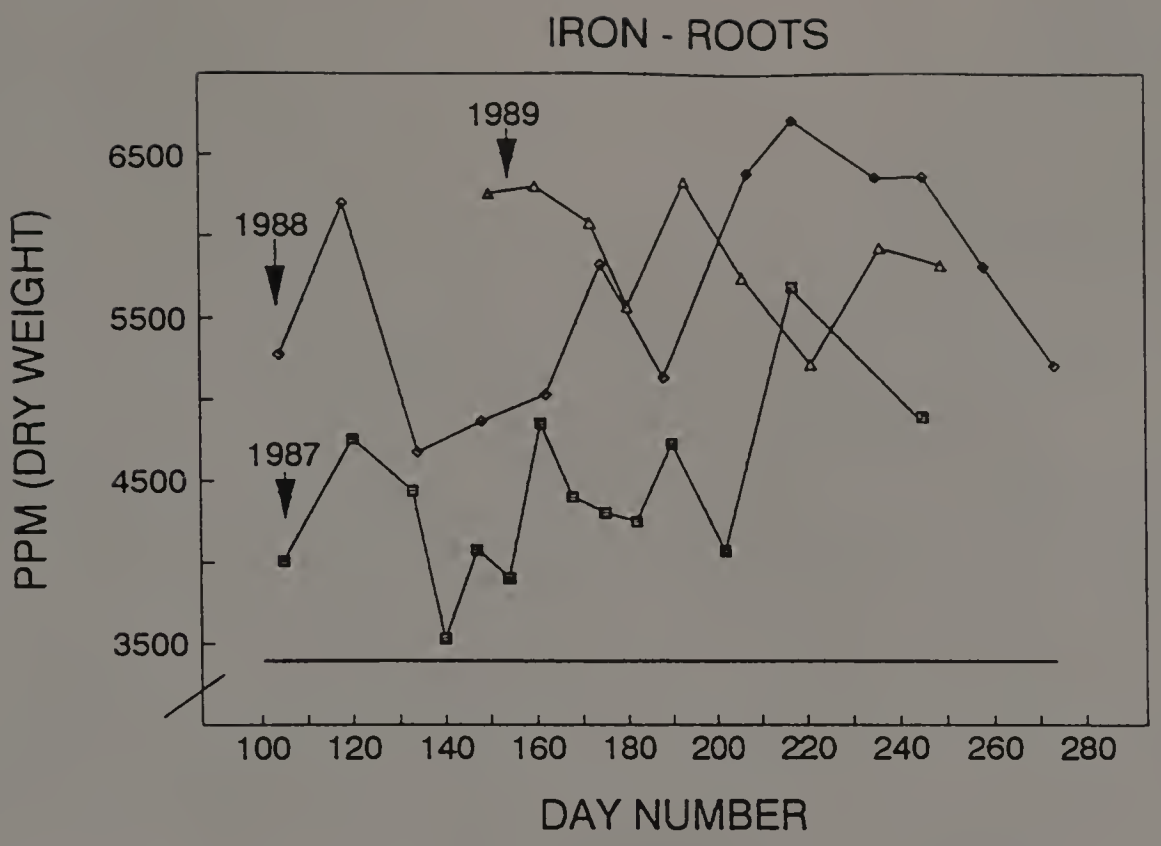

Figure 6.39 Iron (ppm) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

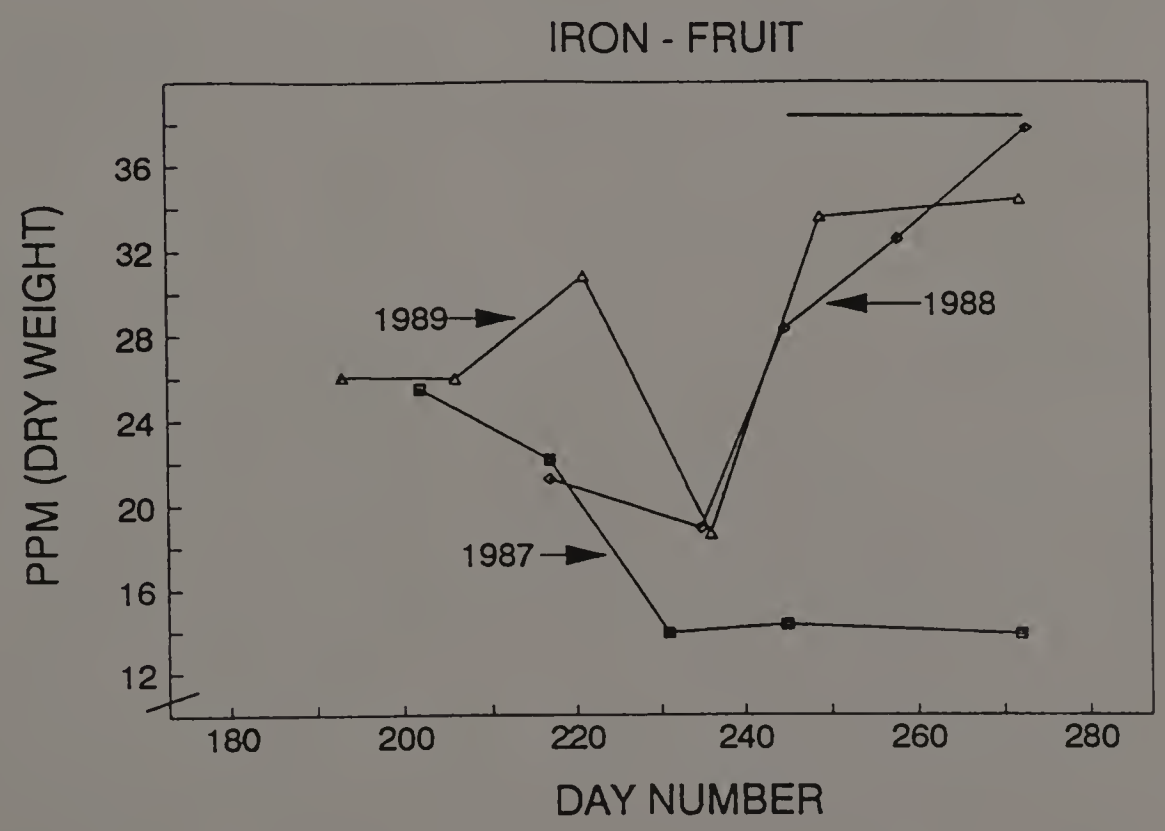

Figure 6.40 Iron (ppm) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987) or 20 (1988 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

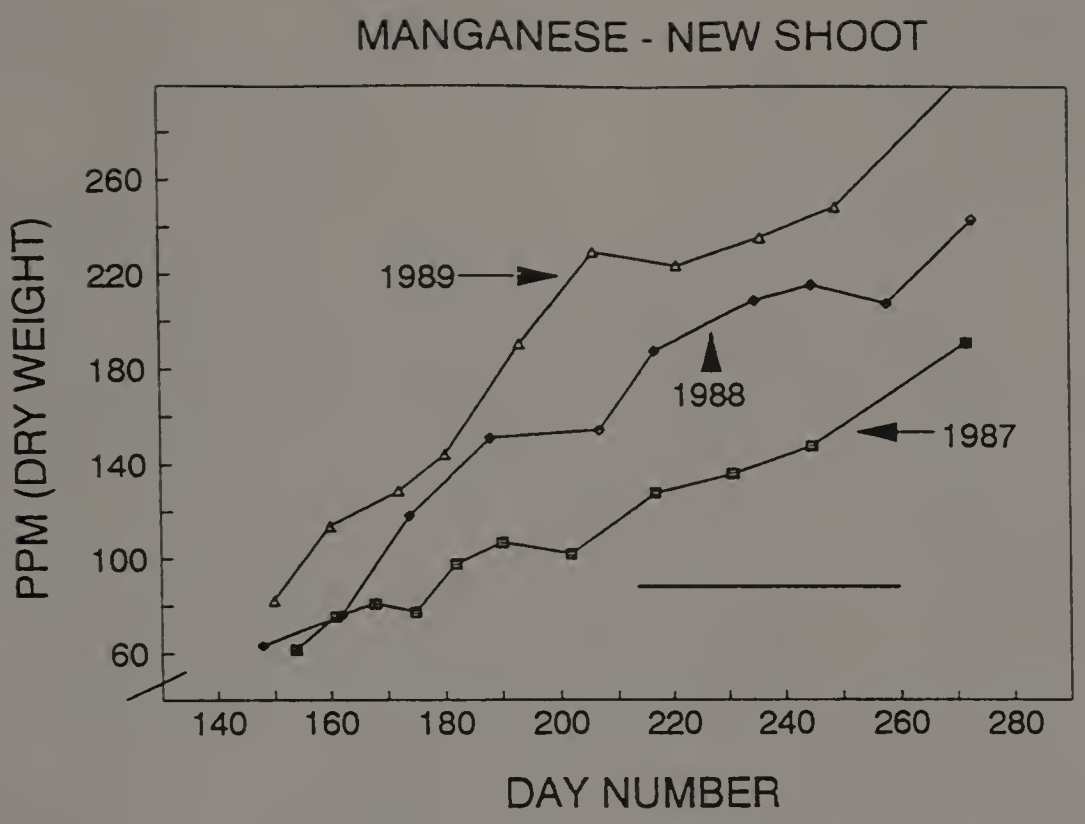

Figure 6.41 Manganese (ppm) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

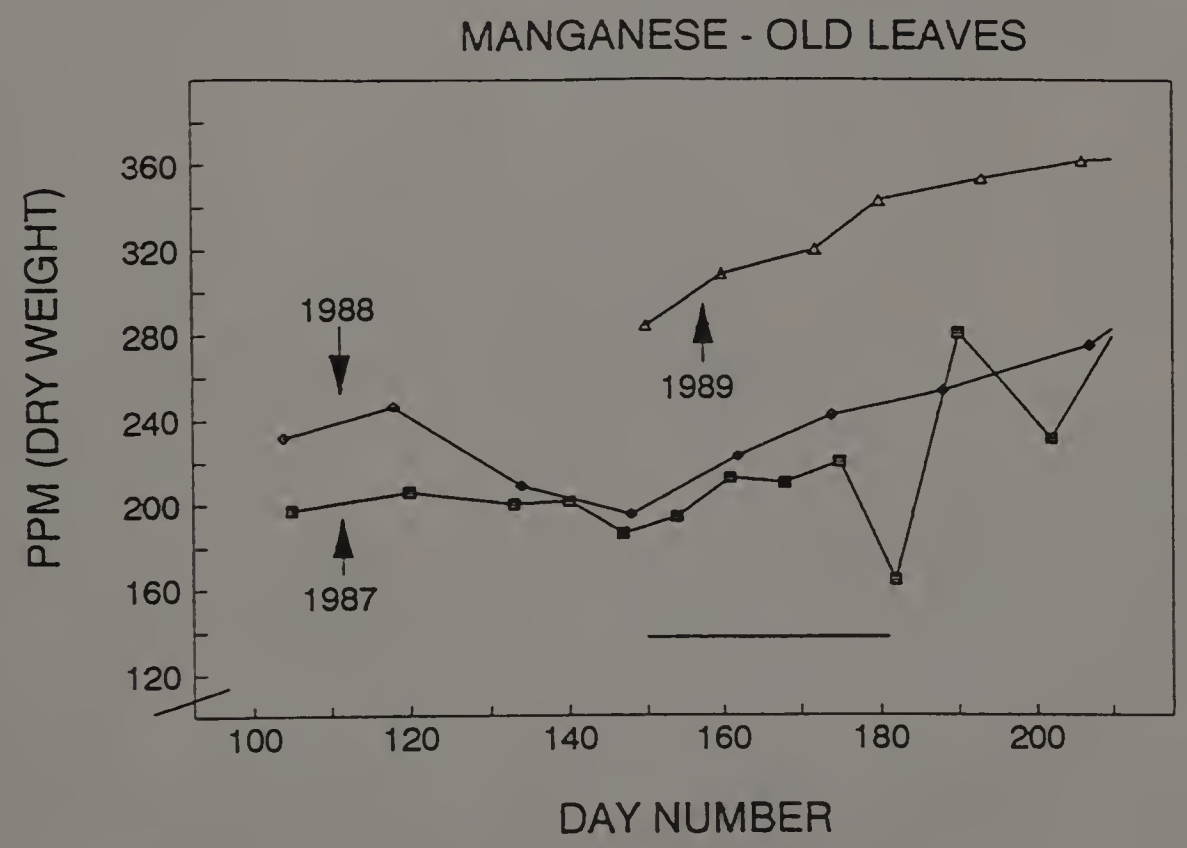

Figure 6.42 Manganese (ppm) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1988) or 20 (1987 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

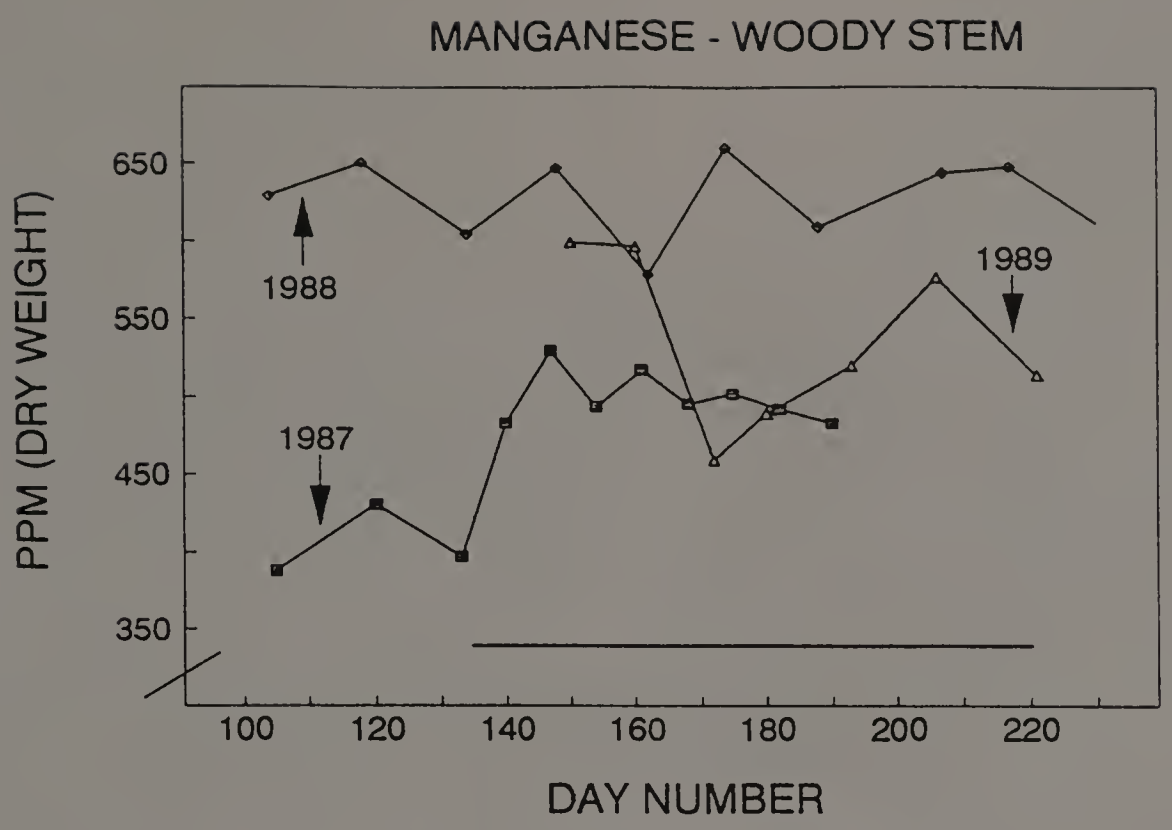

Figure 6.43 Manganese (ppm) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1989) or 20 (1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

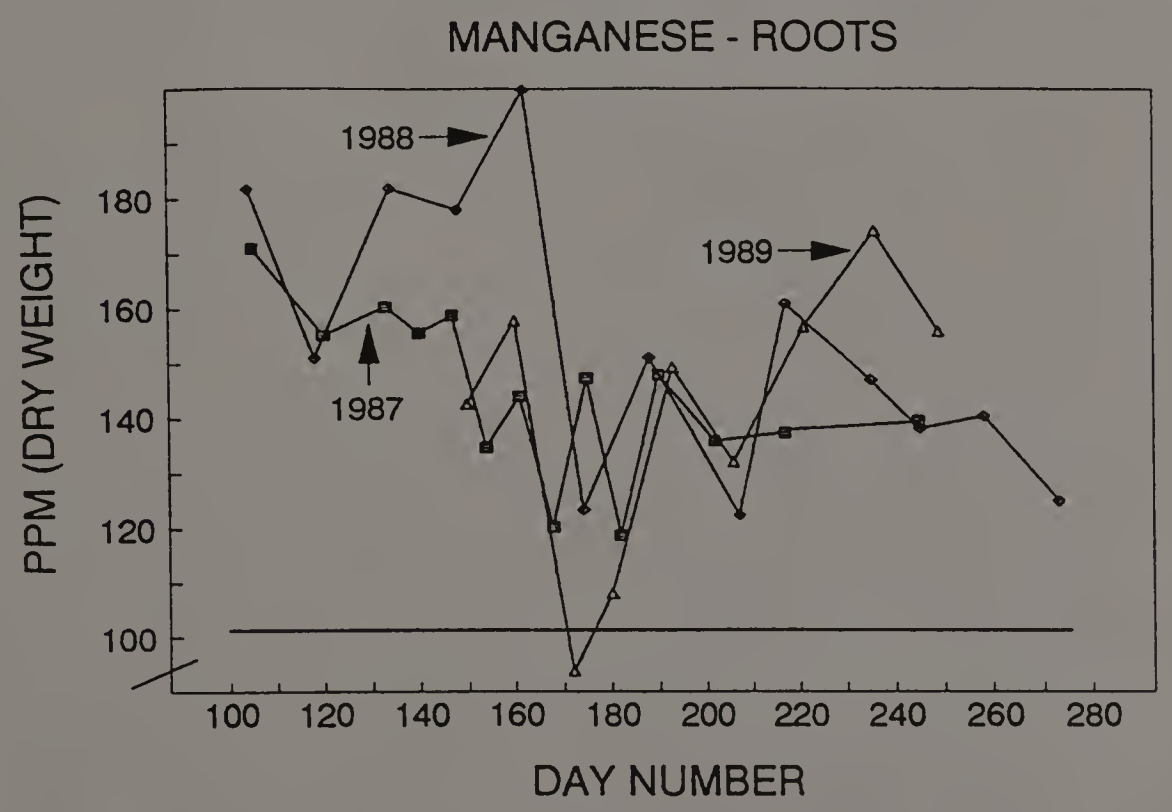

Figure 6.44 Manganese (ppm) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

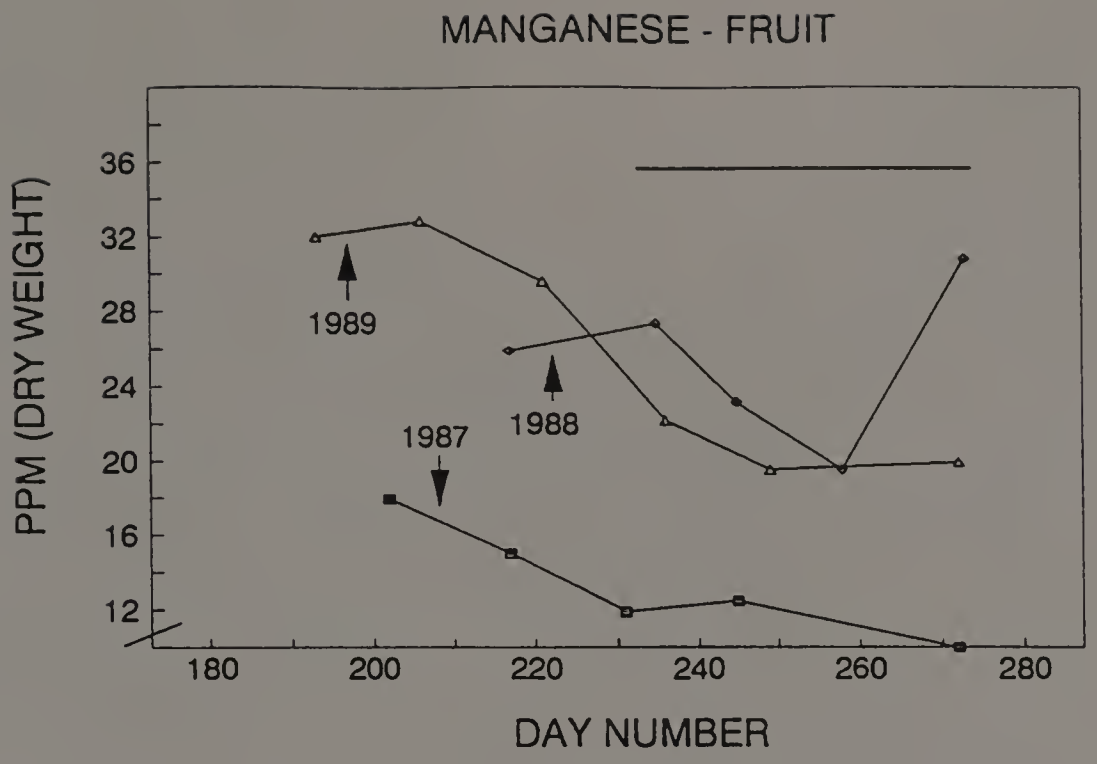

Figure 6.45 Manganese (ppm) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987 and 1989) or 20 (1988) replicates. Horizontal line is the time of statistically determined stability in analytical values.

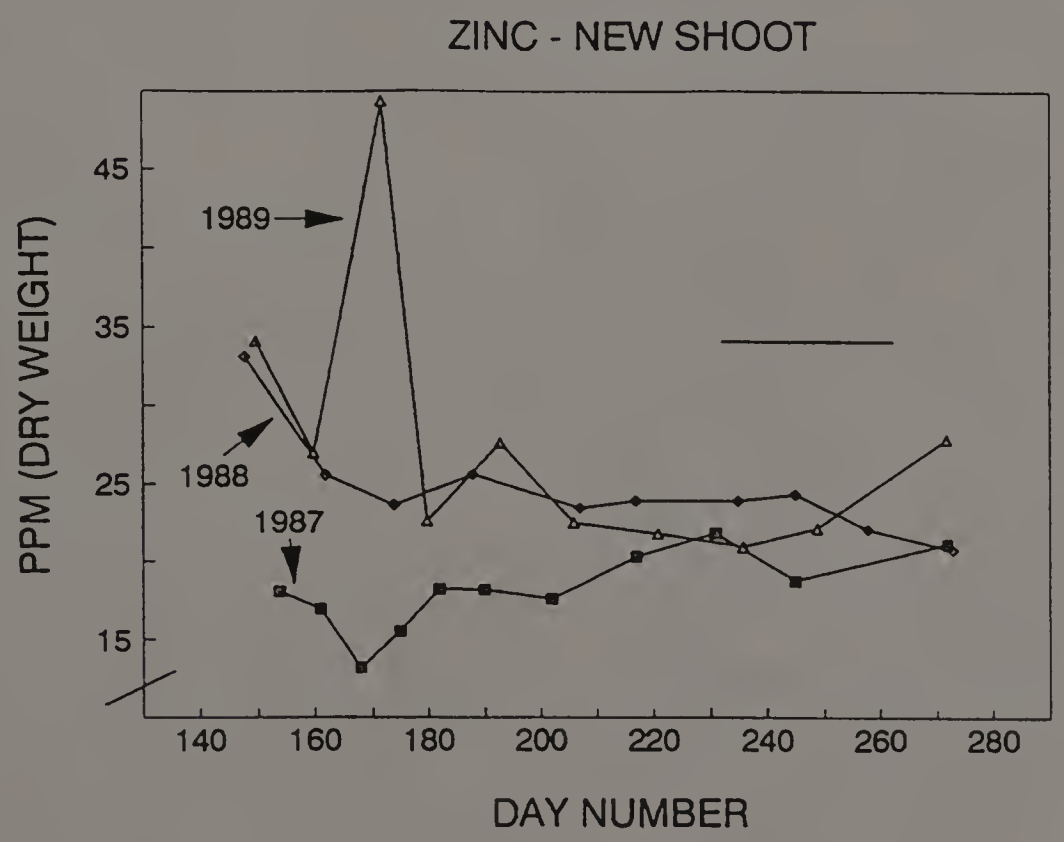

Figure 6.46 Zinc (ppm) in new shoot tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

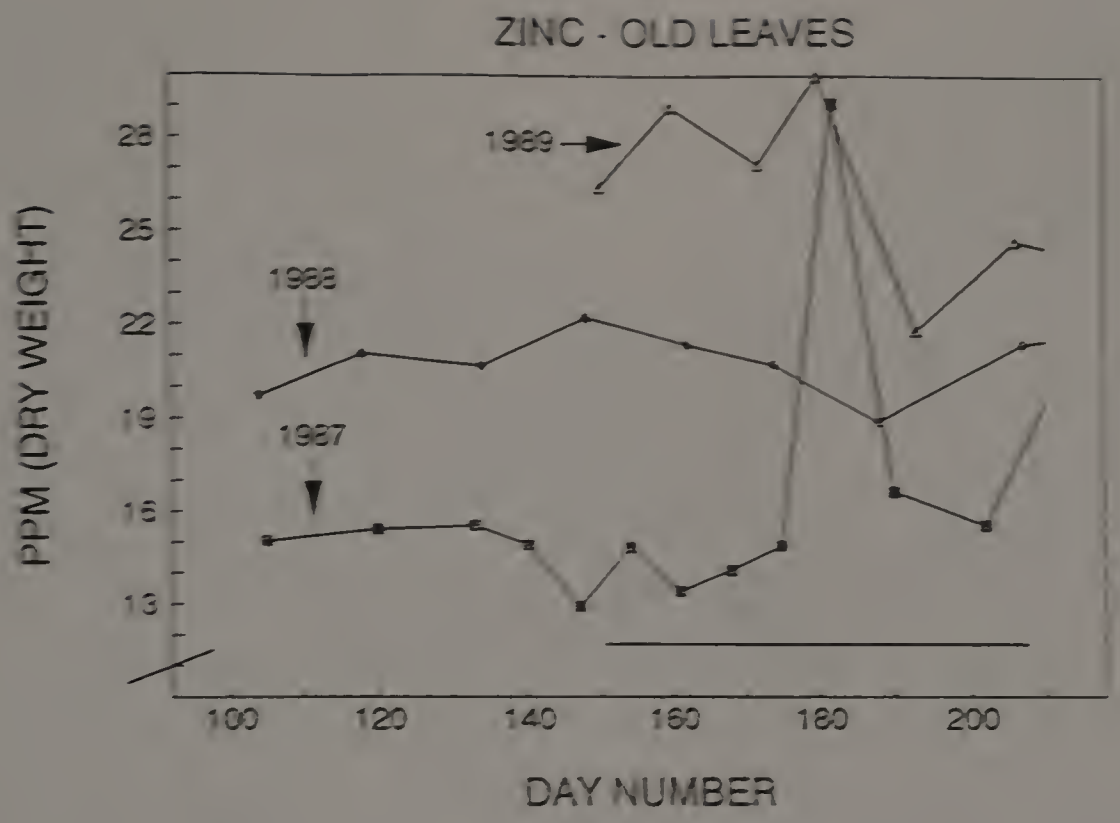

Figure 6.47 Zinc (ppm) in old leaf tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1988) or 20 (1987 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

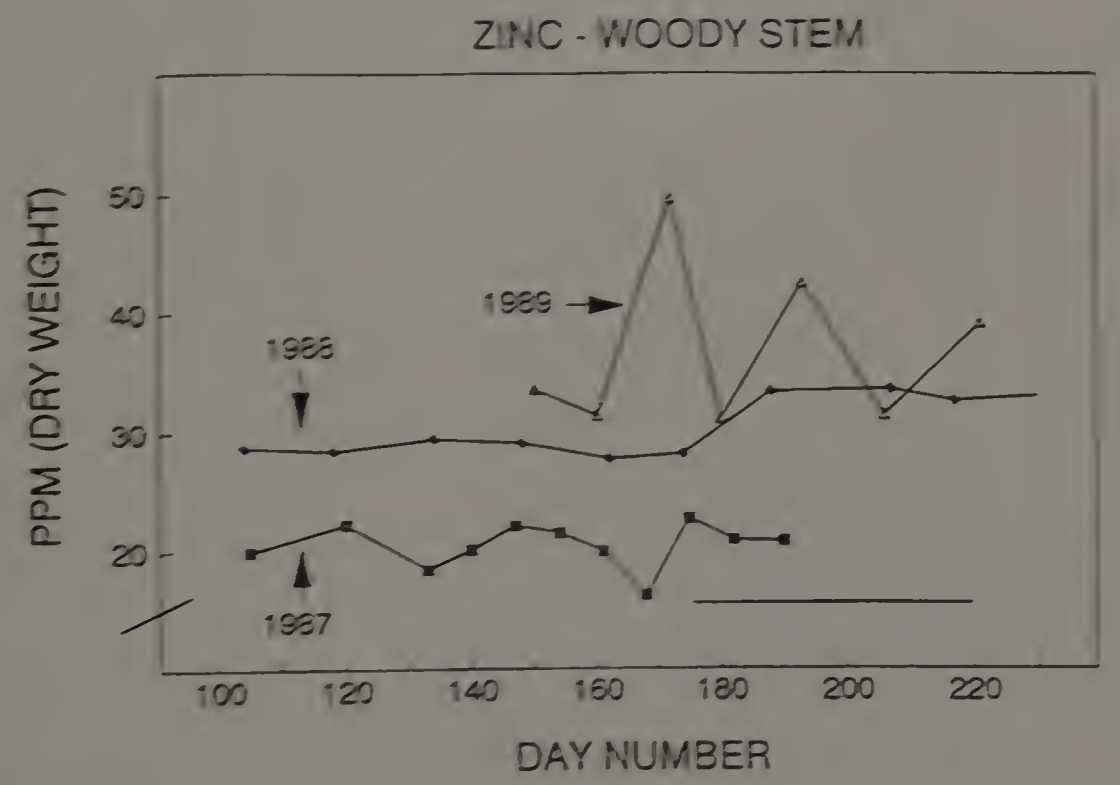

Figure 6.48 Zinc (ppm) in woody stem tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1988) or 20 (1987 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

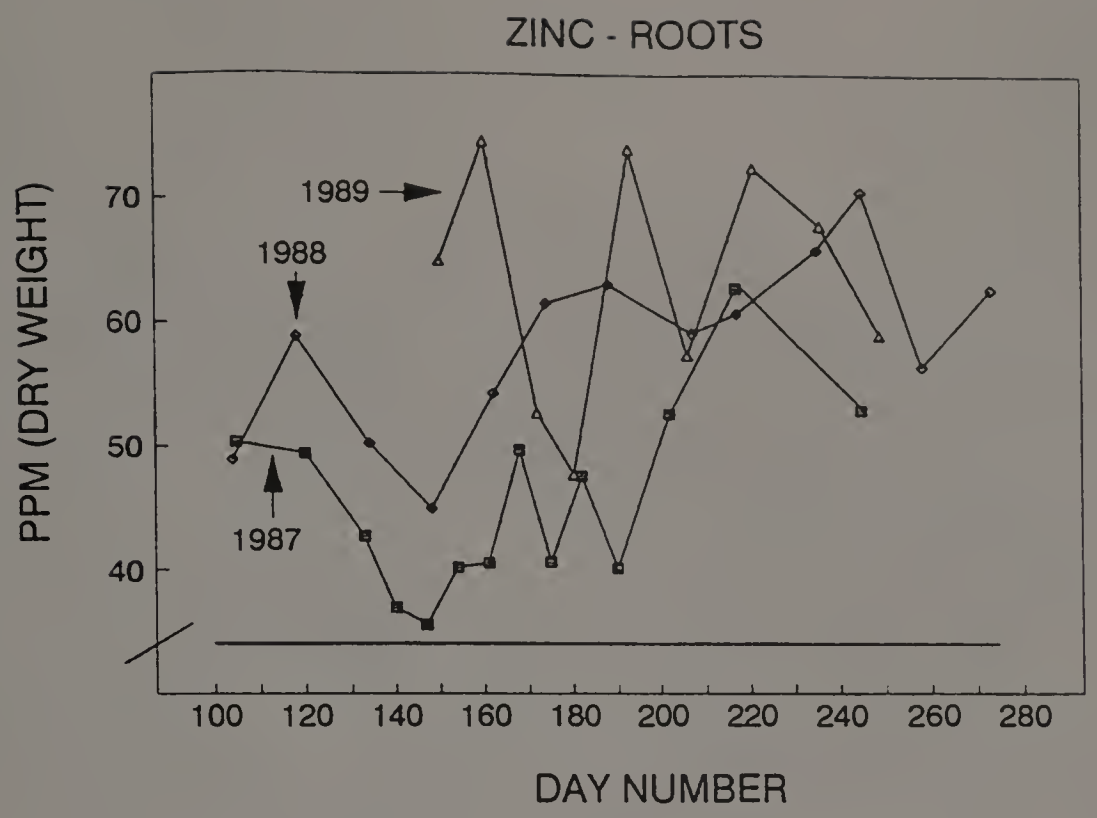

Figure 6.49 Zinc (ppm) in root tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 20 replicates. Horizontal line is the time of statistically determined stability in analytical values.

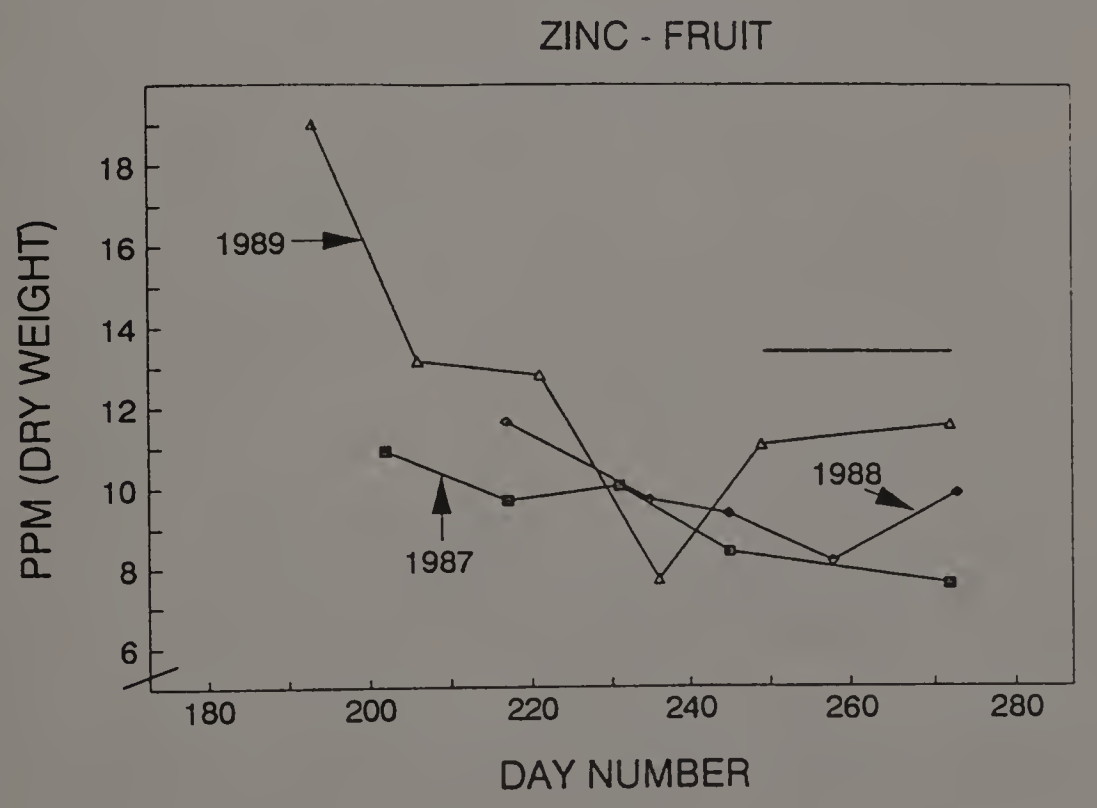

Figure 6.50 Zinc (ppm) in fruit tissue: 1987 (squares), 1988 (diamonds), and 1989 (triangles). Values are means of 15 (1987) or 20 (1988 and 1989) replicates. Horizontal line is the time of statistically determined stability in analytical values.

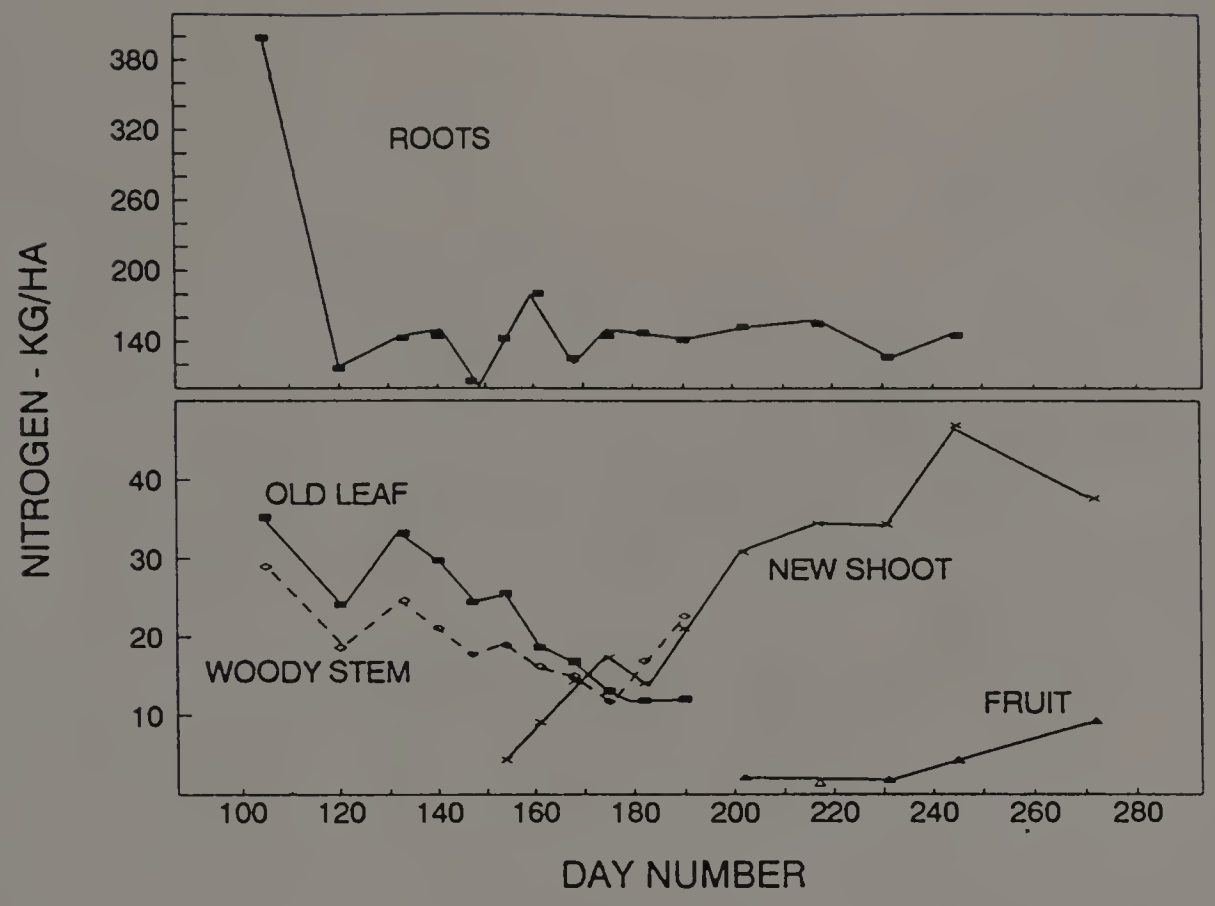

Figure 6.51 Seasonal N content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

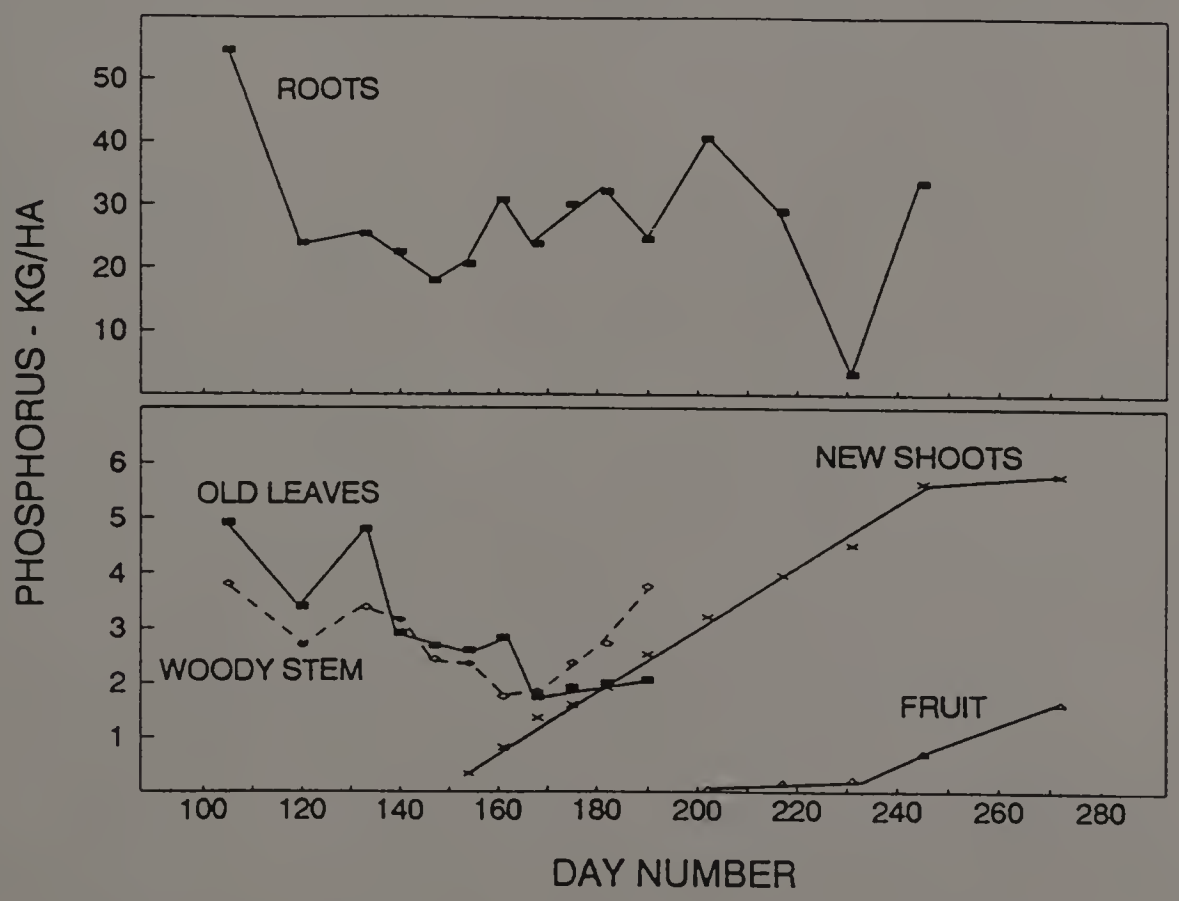

Figure 6.52 Seasonal P content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

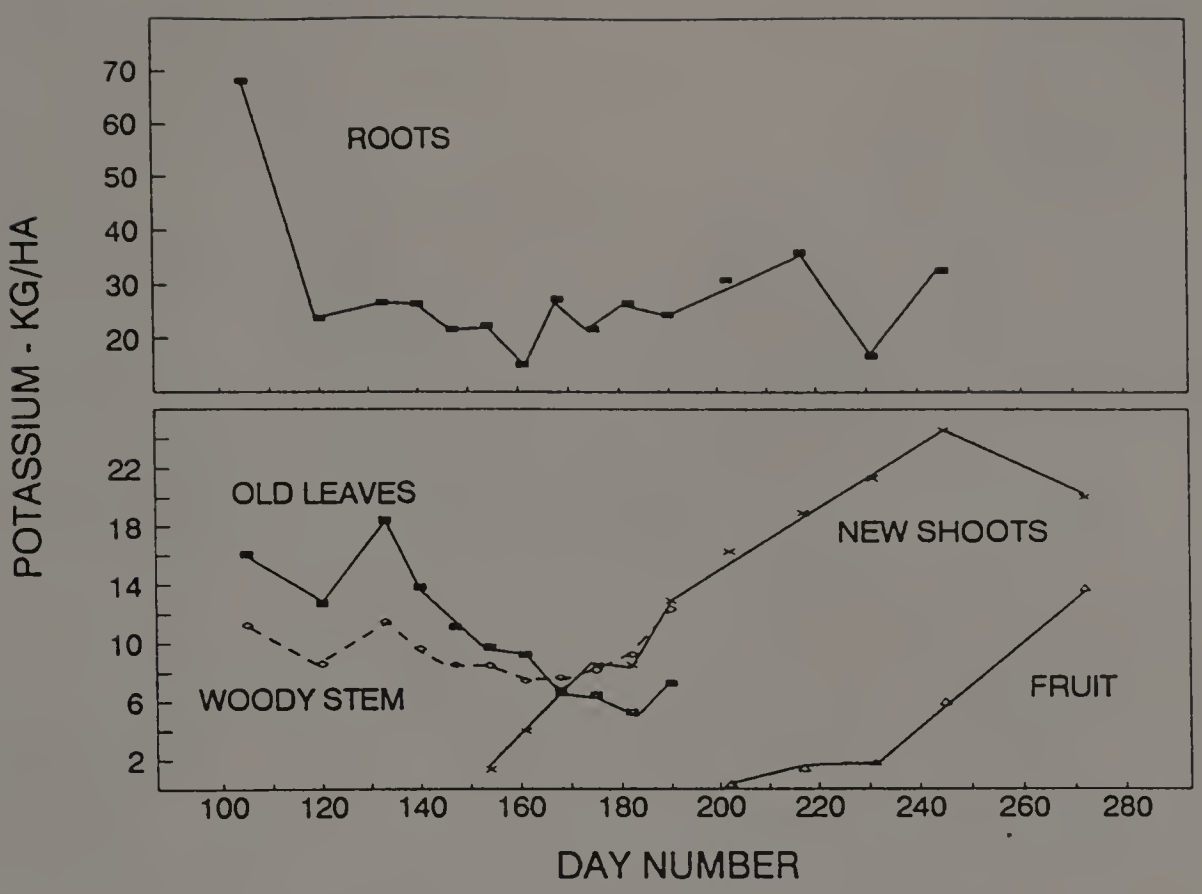

Figure 6.53 Seasonal K content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

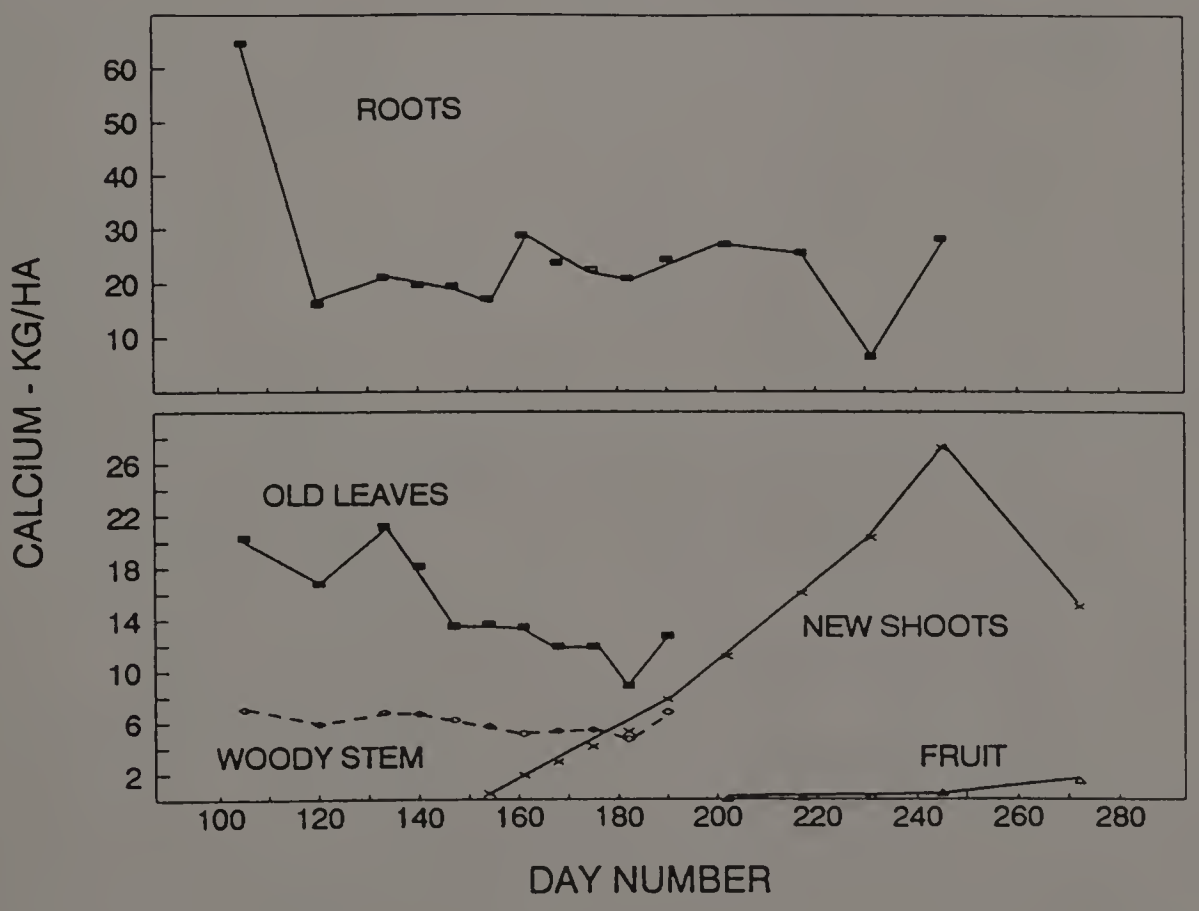

Figure 6.54 Seasonal Ca content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

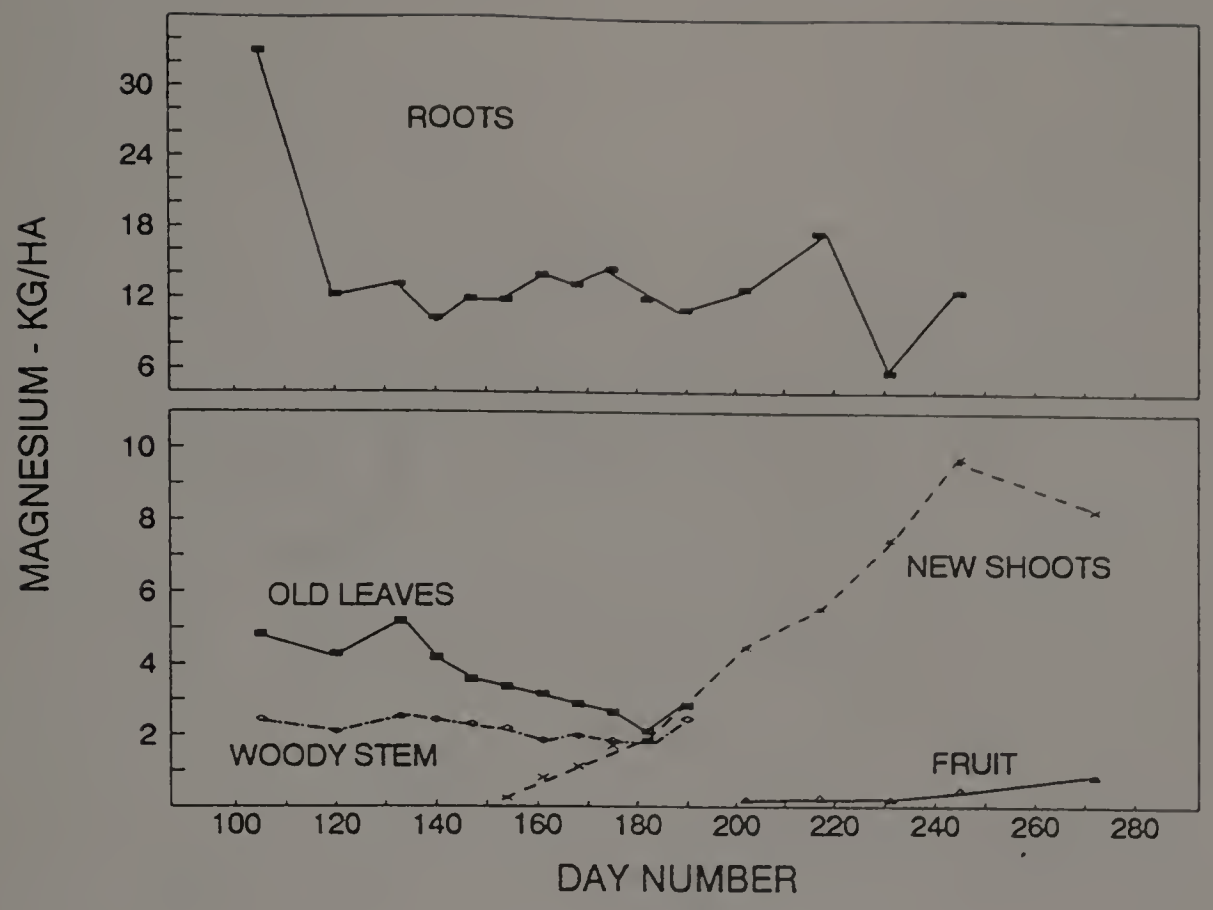

Figure 6.55 Seasonal Mg content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

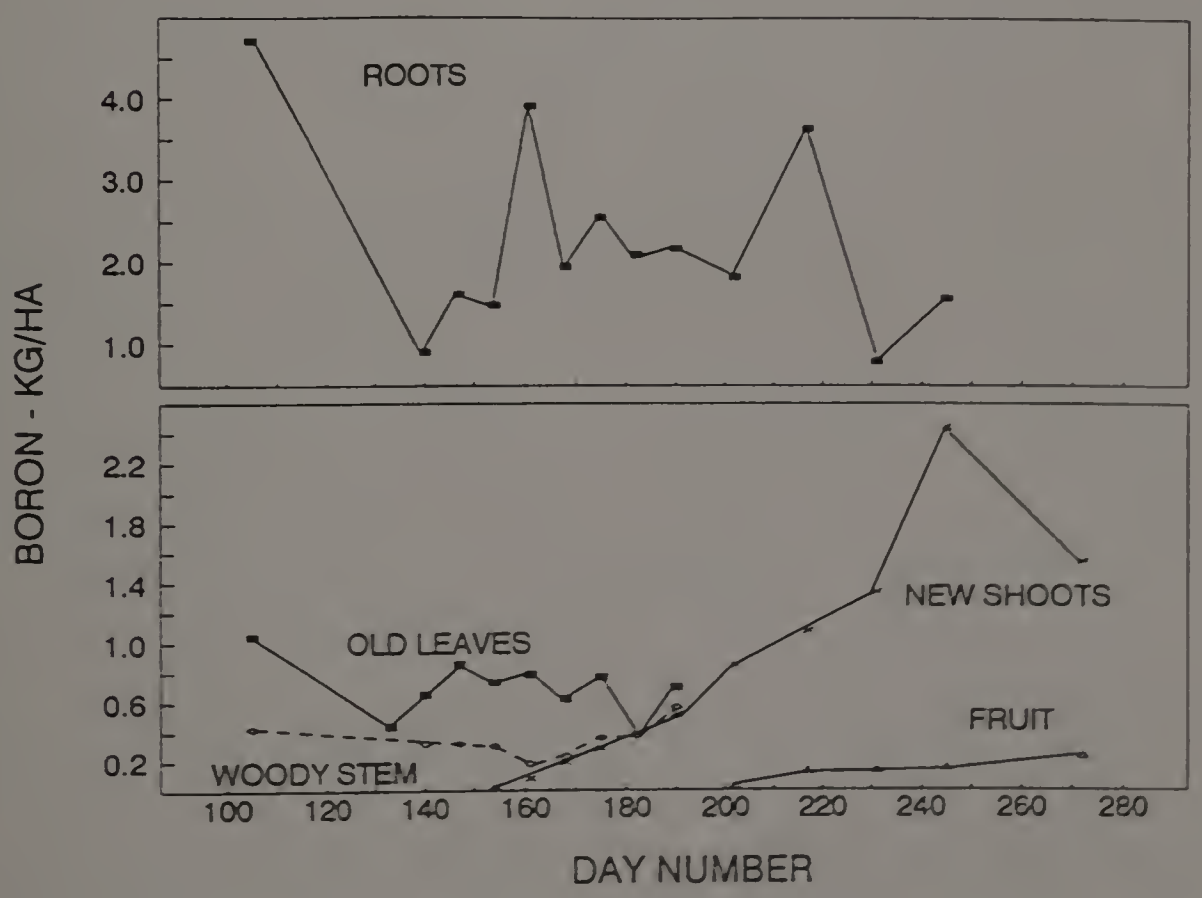

Figure 6.56 Seasonal B content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

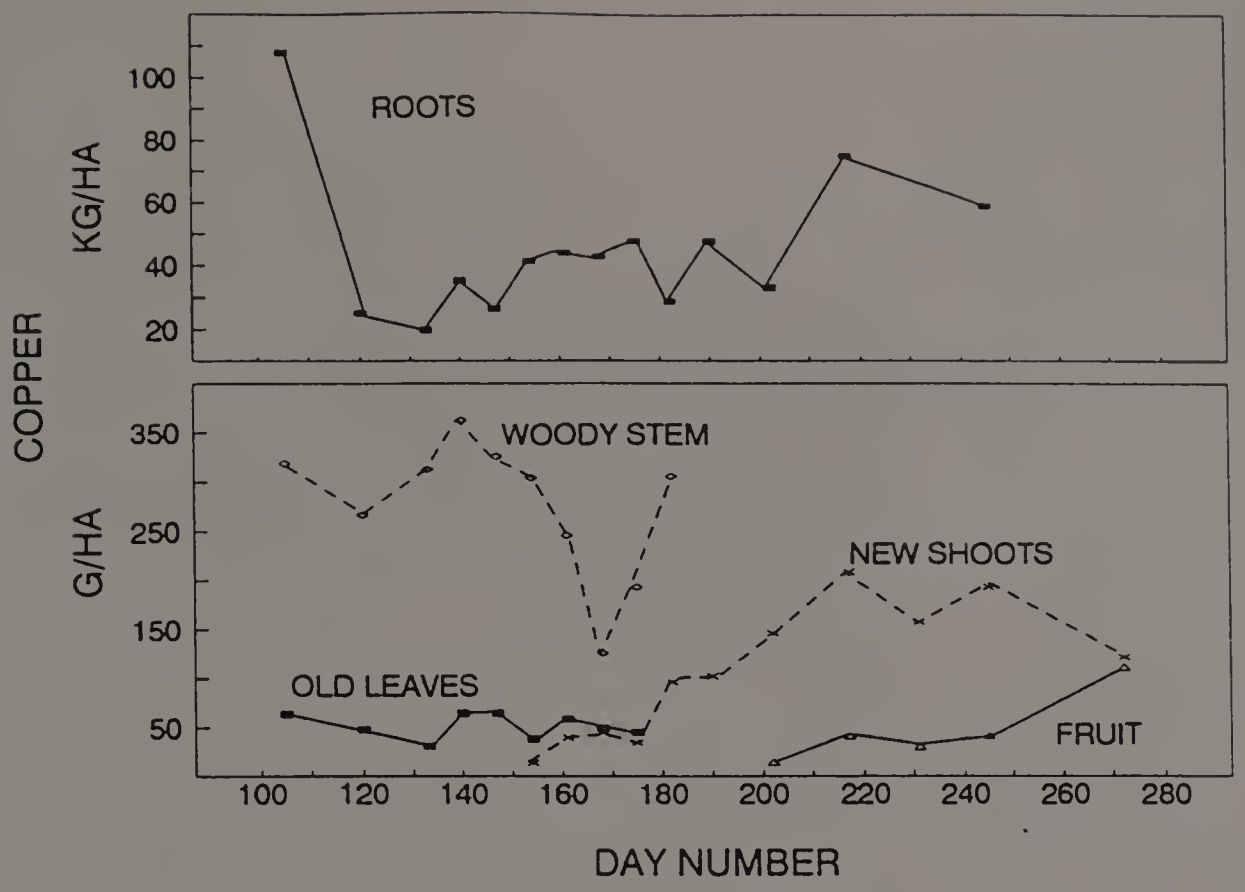

Figure 6.57 Seasonal Cu content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

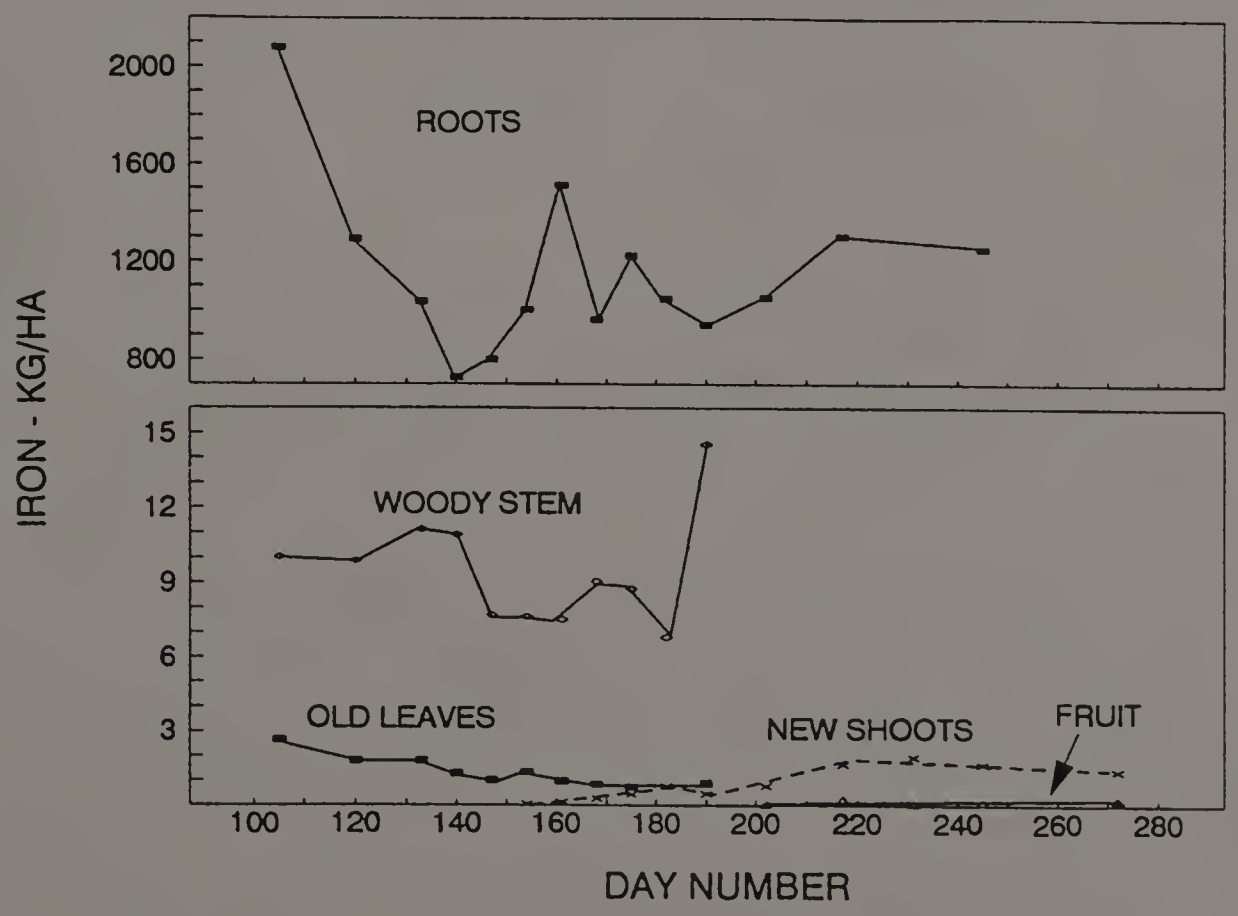

Figure 6.58 Seasonal Fe content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

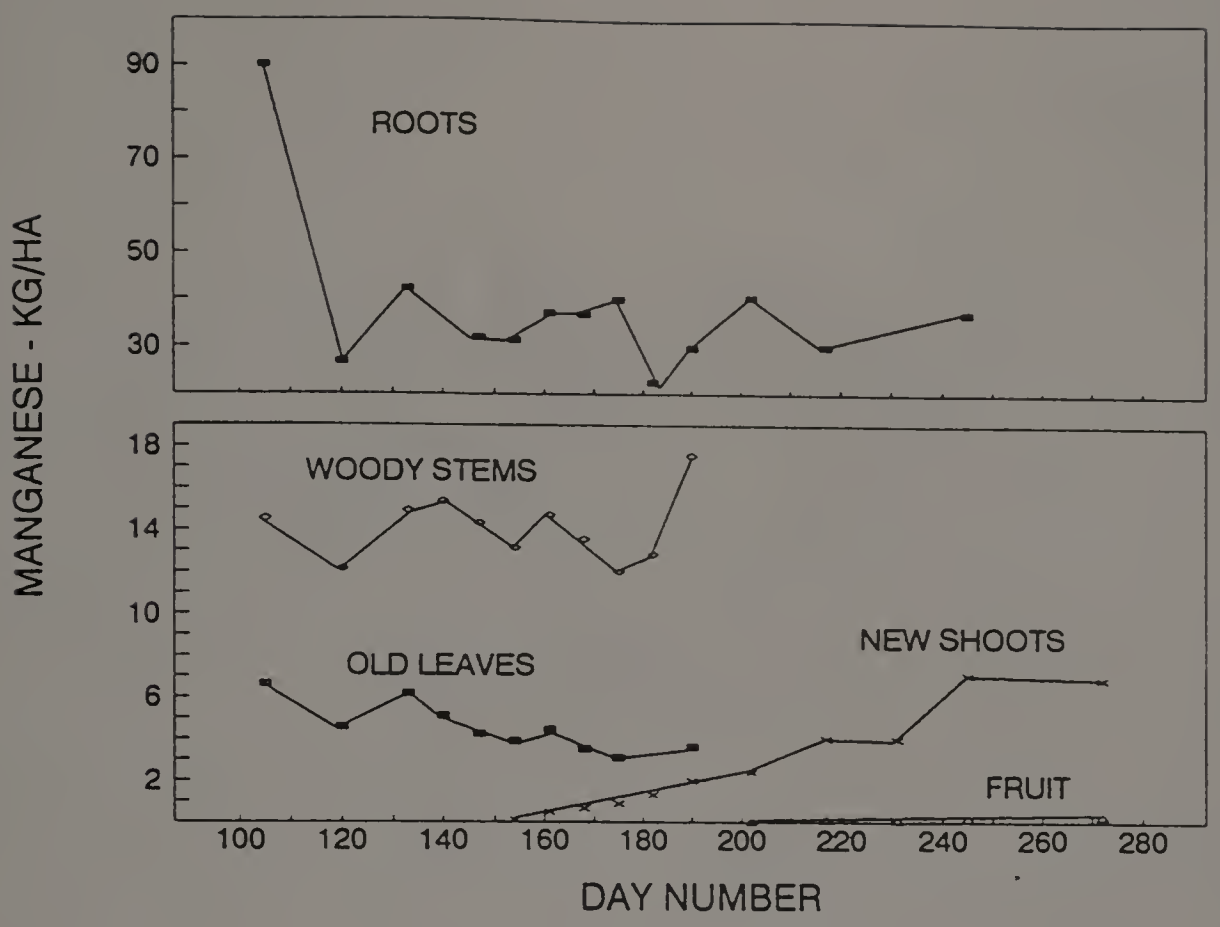

Figure 6.59 Seasonal Mn content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

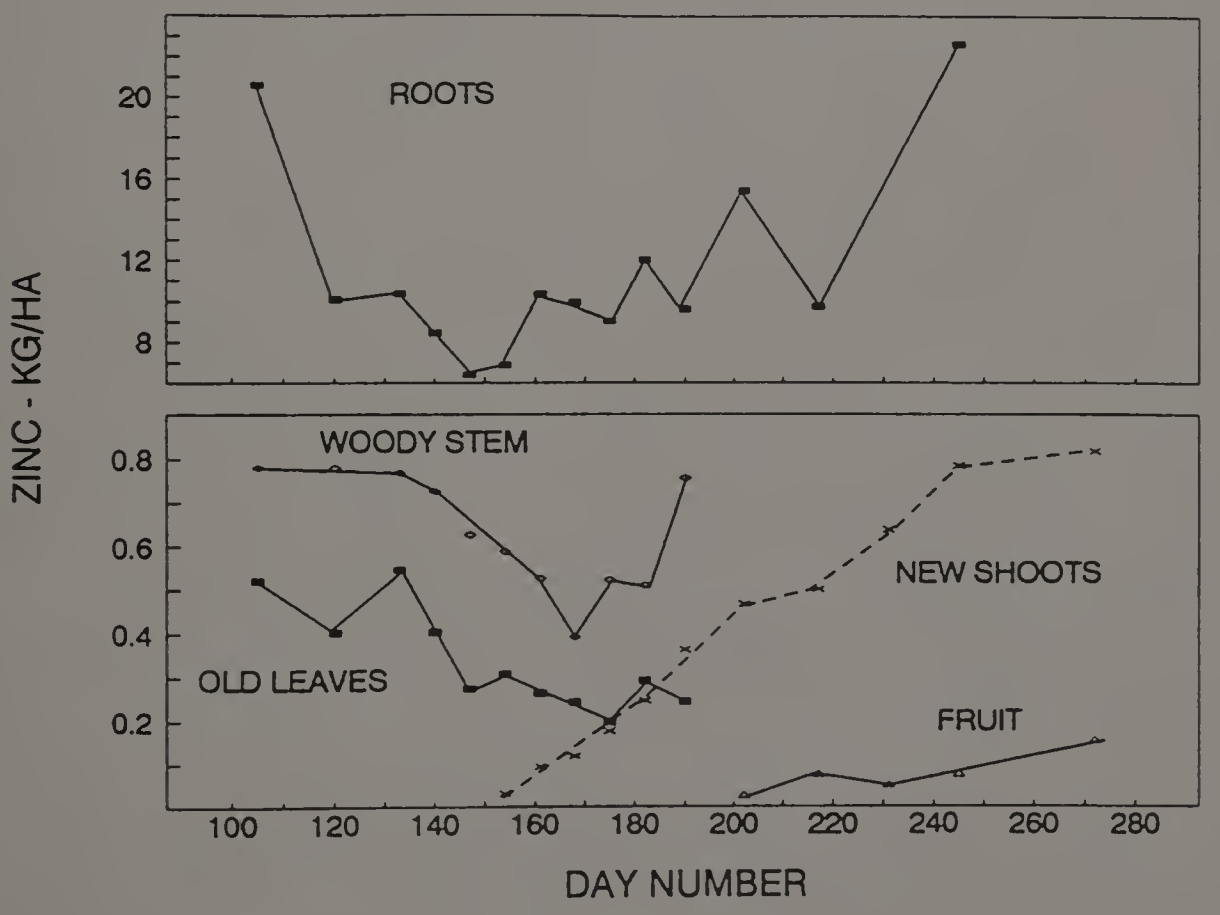

Figure 6.60 Seasonal Zn content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1987 plots, means of 5 replicates.

CHAPTER 7

'EARLY BLACK' CRANBERRY DEVELOPMENT AND TEMPERATURE INTERACTIONS

7.1 Timing of Developmental Events

In recent years, cranberry fertilizer applications have been timed according to developmental stages or events such as budbreak, roughneck (25 mm new growth extension), bloom, fruit set, and bud development. Growers have used a target date to begin scouting for the stages at their farms. However, there has been interest in forecasting development by growing degree days (GDD) or other heat units in order to predict more accurately year to year and location to location the onset of the stages.

7.1.1 Growing Degree Days

Growth stages were recorded during the four years of the nutrient study. The stages were then compared to day number (Table 7.1), GDD-6.5C (Table 7.2), or GDD-9C (Table 7.3). The GDD were accumulated from sheltered ambient upland temperatures at the bog location. Coefficient of variation (CV) had been found to be the best method for comparing base temperatures for GDD models (Arnold, 1959). Based on the CVs for the three types of comparison, day number was a better predictor than GDD. If GDD were to be used as predictors for cranberry developmental stages, the lower base temperature should be used (smaller CVs). In studies of temperate tree fruit crops

Table 7.1 Developmental events for 'Early Black' cranberry. Day numbers. Coefficient of variation (CV) in percent.

Developmental stage	1986	1987	1988	1989	CV
Greening	100	102	105		1.4
Roughneck	147	147	148	145	0.4
Hook	154	154	151	153	0.5
Bloom (1%)	161	161	162	160	0.3
Bloom (50%)	174	175	177	174	0.4
Set (90%)	190	186	196	190	1.1
End growth		245	245	236	1.2

Table 7.2 Developmental events for 'Early Black' cranberry. Growing degree days, base temperature 6.5C. Coefficient of variation (CV) in percent.

Developmental stage	1986	1987	1988	1989	CV
Greening	63	72	52		9.3
Roughneck	416	392	363	392	2.8
Hook	554	579	420	525	6.7
Bloom (1%)	693	709	585	695	4.3
Bloom (50%)	927	1033	943	1016	2.7
Set (90%)	1318	1305	1402	1416	2.1
End growth		2792	2815	2684	1.5

Table 7.3 Developmental events for 'Early Black' cranberry. Growing degree days, base temperature 9C. Coefficient of variation (CV) in percent.

Developmental stage	1986	1987	1988	1989	CV
Greening	17	29	13		24.4
Roughneck	228	222	199	231	3.3
Hook	339	381	243	336	9.0
Bloom (1%)	449	483	364	474	6.1
Bloom (50%)	631	751	662	738	4.2
Set (90%)	958	979	1046	1074	2.7
End growth		2230	2262	2158	1.4

(Richardson, et al., 1985) low temperatures (4.5C) were recommended in models predicting bloom.

Hawker and Stang (1985) compared GDD to cranberry growth stages at three separate Wisconsin locations during a single year, using a base temperature of 9C. They found that hook stage (375 GDD), bloom (510 GDD), early fruit set (850 GDD), and late fruit set (1,000 GDD) occurred at the same number of GDD for each location. A comparison to GDD accumulations (Table 7.3) in Massachusetts for four years at one location showed that using a base temperature of 9C, the timing of the events corresponded well. The average times for hook stage (325 GDD), early bloom (443 GDD), and late bloom (696 GDD) in Massachusetts fell within about 50 GDD of the Wisconsin prediction. However, fruit set (1,014 GDD) was the most closely predicted by the Wisconsin model. While there was good prediction of the average GDD for certain events, the prediction in a given year showed more variability with the 9C base temperature than with 6.5C (Table 7.2). It appeared that GDD models for cranberry development were fairly accurate but did not justify the expense involved in collecting the data. Day number modelling was more accurate and required no special equipment. However, this conclusion was based on a comparison of one site over years. There may be more value in using GDD as predictors to compare several sites with varying microclimates within the same year.

Based on CV comparisons, a base temperature of 6.5C was a better choice than 9C for GDD accumulation for cranberries. These base temperatures were compared with data collected in an upland shelter adjacent to the bog. GDD data were also collected from the canopy level in the bog from 1986 to 1988 with devices which allowed the use

Table 7.4 Developmental events for 'Early Black' cranberry. Growing degree days, base temperature 9C, at canopy level. Coefficient of variation (CV) in percent.

Developmental stage	1986	1987	1988	CV
Greening	34	21	29	13.5
Roughneck	416	274	287	13.9
Hook	526	417	328	13.5
Bloom (1%)	633	516	439	10.7
Bloom (50%)	835	763	721	4.3
Set (90%)	1144	1041	1101	2.7

Table 7.5 Developmental events for 'Early Black' cranberry. Growing degree days, base temperature 6.5C, at canopy level. Coefficient of variation (CV) in percent.

Developmental stage	1986	1987	1988	CV
Greening	48	34	48	10.8
Roughneck	561	397	414	11.4
Hook	697	569	466	11.6
Bloom (1%)	832	694	615	8.9
Bloom (50%)	1086	995	955	3.8
Set (90%)	1464	1233	1411	5.1

Table 7.6 Developmental events for 'Early Black' cranberry. Growing degree days, base temperature 4.5C, at canopy level. Coefficient of variation (CV) in percent.

Developmental stage	1986	1987	1988	CV
Greening	71	55	80	10.6
Roughneck	735	556	605	8.5
Hook	898	755	670	8.6
Bloom (1%)	1061	907	870	6.2
Bloom (50%)	1364	1264	1283	2.4
Set (90%)	1806	1556	1834	5.1

of several base temperatures. Base temperatures of 9C, 6.5C, and 4.5C were compared (Tables 7.4, 7.5, and 7.6). Based on CV comparisons, the most accurate base temperature in the canopy for predicting cranberry development was 4.5C. A comparison of the 9C and 6.5C data for canopy vs. sheltered GDDs showed that more GDD accumulated for each stage in the canopy model. This would be the expected result if the base temperature was too high. The higher daily temperatures at canopy level would introduce a larger error in the GDD accumulation than would the lower sheltered temperatures (Arnold, 1959). Regardless of the location of the temperature sensor, it was apparent that a base temperature of 9C for GDD accumulations in cranberry was too high.

7.1.2 Growth Units

Pilcher (1985) proposed a model for cranberry growth based on a lamboid curve. Growth units were accumulated between 7C and 29C. Two separate relationships were used to describe the two parts of the curve, one between 7C and 18C and the other between 18C and 29C. Using this model the calculated growth units (GU) for bloom and fruit maturity at Long Beach, Washington were 472 and 1,028, respectively (1,500 GU total from budbreak to fruit maturity). The Pilcher (1985) model was applied to Massachusetts cranberry growth from 1986 to 1989 at East Wareham. The results are shown in Table 7.7. The total GU needed to reach fruit maturity from budbreak in Massachusetts were similar to those for Washington. However, in Massachusetts, more of the GU accumulated in the first stage (budbreak to bloom). This may

Table 7.7 Growth unit (Pilcher, 1985) accumulation for 'Early Black' cranberry in Massachusetts.

Year	Budbreak to bloom	Bloom to fruit maturity	Total
1986	621	976	1597
1987	559	997	1556
1988	554	816	1370
1989	636	970	1606
mean	593	940	1533

be related to differences in average temperature and daylength between the two regions, or to the fact that bloom seems to occur about a week earlier in Long Beach (Pilcher, 1985) than in East Wareham, based on day numbers.

The GU model required a more complex set of calculations than did the GDD model and did not provide a significant improvement in predicting development (CV was about the same for the two methods - data not shown). Day number, followed by GDD remained the best methods for predicting cranberry developmental events.

7.2 Relationship between Growing Degree Days and Major Element Concentrations in Cranberry New Shoot Tissue

If GDD were to be used as predictors for developmental events in cranberry at different locations within a season, it might be useful to know how the concentrations of the major elements in the new shoot tissue could be expected to vary with GDD. This would be especially true if the developmental events were then used to schedule fertilizer applications.

The data for concentrations of N, P, K, Ca, and Mg in new shoot tissue of cranberries receiving 335 kg N-P-K/ha were plotted vs. GDD (Figures 7.1 to 7.5, p. 153-155). The plots were compared to those of the same data plotted vs. day number (Figures 6.1, p. 114; 6.6, p. 116; 6.11, p. 119; 6.16, p. 121; and 6.21, p. 124). The plots for N, K, and Mg did not differ in shape or tightness of fit among years for either day number or GDD. In fact, there was a peak in Mg concentration which did not occur at either the same day number (Figure 6.21, p. 124) or the same number of GDD (Figure 7.5, p. 155) in the different years. The data for Ca concentration showed a closer convergence of year curves based on day number (Figure 6.16, p. 121) than based on GDD (Figure 7.4, p. 154). The P concentration data plots were similar for both day number and GDD during the later half of the season. However, in the early season, there was better convergence among years when P concentration was plotted vs. GDD (Figure 7.2, p. 153).

The improvement in fit using GDD in the early season was due to the fact that most of the variation in cumulative GDD from year to year at the experimental site occurred in April and May (Figure 7.6, p. 155). By June the GDD had converged and remained roughly similar for the rest of the season (Figure 7.7, p. 156).

Since in at least one case improved fit was achieved by plotting concentrations vs. GDD compared to plotting vs. day numbers, quadratic regression equations were generated for percent N in new growth vs. day number or GDD (Williams, 1987). Percent N was chosen because no improvement with GDD was detected upon visual inspection of the two types of graph for that element and because N tissue analyses were

Table 7.8 Calculated quadratic equations for seasonal nitrogen movement in new growth of cranberry. Equations correlate sampling date (D) or growing degree days, base 6.5C (G) and nutrient level.

Year	Regression equation		R^2
1987	$0.00015\ D^2 - 0.06957\ D + 8.981$	(n=237)	0.63
1988	$0.00017\ D^2 - 0.07797\ D + 9.637$	(n=198)	0.77
1989	$0.00013\ D^2 - 0.05837\ D + 7.495$	(n=199)	0.72
3 years	$0.00015\ D^2 - 0.07025\ D + 8.895$	(n=634)	0.67
3 years (log)	$0.00011\ D^2 - 0.05047\ D + 5.678$	(n=634)	0.66
1987	$4x10^{-7}\ G^2 - 0.00179\ G + 2\ 709$	(n=237)	0.66
1988	$3x10^{-7}\ G^2 - 0.00136\ G + 2.253$	(n=198)	0.73
1989	$3x10^{-7}\ G^2 - 0.00117\ G + 2.115$	(n=199)	0.72
3 years	$3x10^{-7}\ G^2 - 0.00139\ G + 2.360$	(n=634)	0.66
3 years (log)	$2.3x10^{-7}\ G^2 - 0.00100\ G + 0.973$	(n=634)	0.66

those most often used in the cranberry industry as the basis for fertilizer decisions. The results are shown in Table 7.8. For the individual years, there was a slight improvement in the fit of the curve when GDD were used in 1987 and 1988 (compare R^2 values). However, in 1989 or when all years were combined, plotting percent N vs. GDD has no better fit statistically then plotting percent N vs. day number. Based on the appearance of the curves (Figure 7.1, p. 153), a logarithmic relationship was investigated (log-transformed concentrations). The fit of the curve was not improved vs. day number or GDD by log-transformation of the percent N data (Table 7.8).

As was the case for predicting developmental events, the use of GDD to follow nutrient movement did not significantly improve upon comparisons made on the basis of day number. If a nutrient level is correlated with a particular developmental stage, then the use of GDD

may have limited value between locations within a year. Based on the nutrient data gathered in this study, there was a large demand for N, P, and K beginning at hook stage for the production of new shoot tissue. This demand seemed to increase at fruit set; the levels of N, P, and K in the new shoots fell more rapidly at that time, likely due to mobilization to the developing fruit.

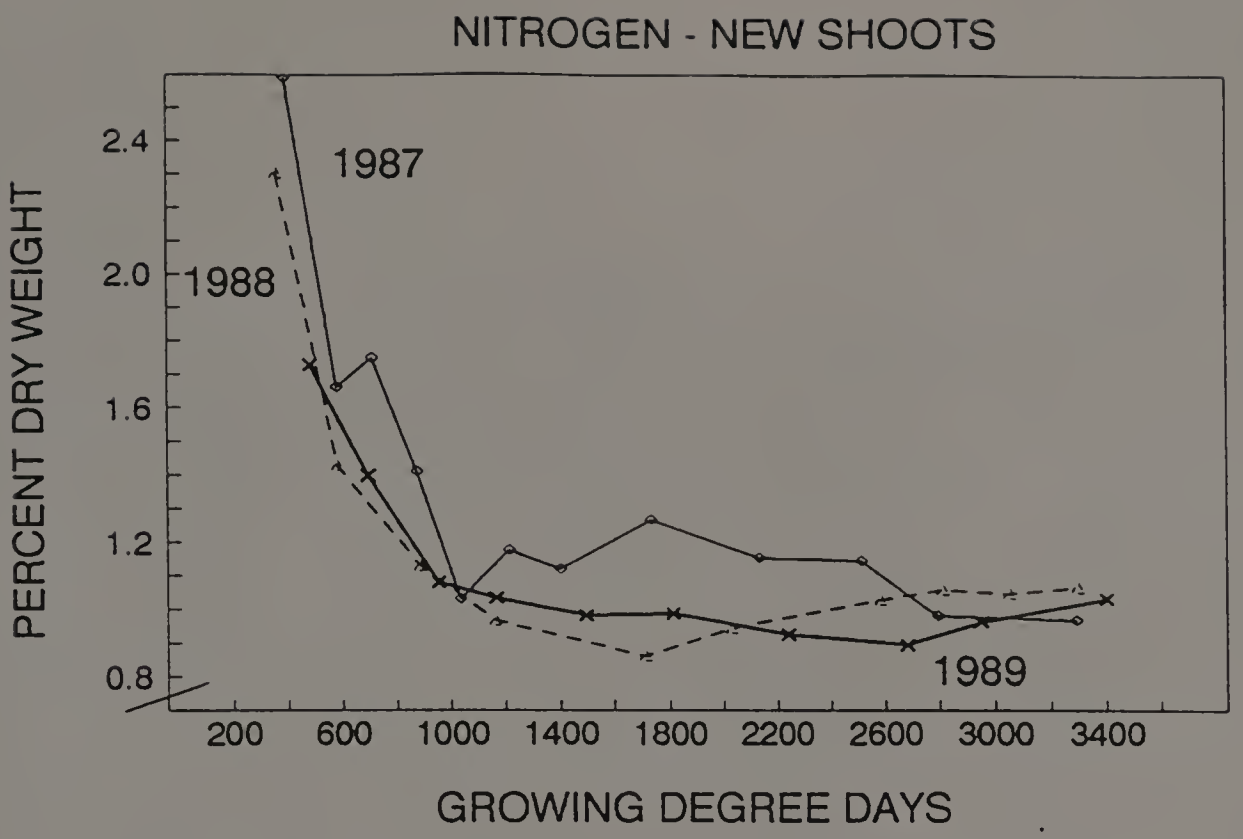

Figure 7.1 Nitrogen (percent dry weight) in new shoot tissue of cranberries receiving 335 kg N-P-K/ha: 1987 (diamonds), 1988 (broken line), and 1989 (x). Values are means of 5 replicates.

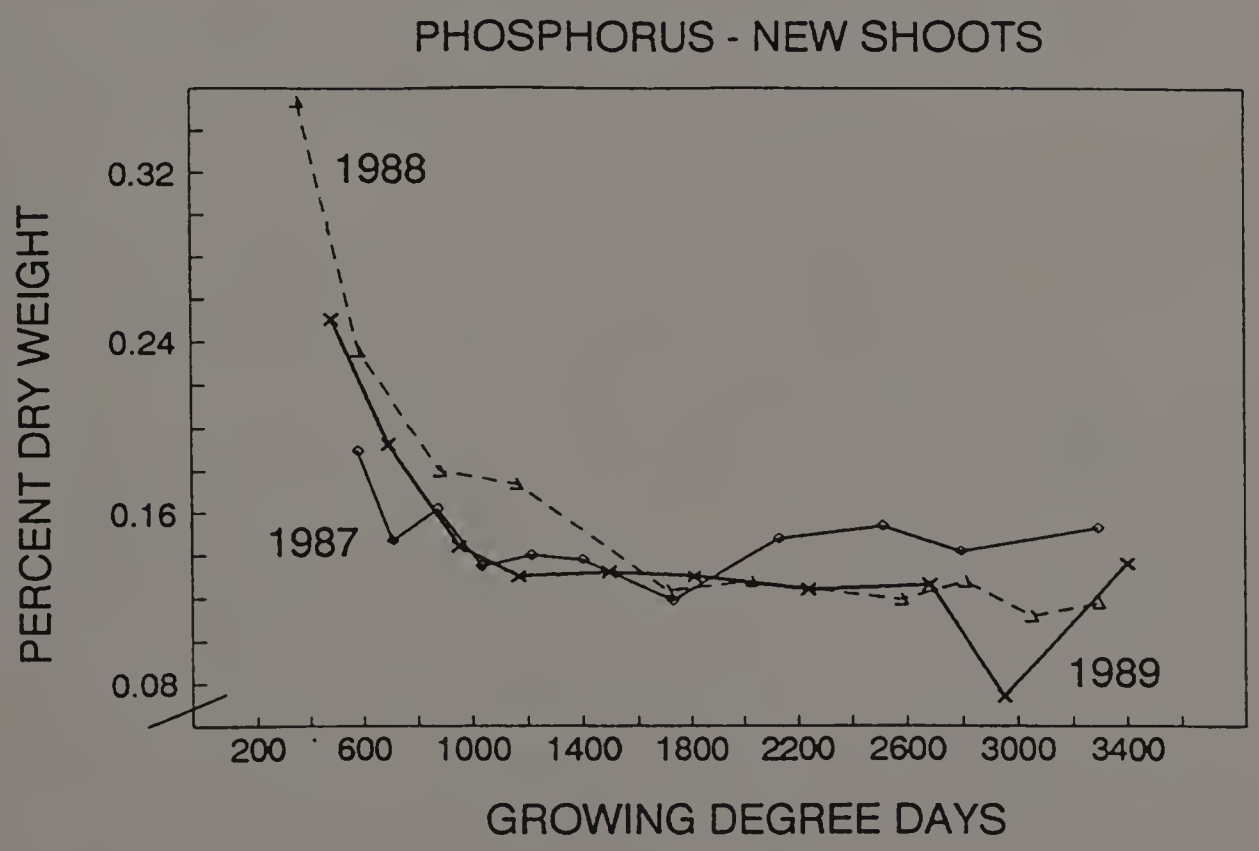

Figure 7.2 Phosphorus (percent dry weight) in new shoot tissue of cranberries receiving 335 kg N-P-K/ha: 1987 (diamonds), 1988 (broken line), and 1989 (x). Values are means of 5 replicates.

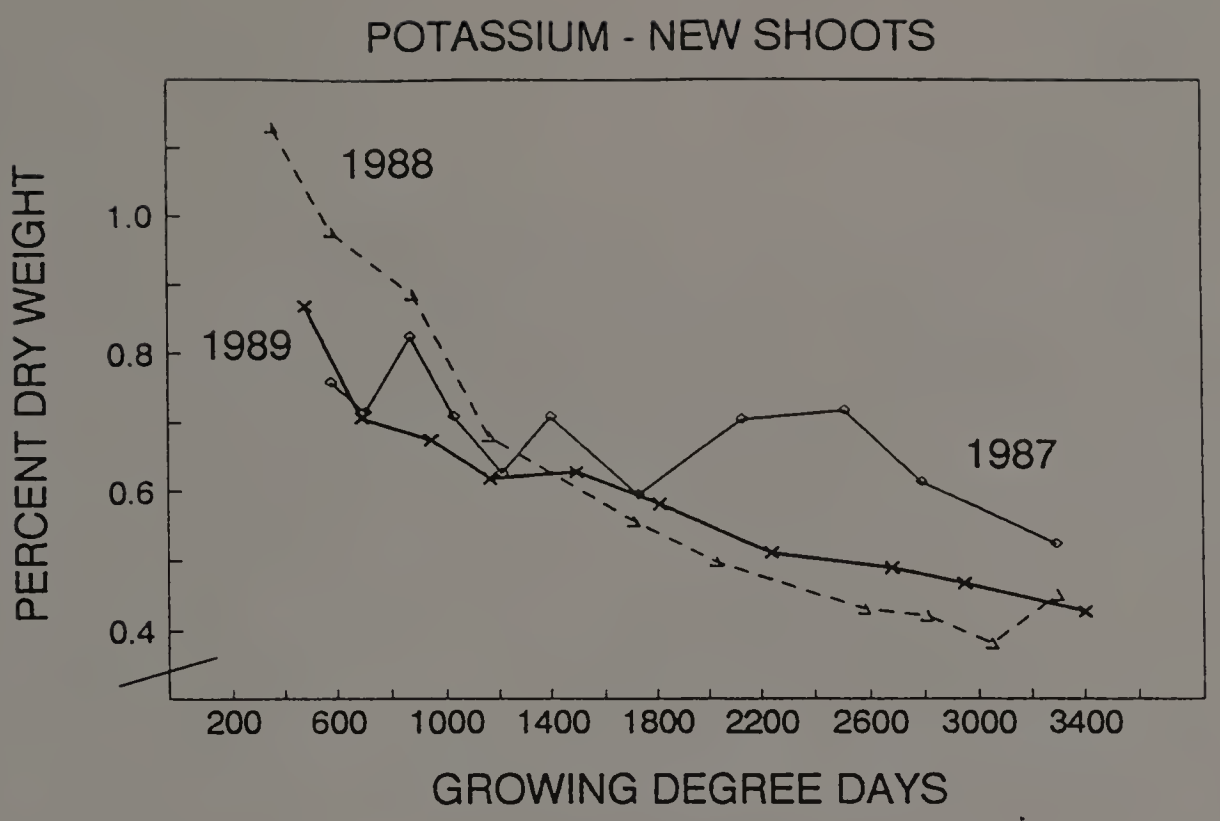

Figure 7.3 Potassium (percent dry weight) in new shoot tissue of cranberries receiving 335 kg N-P-K/ha: 1987 (diamonds), 1988 (broken line), and 1989 (x). Values are means of 5 replicates.

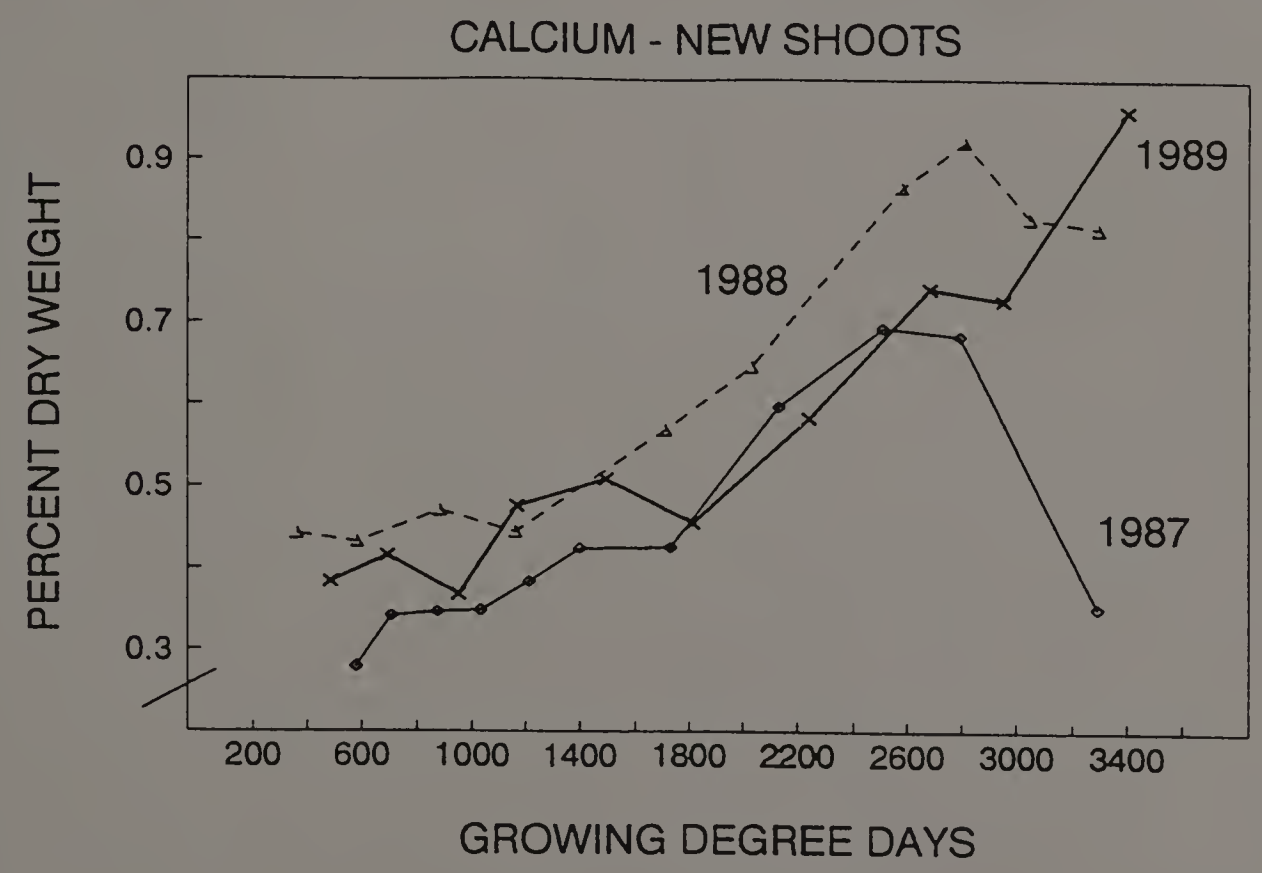

Figure 7.4 Calcium (percent dry weight) in new shoot tissue of cranberries receiving 335 kg N-P-K/ha: 1987 (diamonds), 1988 (broken line), and 1989 (x). Values are means of 5 replicates.

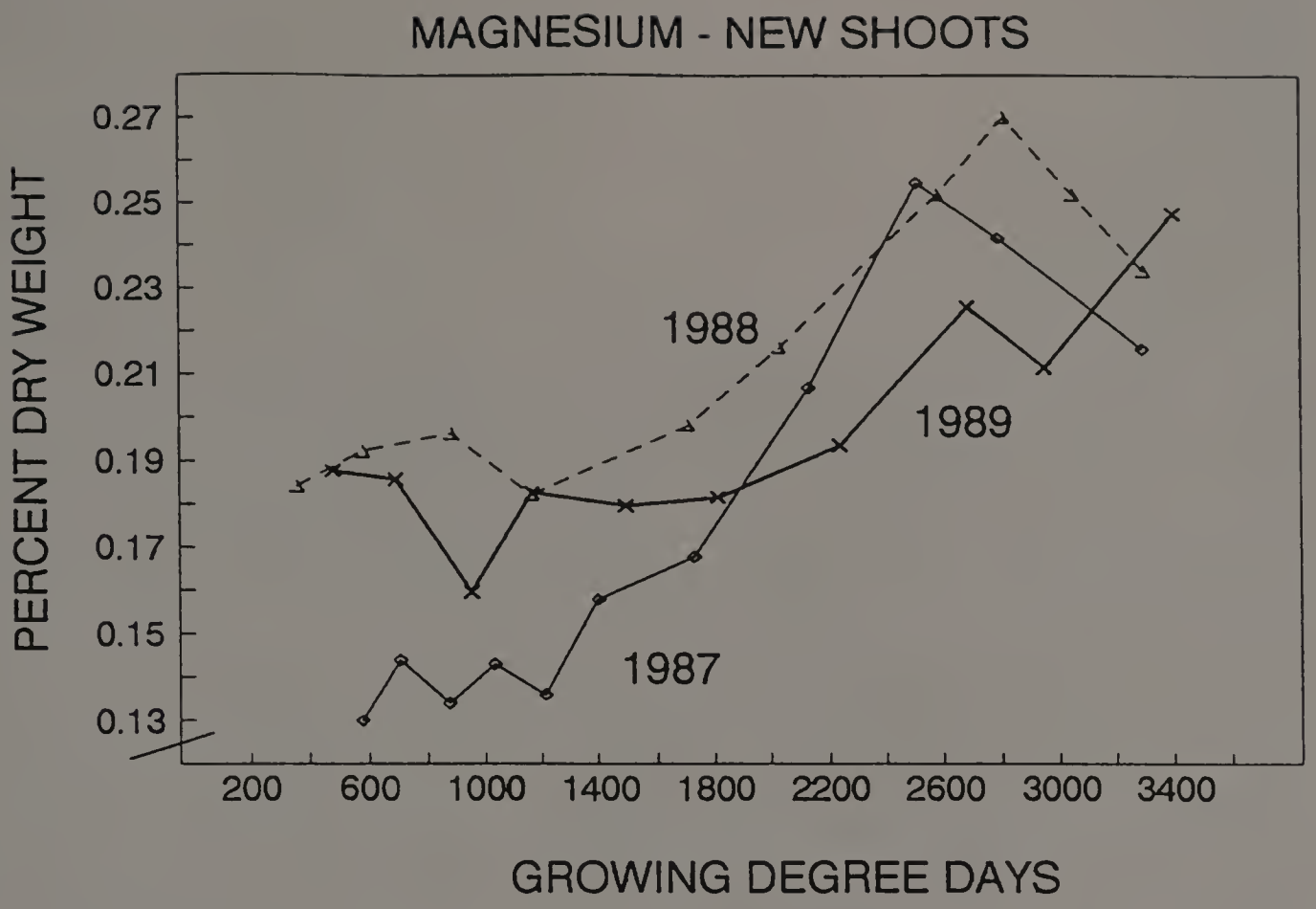

Figure 7.5 Magnesium (percent dry weight) in new shoot tissue of cranberries receiving 335 kg N-P-K/ha: 1987 (diamonds), 1988 (broken line), and 1989 (x). Values are means of 5 replicates.

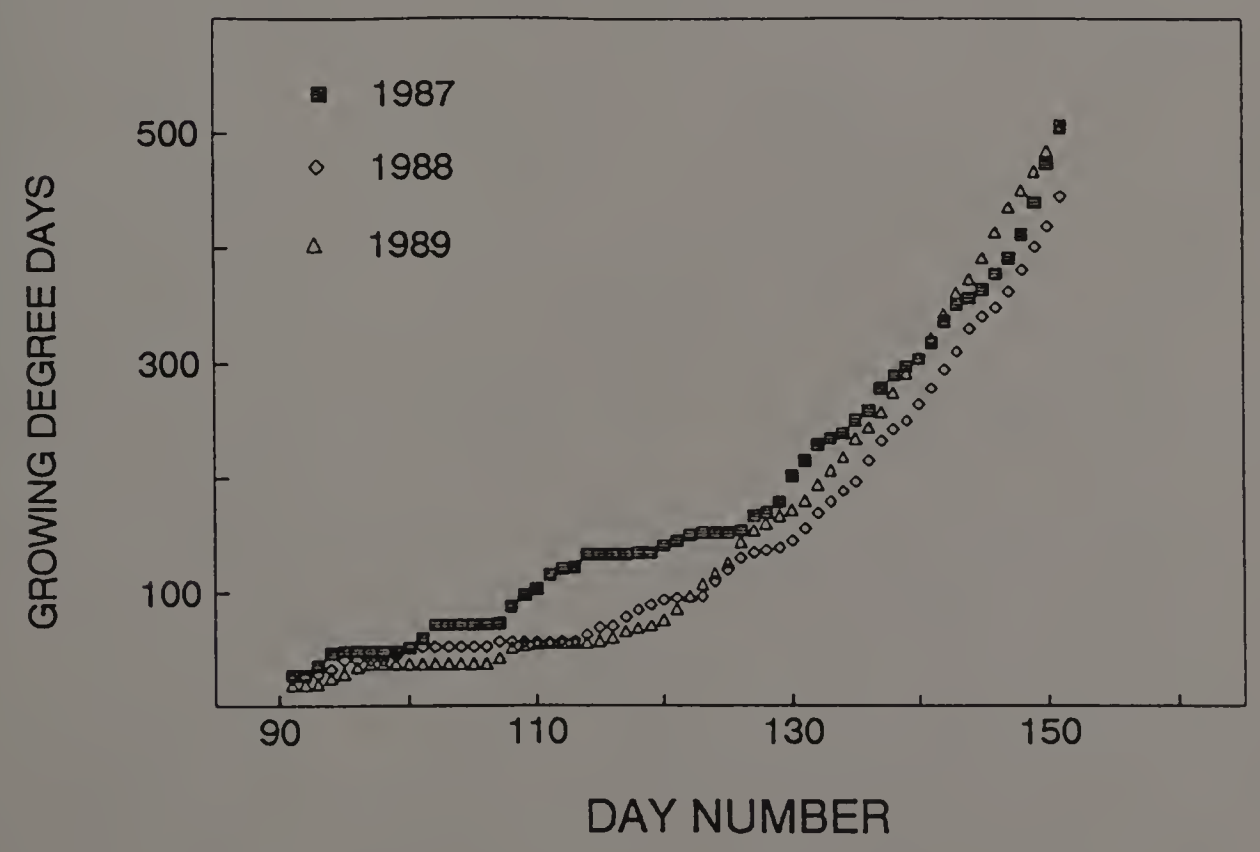

Figure 7.6 Accumulated growing degree days, 1 April to 31 May. Base temperature 6.5C.

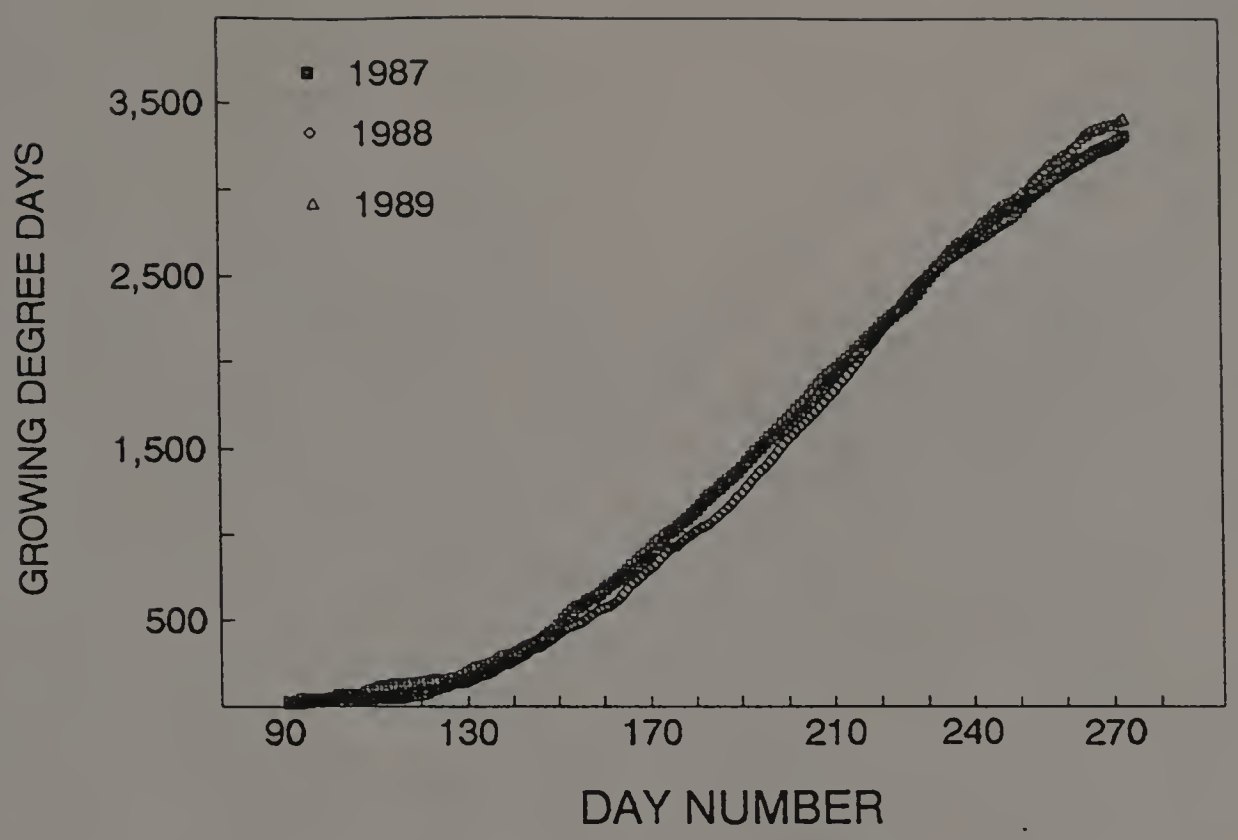

Figure 7.7 Accumulated growing degree days, 1 April to 30 September. Base temperature 6.5C.

CHAPTER 8

DEVELOPMENTAL PATTERNS AND NUTRIENT LEVELS FOR SIX COMMERCIAL CRANBERRY CULTIVARS

8.1 Reproductive Development

Six cultivars were available for study, all receiving the same management practices. The cultivars were 'Early Black', 'Howes', 'Stevens', 'Pilgrim', 'Bergman', and 'Franklin'. 'Early Black' and 'Howes' account for 90% or more of the Massachusetts crop. Both were selections from the wild. 'Stevens', a product of selective breeding in the 1960s, has become more popular in recent years due to its large fruit and high productivity. 'Pilgrim' and 'Bergman' account for very little Massachusetts acreage, but 'Bergman' is one of three major cultivars grown in British Columbia (Eaton and Kyte, 1978). 'Franklin' is a cross between 'Early Black' and 'Howes'.

During the three years of the study (1989 to 1991), 'Bergman', 'Early Black', and 'Franklin' had the shortest average fruit development periods, 73, 76, and 76 days from 50% open bloom to fruit maturity (end of fresh weight accumulation). 'Howes' and 'Pilgrim' were 'late-season' cultivars with average development periods of 88 and 92 days, and 'Stevens' was 'mid-season' at 81 days. The cultivars with the shortest fruit development period also had the earliest bloom dates. 'Howes' bloomed latest in the season among the six cultivars.

8.1.1 Components of Yield

At the end of each season, certain components of yield were determined for each of the six cultivars (Table 8.1). Upright density

Table 8.1 Cultivar evaluation: yield components. Fruit wt is fresh weight for individual fruit and U_T is total uprights per 180 cm^2 area. Values represent the means of 4 replicates. Means followed by the same letter do not differ statistically (Tukey test).

1989					
Cultivar	$\%U_F$	%Set	$Flowers/U_F$		
Early Black	11.2 b	50.7 ab	3.19 ab		
Howes	20.2 a	57.7 a	2.75 ab		
Stevens	7.2 b	60.0 a	2.41 b		
Pilgrim	7.3 b	52.8 ab	2.43 b		
Bergman	22.1 a	38.1 b	3.43 a		
Franklin	11.2 b	46.2 ab	2.61 ab		
Sig. of F	p>0.001	p=0.042	p=0.009		
1990					
Cultivar	$\%U_F$	%Set	$Flowers/U_F$	Fruit wt	
Early Black	38.3 a	35.1 bc	3.71 a	0.70 b	
Howes	43.1 a	56.5 a	3.02 bc	0.83 b	
Stevens	41.2 a	27.6 c	3.45 ab	1.40 a	
Pilgrim	25.6 a	28.3 c	3.71 a	1.34 a	
Bergman	41.2 a	33.6 bc	3.52 ab	0.93 b	
Franklin	28.5 a	44.6 b	2.69 c	0.84 b	
Sig. of F	p>0.05	p<0.001	p<0.001	p<0.001	
1991					
Cultivar	$\%U_F$	%Set	$Flowers/U_F$	Fruit wt	U_T
Early Black	32.4 ab	25.9 ab	4.26 a	0.85 d	100 ab
Howes	42.7 a	31.2 a	3.35 bc	0.94 d	89 b
Stevens	38.5 ab	10.8 c	4.03 a	1.77 b	91 ab
Pilgrim	36.8 ab	13.0 bc	3.81 ab	2.24 a	93 ab
Bergman	30.5 ab	30.2 a	2.72 c	1.17 c	101 a
Franklin	25.9 b	29.8 a	2.95 c	1.14 c	90 ab
Sig. of F	p=0.028	p<0.001	p<0.001	p<0.001	p=0.01

(U_T) was determined only in 1991. All of the cultivars had similar densities of uprights with the exception of 'Howes', which had lower density than 'Bergman'. The proportion of 'Howes' uprights bearing flowers and fruit ($\%U_F$) was in the first rank for all years. 'Howes' had fewer flowers per flowering upright than some of the other cultivars, but fruit set in 'Howes' was in the first rank in all three years. The 'Howes' section at the experimental site had a history of producing high yields. A large proportion of flowering uprights with high fruit set seemed to overcome low upright density, average numbers of flowers per flowering upright, and low weight per fruit. Low upright density with a large percent flowering may have been an advantage in allowing adequate pollinator access to flowers leading to good fruit set. Moderate numbers of flowers per upright would have led to less competition among developing fruit on an upright and perhaps less fruit abortion.

Fruit set in all but 'Bergman' was exceptionally high in 1989. In previous studies, fruit set in cranberry was between 30 and 40 percent (Bain, 1948). One possible explanation was the very low numbers of uprights flowering that year. When the total number of flowers is low, a high percent must set fruit in order to produce a given yield. In other words, high fruit set compensated for small numbers of flowers. Eaton and MacPherson (1978) studied seven cultivars, including 'Bergman', 'Early Black', and 'Pilgrim' for one year in British Columbia. They found no differences in percent set, numbers of flowers, or numbers of flowering uprights among the cultivars represented in this study.

The number of flowers per flowering upright varied from year to year for all of the cultivars. However, 'Early Black' consistently appeared in the first rank, with three or more flowers each year, and 'Franklin' consistently had fewer than three flowers per upright. 'Franklin' had fewer flowers per upright than either of its parent strains in all three years.

Based on visual inspection of fruit, 'Early Black', 'Howes', and 'Franklin' could be classified as small-fruited. This was also true based on fruit weight (Table 8.1). 'Stevens' and 'Pilgrim' were large-fruited in appearance and weight. 'Bergman' was intermediate, with a larger size (volume) than the small-fruited cultivars but a lower weight than the large-fruited cultivars. The large fruit in 'Stevens' and 'Pilgrim' were mainly responsible for high yields for those cultivars. Both tended to be in the middle rank for upright density, flowering, and set, but were significantly greater than the other cultivars in weight per fruit.

High yields could be achieved with any of the cultivars. However, vine stand and flowering response as well as fruit set had to be maximized in order for small-fruited cultivars to produce large crops. With the large-fruited cultivars, average values for other components of yield could be overcome by the size (weight) of the fruit.

8.1.2 Fruit Development

Growth curves for fruit in the six cultivars were constructed. Fresh and dry weight accumulations were correlated with day number

Table 8.2 Calculated polynomial equations for fruit development of cranberry, 6 cultivars. Degree of polynomial chosen based on sequential regression analyses.

Cultivar	Regression equation		R^2
	1989 fresh wt (g)/fruit		
Early Black	$-0.00010\ D^2 + 0.0592\ D - 7.484$	(n=16)	0.97
Howes	$-0.00011\ D^2 + 0.0655\ D - 8.215$	(n=16)	0.98
Stevens	$-0.00018\ D^2 + 0.1086\ D - 13.86$	(n=16)	0.94
Pilgrim	$0.0259\ D - 4.774$	(n=16)	0.95
Bergman	$-0.00014\ D^2 + 0.0824\ D - 10.502$	(n=14)	0.94
Franklin	$-0.00015\ D^2 + 0.0829\ D - 10.26$	(n=14)	0.93
	1990 fresh wt (g)/fruit		
Early Black	$-0.00014\ D^2 + 0.0762\ D - 9.582$	(n=14)	0.96
Howes	$-0.00015\ D^2 + 0.0856\ D - 10.745$	(n=14)	0.98
Stevens	$-0.00031\ D^2 + 0.1701\ D - 21.163$	(n=14)	0.97
Pilgrim	$-0.00025\ D^2 + 0.1395\ D - 17.632$	(n=12)	0.97
Bergman	$-0.00017\ D^2 + 0.0964\ D - 12.358$	(n=13)	0.98
Franklin	$-0.00028\ D^2 + 0.1447\ D - 17.455$	(n=10)	0.98
	1991 fresh wt (g)/fruit		
Early Black	$0.0128\ D - 2.313$	(n=9)	0.97
Howes	$-0.00020\ D^2 + 0.1037\ D - 12.613$	(n=10)	0.99
Stevens	$-0.00039\ D^2 + 0.2052\ D - 24.911$	(n=10)	0.98
Pilgrim	$0.0266\ D - 4.888$	(n=10)	0.93
Bergman	$-0.00034\ D^2 + 0.1696\ D - 19.831$	(n=9)	0.97
Franklin	$-0.00027\ D^2 + 0.1396\ D - 16.685$	(n=9)	0.99

using regression analysis. Generally, the relationship was best described with a second degree polynomial (Tables 8.2 and 8.3). The relationships for fresh weight accumulation in 1989, 1990, and 1991 (Table 8.2) were plotted (Figures 8.1A and B to 8.3A and B, p. 181-182). In all three years, 'Early Black' and 'Howes' had the smallest fruit with very similar developmental curves. The hybrid 'Franklin'

had a somewhat steeper growth curve and larger final weight than either parent. 'Bergman' was grouped with the large-fruited 'Stevens' and 'Pilgrim' based on its 1989 growth curve (Figure 8.1A, p. 180). In 1989, 'Bergman' kept pace with the growth rates of the other two for about half of the developmental period. In 1991, 'Bergman' kept pace for only one third of the growth period, and in 1990 its growth rate only kept pace with that of 'Pilgrim' for about one week. In two of the three years, the best fitting growth curve for 'Pilgrim' was linear. The highest early rates of growth seemed to consistently translate into the largest fruit at the end of the season.

Table 8.3 Calculated polynomial equations for fruit development of cranberry, 6 cultivars. Degree of polynomial chosen based on sequential regression analyses.

Cultivar	Regression equation		R^2
	1989 dry wt (g)/fruit		
Early Black	$-9.6\times10^{-7}\ D^2 + 0.0057\ D - 0.728$	(n=14)	0.98
Howes	$-9.8\times10^{-7}\ D^2 + 0.0059\ D - 0.758$	(n=14)	0.98
Stevens	$-15.8\times10^{-7}\ D^2 + 0.0963\ D - 1.244$	(n=14)	0.96
Pilgrim	$0.0025\ D - 0.464$	(n=14)	0.96
Bergman	$0.0022\ D - 0.395$	(n=12)	0.94
Franklin	$-17.0\times10^{-7}\ D^2 + 0.0090\ D - 1.139$	(n=12)	0.96
	1990 dry wt (g)/fruit		
Early Black	$-8.9\times10^{-7}\ D^2 + 0.0056\ D - 0.751$	(n=14)	0.98
Howes	$-11.2\times10^{-7}\ D^2 + 0.0069\ D - 0.911$	(n=14)	0.99
Stevens	$-17.7\times10^{-7}\ D^2 + 0.0111\ D - 1.479$	(n=14)	0.98
Pilgrim	$-16.7\times10^{-7}\ D^2 + 0.0103\ D - 1.359$	(n=12)	0.97
Bergman	$-7.6\times10^{-7}\ D^2 + 0.0056\ D - 0.798$	(n=13)	0.99
Franklin	$-20.6\times10^{-7}\ D^2 + 0.0011\ D - 0.415$	(n=10)	0.99

The 'best-fit' equations for dry weight accumulation in cultivar fruit were calculated (Table 8.3). The linear relationships between dry weight accumulation and day number were plotted for the 1989 data based on the fact that for two of the cultivars, the quadratic relationships were not statistically significant ($p>0.05$). The relationships among the cultivars for dry weight-based growth rates in 1989 (Figures 8.4A and B, p. 183) were similar to those for fresh weight-based rates. 'Early Black' and 'Howes' diverged only late in the season, but 'Franklin' maintained a steeper growth curve throughout the period. As for fresh weight, the 'Bergman' growth rate diverged from those of 'Stevens' and 'Pilgrim' about half way through the growth period. The regression lines generated from the 1990 dry weight data (Figures 8.5A and B, p. 184) were remarkably similar among cultivars to those for the fresh weight accumulation in that year (Figures 8.2A and B, p. 181). The growth rates for the six cultivars in 1990 were quite distinct from one another. It should be noted that the regression relationships for fruit development were heavily weighted towards the linear component (little contribution of the quadratic). However, the quadratic coefficient was significant and the R^2 values for the equations were improved in going from linear to quadratic.

The early fruit development period growth rate was important in determining the final fruit weight. During those early weeks dry weight, including mineral elements, accumulated rapidly. Nutrition needed to be adequate during that time. Additionally, enough carbohydrate reserve must have been available for transport to the developing fruit. Adequate, functional foliage needed to be present

prior to the onset of fruit development to satisfy the demand for photosynthate (Roper et al., 1992). The amount of foliage present in turn depended on adequate mineral nutrition early in the season. Fruit fresh weight actually declined late in the season in some cases, most likely due to water loss associated with over-ripeness.

The important factors in maximizing fruit harvest weight were adequate nutrition to support early fruit development and harvesting before the fruit began to decline in weight. For the early cultivars ('Early Black', 'Bergman', and 'Franklin') harvest should occur by the end of September.

Weekly during the 1991 growing season, developing fruit from the six cultivars were separated into six size classes, less than 5.6 mm, 5.6-8 mm, 8-11.2 mm, 11.2-13.2 mm, 13.2-16 mm, and larger than 16 mm. The first collection was done in the second week of July. The size classes were determined by the ability of the fruit to pass through stacked sieves with openings of the various diameters. The percentages of fruit in each size class were calculated on the basis of total weight of fruit in the sample (Figures 8.6A to 8.11A, p. 185-190) or on the basis of fruit numbers in the sample (Figures 8.6B to 8.11B, p. 185-190). Large numbers of fruit in a small size class would contribute less to the total weight of fruit than would large numbers of larger-sized fruit.

The six cultivars could be divided into three groups based on the developmental patterns for fruit size classes. The first group, 'Early Black' and 'Howes', had initially large numbers of the smallest size fruit and smaller numbers of 5.6-8 mm fruit declining during the first five weeks of development (Figures 8.6 and 8.7A and B, p. 185-

186). During the first two weeks, 8-11.2 mm fruit increased and then began to decline in week three, as the 11.2-13.2 mm and 13.2-16 mm fruit increased. These patterns reflect the growth of individual fruit which move from one size class to another over time. By the end of the season, almost all of the fruit for these cultivars were between 11.2 and 16 mm in size. Less than 10% were larger or smaller.

The second group was comprised of 'Bergman' and 'Franklin'. In this group fruit moved out of the two smallest size classes more rapidly than did those in the first group (Figures 8.10 and 8.11A and B, p. 189-190). By week four, the 11.2-13.2 mm and 13.2-16 mm classes were dominant. At the end of the season, most of the fruit were 13.2-16 mm in diameter, with 15% (by weight) larger than 16 mm, and the same amount 11.2-13.2 mm. Less than 5% were fruit in the three smallest classes.

In the third group, 'Stevens' and 'Pilgrim', the two smallest size classes made insignificant contributions to total weight from the second week (Figures 8.8 and 8.9A and B, p. 187-188), although they were present until week five. Fruit in the 13.2-16 mm size class were making significant contributions to total weight by week two, and by week five only the three largest size classes were important. At the end of the season, all 'Pilgrim' fruit were greater than 16 mm in diameter and 'Stevens' were about half that size and half between 13.2 and 16 mm.

This study reinforced the previous information regarding fruit weight accumulation. Large fruit rapidly became large early in the growing period. The important transition time from small to large fruit occurred from week 3 to 5 (late July to early August). Any

effect of fertilizer on fruit development would have to occur early in that period. Most likely later fruit enlargement is due to accumulation of water and carbohydrates.

8.1.3 Yield Analyses

Yield analyses were performed in 1991 for the six cultivars. Samples (30 x 30 cm, 8 replicates) were assessed for upright density (U_T), percent of uprights flowering (%U_F), flowers per flowering upright (flower/U_F), percent fruit set, and weight per fruit. Yield

Table 8.4 Stepwise regression models for yield component data, regression with constant. Variables chosen from: U_T, %U_F, flower/U_F, %set, g/fruit, yield. Regression equations chosen based on yield component analysis, regression coefficients significant at 5% level.

Cultivar	Variables chosen in step analysis
Early Black	none
Howes	%U_F, %set, g/fruit
Stevens	%U_F, flower/U_F, %set
Pilgrim	U_T, %U_F, %set
Bergman	U_T, %U_F, flower/U_F, %set, g/fruit
Franklin	U_T, %U_F, flower/U_F, %set, g/fruit

	Regression equations, Yield=
E. Black	7.58 + 0.79 U_T + 0.99 %U_F + 0.74 flower/U_F + 1.06 %set
Howes	11.36 + 0.39 %U_F + 0.89 %set + 1.37 g/fruit
Stevens	12.45 + 0.88 %U_F + 0.95 %set
Pilgrim	6.24 + 1.14 U_T + 0.60 %U_F + 0.62 %set
Bergman	5.77 + 1.08 U_T + 0.93 %U_F + 1.43 flower/U_F + 1.17 %set
Franklin	10.51 + 1.03 %U_F + 1.45 flower/U_F + 0.91 %set

Table 8.5 Stepwise regression models for yield component data, regression without constant. Variables chosen from: U_T, $\%U_F$, flower/U_F, %set, g/fruit, yield. Regression equations chosen based on yield component analysis, regression coefficients significant at 5% level.

Cultivar	Variables chosen in step analysis
Early Black	U_T, flower/U_F
Howes	U_T, $\%U_F$, g/fruit
Stevens	U_T, $\%U_F$, %set, g/fruit
Pilgrim	U_T, %set, g/fruit
Bergman	U_T
Franklin	flower/U_F

	Regression equations, Yield=
E. Black	1.528 U_T + 1.854 flower/U_F
Howes	2.236 U_T + 1.749 $\%U_F$ + 2.311 flower/U_F + 1.197 %set
Stevens	2.523 U_T + 1.816 $\%U_F$
Pilgrim	2.398 U_T + 0.700 %set
Bergman	1.987 U_T
Franklin	2.502 U_T + 1.392 %set

was determined for each sample area. All of the variables were log-transformed for the analyses.

First, the data were subjected to stepwise regression, with and without a constant, to choose variables for a yield model. The variables chosen for the six cultivars were not the same (Tables 8.4 and 8.5, upper half). No variables were selected in this process for 'Early Black' when regression with a constant in the model was attempted. Based on a model including a constant, the stepwise regression process selected percent of uprights flowering and percent fruit set as determinants of yield for all of the other cultivars and selected all of the other variables for three cultivars each. Based

on a stepwise regression model which did not include a constant, upright density and fruit weight were the most often chosen determinants of yield. Not surprisingly, fruit weight was important for 'Stevens' and 'Pilgrim'. However, fruit weight was also selected as a determinant of yield for 'Howes'.

When the variables were forced into regression equations in order of developmental events, models were selected based on the significance (5% level) of the regression coefficients (Jolliffe, et al., 1982). In models including a constant, percent flowering uprights and fruit set were important determinants of yield for all six cultivars (Table 8.4, bottom half). When the constant was removed from the model, upright density was selected as a determinant of yield for all cultivars (Table 8.5, bottom half). Fruit set was important for three of the cultivars. Interestingly, fruit weight was not selected in these analyses, even for the large-fruited cultivars.

Each yield component was used as the dependent variable for regression with the previous ones as the independent variables. Based on the regression coefficients, certain correlations between variables were determined to be significant (5% level). None of the variables were correlated for 'Early Black' and 'Stevens'. The number of flowers per upright and fruit weight were positively correlated for 'Bergman'. The positive correlation indicated a common factor that affected both variables. Flower bud initiation and ovule differentiation within the developing flower buds could have been affected by the same climatic or nutritional factors. Seeds produced from those ovules would then influence fruit weight. Negative correlations between variables were found for the other cultivars.

Negative correlations indicated compensation of one component by another (Shawa et al., 1981). Upright density was negatively correlated with percent flowering uprights and flowers per upright in 'Howes'. 'Howes' normally have a fairly sparse vine stand (Table 8.1). Dense vine stands could have been due to excess vegetative growth at the expense of flowering response. 'Pilgrim' showed negative correlations between fruit weight and percent flowering uprights, fruit set, and flowers per upright. Increases in any of those factors would be associated with increased fruit production. A large load of fruit would then be enough of a drain on plant resources to lead to lower weights for individual fruit. Fruit set for 'Franklin' was negatively correlated with upright density, perhaps due to difficulty for pollinators to get to fruit in thick stands. Of interest was the finding that none of the correlations among variables was shared among the cultivars. This method did not determine correlations between the yield component variables and yield (insufficient degrees of freedom).

Analysis of a correlation matrix of the yield component and yield data showed no correlations for 'Early Black', 'Pilgrim', and 'Bergman' variables. Fruit set and yield were positively correlated for 'Howes', 'Stevens', and 'Franklin'. The only negative correlation by this method was upright density and fruit set for 'Franklin', confirming the previous correlation analysis.

Yield analyses showed that the most important overall determinants of yield were fruit set and percent of uprights flowering, followed by upright density. Fruit weight was important, especially for the large-fruited cultivars. In a study of seven

cultivars, fruit weight became an important determinant when comparing cultivars (Eaton and MacPherson, 1978). 'Bergman' in British Columbia (Eaton and MacPherson, 1978) had flowering uprights, flowers per upright, and fruit set as the important determinants of yield. All of these components were selected for 'Bergman' by the similar yield analysis (using a constant) in this study. The cultivars did not all have the same important determinants of yield. This should be taken into account in attempts to predict experimental effects across cultivars. A treatment which affects a single yield component might have a greater effect on yield in one cultivar than in another, depending on the importance of that component in determining yield for each of the cultivars in question.

'Howes', 'Pilgrim', and 'Franklin' all showed compensation of one yield component by another. This may have been due to competition for resources among the different developmental processes (Shawa et al., 1981). This was especially likely for 'Pilgrim' where fruit weight was negatively correlated with variables that determined fruit number. Cranberry growers have maintained that high fruit set was associated with small fruit size. This negative relationship was only found for 'Pilgrim' in this study. Another possible explanation for negative correlations between yield components was some positive effect on one component having a negative effect on another. For example, excess vegetative response positively affecting upright density at the expense of reproductive processes. This would explain the negative correlations for 'Howes' and 'Franklin'. If the compensation between yield components was due to nutritional effects,

'Pilgrim' may have been deficient, while 'Howes' and 'Franklin' were exhibiting luxury consumption.

8.2 Nutrient Element Concentrations

During each of the study years (1989 and 1990), all six cultivars received the same fertilizer dose, 310 kg N-P-K/ha in 1989 and 270 kg N-P-K/ha in 1990 (10N-8.7P-8.3K). Tissue samples were collected every seven to ten days from new uprights (top 5 cm) from about four weeks after budbreak until mid-September. Fruit samples were collected from two weeks after fruit set until harvest. Samples were analyzed for ten mineral elements.

8.2.1 New Shoots

At each collection date, four tissue sample types were taken from 5 cm shoot tips: vegetative uprights only, flowering uprights only, mixed vegetative and flowering uprights, and leaves only from mixed uprights. Because analysis of variance (ANOVA) showed no significant tissue type by cultivar interaction, the data for tissues were pooled within each cultivar for analyses examining cultivar and sampling date effects. The seasonal average nutrient element content in new shoots varied by cultivar (Table 8.6). In both years, only copper concentration was not different among cultivars. Differences in K were not significant in 1990. With the exception of Zn in both years and P in 1989, 'Stevens' had as high or higher average concentrations of all of the elements compared to the other cultivars.

Table 8.6 Seasonal average element concentrations in new shoots of cranberry, 6 cultivars. Means followed by the same letter do not differ statistically (Tukey test).

1989					
Cultivar	%N	%P	%K	%Ca	%Mg
Early Black	0.96 c	0.11 c	0.46 ab	0.57 b	0.20 d
Howes	1.09 ab	0.13 b	0.45 ab	0.61 ab	0.24 a
Stevens	1.09 ab	0.13 b	0.49 a	0.59 ab	0.23 ab
Pilgrim	1.21 a	0.14 a	0.49 a	0.62 ab	0.21 bc
Bergman	0.96 c	0.11 c	0.41 b	0.65 a	0.19 d
Franklin	1.05 bc	0.13 ab	0.47 a	0.57 b	0.21 cd
Sig. of F	p<0.001	p<0.001	p=0.002	p=0.018	p<0.001
Cultivar	ppm B	ppm Cu	ppm Fe	ppm Mn	ppm Zn
Early Black	39 c	6 a	67 c	298 b	18 d
Howes	38 c	7 a	62 c	170 d	32 a
Stevens	47 ab	9 a	99 a	407 a	22 bc
Pilgrim	51 a	7 a	81 b	315 b	24 b
Bergman	40 c	5 a	74 bc	239 c	20 c
Franklin	46 b	6 a	75 bc	221 cd	22 c
Sig. of F	p<0.001	p>0.05	p<0.001	p<0.001	p<0.001
1990					
Cultivar	%N	%P	%K	%Ca	%Mg
Early Black	0.93 b	0.13 b	0.53 a	0.64 bc	0.20 cd
Howes	1.07 a	0.15 ab	0.51 a	0.69 abc	0.23 bc
Stevens	0.99 ab	0.16 a	0.52 a	0.81 a	0.28 a
Pilgrim	1.06 ab	0.14 ab	0.54 a	0.77 ab	0.23 b
Bergman	1.02 ab	0.12 b	0.49 a	0.75 ab	0.20 d
Franklin	1.08 a	0.16 a	0.58 a	0.60 c	0.20 d
Sig. of F	p=0.013	p<0.001	p>0.05	p<0.001	p<0.001
Cultivar	ppm B	ppm Cu	ppm Fe	ppm Mn	ppm Zn
Early Black	38 bc	6 a	42 d	290 bc	18 d
Howes	35 c	6 a	54 c	226 c	31 a
Stevens	44 a	6 a	85 a	360 a	25 b
Pilgrim	42 ab	6 a	68 b	264 bc	25 b
Bergman	44 ab	6 a	62 bc	286 bc	21 c
Franklin	45 a	6 a	57 c	304 ab	23 bc
Sig. of F	p<0.001	p>0.05	p<0.001	p<0.001	p<0.001

This may have been due to the high productivity of this cultivar creating a high nutrient demand. The other large-fruited cultivar, 'Pilgrim', also had high average nutrient concentrations. 'Early Black', the cultivar with the smallest fruit, had the lowest average nutrient concentrations in both seasons. Cultivar differences were significant for all elements except Mn and Cu in red raspberry (John and Daubeny, 1972). However, the significant differences in yield among the raspberry cultivars studied were not significantly correlated with element levels by simple linear regression. Similarly, the highest yields in cranberry ('Bergman' in 1989 and 'Stevens' in 1990) were not necessarily associated with the highest or lowest average element contents in the cultivar tissues. It has been suggested (John and Daubeny, 1972) that differences in element levels among cultivars could be due to differences in ability of roots to assimilate nutrients without regard to critical element levels.

The element concentrations for the six cultivars in 1989 were plotted vs. day number (Figures 8.12 to 8.21, p. 191-195). All cultivars showed declining patterns for N, P, and K levels and increasing patterns for Ca during the season. Levels of Mg rose slightly for most of the cultivars during the season. The patterns for the minor elements were more variable by cultivar, with the exception of Cu. The effect of sampling date was significant for all elements tested. The cultivar by sampling date interaction was significant for all elements except Cu in 1989. When highbush blueberry element levels on various sampling dates for different cultivars were examined in a single year, the date effect and the cultivar by date interaction were significant for all of the elements

examined (Eaton and Meehan, 1971). However, the authors warned that the relationships between sampling date, cultivar, and element levels might not hold in all years. The sampling date by cultivar interactions were not the same for cranberry in 1989 and 1990. The 1990 element levels showed significant date by cultivar interactions for K, Mg, Fe, Mn, and Zn only (data not shown).

Because all elements except Cu showed significant cultivar by date interaction, profile analyses to identify adjacent date differences were done using a C-matrix composed of cultivar vs. date data. The periods of stable nutrient levels identified were then valid across all cultivars (horizontal lines on Figures 8.12 to 8.21, p. 191-195). However, because a stable period had to be valid across all cultivars to be identified, and because the nutrient patterns among the cultivars differed, the common stable periods were often short (two weeks or less). Profile analysis within cultivars was not possible due to insufficient degrees of freedom.

8.2.2 Fruit

The nutrient concentration in fruit from the six cultivars in 1989 and 1990 were plotted against sampling date (Figures 8.22 to 8.31A and B, p. 196-205). The patterns of element concentration change over time for each element were similar between the two years. The shapes of the curves were similar for the different cultivars but the actual concentrations were quite different for some of the elements. 'Stevens' had the lowest N concentrations in fruit, but mid-level N concentrations in shoot tissue (Figure 8.12, p. 191). The

concentrations of K in 'Howes' fruit, but not in 'Howes' shoots (Figure 8.14, p. 192), in both years were noticeably lower than those in the other cultivars. If the low fruit K levels were related to lack of K availability to the plants, it was not apparent in the shoot tissue analyses and the 'Howes' bog section had average yields in both seasons. 'Bergman' had the highest Ca levels in both fruit and new shoots (Figure 8.15, p. 192). The high Ca levels in 'Bergman' fruit were not associated with superior fruit quality. Fruit from that cultivar tended to be subject to physiological and fungal breakdown early in the harvest period.

Levels of minor elements in the fruit tended to fluctuate more during fruit development than did those for major elements. Despite the variability, the pattern changes for the cultivars tended to be the same. Concentrations of B, Mn, and Zn declined as the fruit matured, while Cu and Fe levels remained generally steady with occasional peaks (Figures 8.27 to 8.31 A and B, p. 201-205). Only Mn levels showed noticeable differences among cultivars (Figures 3.30A and B, p. 204). 'Howes' fruit had the lowest Mn in both years, while 'Early Black' and 'Bergman' had the highest levels. The levels of Mn in shoots (Figure 8.20, p. 195) did not parallel those in fruit. Yield did not seem to be associated with Mn content of fruit. The two highest yielding cultivars in 1989 were 'Bergman' and 'Howes', representing the highest and lowest Mn levels for fruit.

The concentrations of the elements at the end of the fruit dry weight accumulation period (or at harvest) were tabulated (Table 8.7). The concentration of the major elements in fruit were stable within cultivars over the two years of the study with the exception of K in

Table 8.7 End of season element concentrations in fruit of cranberry, 6 cultivars. 'Early Black' = EB, 'Howes' = H, 'Stevens' = S, 'Pilgrim' = P, 'Bergman' = B, 'Franklin' = F.

Element	Year	EB	H	S	P	B	F
%N	1989	0.24	0.29	0.27	0.35	0.29	0.29
	1990	0.48	0.38	0.28	0.37	0.45	0.48
%P	1989	0.08	0.08	0.07	0.08	0.08	0.07
	1990	0.09	0.08	0.08	0.09	0.10	0.10
%K	1989	0.65	0.51	0.59	0.60	0.65	0.58
	1990	0.67	0.52	0.58	0.61	0.77	0.82
%Ca	1989	0.07	0.05	0.04	0.05	0.06	0.05
	1990	0.07	0.06	0.06	0.08	0.09	0.07
%Mg	1989	0.05	0.05	0.05	0.06	0.05	0.04
	1990	0.06	0.04	0.05	0.06	0.06	0.06
ppm B	1989	10	11	13	10	11	11
	1990	14	16	16	11	13	16
ppm Cu	1989	9	6	4	7	3	16
	1990	6	4	4	6	4	5
ppm Fe	1989	19	16	24	21	19	22
	1990	15	13	15	20	22	35
ppm Mn	1989	27	12	17	17	24	16
	1990	21	17	20	20	33	26
ppm Zn	1989	11	11	8	11	7	21
	1990	7	7	6	9	10	8

'Franklin' and N in 'Early Black', 'Howes', 'Bergman', and 'Franklin', all of which were high in 1990. Minor element concentrations were quite variable between years but less so among cultivars.

Based on the concentrations (dry weight basis) of the elements in the fruit at the end of the season and the percent dry weight of fruit from the different cultivars, the amount of mineral elements removed from a cranberry bog could be calculated for the six cultivars

Table 8.8 Weight of elements (kg/ha or g/ha) removed from a cranberry bog in a 100 bbl/A crop, based on percent dry weights. 'Early Black' = EB, 'Howes' = H, 'Stevens' = S, 'Pilgrim' = P, 'Bergman' = B, 'Franklin' = F.

Element	Year	EB	H	S	P	B	F
N	1989	2.83	3.49	3.13	3.79	3.42	3.62
(kg/ha)	1990	6.20	5.12	3.73	4.23	5.18	5.52
P	1989	0.94	0.96	0.81	0.87	0.94	0.87
(kg/ha)	1990	1.16	1.08	1.07	1.03	1.19	1.15
K	1989	7.67	6.14	6.83	6.50	7.66	7.23
(kg/ha)	1990	8.65	7.00	7.73	7.23	9.13	9.44
Ca	1989	0.83	0.84	0.58	0.54	0.71	0.62
(kg/ha)	1990	0.90	0.94	0.80	0.95	0.83	0.81
Mg	1989	0.59	0.60	0.58	0.65	0.59	0.50
(kg/ha)	1990	0.77	0.54	0.67	0.69	0.71	0.69
B	1989	11.8	12.0	12.7	10.8	13.0	13.7
(g/ha)	1990	18.1	21.6	21.3	12.6	19.0	18.4
Cu	1989	10.6	10.8	6.9	7.6	3.5	20.0
(g/ha)	1990	7.7	5.4	5.3	6.9	4.7	5.8
Fe	1989	22.9	22.9	18.5	22.7	22.4	27.4
(g/ha)	1990	19.4	17.5	20.0	22.8	26.1	40.3
Mn	1989	31.8	32.5	13.9	18.4	28.3	20.0
(g/ha)	1990	27.1	22.9	26.6	22.8	39.1	29.9
Zn	1989	13.0	13.2	9.3	11.9	8.2	26.2
(g/ha)	1990	9.0	9.4	8.0	10.3	11.9	9.2
% dry	1989	10.54	10.75	10.34	9.67	10.52	11.13
weight	1990	11.53	12.03	11.89	10.20	10.59	10.28

(Table 8.8). The calculations were based on removal in a 100 bbl/A (11.2 Mg/ha) crop. The nutrient removed in the highest amounts from the bog was K for all cultivars, followed by N. Calculated removal of N was very variable due to the variability in N content of the fruit between the two years (Table 8.7). Generally, one kg/ha or less of P,

Ca, and Mg were removed. Despite high levels of some of the minor elements in cranberry foliage, minor elements did not accumulate in fruit (Table 8.7) and at most 30 g/ha were removed in the 100 bbl/A crop, confirming the low minor element requirements for this plant.

The dry weight percent of fruit varied with cultivar and between years for the individual cultivars. This could have been related to crop load (cultivar differences) or photosynthate availability (cultivar and year differences). While the differences in dry weight did not have a great impact on the calculated removal of nutrients on a 100 bbl/A basis, often cranberry crops, especially for 'Stevens', exceed 300 bbl/A. The dry weight percent of 'Pilgrim' was lowest among the six cultivars. However, higher element concentrations compensated and the calculated removal of elements in a 100 bbl/A crop of 'Pilgrim' was similar to that for the other cultivars.

The amount of elements removed from a bog in a 100 bbl/A crop has been calculated previously (Shawa et al., 1984) based on element content of fresh fruit. The published values for P, K, and Mg were similar to those found here, but the published values for Ca was higher and those for Fe, Mn, and Cu were much higher. The higher published values could all be accounted for by the higher nutrient concentrations (2 to 3 times higher for the minor elements) on which those calculations were based.

Calculations of removal of nutrients in a 100 bbl/A crop of 'Early Black' were done for the N-P-K experiment (Tables 6.15 and 6.16 p. 108, 110). The results were similar to those found for 'Early Black' in the cultivar study. The calculated N removal for the N-P-K study, based on three years of data, is most likely the best estimate,

falling between the extremes in the cultivar study. In most years, the amount of N removed in a 100 bbl/A crop is between 5 and 6 kg/ha and K removal is between 7 and 9 kg/ha.

Although some differences in nutrient levels and patterns were apparent among the six cultivars, the nutrient demand for a given level of fruit production seemed to be similar. However, the yield potentials for all cultivars were not the same, and it was this fact that determined that the fertilizer needs for the six cultivars were not necessarily the same. Providing the same dose of fertilizer to all six cultivars in 1989 and 1990 may have led to deficiencies or excesses.

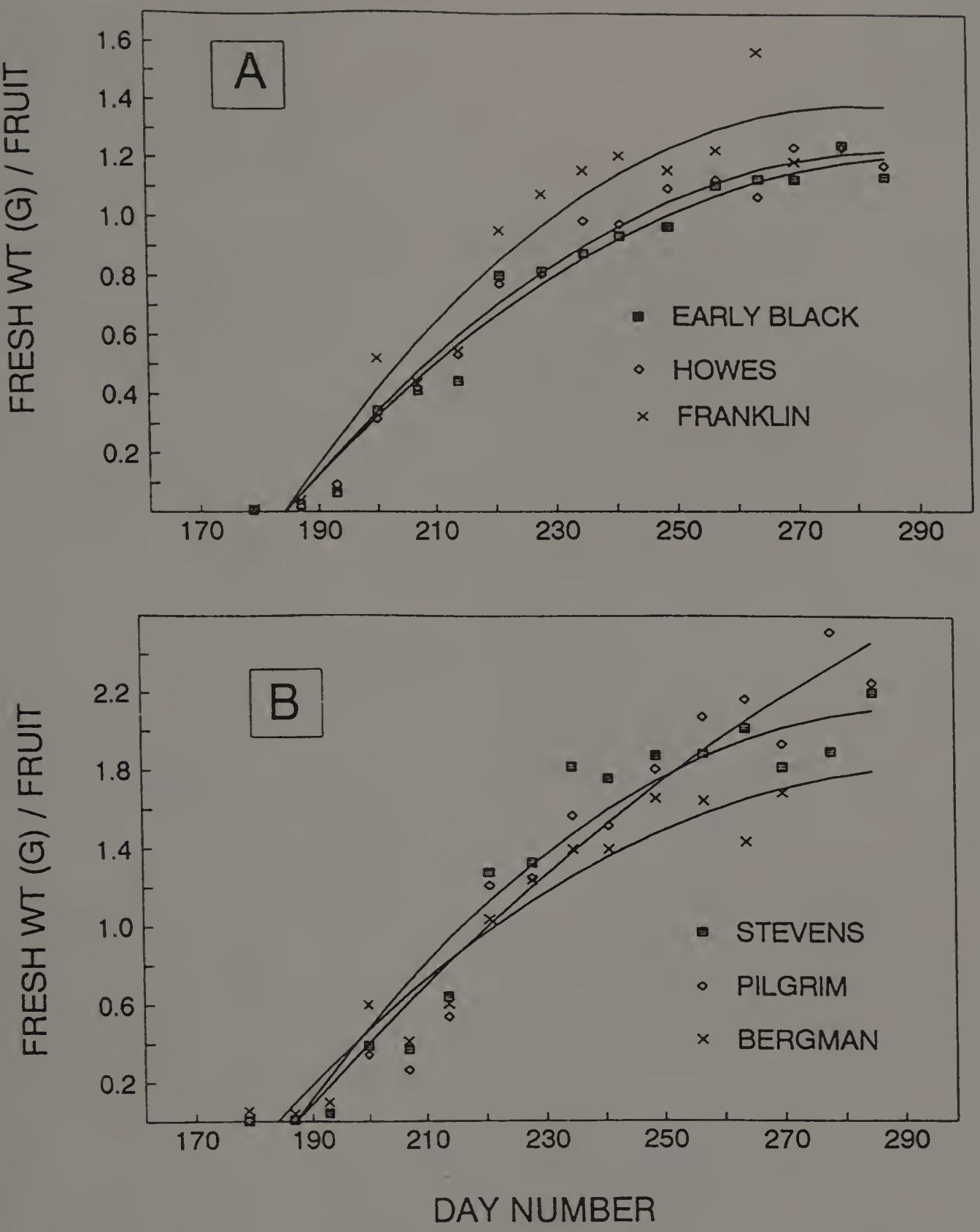

Figure 8.1 Fruit development (fresh weight) in 1989. Lines are from calculated regression (Table 8.2). A: small fruited cultivars; B: large fruited cultivars.

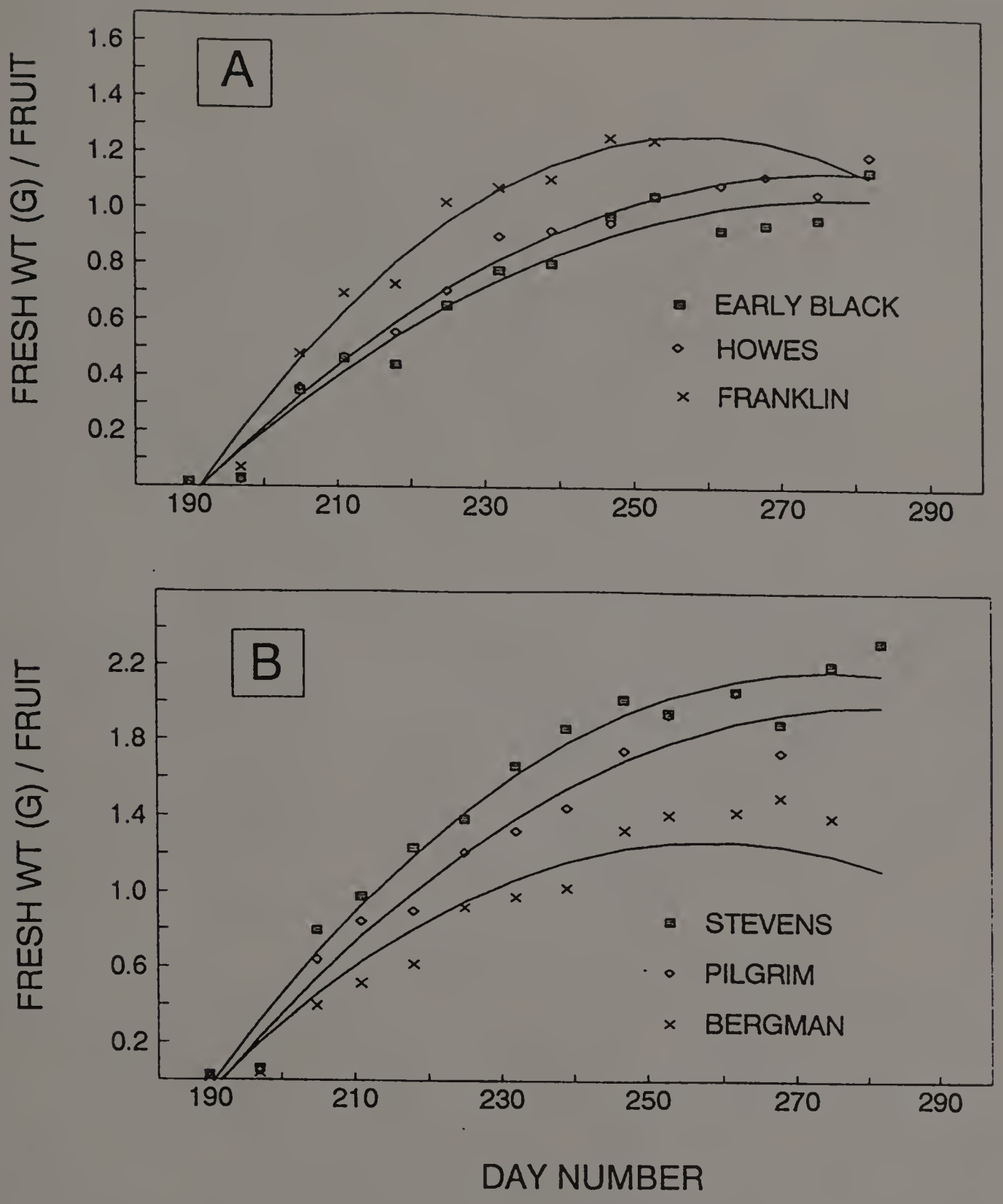

Figure 8.2 Fruit development (fresh weight) in 1990. Lines are from calculated regression (Table 8.2). A: small fruited cultivars; B: large fruited cultivars.

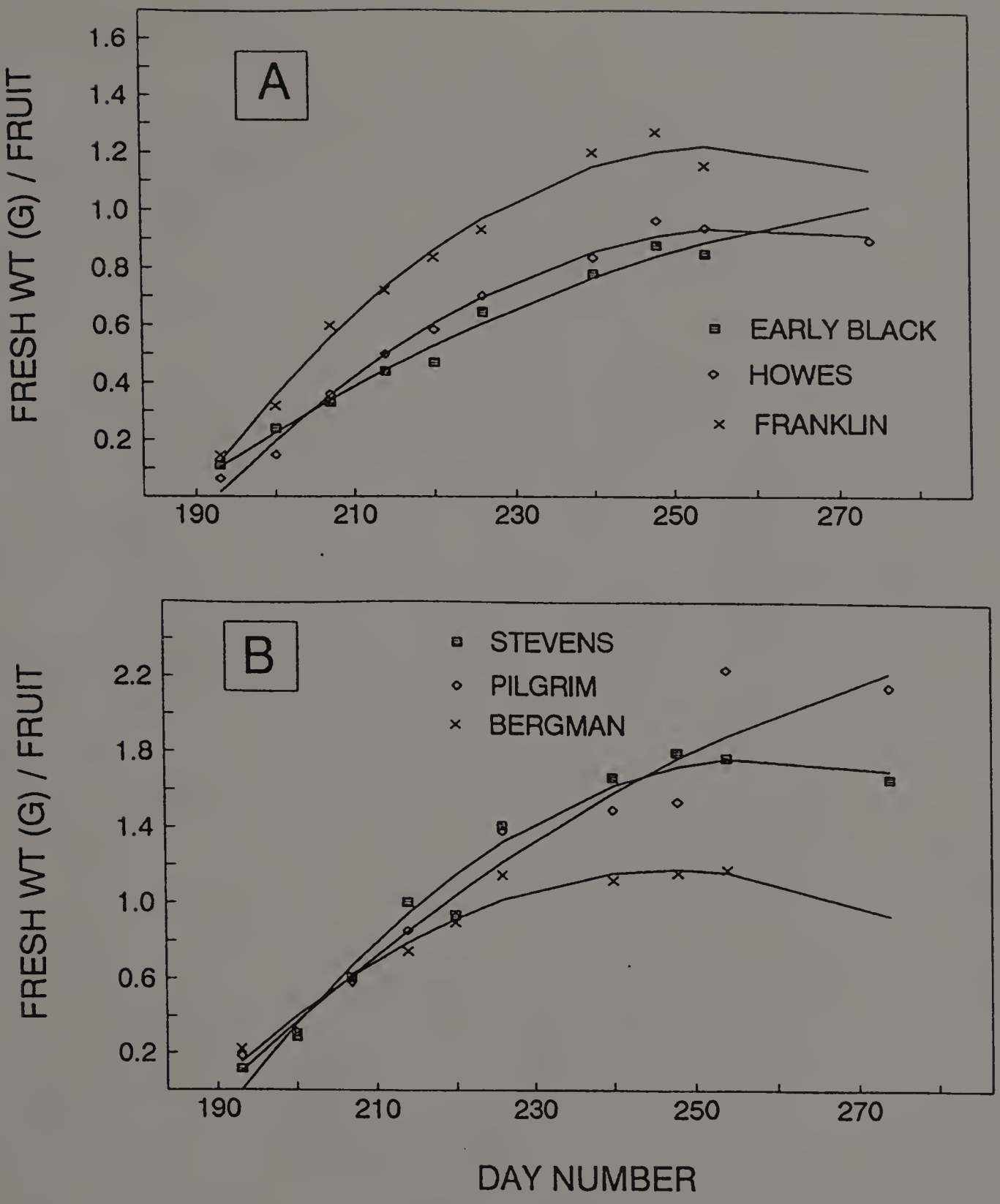

Figure 8.3 Fruit development (fresh weight) in 1991. Lines are from calculated regression (Table 8.2). A: small fruited cultivars; B: large fruited cultivars.

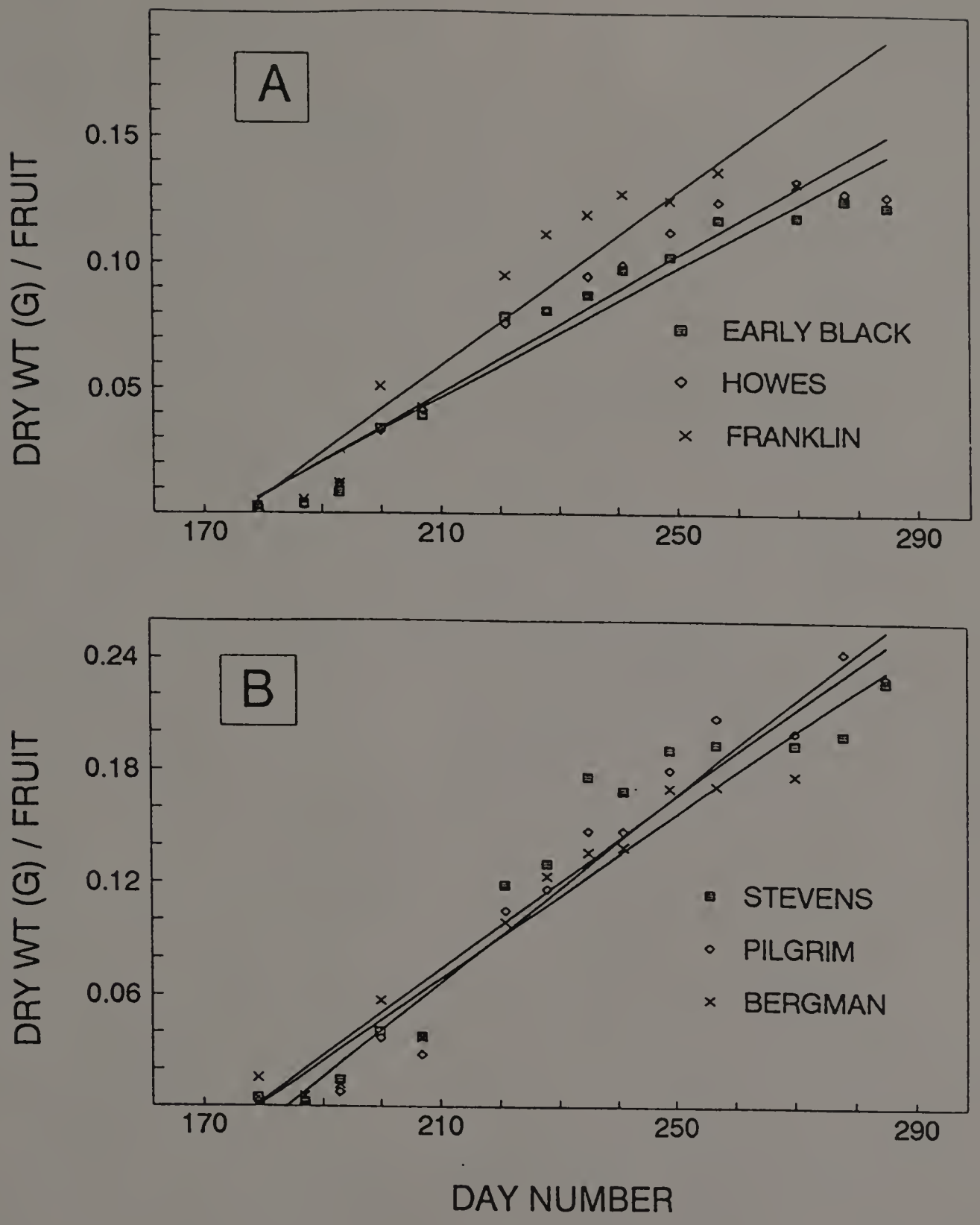

Figure 8.4 Fruit development (dry weight) in 1989. Lines are from calculated regression (Table 8.3). A: small fruited cultivars; B: large fruited cultivars.

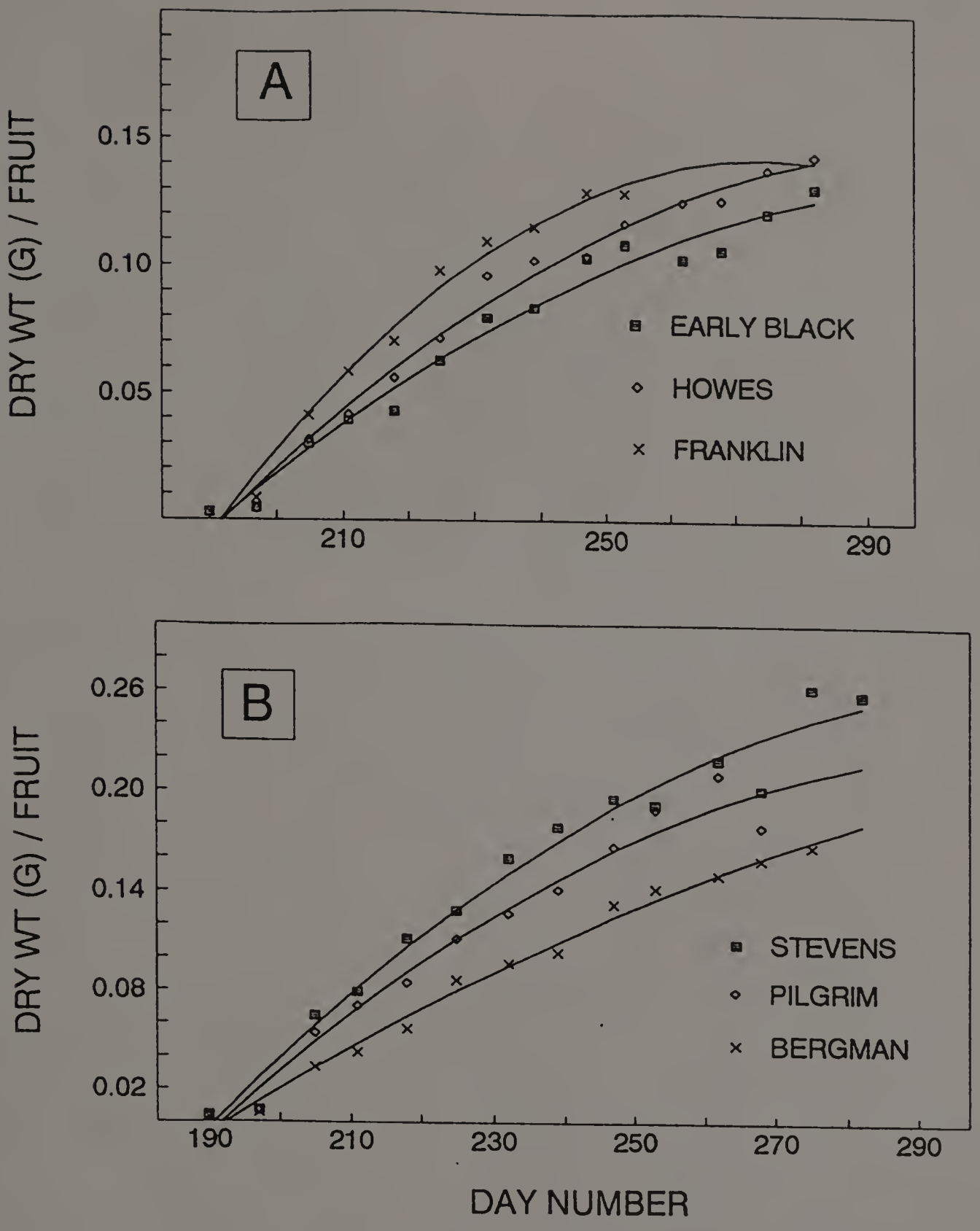

Figure 8.5 Fruit development (dry weight) in 1990. Lines are from calculated regression (Table 8.3). A: small fruited cultivars; B: large fruited cultivars.

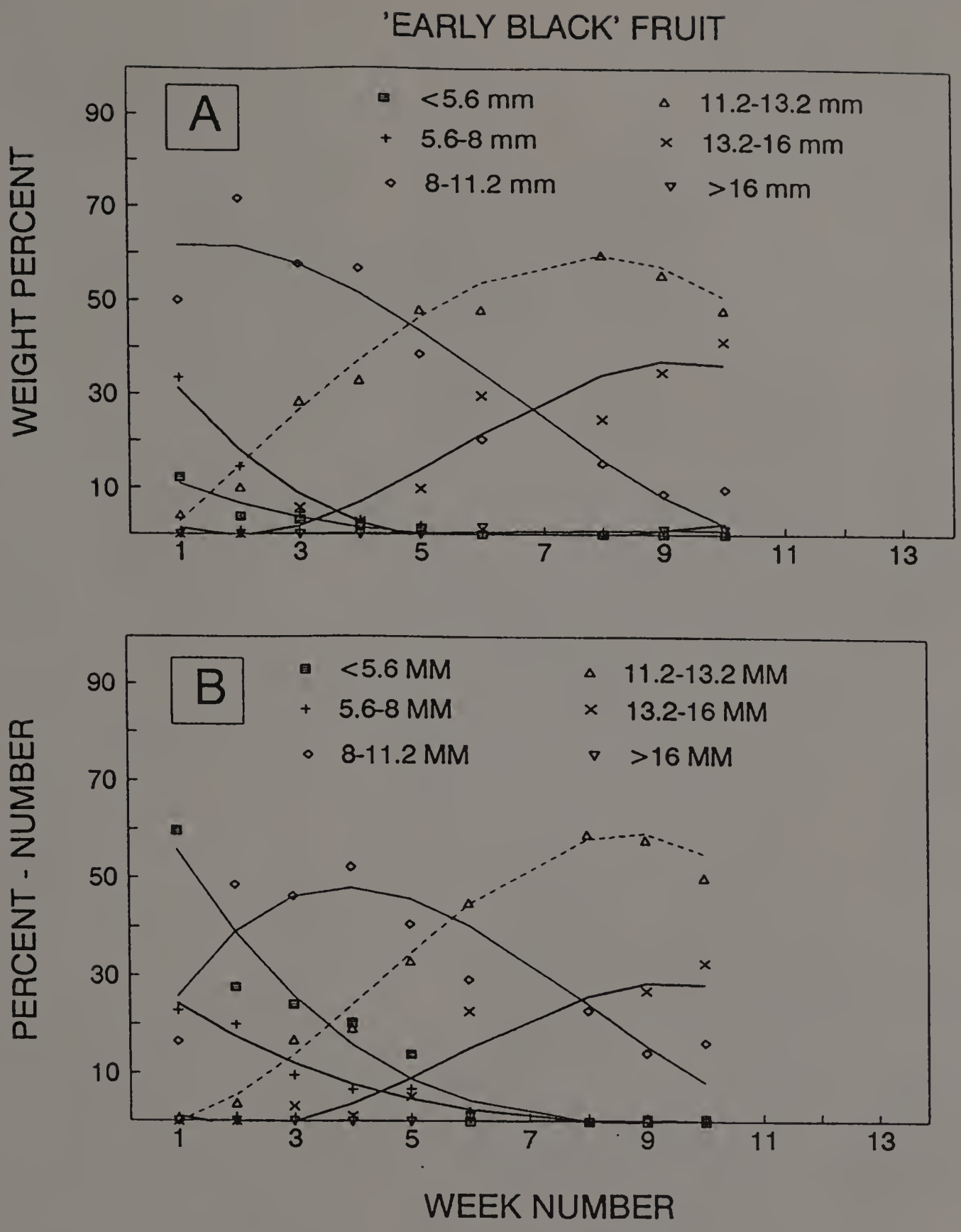

Figure 8.6 'Early Black' fruit development, 1991. Percent of total fruit for each size class in a 180 cm^2 area, mean of 4 replicates. Lines are from calculated regression. A: size and weight; B: size and number.

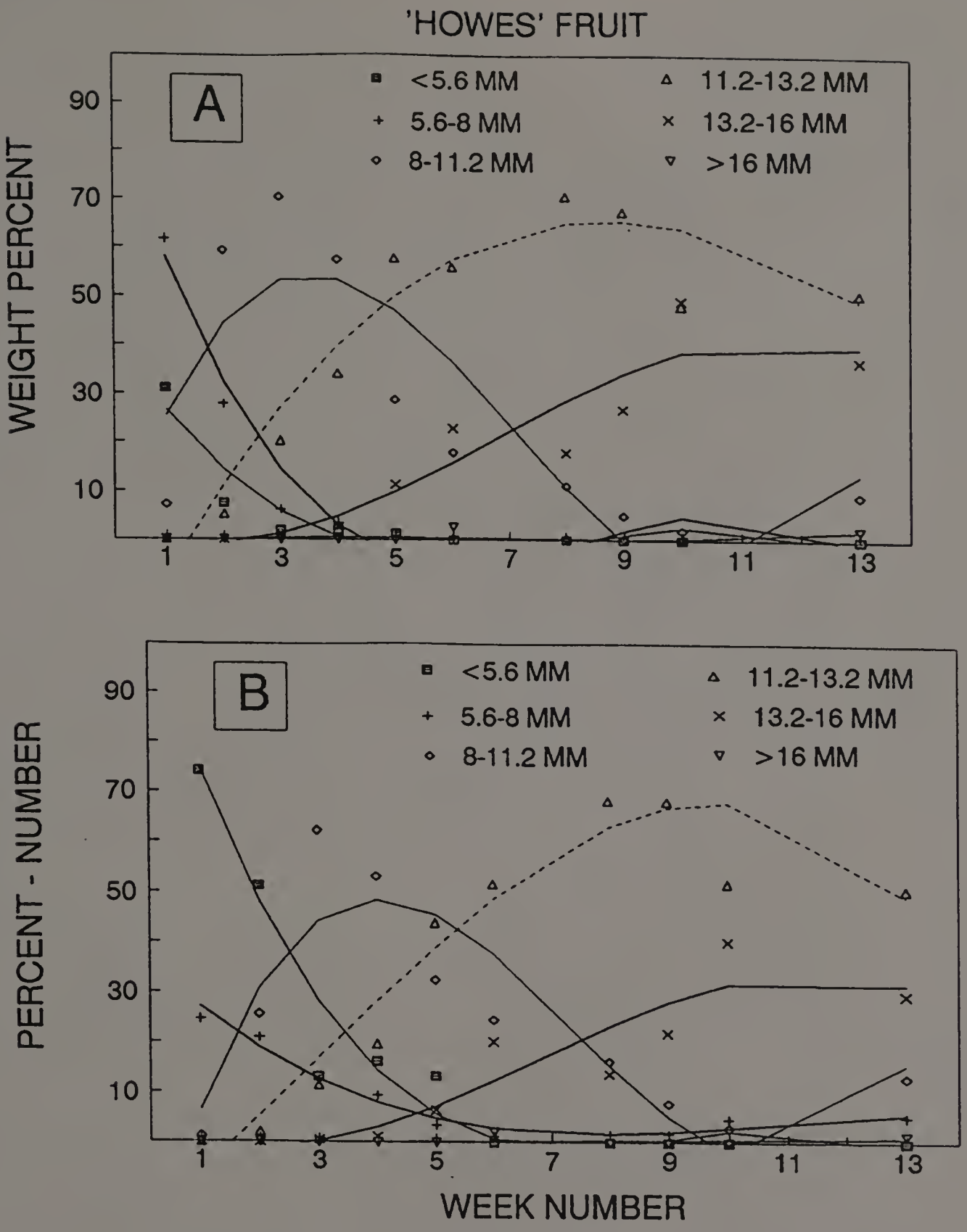

Figure 8.7 'Howes' fruit development, 1991. Percent of total fruit for each size class in a 180 cm^2 area, mean of 4 replicates. Lines are from calculated regression. A: size and weight; B: size and number.

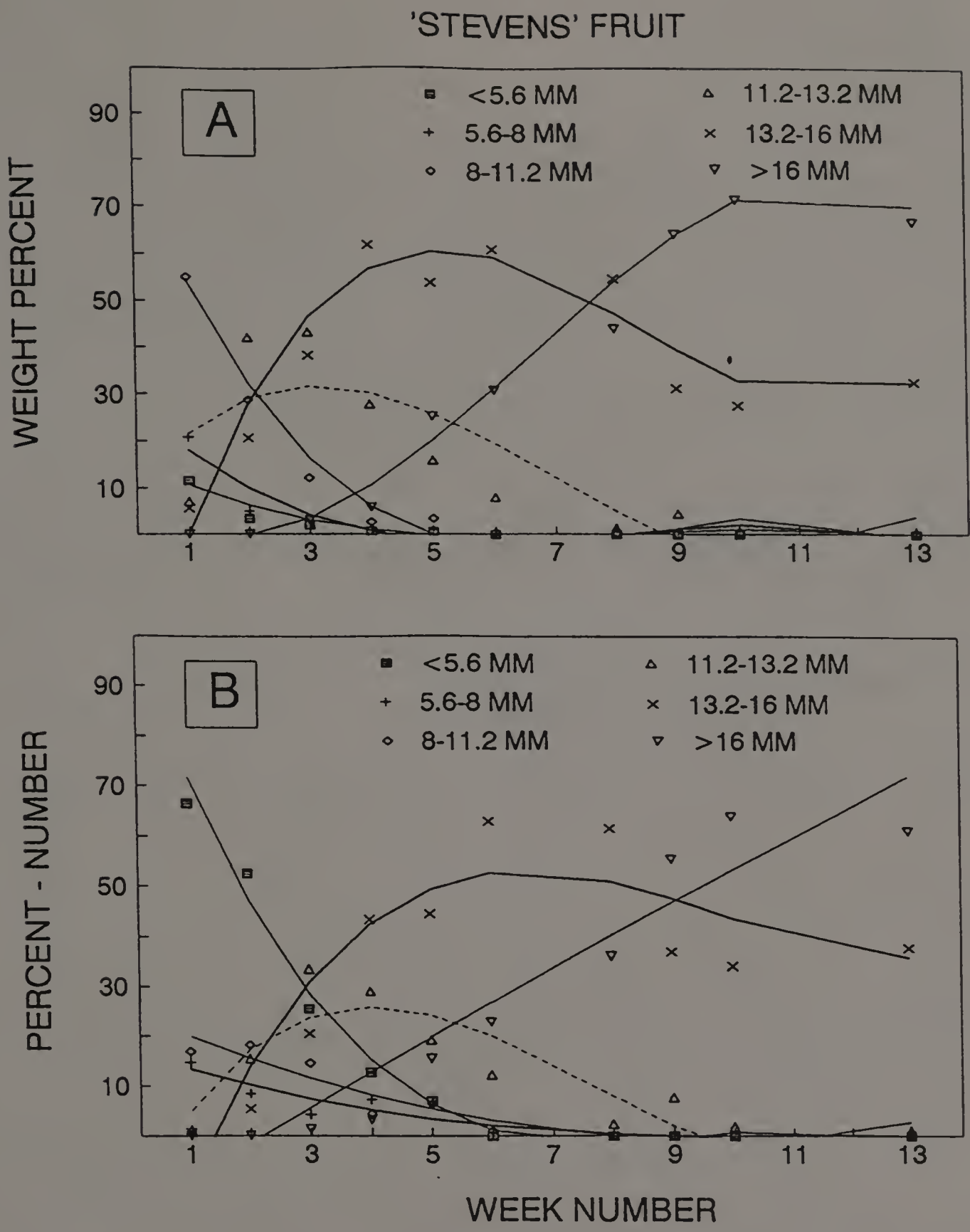

Figure 8.8 'Stevens' fruit development, 1991. Percent of total fruit for each size class in a 180 cm^2 area, mean of 4 replicates. Lines are from calculated regression. A: size and weight; B: size and number.

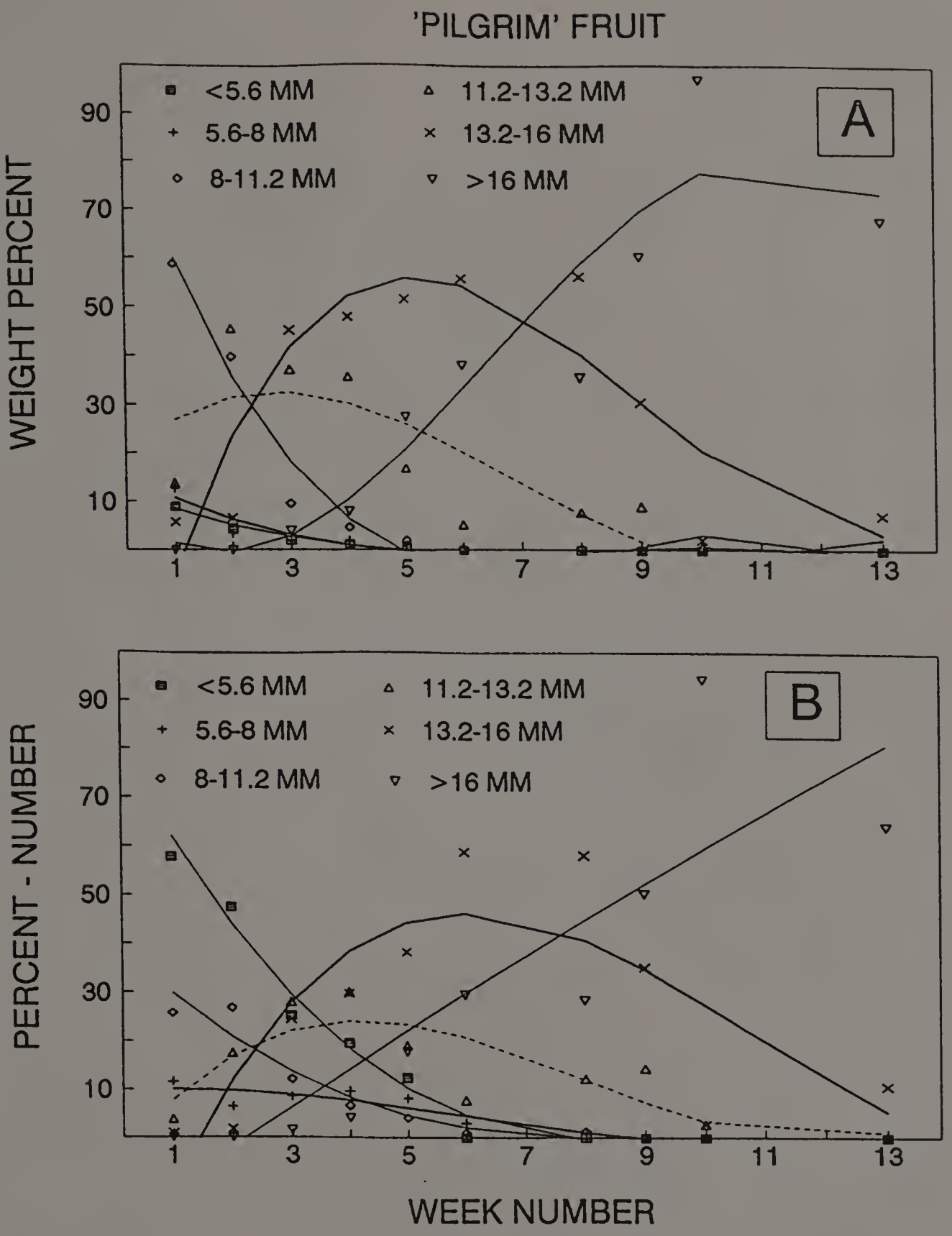

Figure 8.9 'Pilgrim' fruit development, 1991. Percent of total fruit for each size class in a 180 cm^2 area, mean of 4 replicates. Lines are from calculated regression. A: size and weight; B: size and number.

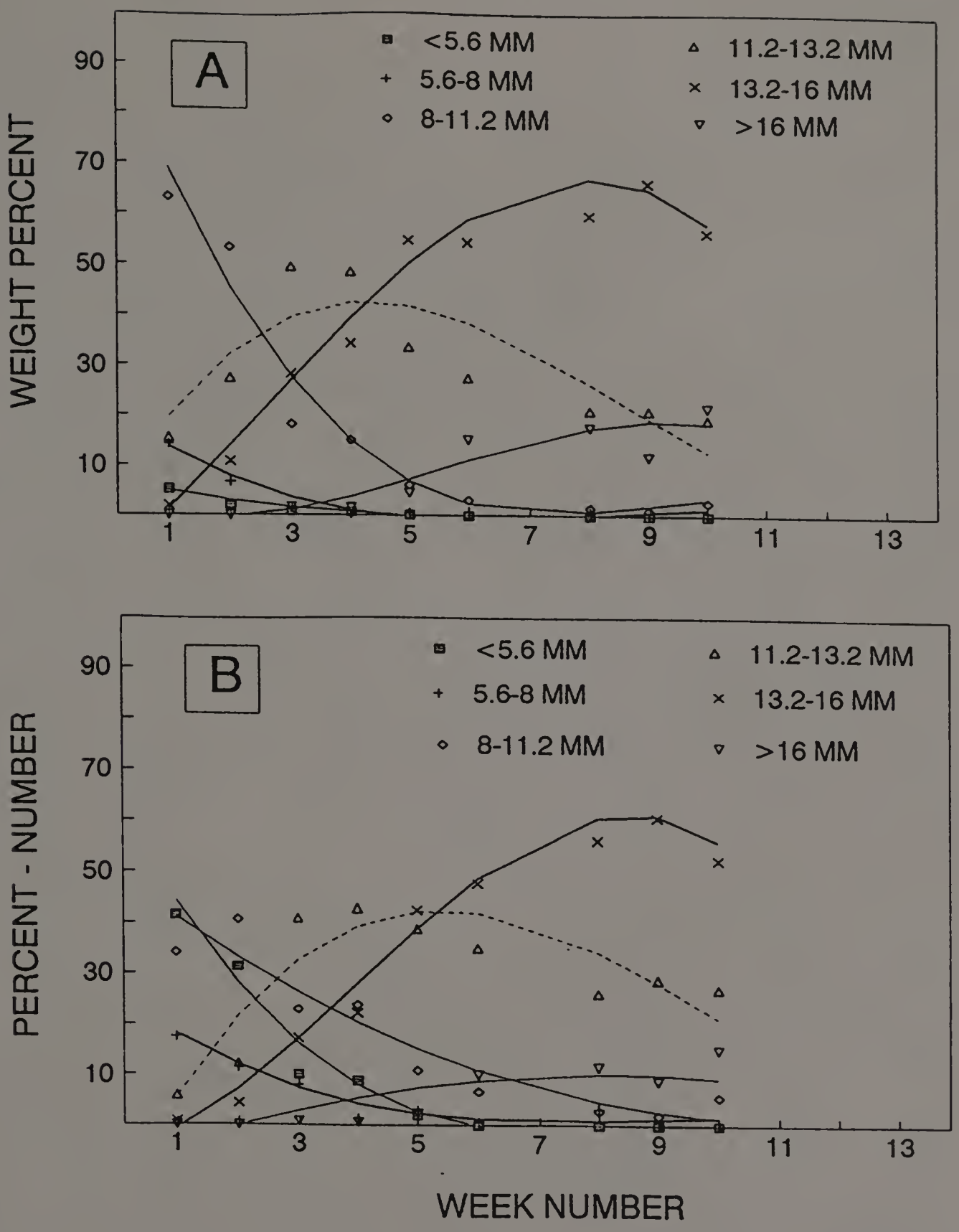

Figure 8.10 'Bergman' fruit development, 1991. Percent of total fruit for each size class in a 180 cm^2 area, mean of 4 replicates. Lines are from calculated regression. A: size and weight; B: size and number.

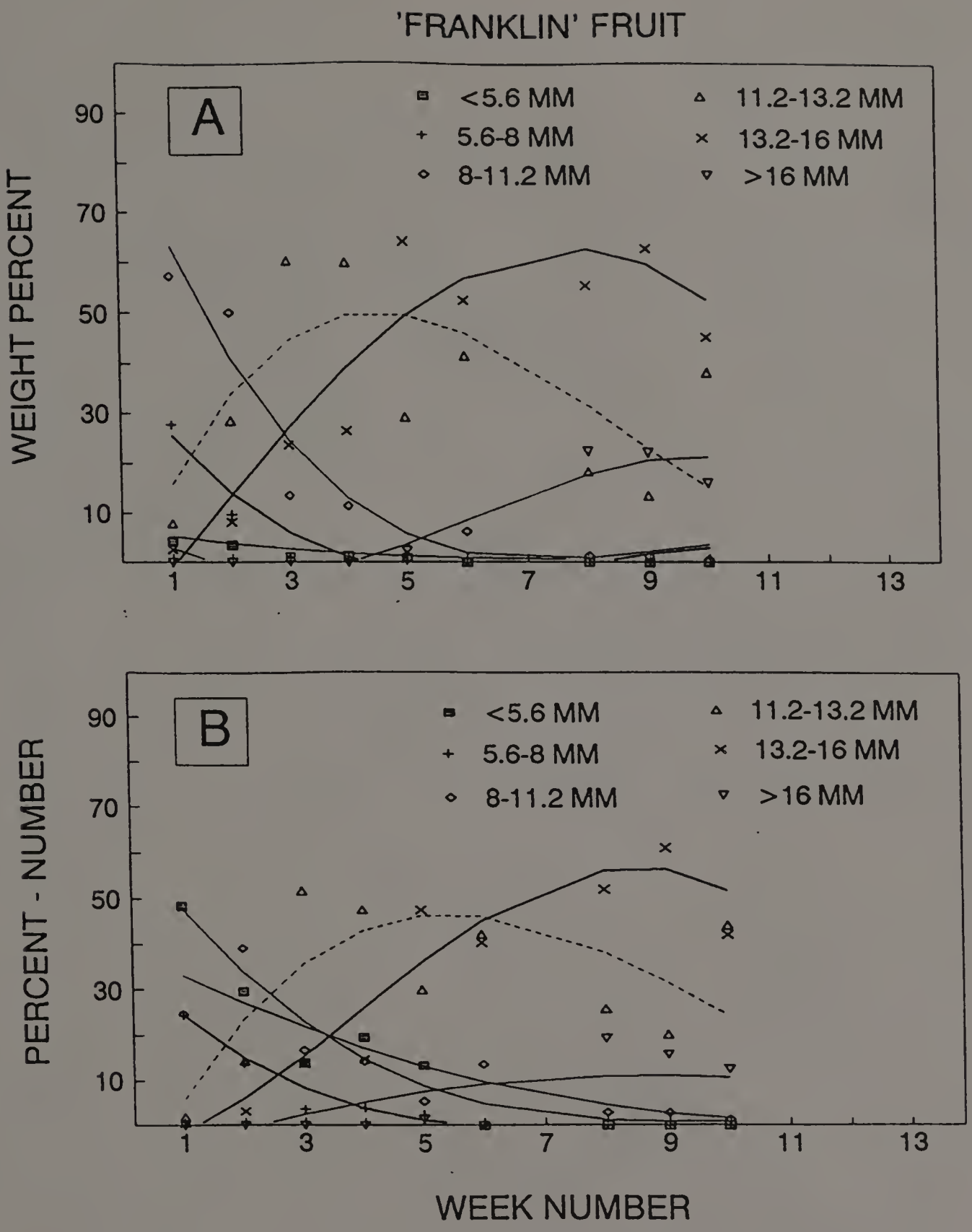

Figure 8.11 'Franklin' fruit development, 1991. Percent of total fruit for each size class in a 180 cm^2 area, mean of 4 replicates. Lines are from calculated regression. A: size and weight; B: size and number.

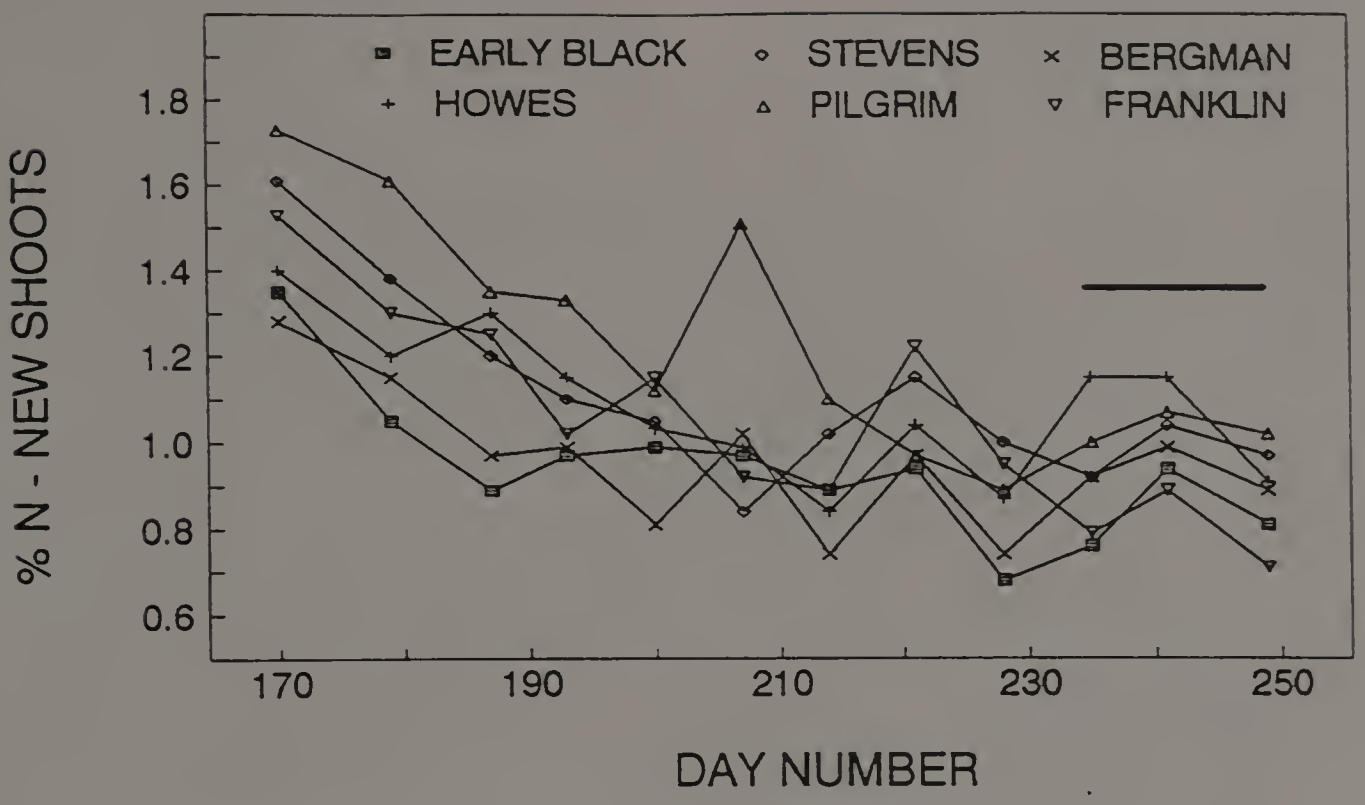

Figure 8.12 N concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

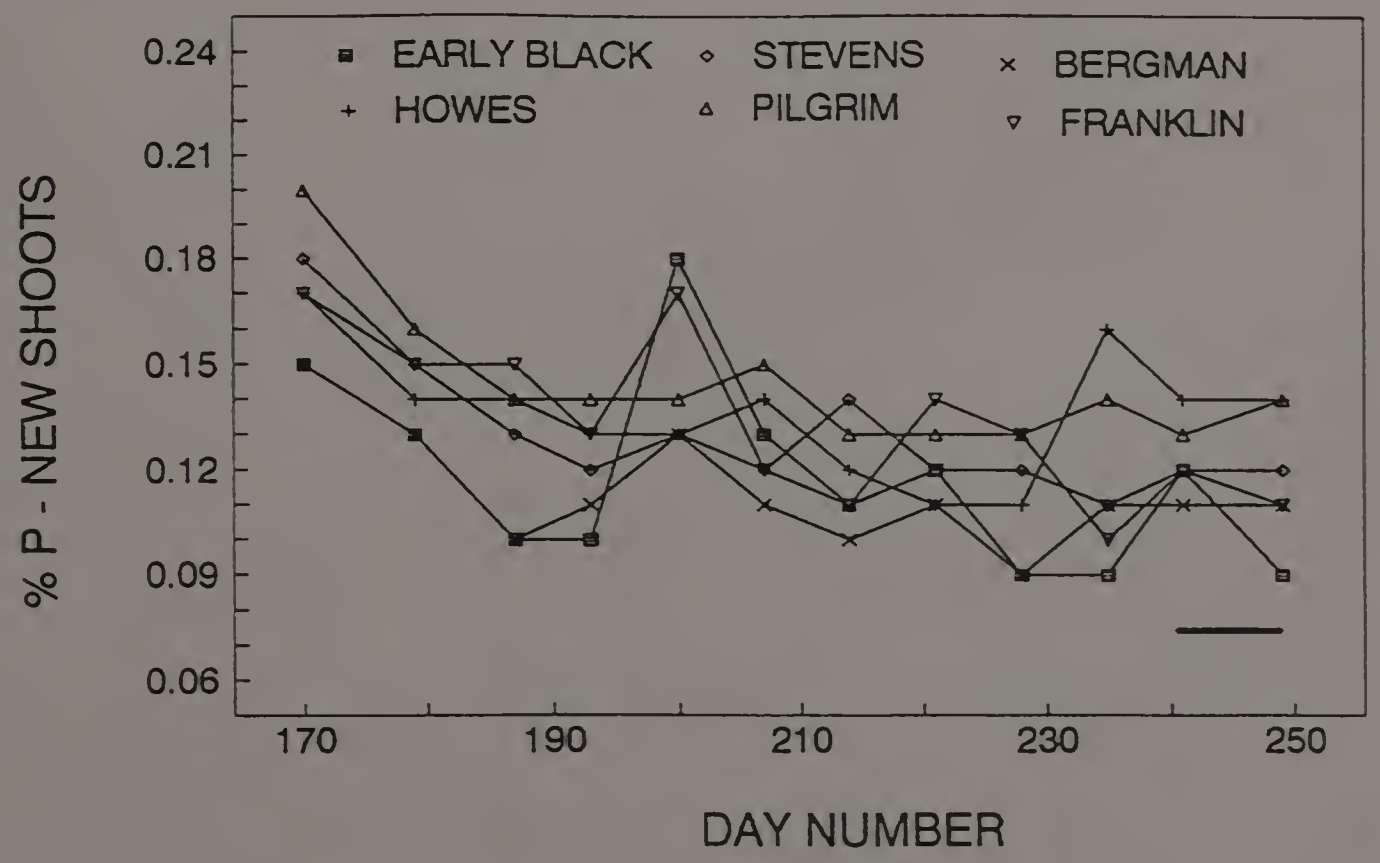

Figure 8.13 P concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

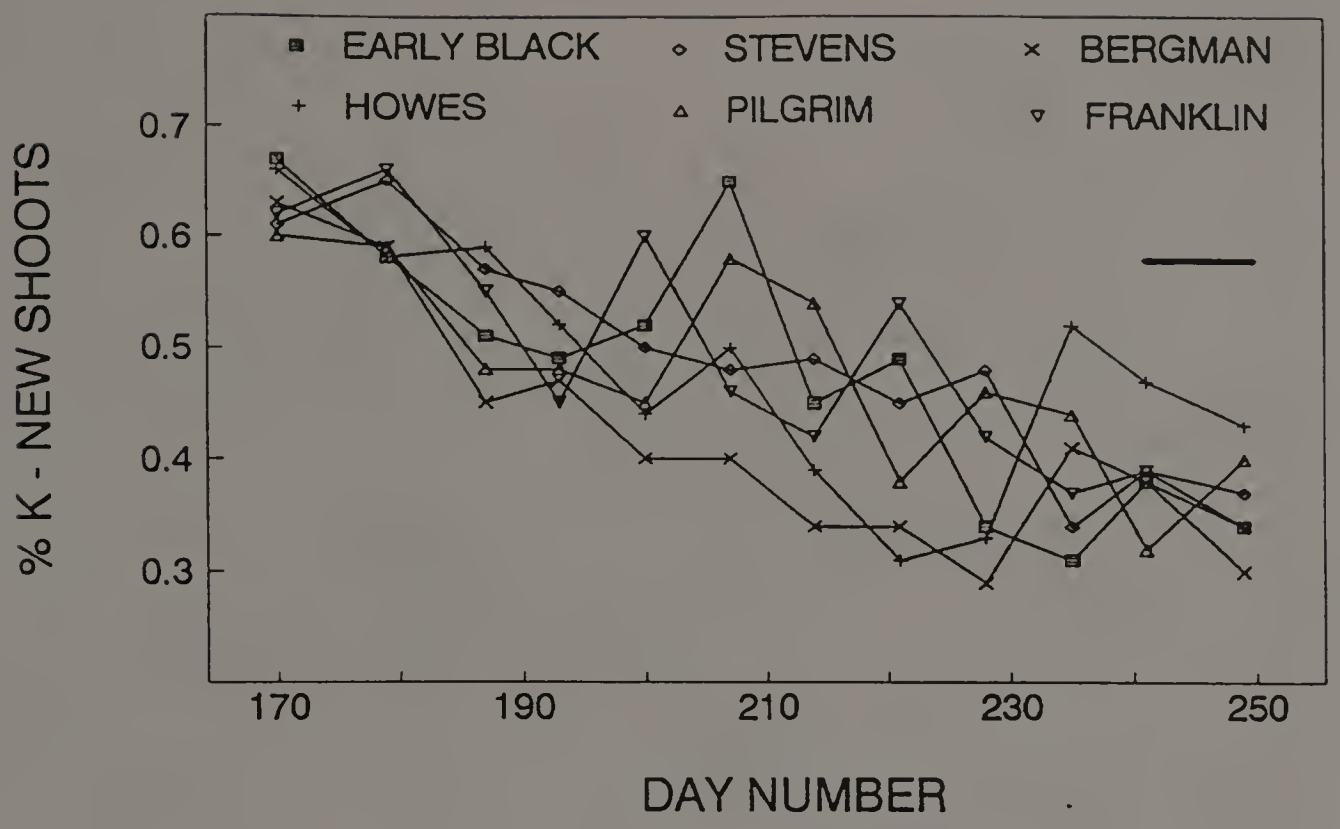

Figure 8.14 K concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

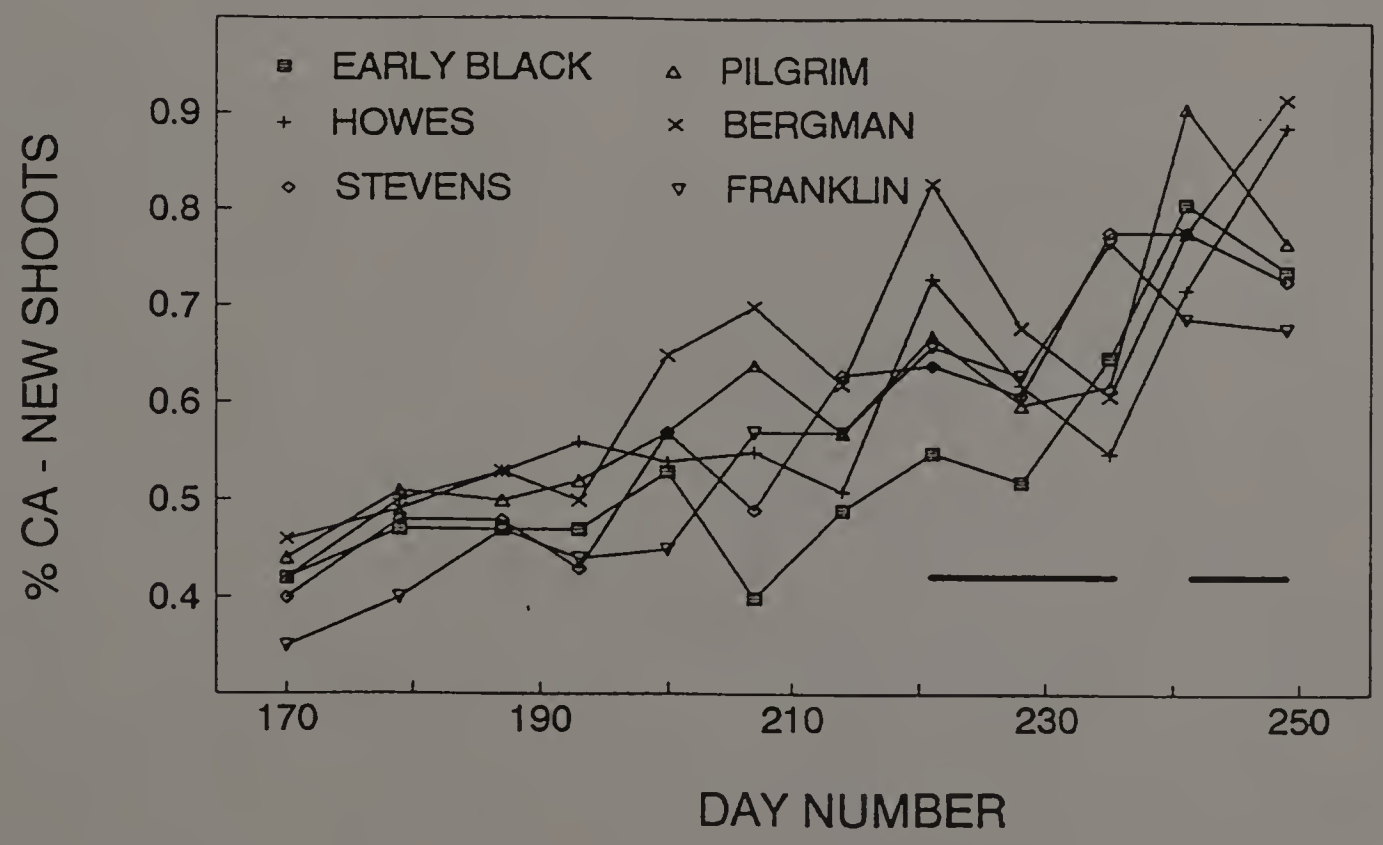

Figure 8.15 Ca concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

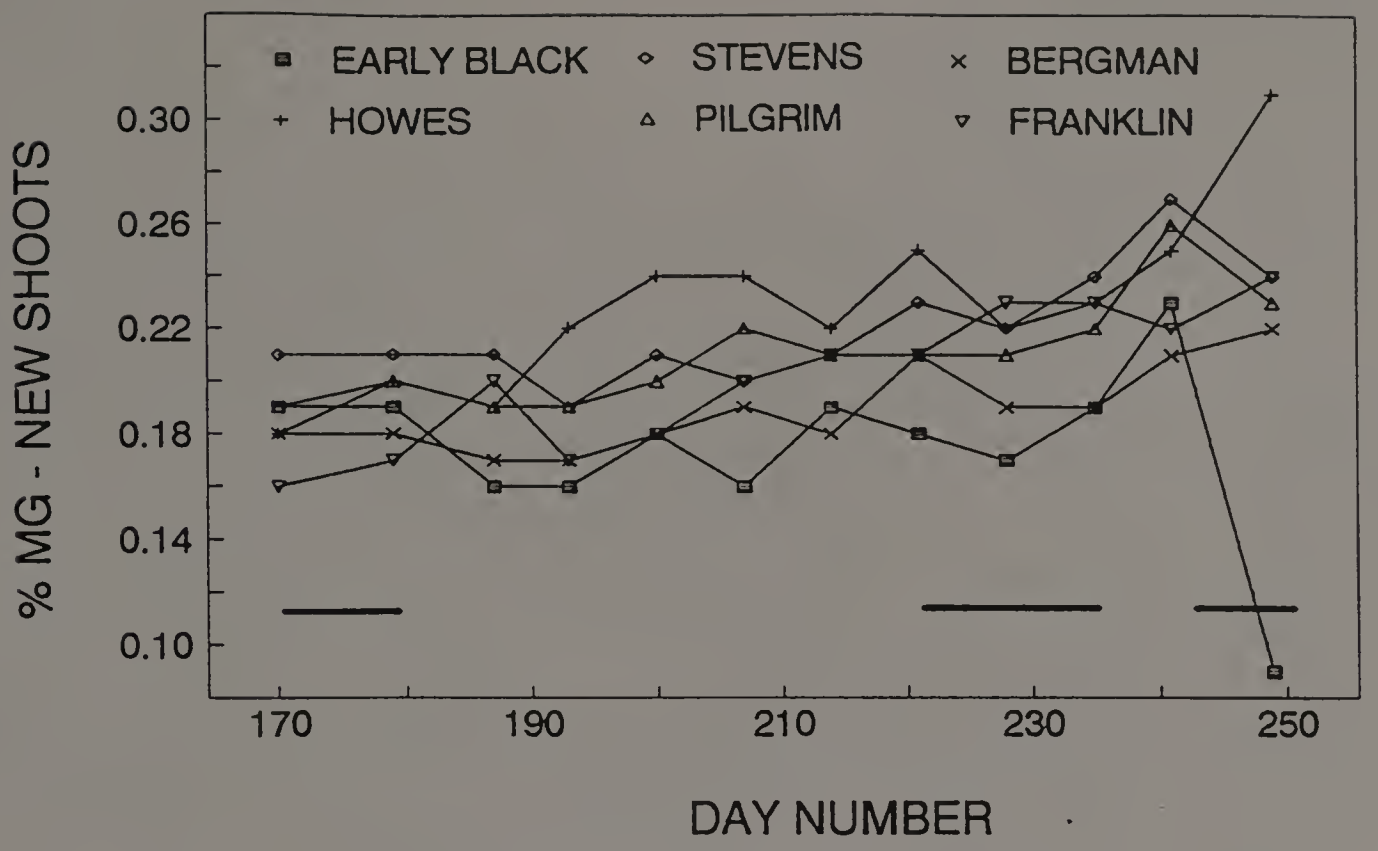

Figure 8.16 Mg concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

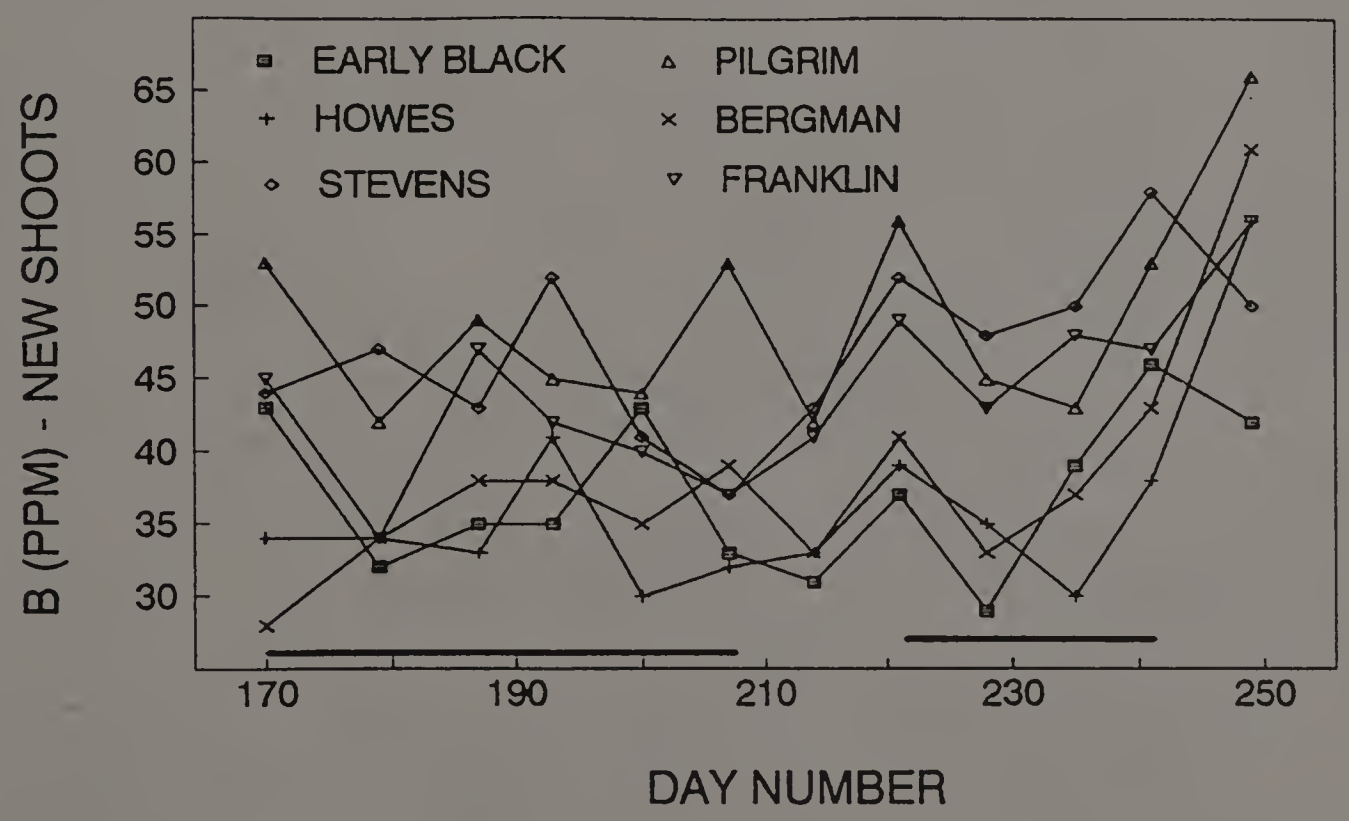

Figure 8.17 B concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

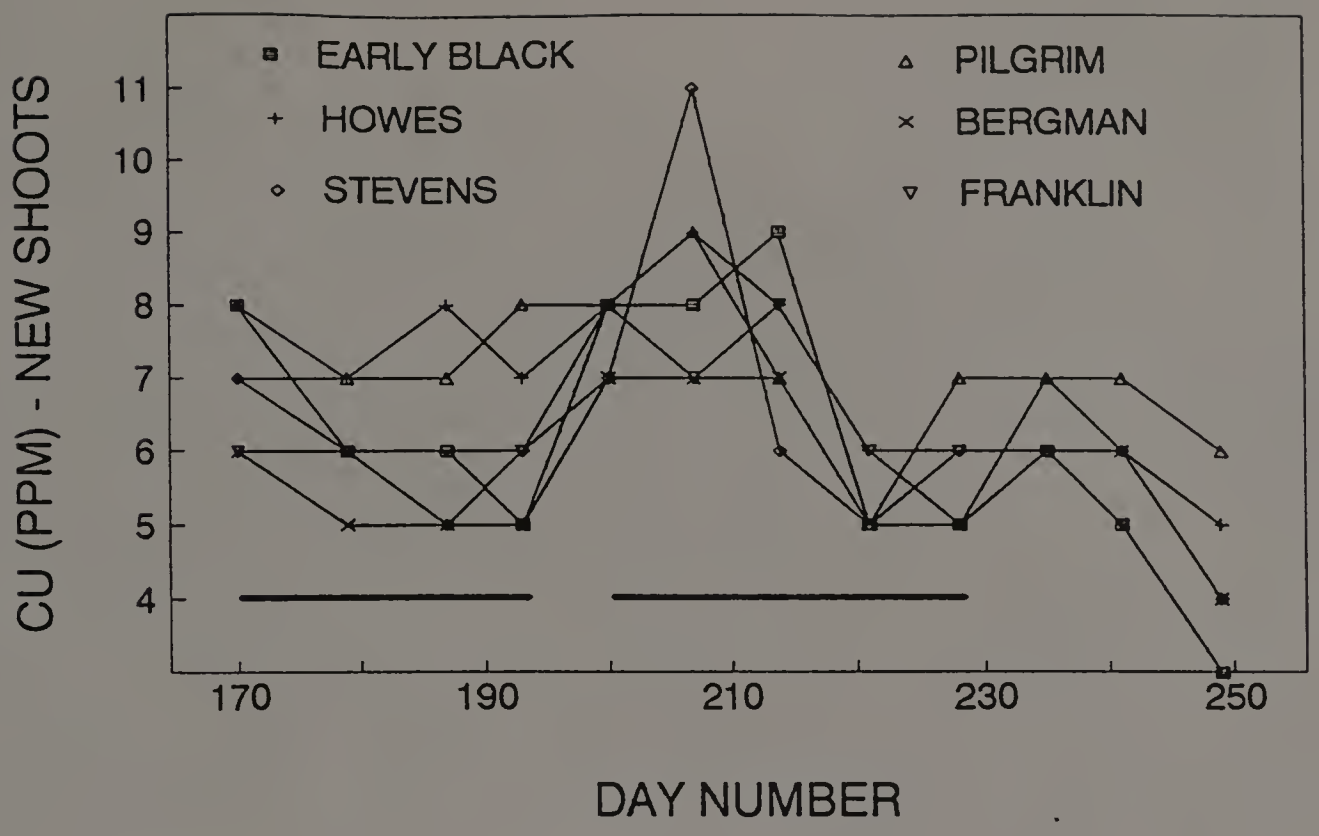

Figure 8.18 Cu concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

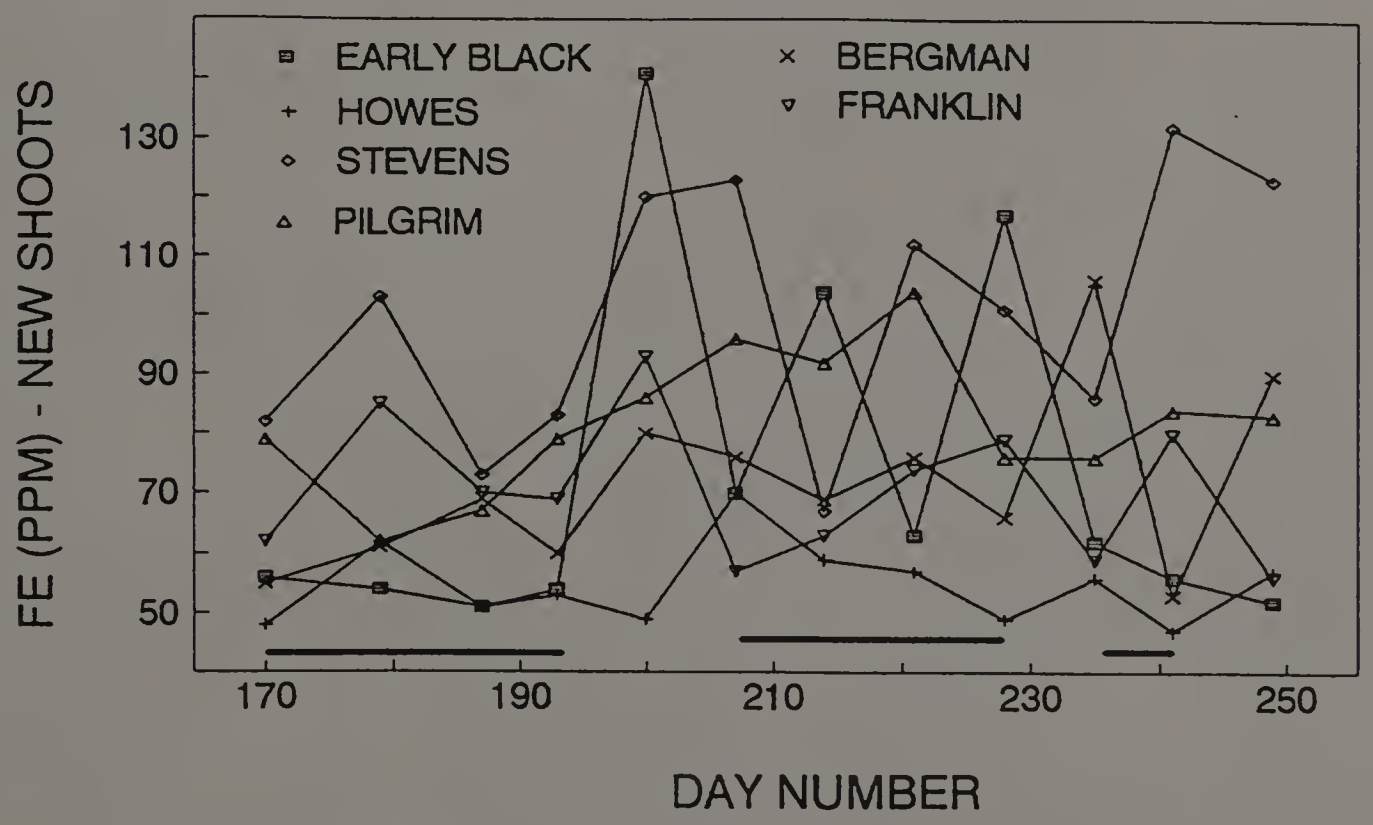

Figure 8.19 Fe concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

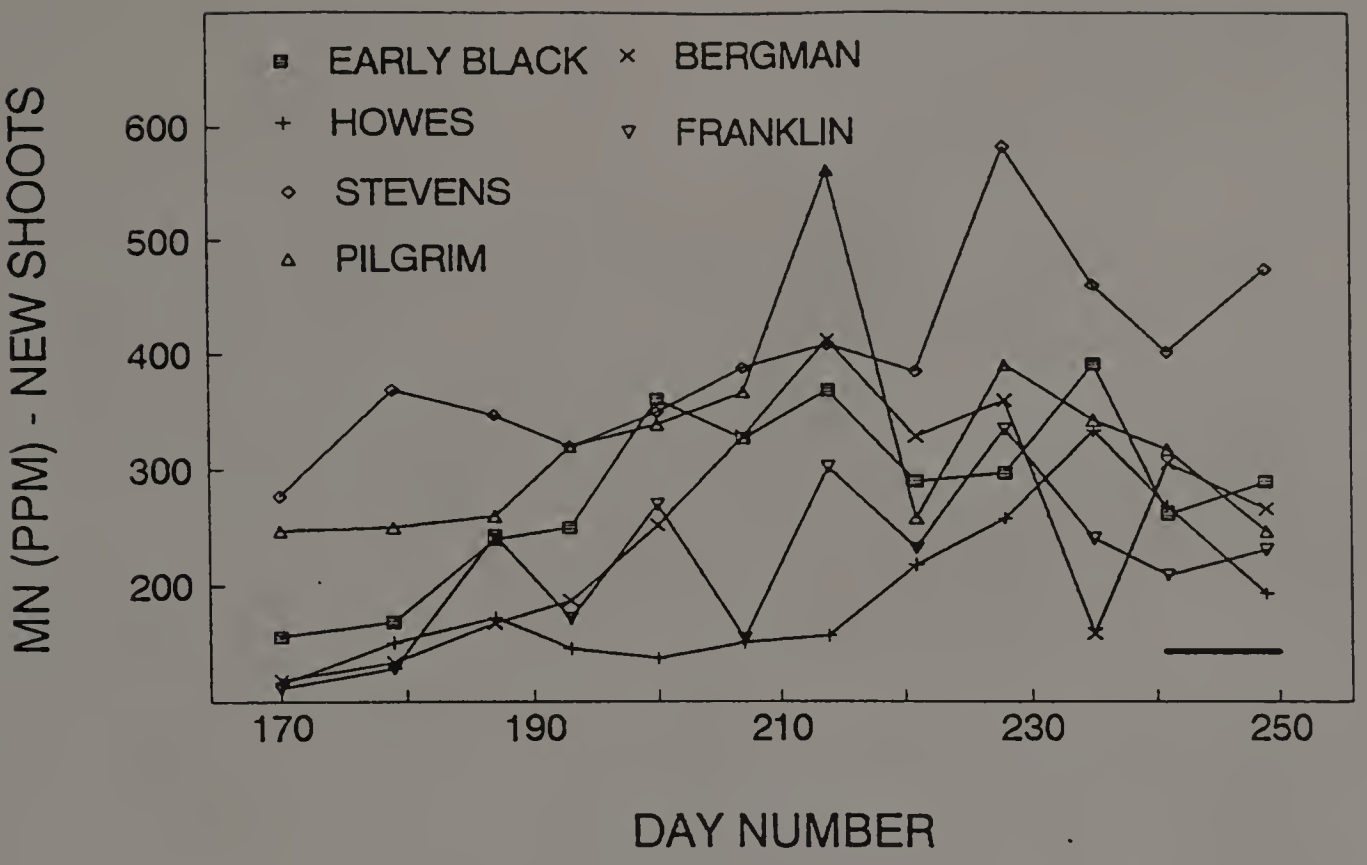

Figure 8.20 Mn concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

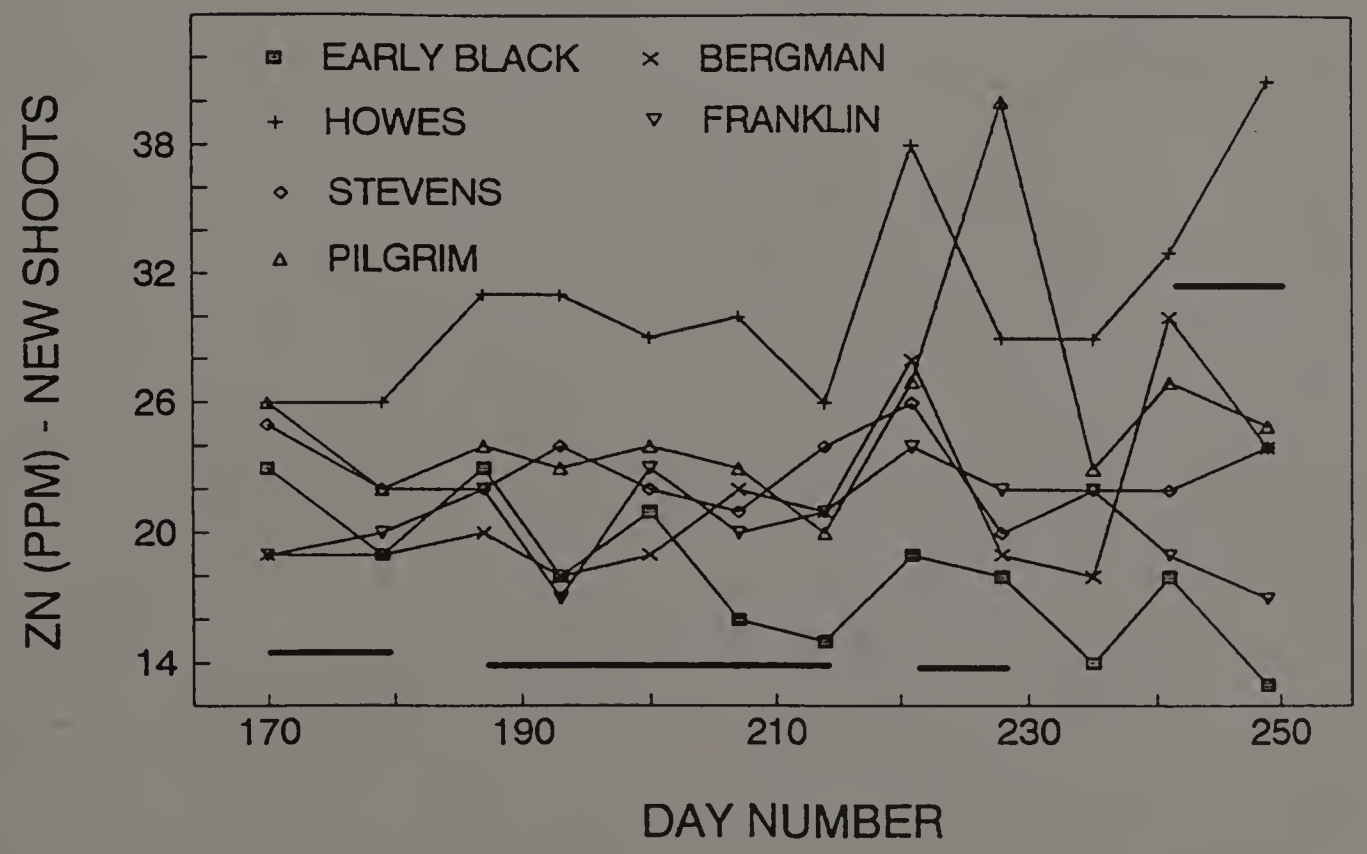

Figure 8.21 Zn concentration (dry weight) in new shoots of cranberry, 6 cultivars, 1989. Horizontal line represents stable concentration across cultivars (profile analysis of cultivar x date interaction).

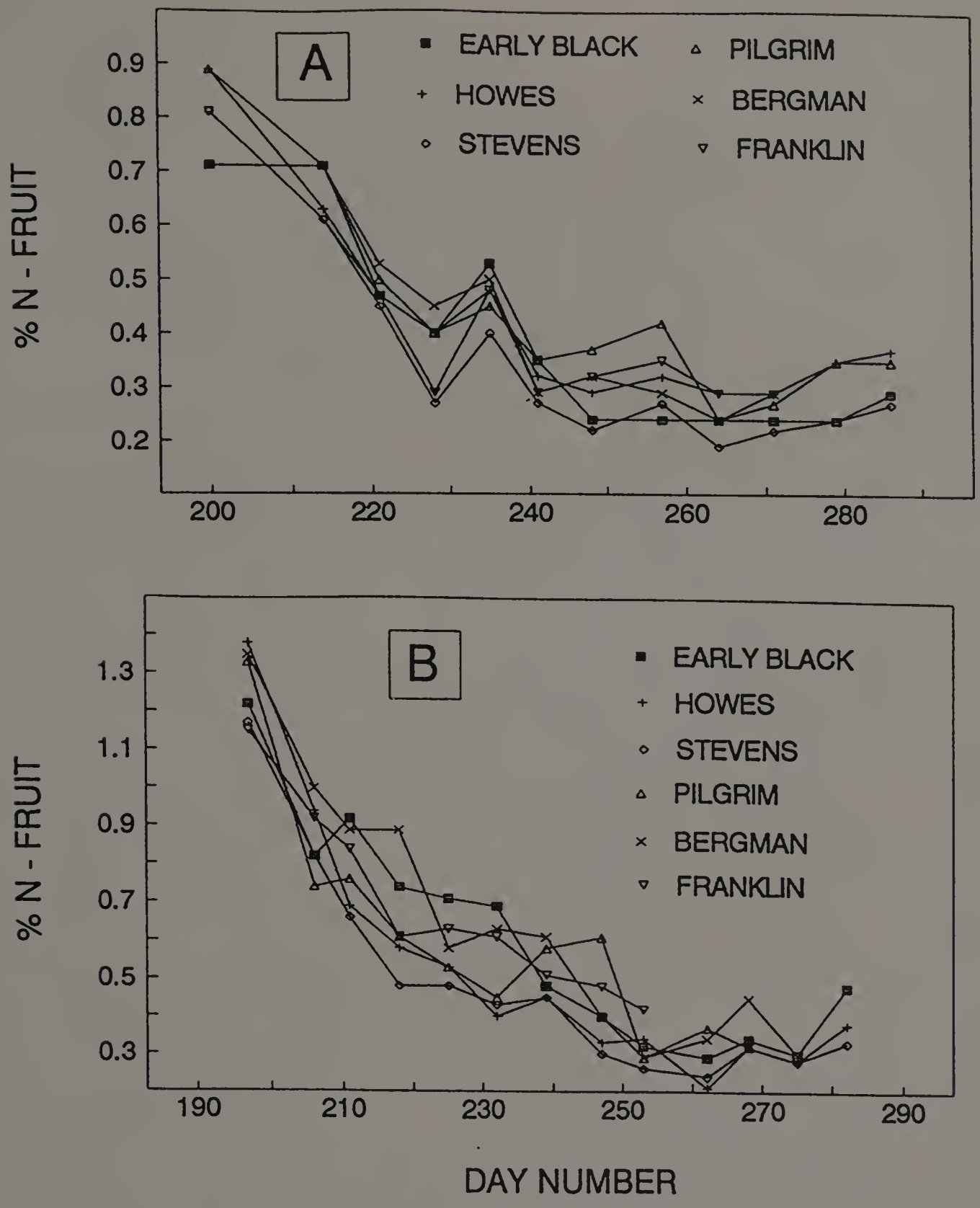

Figure 8.22 N concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

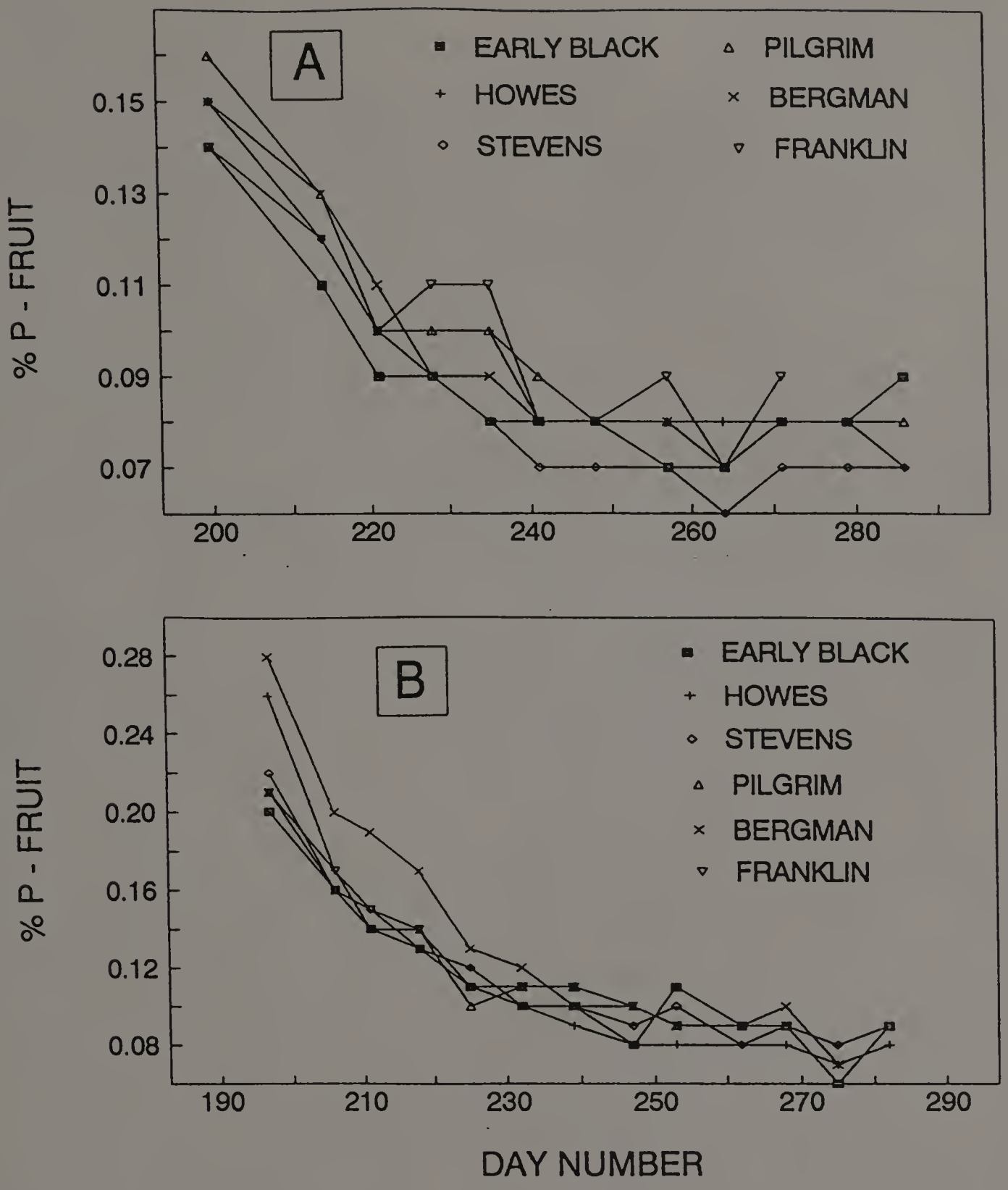

Figure 8.23 P concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

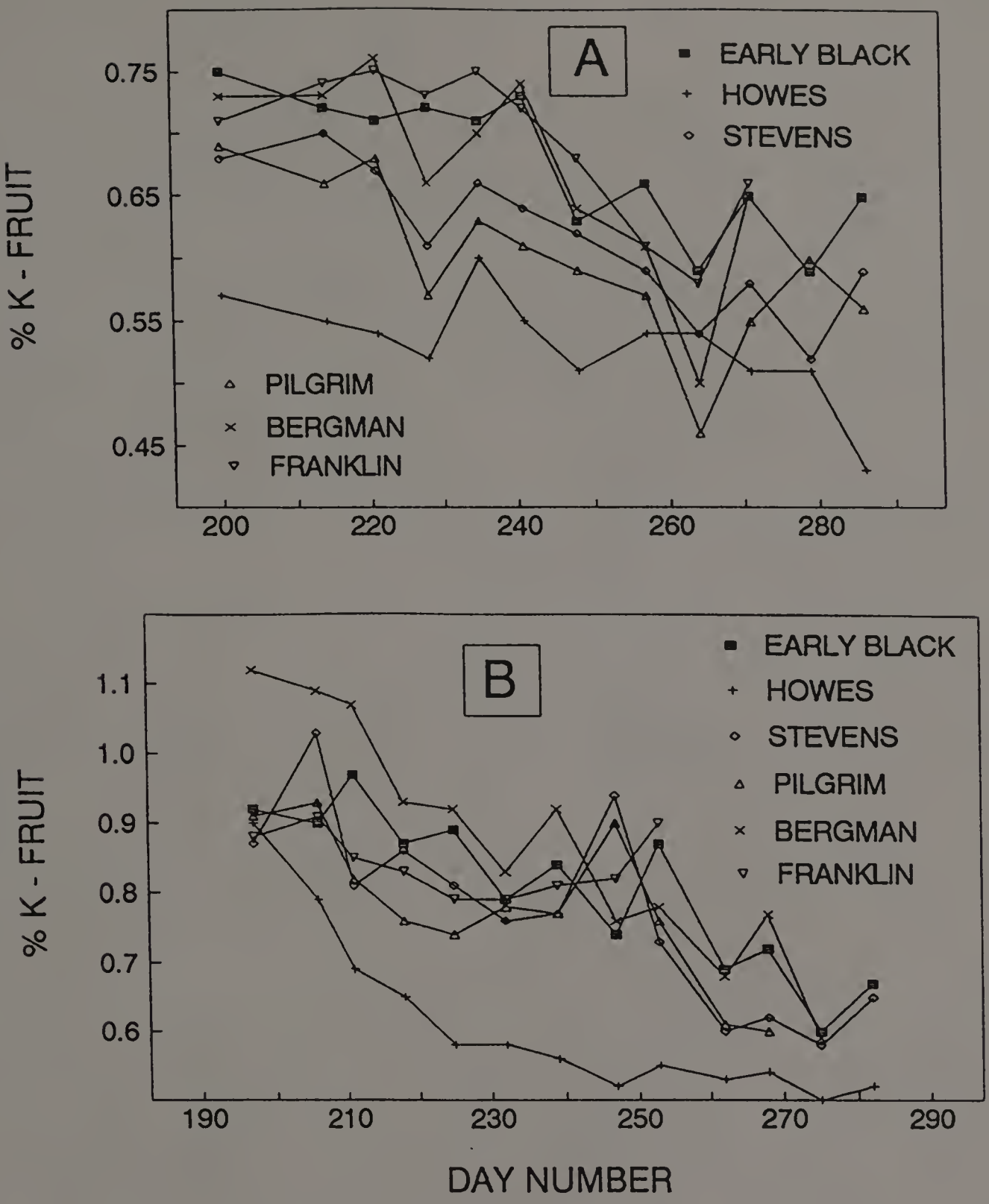

Figure 8.24 K concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

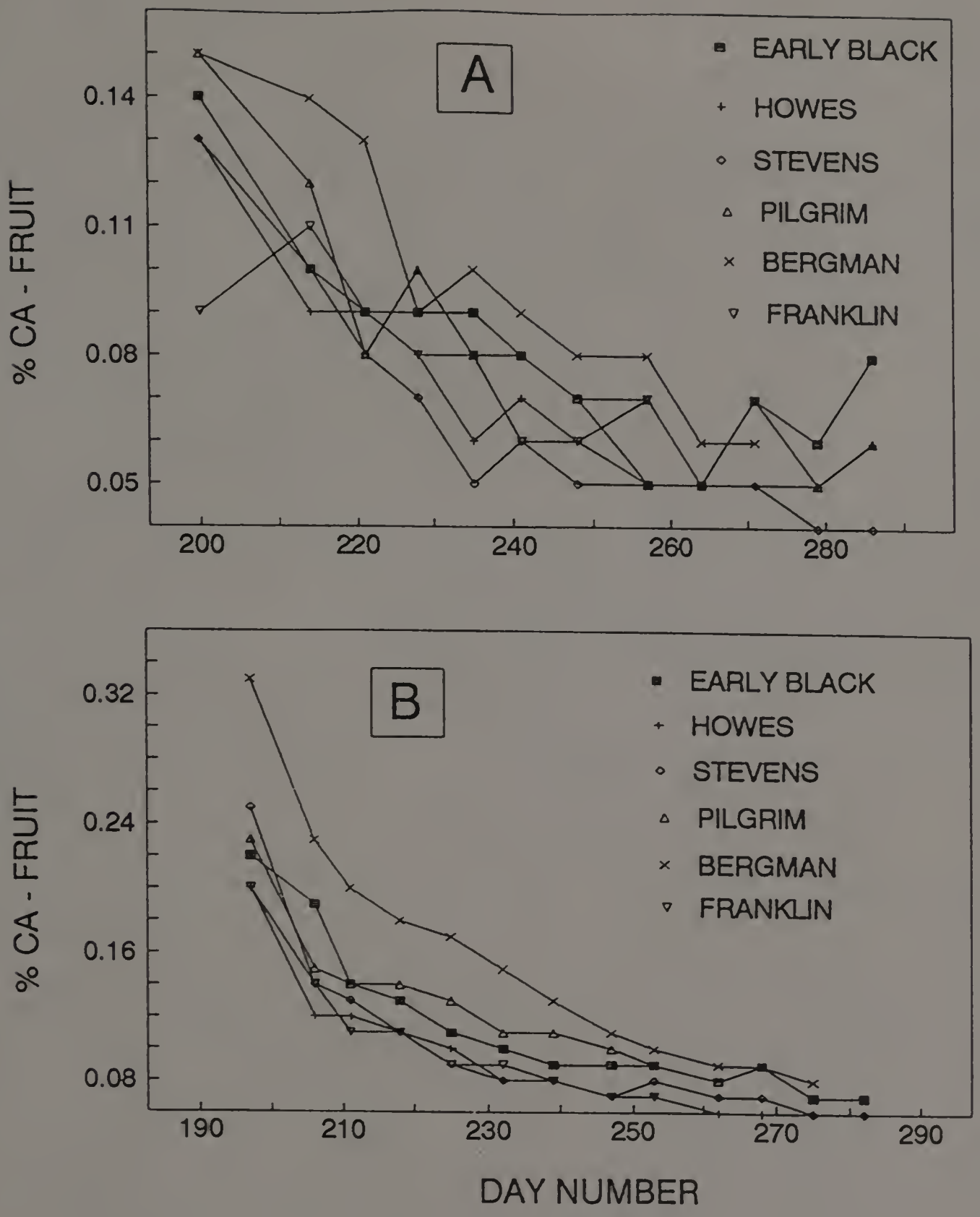

Figure 8.25 Ca concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

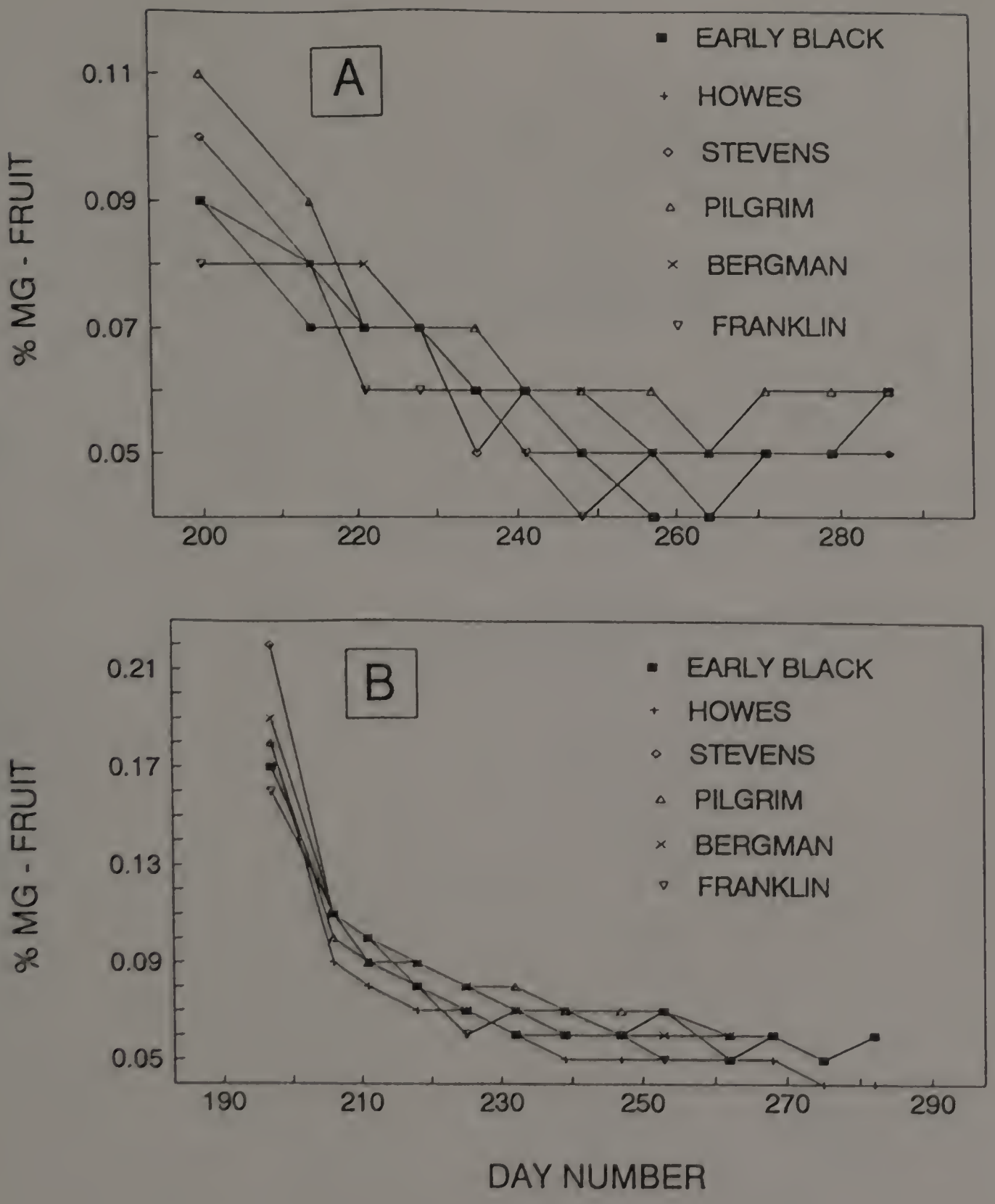

Figure 8.26 Mg concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

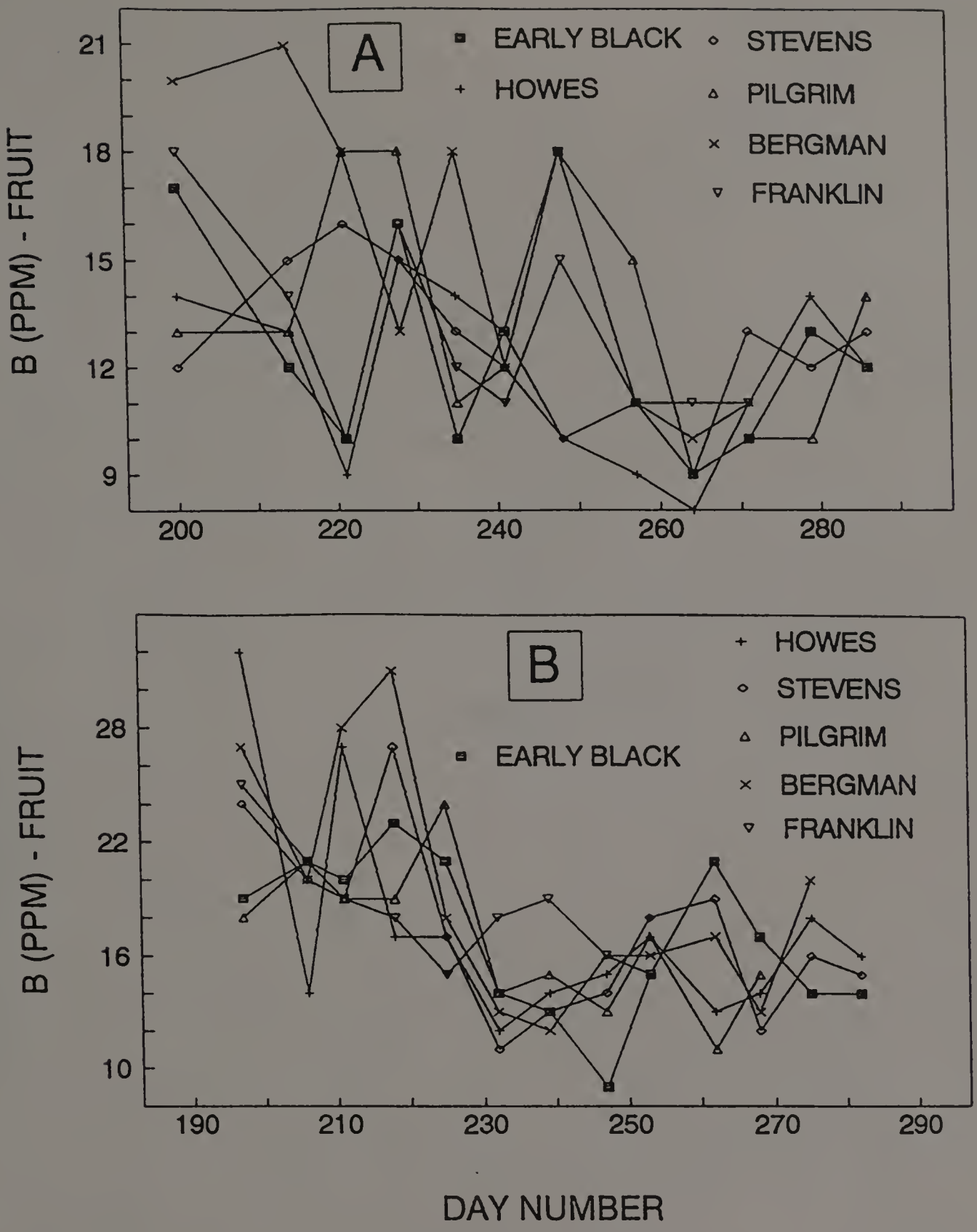

Figure 8.27 B concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

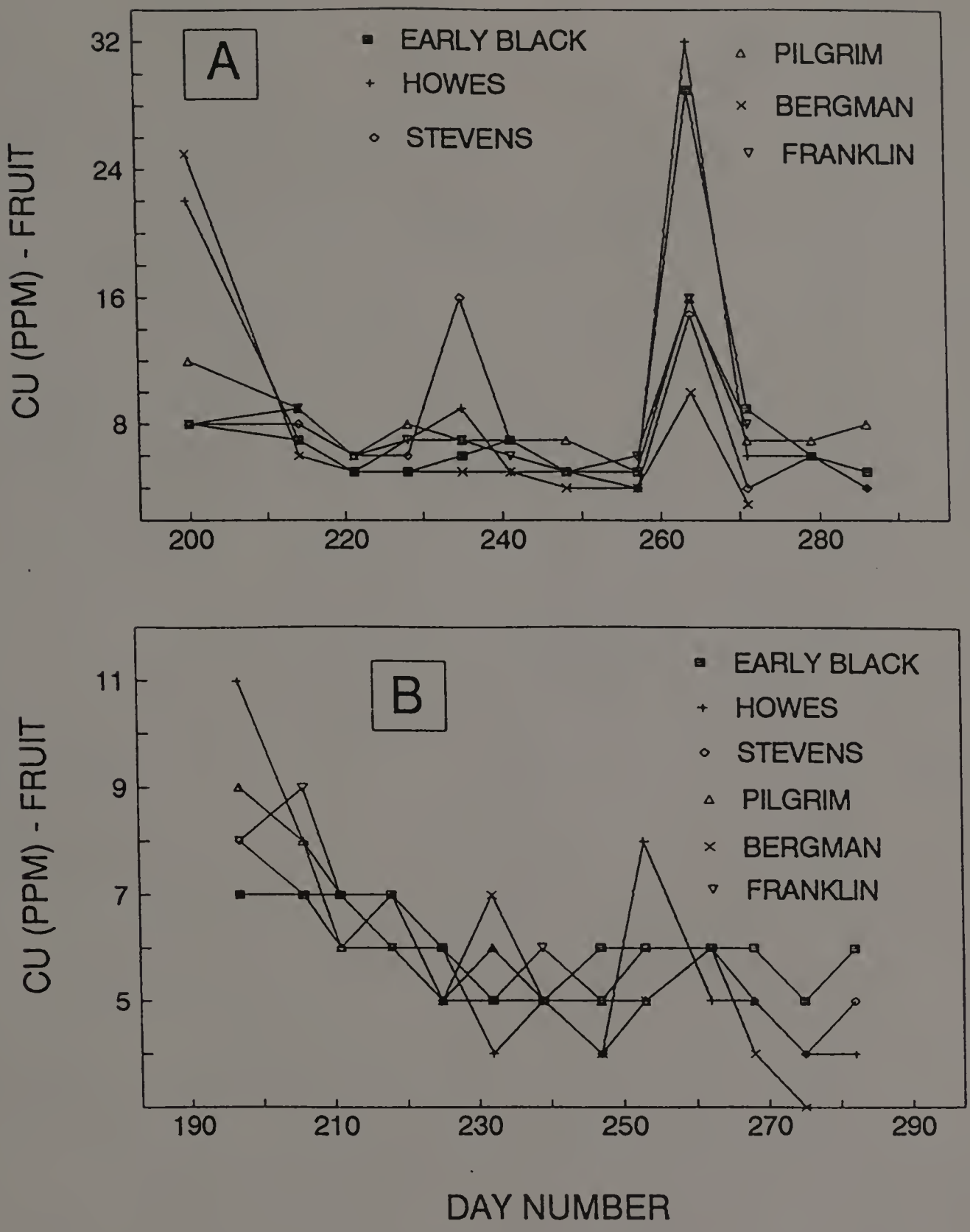

Figure 8.28 Cu concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

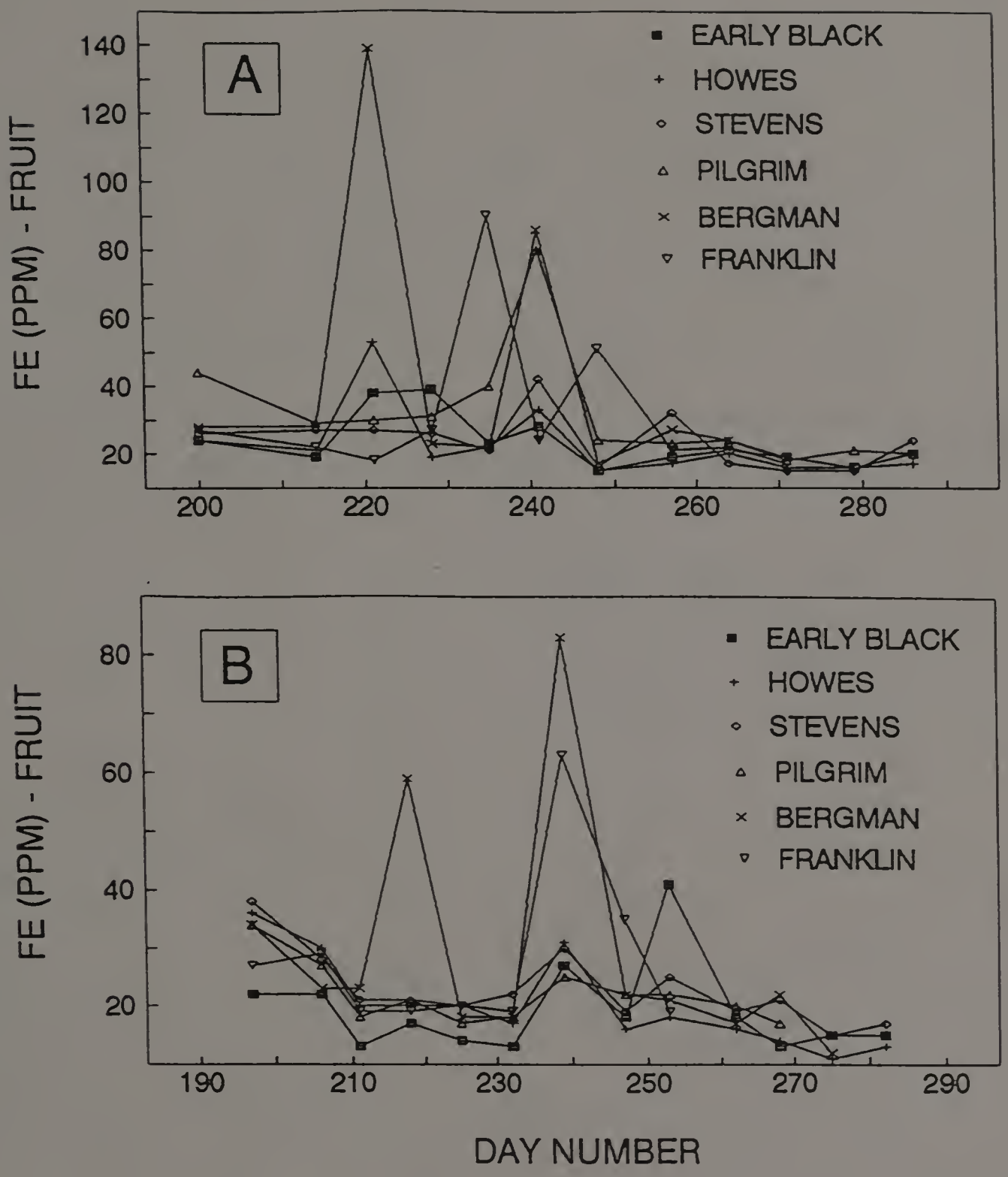

Figure 8.29 Fe concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

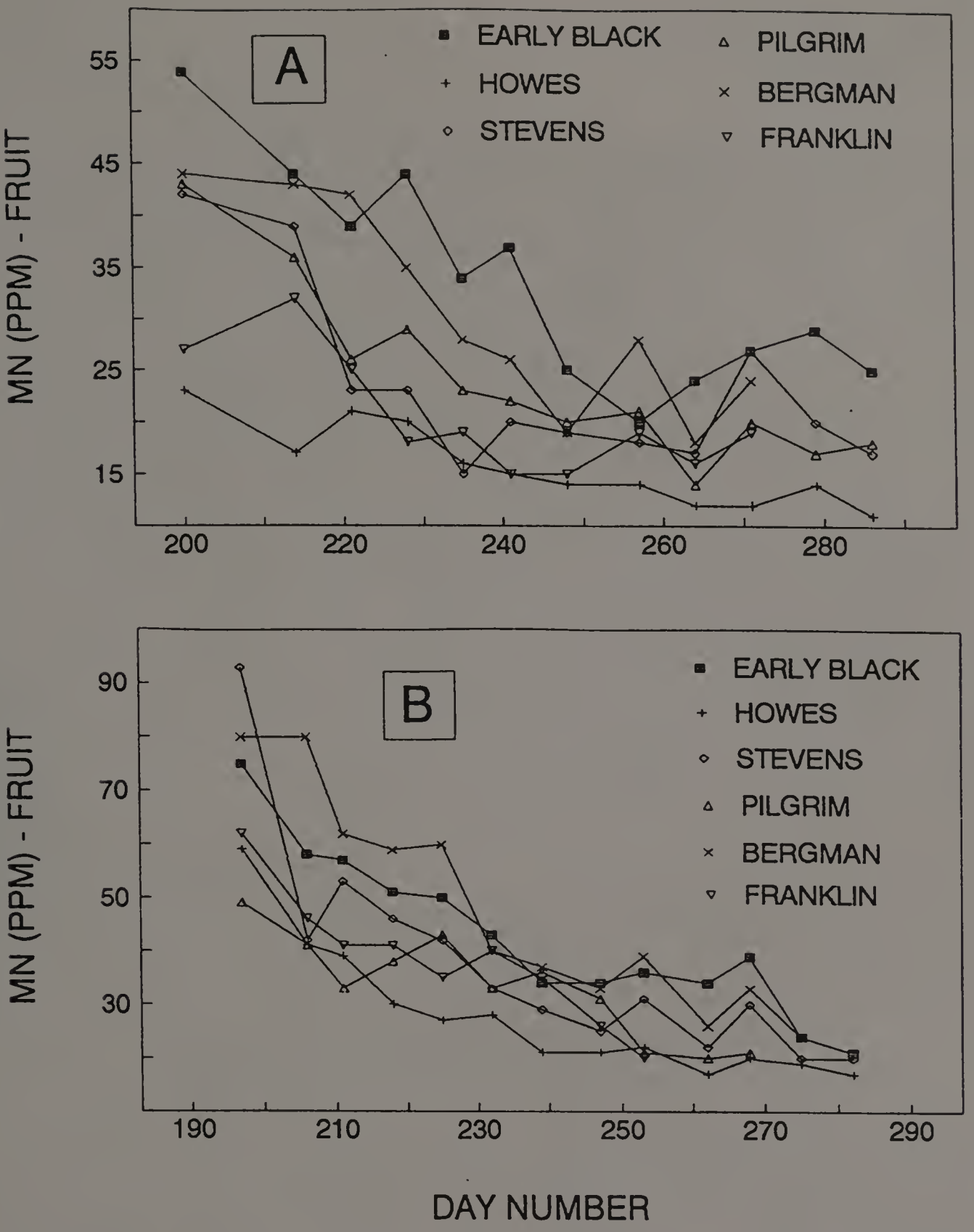

Figure 8.30 Mn concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

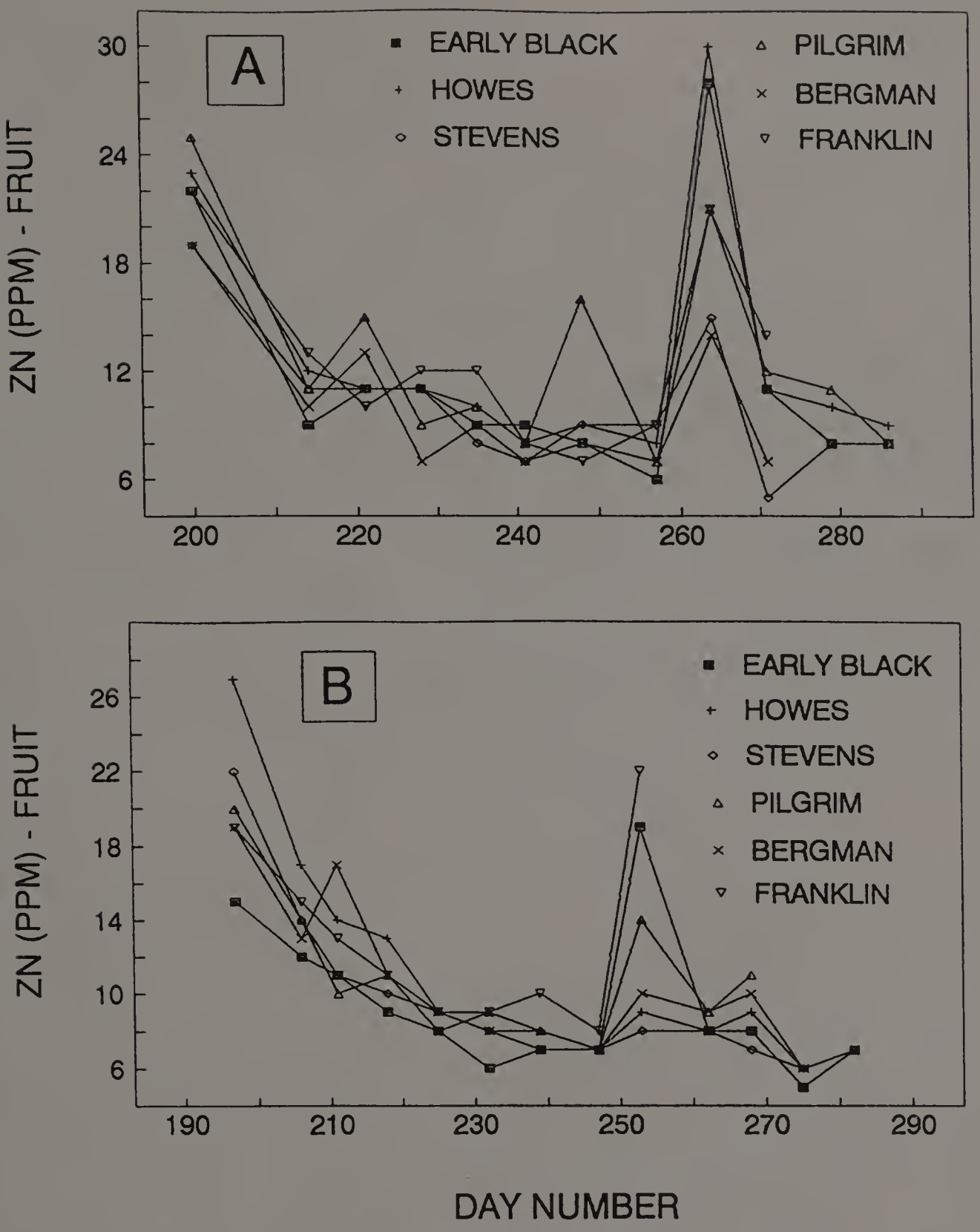

Figure 8.31 Zn concentration (dry weight) in fruit of cranberry, 6 cultivars. A: 1989; B: 1990.

CHAPTER 9

DETERMINATION OF CRANBERRY NUTRIENT STATUS: TISSUE TO SAMPLE, TIME TO SAMPLE, AND STANDARD VALUES FOR TEN ELEMENTS IN 'EARLY BLACK'

9.1 Tissue to Sample

Tissue samples for nutrient analysis in cranberry had previously been collected from new shoots. However, confusion existed regarding which new shoots or parts thereof should be used. Eaton and Meehan (1973) used leaves only from entire new uprights (vegetative and flowering mixed). Eck (1971) analyzed vegetative uprights, flowering uprights, and leaves from runners separately. Dana (1981c) proposed the use of whole shoot tips from uprights for routine tissue testing of cranberries. DeMoranville and Deubert (1986) collected leaves only from upright shoots.

Eck (1971) showed that N content of runner leaves, vegetative uprights, and flowering uprights all increased with increasing N fertilizer level. However, the N concentrations in the different tissues at a single fertilizer level were different. Based on these results, the possibility existed for errors in the interpretation and comparison of cranberry tissue analyses due to lack of a universal standard for collecting the sample material.

Four types of tissue samples from the top 5 cm of new upright shoots were compared as part of the study of cultivar nutrient differences. The tissue sample types were vegetative uprights (whole tips), flowering uprights (whole tips), a mixture of vegetative and flowering uprights (whole tips), and leaves stripped from the mixed

uprights. Analysis of variance (ANOVA) for each of the ten analyzed elements for 1989 and 1990 by cultivar, tissue, and sampling date showed significant ($p<0.05$) effects of cultivar, date, and tissue but no significant cultivar by tissue interaction (except for B in 1990). Based on the lack of significant tissue by cultivar interaction, further statistical tests were performed on tissue data pooled across cultivars.

The average elemental concentrations in the different tissues were not the same (Table 9.1). The most common difference was between flowering and vegetative uprights. The differences were more apparent when the values over the whole season were compared (Figures 9.1 to 9.10 A and B, p. 222-231). Up to the time of fruit set (early July), the concentrations of the elements were the same in both upright types. From that time on, N and K concentrations in flowering uprights were lower than those in vegetative uprights (Figures 9.1 and 9.3 A and B, p. 222 and 224). The lower N concentration in flowering uprights confirms the differences found by Eck (1971). The concentrations of P in flowering uprights fell below those in vegetative uprights (Figure 9.2 A and B, p. 223), but not until later in the season. The concentrations of Ca, Mg, B (1989 only), Fe, and Mn were higher in flowering uprights than in vegetative uprights after fruit set. No differences in concentrations of Cu or Zn occurred between the two upright types.

The low concentrations of N and K in flowering uprights were most likely due to the demand for those elements in the developing fruit. Because those two elements were present in the highest concentrations in fruit tissue, it was possible that uptake from the

Table 9.1 Nutrient levels in 4 tissues from new shoots of cranberry. Means followed by the same letter do not differ statistically (Tukey test).

1989

Tissue	%N	%P	%K	%Ca	%Mg
U_F	0.98 b	0.12 a	0.40 b	0.66 a	0.23 a
U_N	1.06 ab	0.13 a	0.50 a	0.54 c	0.20 c
Mixed U	1.06 ab	0.13 a	0.47 a	0.59 bc	0.20 bc
Leaves	1.14 a	0.13 a	0.46 a	0.63 ab	0.22 ab
Sig. of F	p<0.001	p>0.05	p<0.001	p<0.001	p<0.001

	ppm B	ppm Cu	ppm Fe	ppm Mn	ppm Zn
U_F	46 a	6 a	79 a	344 a	23 a
U_N	40 c	6 a	73 a	250 bc	23 a
Mixed U	42 bc	8 a	75 a	279 b	23 a
Leaves	45 ab	7 a	77 a	228 c	22 a
Sig. of F	p=0.001	p>0.05	p>0.05	p<0.001	p>0.05

1990

Tissue	%N	%P	%K	%Ca	%Mg
U_F	0.95 b	0.14 a	0.51 a	0.74 a	0.23 a
U_N	1.03 ab	0.14 a	0.55 a	0.66 a	0.21 a
Mixed U	1.02 ab	0.14 a	0.55 a	0.68 a	0.22 a
Leaves	1.11 a	0.14 a	0.51 a	0.76 a	0.23 a
Sig. of F	p=0.001	p>0.05	p>0.05	p>0.05	p>0.05

	ppm B	ppm Cu	ppm Fe	ppm Mn	ppm Zn
U_F	40 a	6 a	63 a	351 a	24 a
U_N	42 a	6 a	59 a	267 b	23 a
Mixed U	39 b	6 a	61 a	288 b	24 a
Leaves	44 a	7 a	64 a	250 b	24 a
Sig. of F	p=0.018	p=0.041	p>0.05	p<0.001	p>0.05

roots could not keep pace with demand in the fruit. The elements which were present in higher concentration in flowering uprights (Ca, Mg, B, Fe, and Mn) may have accumulated as a result of increased root activity (or an increase in new root production) in response to fruiting, such that while demand for N and K was not met, demand for the other elements was exceeded.

The low levels of N and K in flowering uprights may be one of the factors responsible for the biennial bearing of cranberry uprights (Eaton, 1978; Strik et al., 1991). Eaton (1978) showed that flower bud induction for the following season occurred at about the same time as fruit set in the current season and that removal of the developing fruit early in the period led to an increase in flower bud production on flowering uprights. He suggested that the developing buds were competing with existing fruit for nutrients. If that were the case, depletion of N and K in flowering uprights may have been a factor in the low incidence of return bloom in cranberry uprights (Strik et al., 1991). Eck (1977) found that biennial bearing highbush blueberries had higher N and lower Ca in the 'off' year. This would correspond to the higher N and lower Ca in vegetative cranberry uprights in this study.

Element concentrations in samples of mixed vegetative and flowering uprights tended to fall between those of the separately sampled uprights (Table 9.1). Based on the seasonal average, the concentrations in mixed samples were statistically similar to those in vegetative uprights. Over the entire season, N, B, and Fe (Figures 9.11 to 9.13, p. 232-233), concentrations held that pattern. The relationships among the patterns for P were more variable (Figure 9.14, p. 233), while the concentrations of K, Ca, Mg, and Mn (Figure 9.15 to 9.18, p. 234-235) in mixed samples tended to fall between those of the two other types. The tendency for the mixed sample to more resemble the vegetative uprights was due to the higher proportions of vegetative uprights in a randomly collected mixed

sample. The percent of flowering uprights in this study varied between 10 and 45, usually averaging about 30-35%.

Mixed upright samples consisting of whole shoot tips were compared to just leaves from mixed upright tips. The average seasonal element concentrations in the two tissue types were generally not different (Table 9.1). However, over the course of the season, the tissue types diverged. Concentrations of N, Ca, Mg, and B were higher in leaf only samples (Figure 9.19 to 9.22, p. 236-237); concentrations of K and Mn were lower in leaf only samples (Figure 9.23 and 9.24, p. 238); and the tissue types did not differ in P, Cu, Fe, or Zn concentrations.

Based on all of the differences found in element concentrations among tissue types, a single type should be chosen and used throughout the cranberry industry and among cranberry researchers so that results can be properly interpreted and compared. The choice should be based on ease of collection and how meaningful the test results would be. Leaf only sampling was eliminated in order to simplify sample collecting. However, cranberry shoots do become woody late in September. Shoot tip samples collected after the stems become woody may show lower than expected element concentrations due to the lower concentrations in woody stem tissue, which would then make up a significant portion of the sample weight.

Mixed vegetative and flowering upright tip samples were selected for future sampling. If samples were collected before fruit set, there were no differences among the three upright sample types and collecting a mixed sample was less labor intensive. After fruit set, the mixed upright sample gave a compromise (middle-range) value

between those of the other two types. Samples collected after fruit set would be used to determine nutritional needs for bud development and the following season. The relative contribution of vegetative uprights to both the mixed sample results and the following crop (Eaton, 1978) were similar, with the vegetative uprights making a larger contribution than the flowering uprights. A sample of purely vegetative uprights would take longer to collect and would have the potential for underestimating the need for N and K. A sample of purely flowering uprights would not be representative of the needs of the bog. These uprights only accounted for 30-35% of the current stand and only about 25% of them would produce flower buds for the following season (Strik et al., 1991).

9.2 Time to Sample

Changes in the concentrations of the elements were observed during the season and were discussed in Chapters 6 and 8. These changes made the choice of a standard sampling time (date range) necessary if the results of cranberry nutrient analyses were to be compared to one another and to standard values. The sample time period should be a time when nutrient element concentrations were not changing for at least two weeks. John and Daubeny (1972) suggested that raspberry tissue samples should be collected after the first flush of new growth had ended and before remobilization of elements during leaf senescence. While cranberry leaves did not drop in the fall, some remobilization prior to dormancy could be expected. Periods of element concentration stability for six cultivars were

Table 9.2 Dates of stable element concentrations in cranberry new shoot tissue, six cultivars. The last sample dates were 6 September, 1989 and 25 September, 1990.

Element	1989	1990
N	2 Aug.-6 Sept.	30 July-13 Aug. 10-25 Sept.
P	16 Aug.-6 Sept.	30 July-25 Sept.
K	16 Aug.-6 Sept.	3-16 July 30 July-25 Sept.
Ca	9-23 Aug. 29 Aug.-6 Sept.	10-25 Sept.
Mg	19-28 June 9 Aug.-6 Sept.	16 July-25 Sept.
B	19 June-26 July 9 Aug.-6 Sept.	30 July-25 Sept.
Cu	19 June-12 July 19 July- 6 Sept.	30 July-25 Sept.
Fe	19 June-12 July 26 July-6 Sept.	19 June-27 Aug. 27 Aug.-25 Sept.
Mn	16 Aug.-6 Sept.	13 Aug.-25 Sept.
Zn	19 June-23 Aug. 29 Aug.-6 Sept.	13 Aug.-27 Aug. 27 Aug.-25 Sept.

determined using difference contrasts and profile analyses following ANOVA by date of sampling. The stable periods for each element in 1989 and 1990 were roughly similar (Table 9.2). Based on these stable periods, 10 August to 15 September was selected as a common sampling period for the six cultivars. This period avoided rapid new growth in June and July and dormancy-related events in late-September.

Based on the results of profile analyses of the data from the N-P-K experiment (see Tables A.1 to A.10, p. 254-259), a sampling period

of 5 August to 15 September was chosen for 'Early Black'. Because this cultivar matures fruit and becomes dormant earlier than many others, sampling early during this period would be preferred (e.g. mid- to late August).

Chaplin and Martin (1979) found stable periods for nutrient element concentrations in 'McFarlin' cranberry. A stable period in late August was found for all elements except Mg, Mn and Fe, which had stable levels in June and July. They recommended separate sampling periods for the two groups of elements. DeMoranville and Deubert (1986) found stable element concentrations in 'Howes' cranberry late in the summer. The concentrations of N, K, Ca, and Mg were stable from 15 August to 10 September, while that of P was only stable from 15 July to 15 August. All available research on cranberry tended to support a late August sampling period for tissue analyses.

9.3 Standard Nutrient Concentration Values for 'Early Black' Cranberry

Once standard time and tissue to sample had been chosen, standard values for element concentration in that tissue had to be established. Simple linear regression of yield of 'Early Black' vs. element concentration in new shoot tips (mixed sample collected late in August) was attempted, using the data from the N-P-K experiment. The relationships for P, K, Cu, Fe, and Mn were not significant. All of the other elements tested showed significant positive linear relationships between yield and element concentration. Quadratic relationships were then calculated for those elements (Table 9.3). In all cases the quadratic equations were associated with higher R^2

Table 9.3 Quadratic equations relating yield (kg/ha) to element concentration in 'Early Black' cranberry new shoots. All equations were significant at a maximum of p=0.02, n=60.

Element		R^2
N	$Y = - 40932 + 100905\ (\%N) - 41352\ (\%N)^2$	0.137
P	NS	
K	NS	
Ca	$Y = 59490 - 146796\ (\%Ca) + 118308\ (\%Ca)^2$	0.184
Mg	$Y = - 180048 + 1604056\ (\%Mg) - 3205049\ (\%Mg)^2$	0.276
B	$Y = - 8766 + 1020\ (ppm\ B) - 9\ (ppm\ B)^2$	0.129
Cu	NS	
Fe	NS	
Mn	NS	
Zn	$Y = - 37282 + 4110\ (ppm\ Zn) - 71\ (ppm\ Zn)^2$	0.217

values than the corresponding linear equations. While the R^2 values for the equations were not large, the regression relationships were statistically significant. Eaton and Meehan (1973) found significant positive linear relationships between yield of 'Ben Lear' cranberry and both Ca and Mg concentration in upright leaves, with similar low R^2 values (approximately 0.1). They also found a significant negative linear relationship between yield and K concentration. The relationship between 'Early Black' yield and K concentration in upright tips was also negative in this study but not statistically significant. John and Daubeny (1972) found no significant linear relationships between yield and element concentration in raspberry.

The estimated values for yield vs. element concentration were plotted for those elements with significant relationships to yield (Figures 9.25 to 9.29, p. 239-241). In theory, the upward slope of

the curve represents less than optimum nutrient content, whereas the downward sloping range represents excess. However, the maximum yields predicted in these relationships were not as high as the actual yields in many of the plots, a definite problem, considering the fact that the plot yields were well below the maximum cranberry yields achieved in commercial settings. Based on these calculations, the standard ranges for the five elements should be 1.05-1.20% N, >0.9% Ca, 0.23-0.26% Mg, 50-60 ppm B, and 27-30 ppm Zn. All of these ranges were high in comparison to mean values from 287 'Early Black' samples collected during the stable periods from 1987 to 1990 (Table 9.5). The calculated ranges did roughly correspond to published standards for cranberries in the Pacific Northwest (Shawa et al., 1984). However, those standards had very wide ranges (e.g. 0.96-1.4% N, 0.61-1.6% Ca, and 26-60 ppm B) and were probably not too meaningful. The calculated values were outside the much narrower ranges recommended for 'Searles' cranberry in Wisconsin (Dana, 1981c; Roper and Coombs, 1992).

While the ranges of observed element concentrations in 'Early Black' were fairly wide, most of the values were clustered around the means (low CV, Table 9.5). For this reason, standard values were selected based on bracketing the mean values. The standard ranges for N, P, and K were made to include higher values above the mean than were the standards for the other elements, to compensate for the fact that many of the samples used to generate the means were from underfertilized plots (lower than standard levels of N-P-K fertilizer). The proposed standards (Table 9.4) differed somewhat from those previously published for cranberry. In comparison to the

Table 9.4 Recommended element concentrations for 'Early Black' cranberry new shoot tips sampled between 5 August and 15 September.

Element	Low	Normal	High
N (%)	<0.90	0.95-1.05	>1.20
P (%)	<0.09	0.11-0.14	>0.18
K (%)	<0.30	0.40-0.65	>0.80
Ca (%)	<0.50	0.60-0.80	>0.90
Mg (%)	<0.20	0.20-0.25	>0.26
B (ppm)	<20	30-50	>70
Cu (ppm)	<4	4-7	>10
Fe (ppm)	<30	40-80	>100
Mn (ppm)	<100	150-250	>400
Zn (ppm)	<15	15-30	>35

standards for 'Searles' cranberry in Wisconsin (Dana, 1981c; Roper and Coombs, 1992), the proposed standards were lower for P and K and higher for N, Ca, Mg, and B. The Wisconsin standards (Dana, 1981c) were formulated based on the same methods used for these Massachusetts 'Early Black' standards. Compared to major element standards for 'Howes' in Massachusetts (DeMoranville and Deubert, 1986), the proposed standards for 'Early Black' were lower for N and Ca. The proposed standards for 'Early Black' fell within the rather wide range proposed for cranberries in the Pacific Northwest (Shawa et al., 1984) with the exception of K (higher in Massachusetts) and Cu (lower).

The results of published research were compared to the proposed standard values. Eck (1971) found 0.95% N in flowering uprights and 1.0% N in vegetative uprights of 'Early Black' cranberry fertilized with 33 kg N/ha and growing normally. In culture experiments with

rooted cuttings Stieber and Peterson (1987) showed N deficiency symptoms at 0.8% N in cranberry shoots. Eaton and Meehan (1973) proposed values of 1% N, 0.1% P, 0.34-0.40% K, 0.6-0.7% Ca, and greater than 0.31% Mg for 'Ben Lear' cranberry based on balancing the effects of element levels in the foliage on fruit sugar content, fruit anthocyanin content, and yield. They found that foliar concentrations of Fe >50 ppm or Mn >150 ppm had adverse effects on fruit soluble solid content. Based on field and laboratory experiments, Greidanus and Dana (1972) proposed 0.11% as the critical level for P. Based on the performance of 'Early Black' cuttings in sand culture, Torio and Eck (1969) suggested critical levels of >0.076% for P and <0.56% for K. Dana and Steinmann (1989b) proposed a critical value for K of 0.26% based on research with rooted 'Stevens' cuttings in solution culture. The agreement between the proposed standards for 'Early Black' and these research results was quite good. The exceptions were the proposed K critical value (Dana and Steinmann, 1989b) which was developed using purely vegetative cuttings and the proposed values of Eaton and Meehan (1973) for 'Ben Lear'. Those values were lower for P and K and higher for Mg than those proposed here. However, the P and K standards for 'Ben Lear' were proposed based on effect on fruit chemical composition, not growth or yield response.

9.4 Nutrient Concentration Ranges in Six Cranberry Cultivars

The concentration ranges for ten elements in new shoot tips of six cranberry cultivars collected between 10 August and 15 September were tabulated (Tables 9.5, 9.6, and 9.7). The mean values for 'Early

Table 9.5 Element concentrations in cranberry new shoot tips. Samples collected between 5 August and 15 September, 187 samples for 'Early Black', 8 for 'Howes'.

Element	Mean	Range	CV
		'Early Black'	
N (%)	0.97	0.64-1.46	1.18
P (%)	0.12	0.06-0.20	1.59
K (%)	0.50	0.28-0.93	1.79
Ca (%)	0.73	0.41-1.20	1.38
Mg (%)	0.23	0.09-0.32	1.02
B (ppm)	43	19-102	2.53
Cu (ppm)	6	2-28	2.90
Fe (ppm)	61	19-130	2.02
Mn (ppm)	200	59-430	2.44
Zn (ppm)	22	13-43	1.41
		'Howes'	
N (%)	0.98	0.81-1.15	4.71
P (%)	0.13	0.11-0.16	5.29
K (%)	0.43	0.31-0.55	6.84
Ca (%)	0.73	0.55-0.89	5.61
Mg (%)	0.25	0.22-0.31	3.94
B (ppm)	40	30-56	6.68
Cu (ppm)	6	5-7	4.35
Fe (ppm)	60	47-82	6.87
Mn (ppm)	249	183-335	7.23
Zn (ppm)	33	29-41	5.02

Black' (Table 9.5) tissue elements were used to formulate the standards discussed in the previous section. If the 'Early Black' standard values were applied to the other five cultivars, not all mean

Table 9.6 Element concentrations in cranberry new shoot tips. Samples collected between 5 August and 15 September, 8 samples for each cultivar.

Element	Mean	Range	CV
		'Stevens'	
N (%)	0.98	0.81-1.15	3.55
P (%)	0.13	0.11-0.15	3.70
K (%)	0.40	0.34-0.48	4.25
Ca (%)	0.80	0.61-1.12	7.28
Mg (%)	0.26	0.22-0.32	4.77
B (ppm)	49	35-58	4.80
Cu (ppm)	5	4-6	5.97
Fe (ppm)	102	81-132	6.59
Mn (ppm)	426	337-583	6.47
Zn (ppm)	24	20-33	6.05
		'Pilgrim'	
N (%)	0.99	0.89-1.10	3.03
P (%)	0.13	0.11-0.14	2.52
K (%)	0.44	0.32-0.56	5.76
Ca (%)	0.78	0.60-1.04	8.34
Mg (%)	0.23	0.20-0.27	3.96
B (ppm)	51	39-66	6.00
Cu (ppm)	6	4-7	7.16
Fe (ppm)	78	60-104	5.99
Mn (ppm)	312	209-406	7.88
Zn (ppm)	27	21-40	7.44

values fell within the normal range. The 'Howes' Zn level was slightly above the 'Early Black' norm. The Mn levels in all of the other cultivars except 'Howes' were above the range proposed for

Table 9.7 Element concentrations in cranberry new shoot tips. Samples collected between 5 August and 15 September, 8 samples for each cultivar.

Element	Mean	Range	CV
		'Bergman'	
N (%)	0.91	0.74-1.07	4.51
P (%)	0.11	0.09-0.11	2.55
K (%)	0.35	0.27-0.42	5.87
Ca (%)	0.81	0.61-1.07	6.31
Mg (%)	0.21	0.18-0.24	3.22
B (ppm)	45	33-61	7.73
Cu (ppm)	5	4-6	5.76
Fe (ppm)	73	53-61	8.96
Mn (ppm)	315	159-394	8.27
Zn (ppm)	23	18-30	6.87
		'Franklin'	
N (%)	0.98	0.79-1.22	5.55
P (%)	0.13	0.10-0.15	4.63
K (%)	0.45	0.34-0.56	6.60
Ca (%)	0.67	0.54-0.84	5.37
Mg (%)	0.22	0.18-0.24	3.49
B (ppm)	49	37-57	4.77
Cu (ppm)	5	3-6	7.77
Fe (ppm)	63	41-80	7.53
Mn (ppm)	269	210-360	7.39
Zn (ppm)	21	17-25	4.74

'Early Black'. This is of interest when one considers the finding of Eaton and Meehan (1973) that high Mn levels could be deleterious. The sections from which the samples were collected were not particularly

high-yielding (below the Massachusetts average). In addition, the 'Stevens' had high Fe levels. However, anecdotal evidence from Massachusetts indicated that high bog Fe content was associated with high yields. Presumably, the tissues of cranberry plants in those bogs contained high Fe levels as well. It should be noted that there has never been clear evidence that high tissue concentrations of Mn or Fe were associated with poor yields. The 'high' levels for those elements in any proposed standards for cranberry were not necessarily deleterious to cranberry production.

Dana (1981c) published ranges for elements found in shoots of cranberries from Wisconsin marshes. Concentrations of Ca, Mg, B, and Mn above the Wisconsin range and K concentrations below the Wisconsin range were routinely found for all six Massachusetts cranberry cultivars studied. This emphasized the difficulty in using information from other growing areas in the culture of cranberries in Massachusetts.

The levels of K in 'Bergman' tissue were low. However, the 'Bergman' planting was one of the highest yielding in this study. Fruit quality (firmness) was poor for 'Bergman'. Poor quality may have been related to low K levels in the plants, although Ca deficiencies are more likely to be associated with poor fruit quality. While none of the cultivar sections in this study was high yielding, the element means and ranges presented here (Tables 9.5 to 9.7) could be used as a guideline for the minimum acceptable element concentration values for those cultivars. Further research with a wider range of yields would be needed to establish more definitive standards for the cultivars other than 'Early Black'.

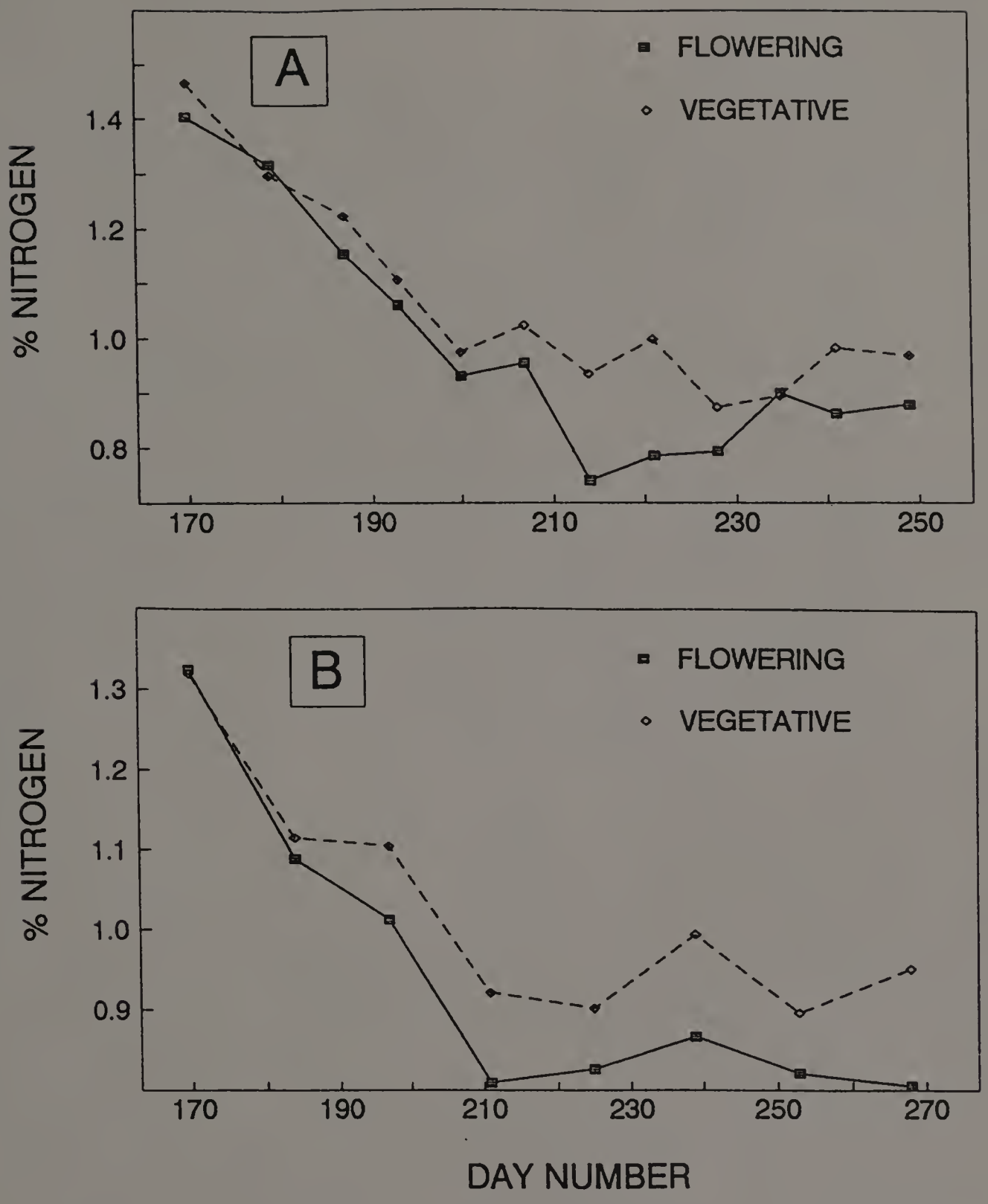

Figure 9.1 N concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

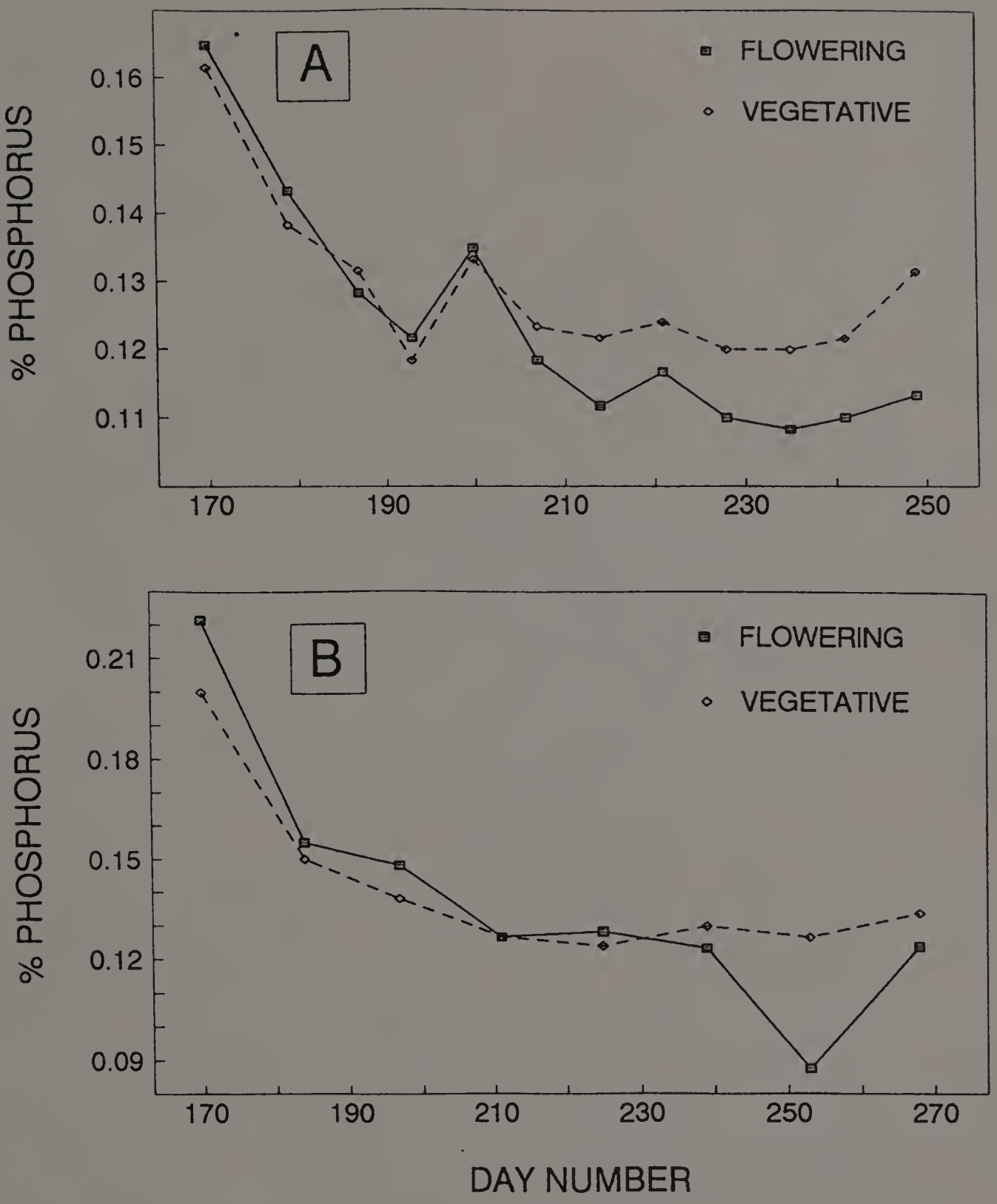

Figure 9.2 P concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

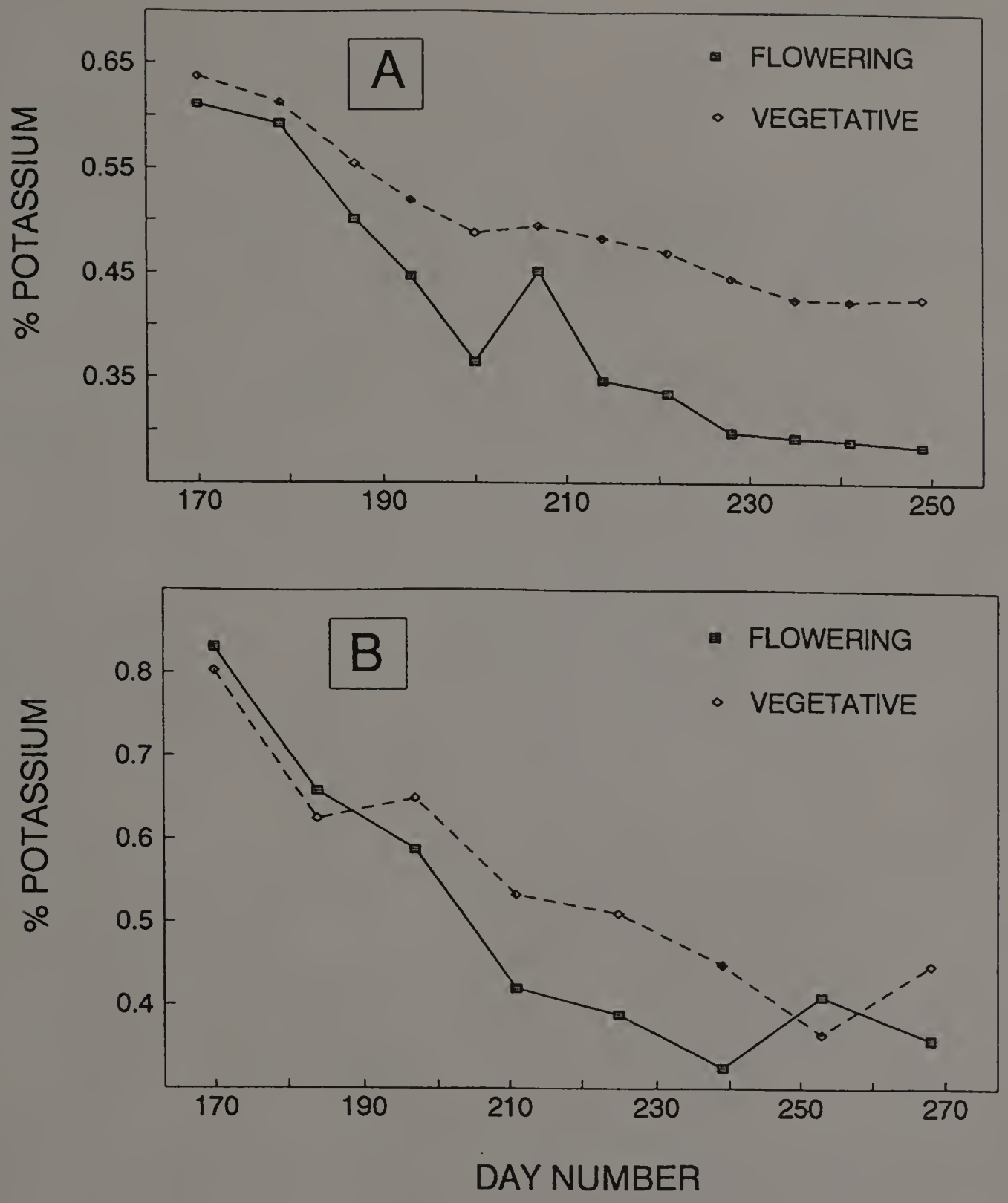

Figure 9.3 K concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

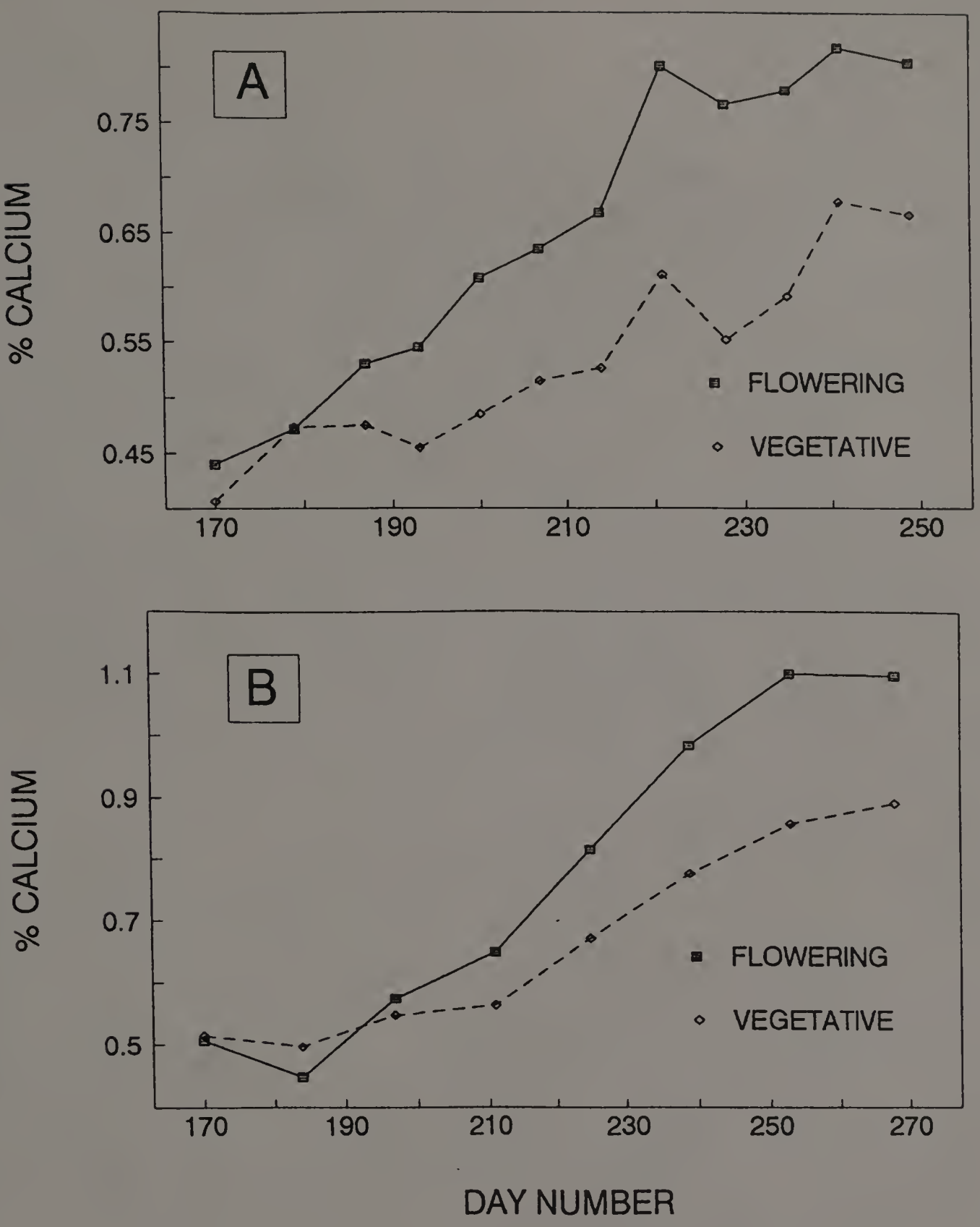

Figure 9.4 Ca concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

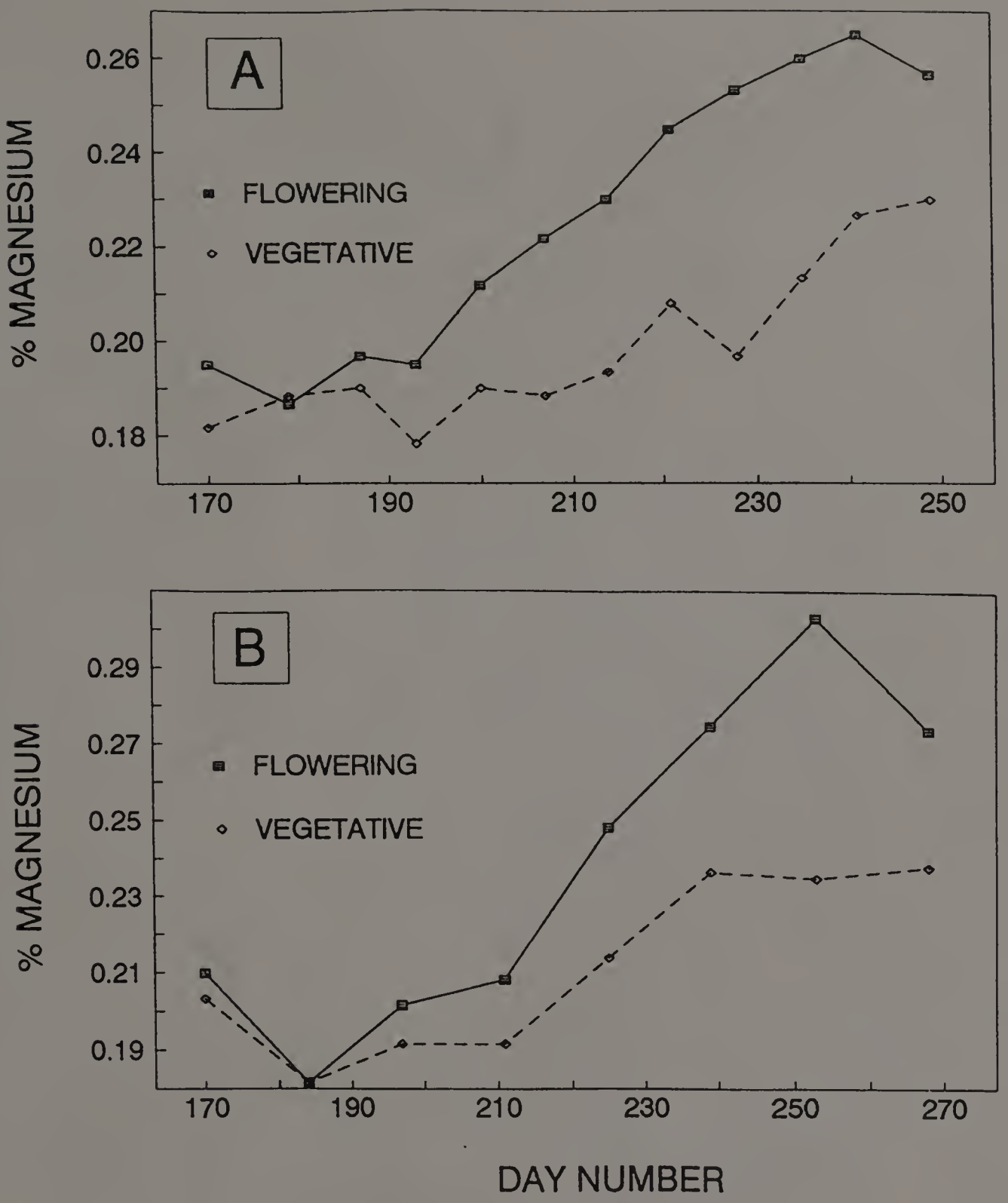

Figure 9.5 Mg concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

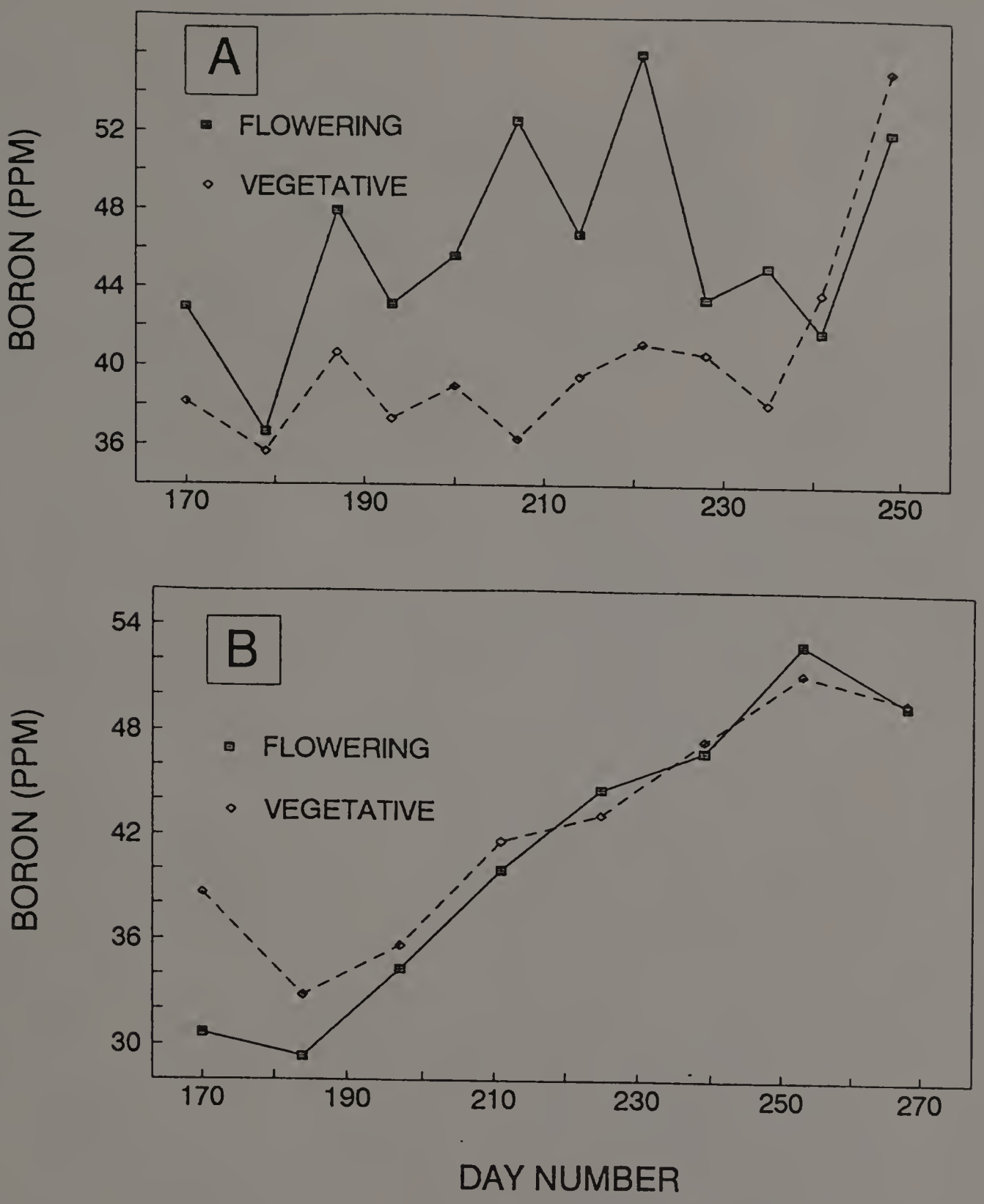

Figure 9.6 B concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

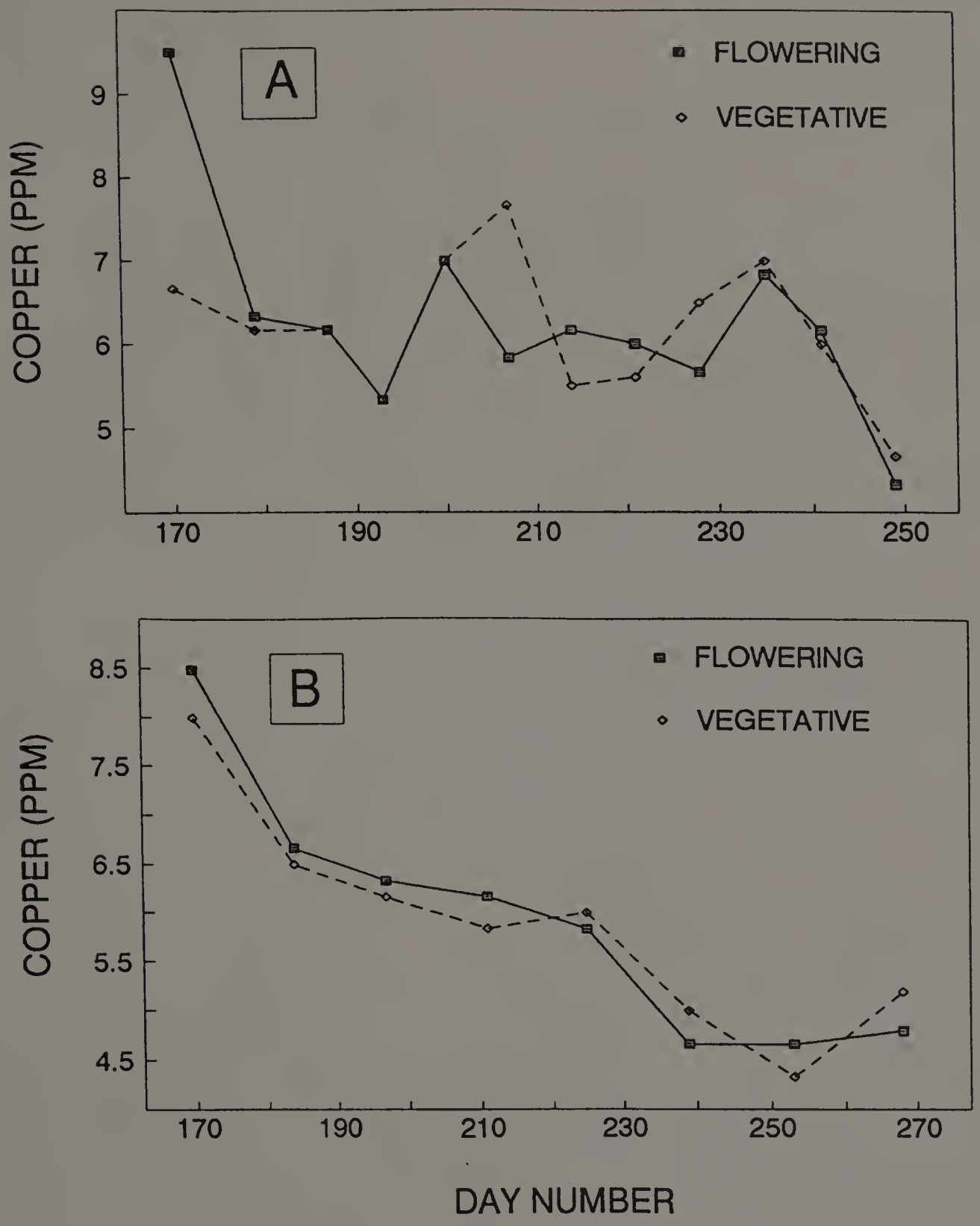

Figure 9.7 Cu concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

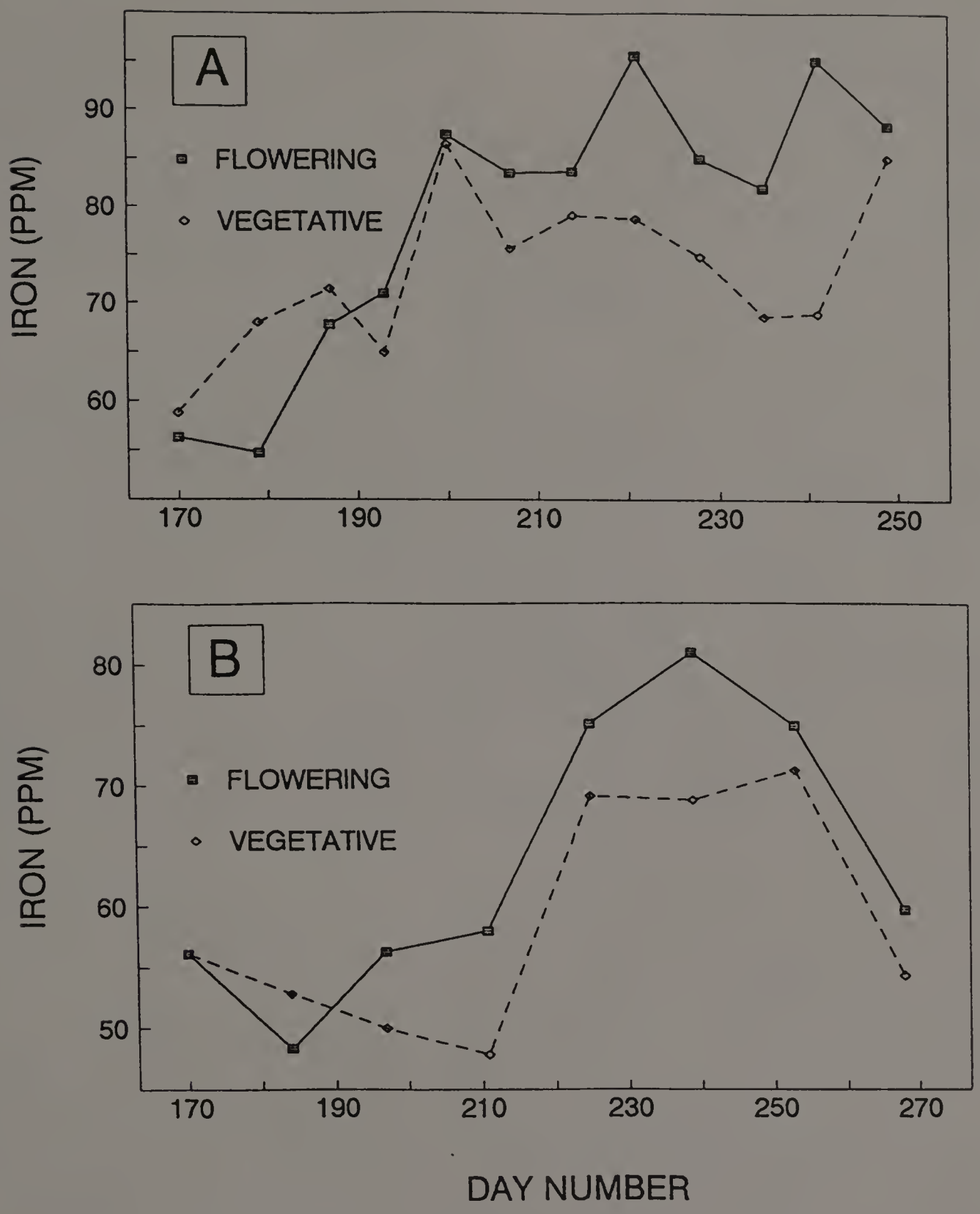

Figure 9.8 Fe concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

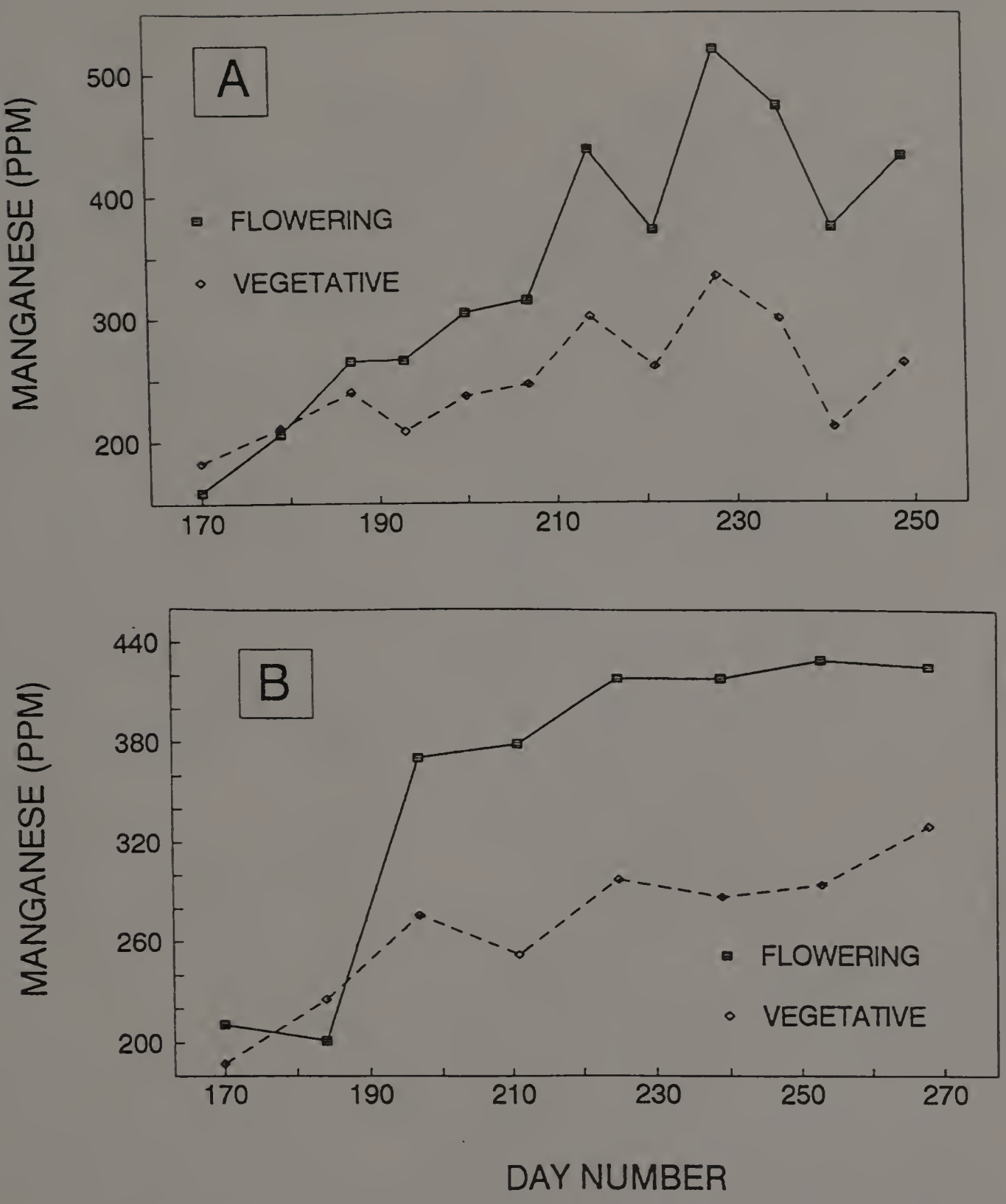

Figure 9.9 Mn concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

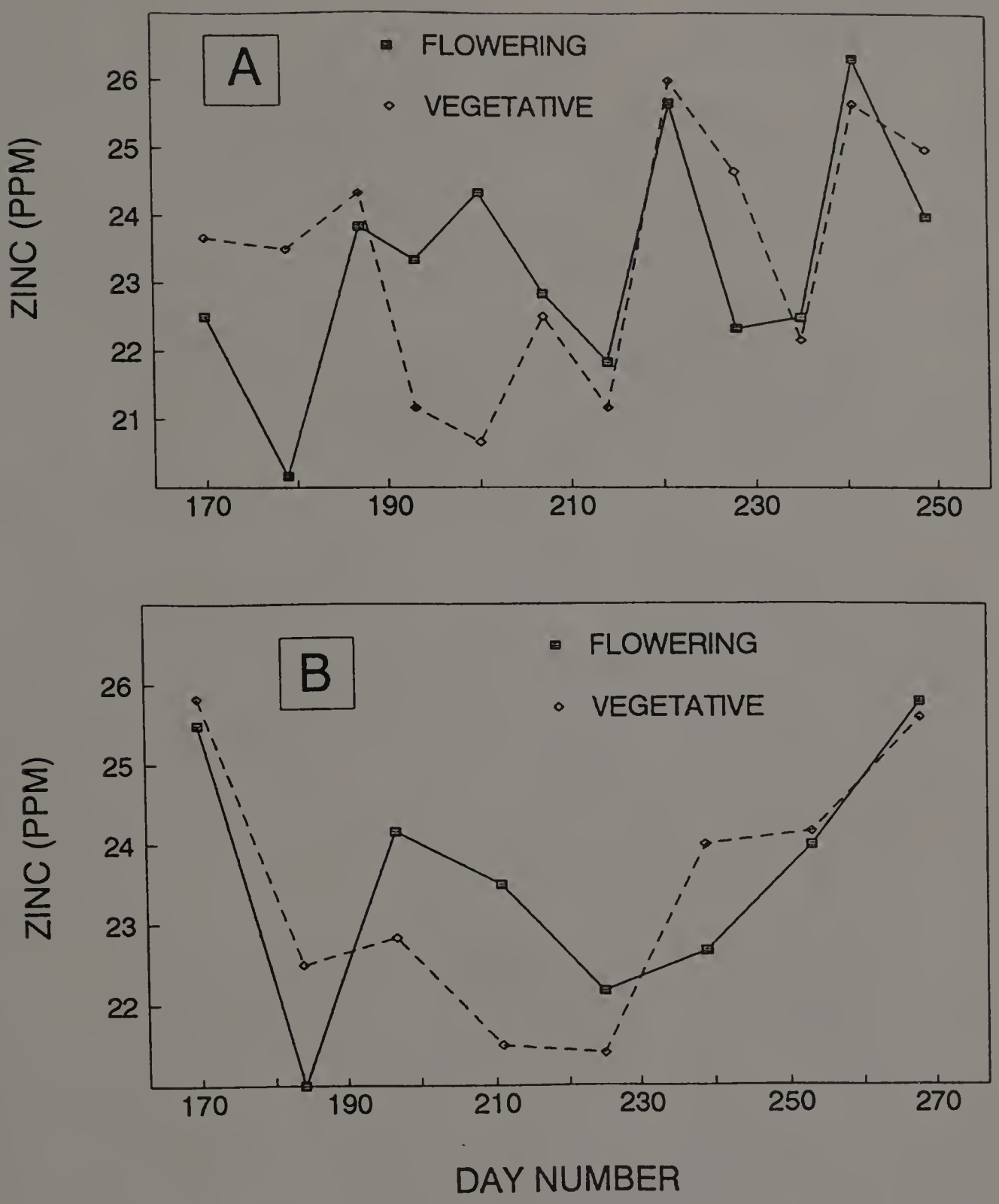

Figure 9.10 Zn concentration (dry weight) in vegetative and flowering (reproductive) new uprights of cranberry, top 5 cm. Data points are the mean of 6 cultivars. Solid line = flowering. A: 1989; B: 1990.

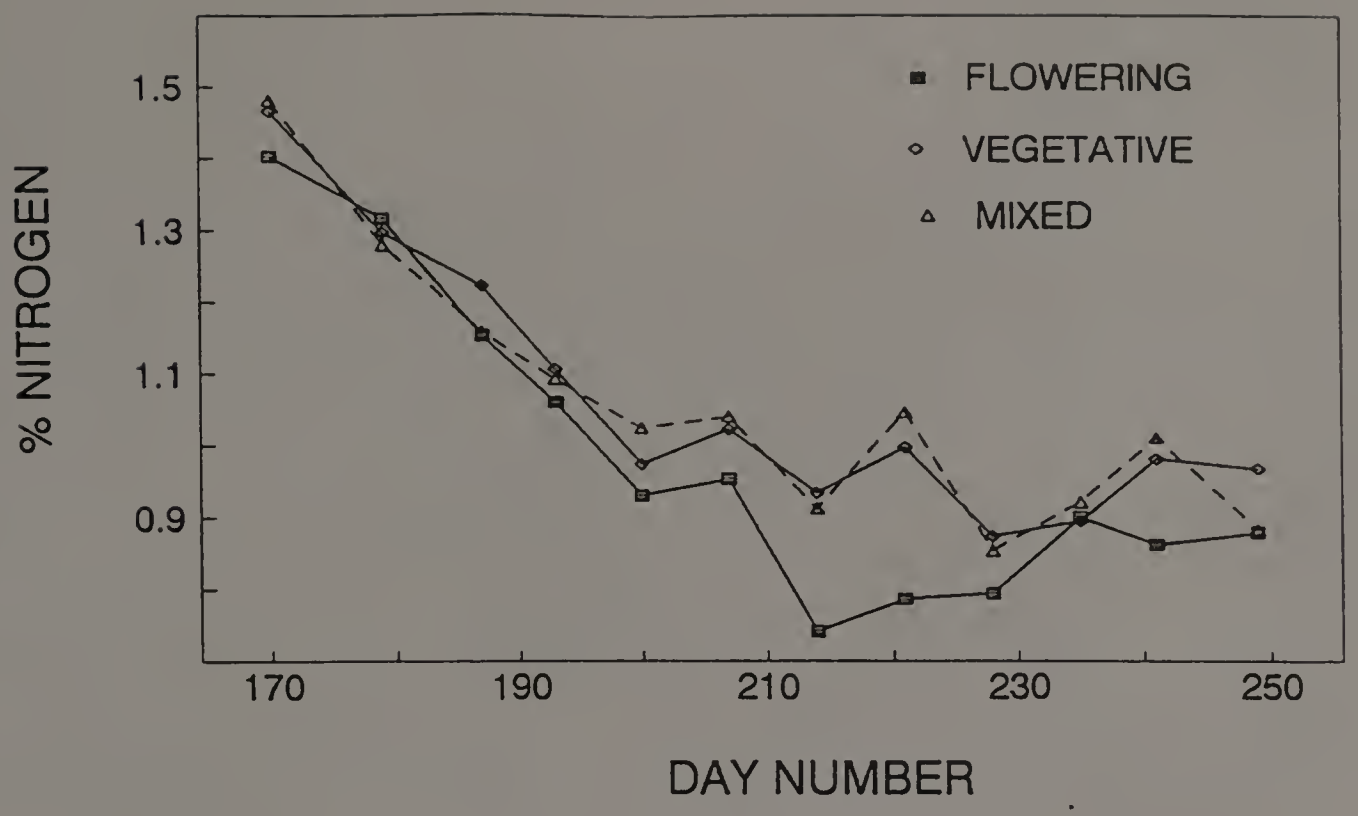

Figure 9.11 N concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

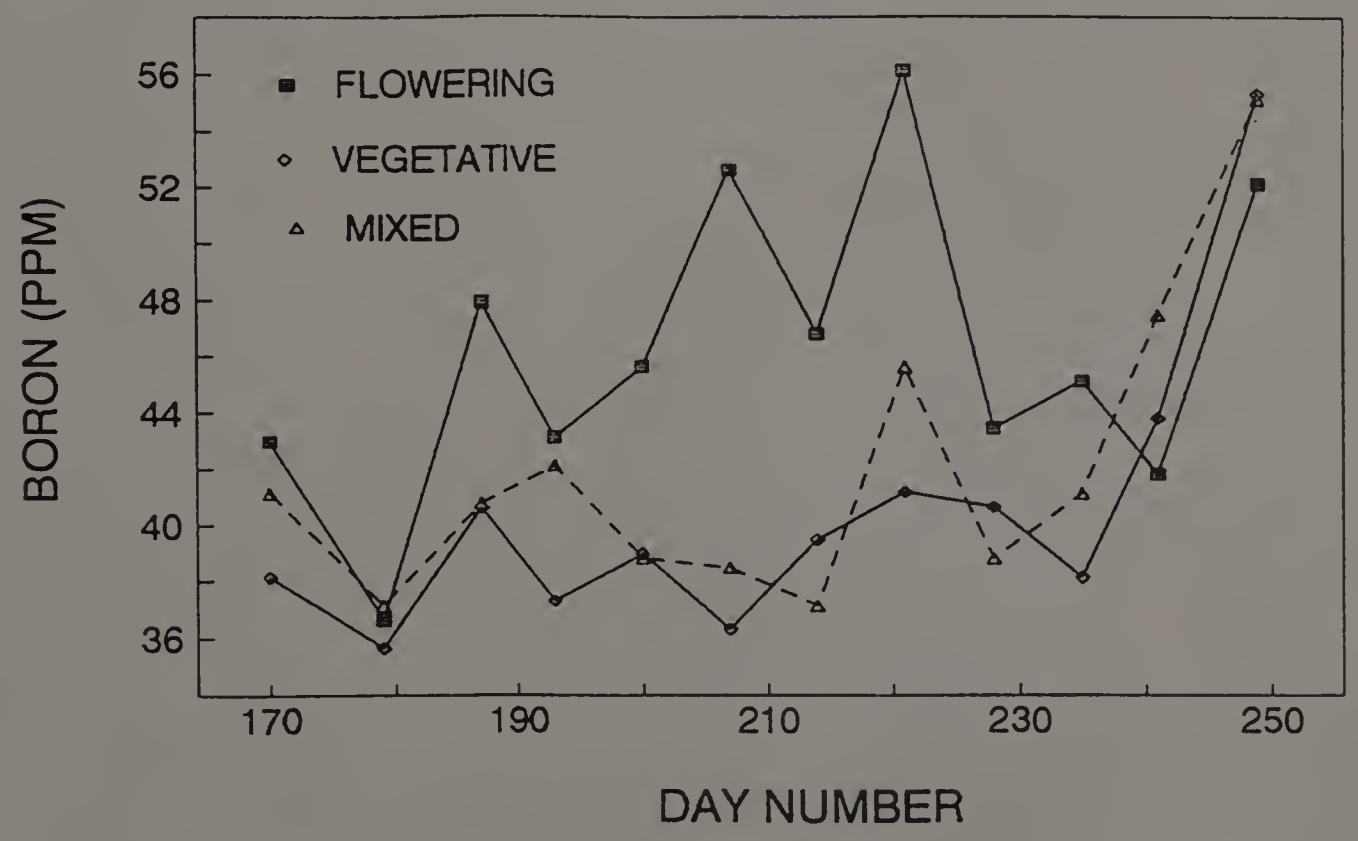

Figure 9.12 B concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

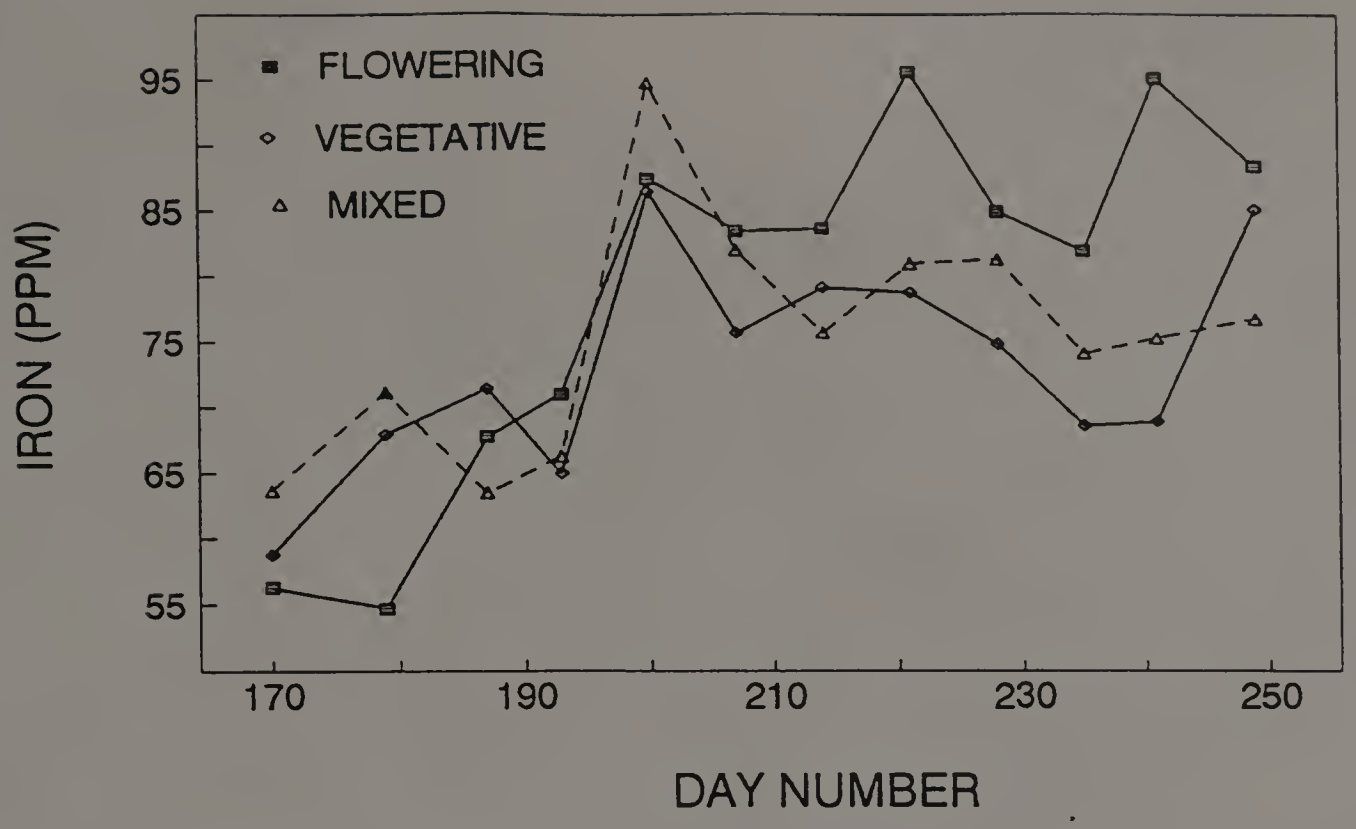

Figure 9.13 Fe concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

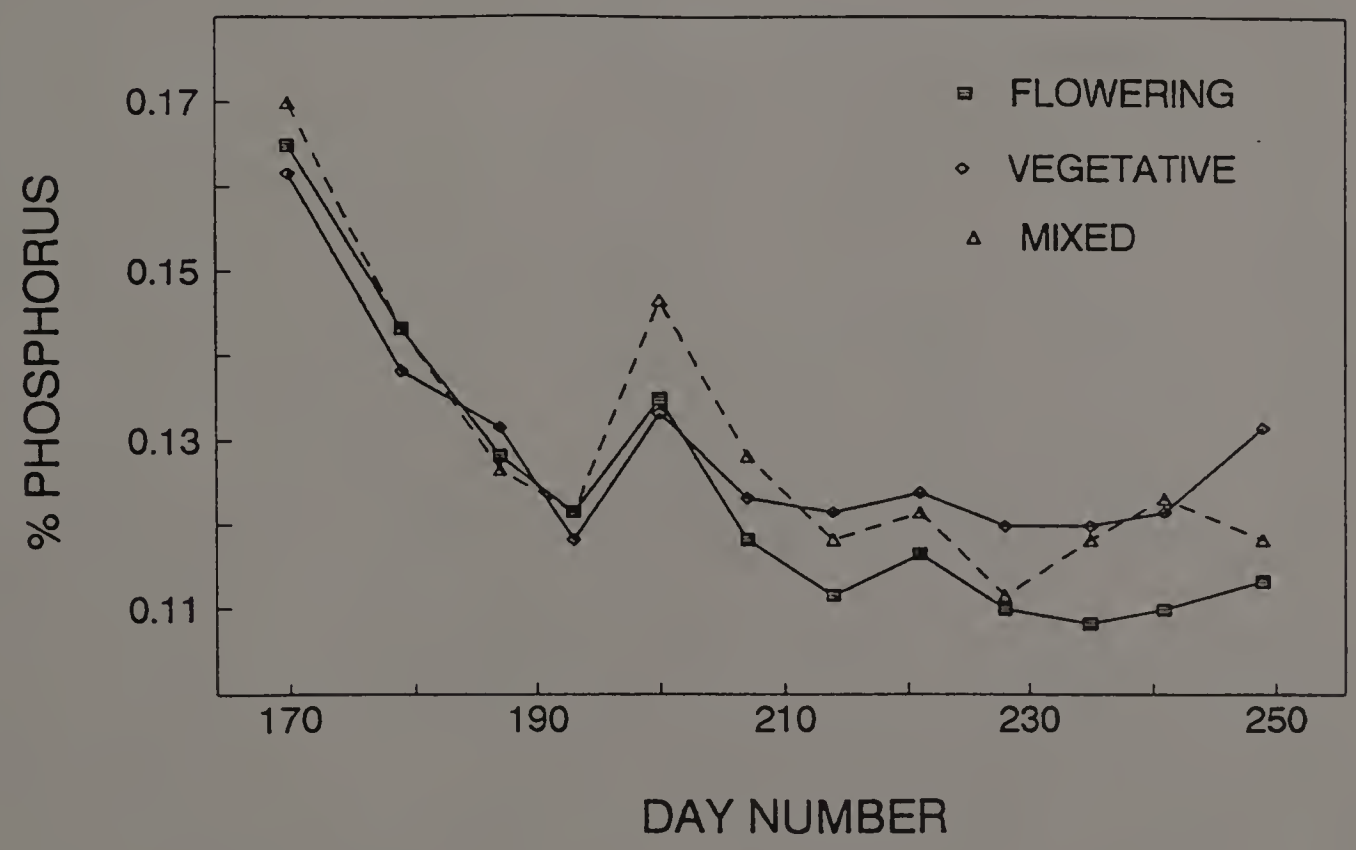

Figure 9.14 P concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

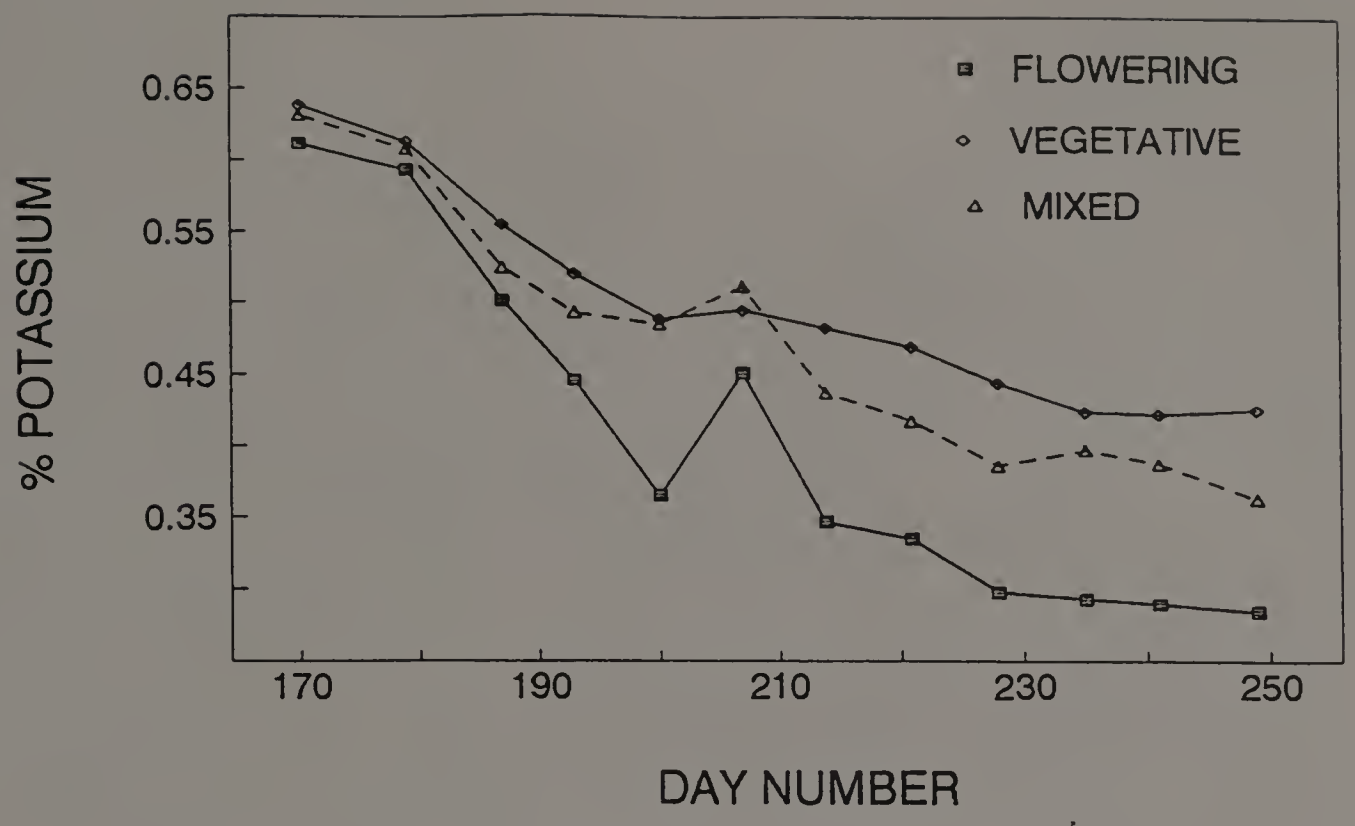

Figure 9.15 K concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

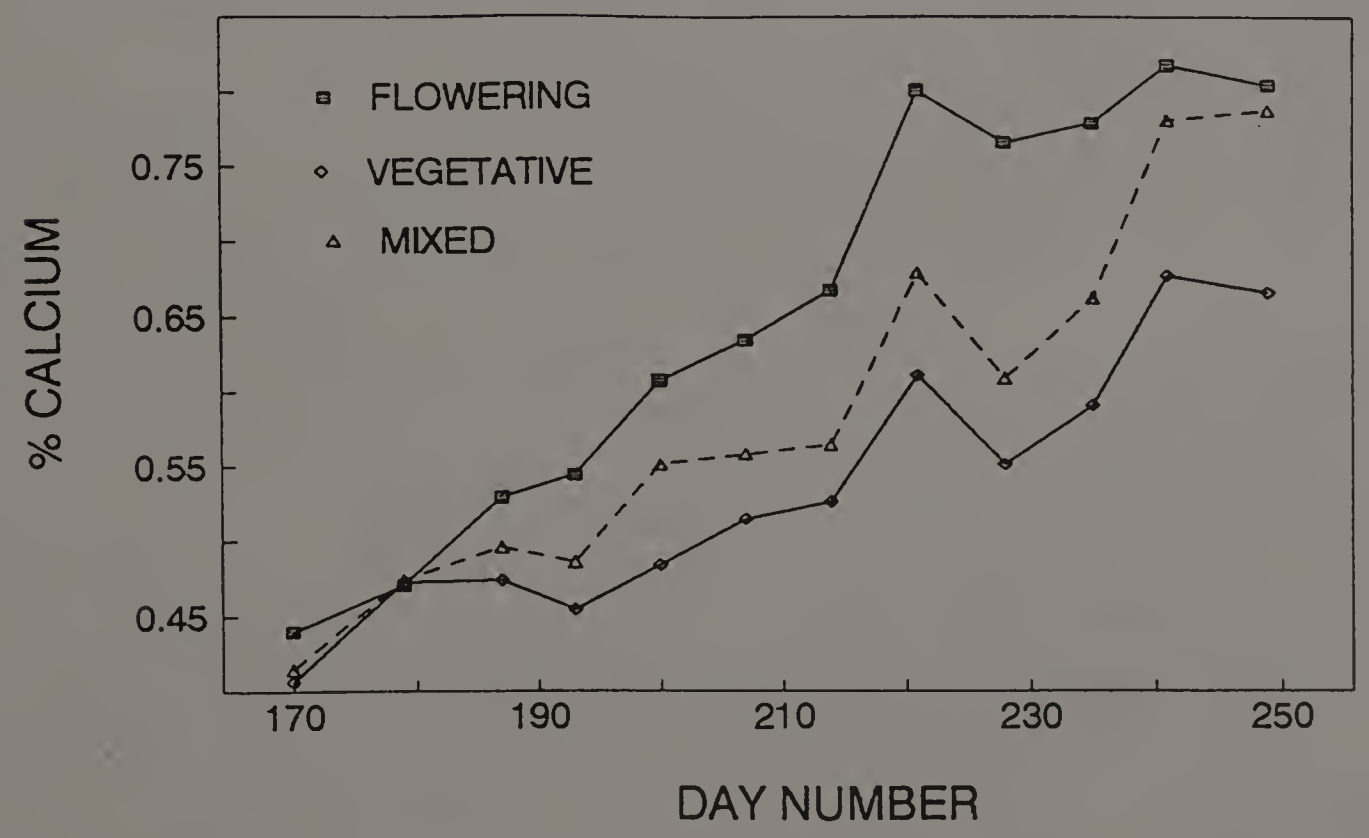

Figure 9.16 Ca concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

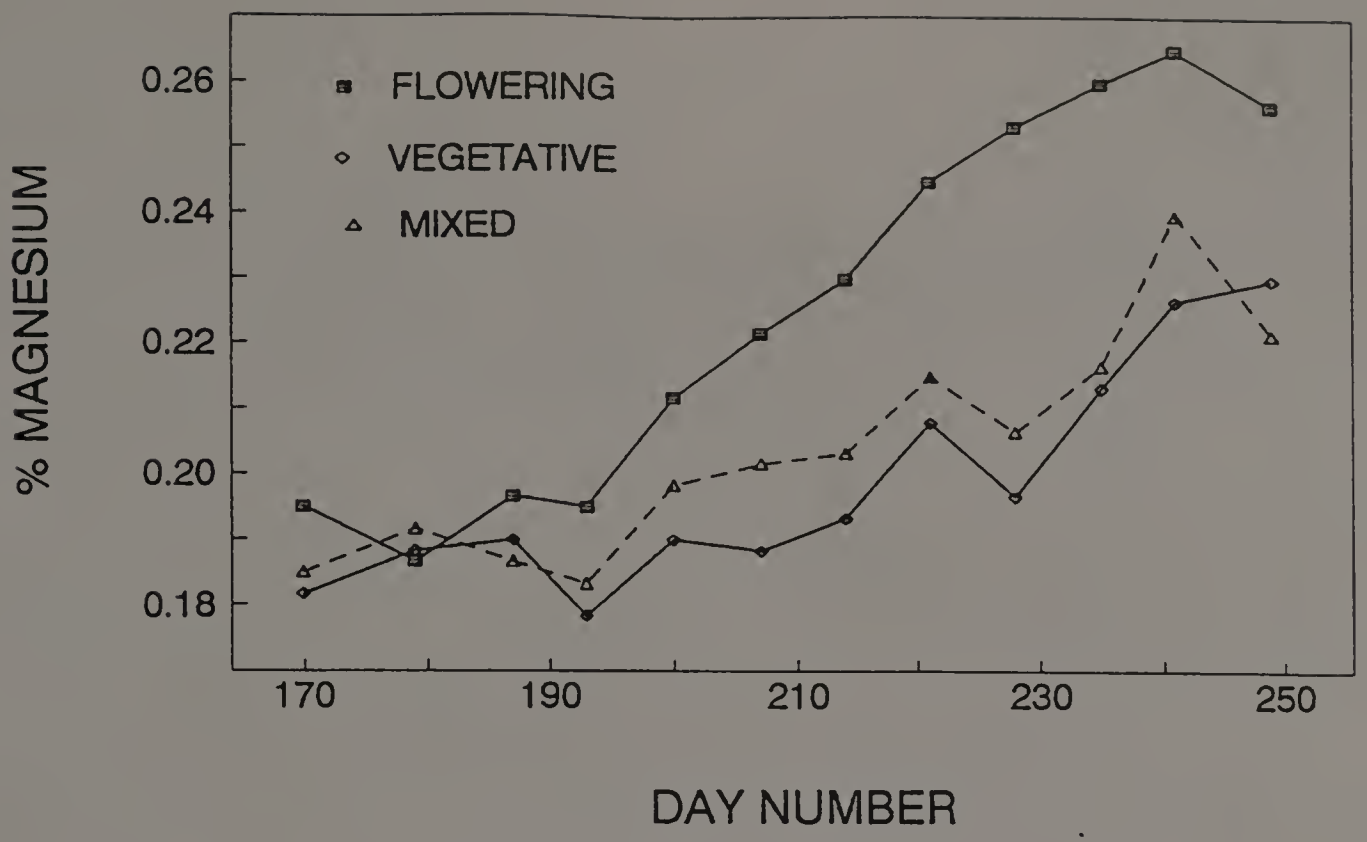

Figure 9.17 Mg concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

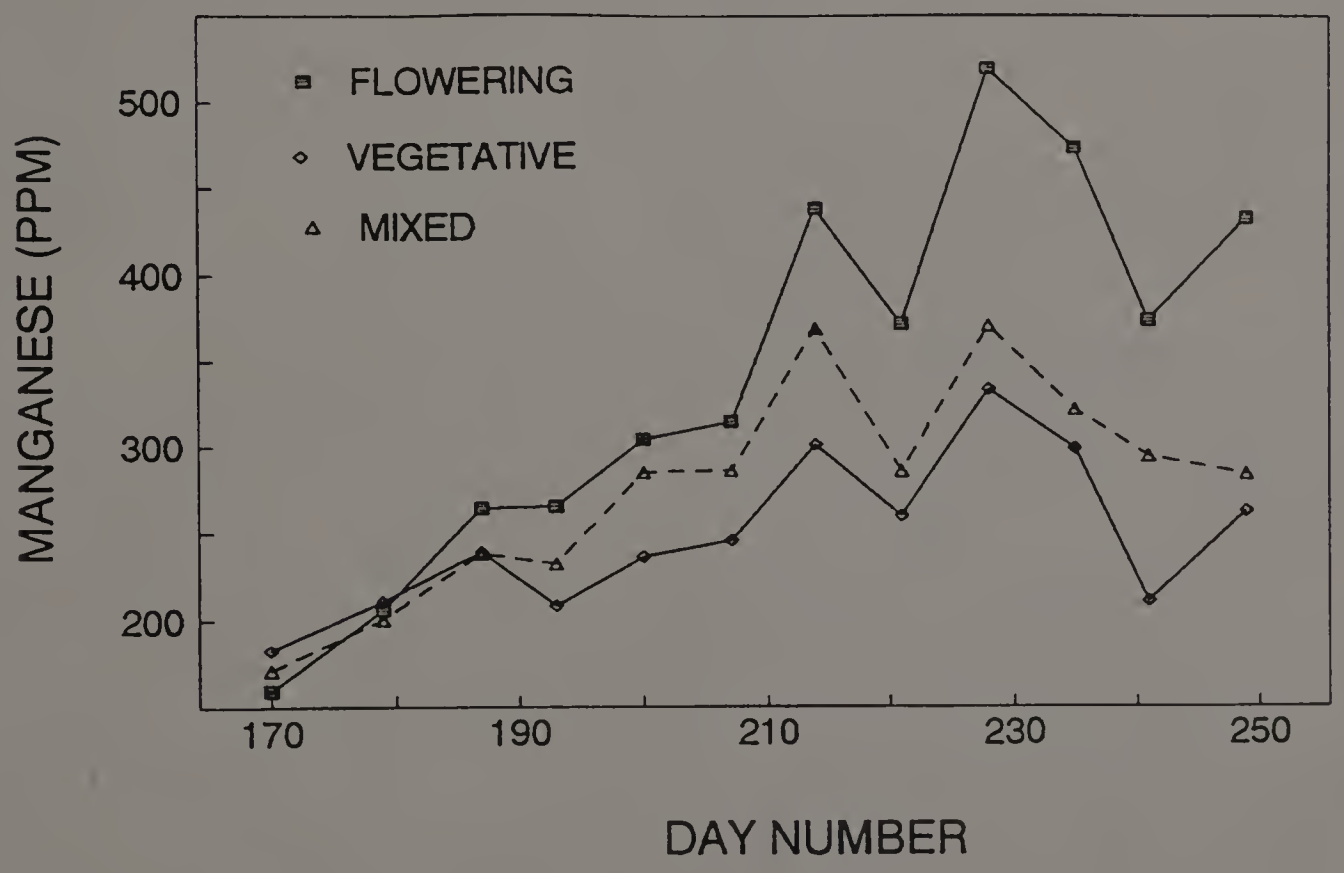

Figure 9.18 Mn concentration (dry weight) in new cranberry upright tissue, top 5 cm. Data points are mean of 6 cultivars, 1989. Broken line represents mixed vegetative and flowering uprights.

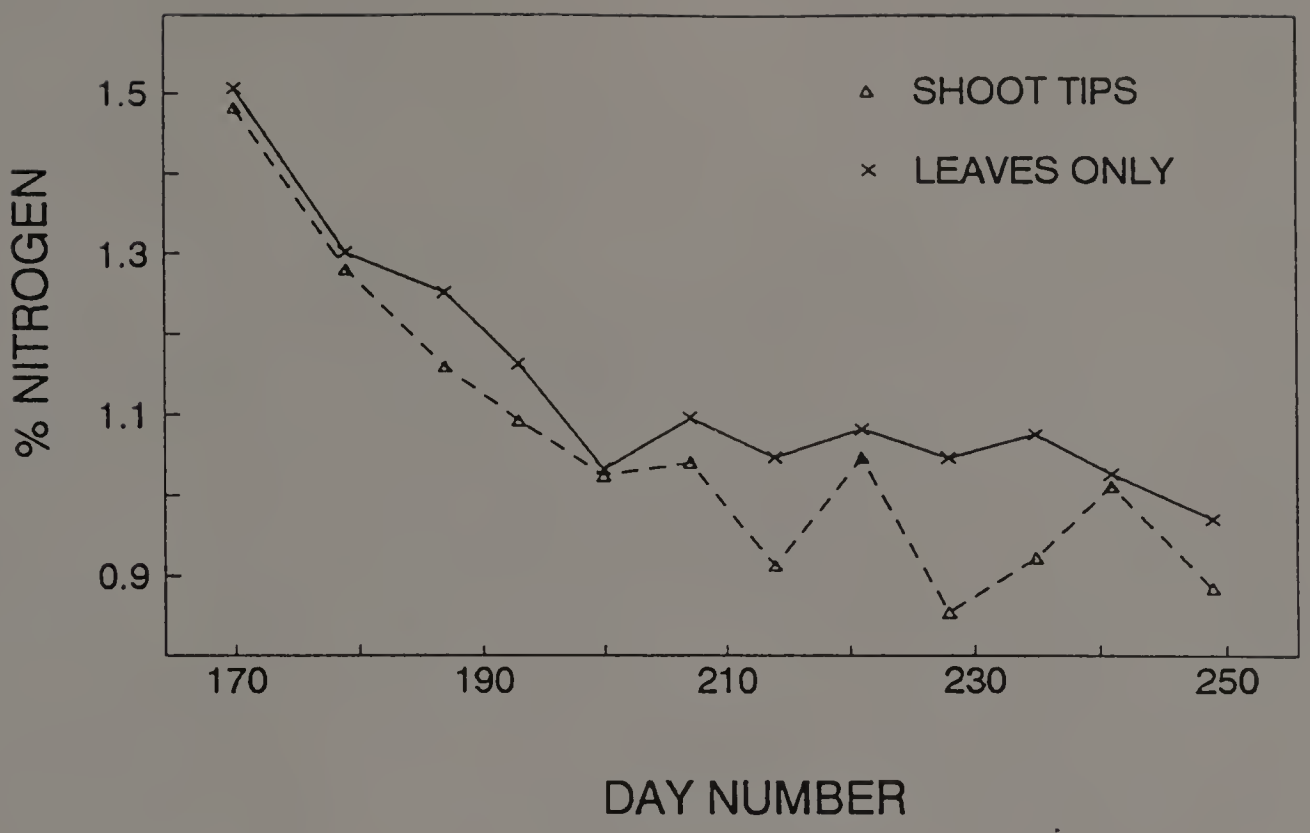

Figure 9.19 N concentration (dry weight) in new shoot tissues of cranberry, mixed vegetative and flowering uprights. Data points are the mean of 6 cultivars, 1989. Solid line = leaves only.

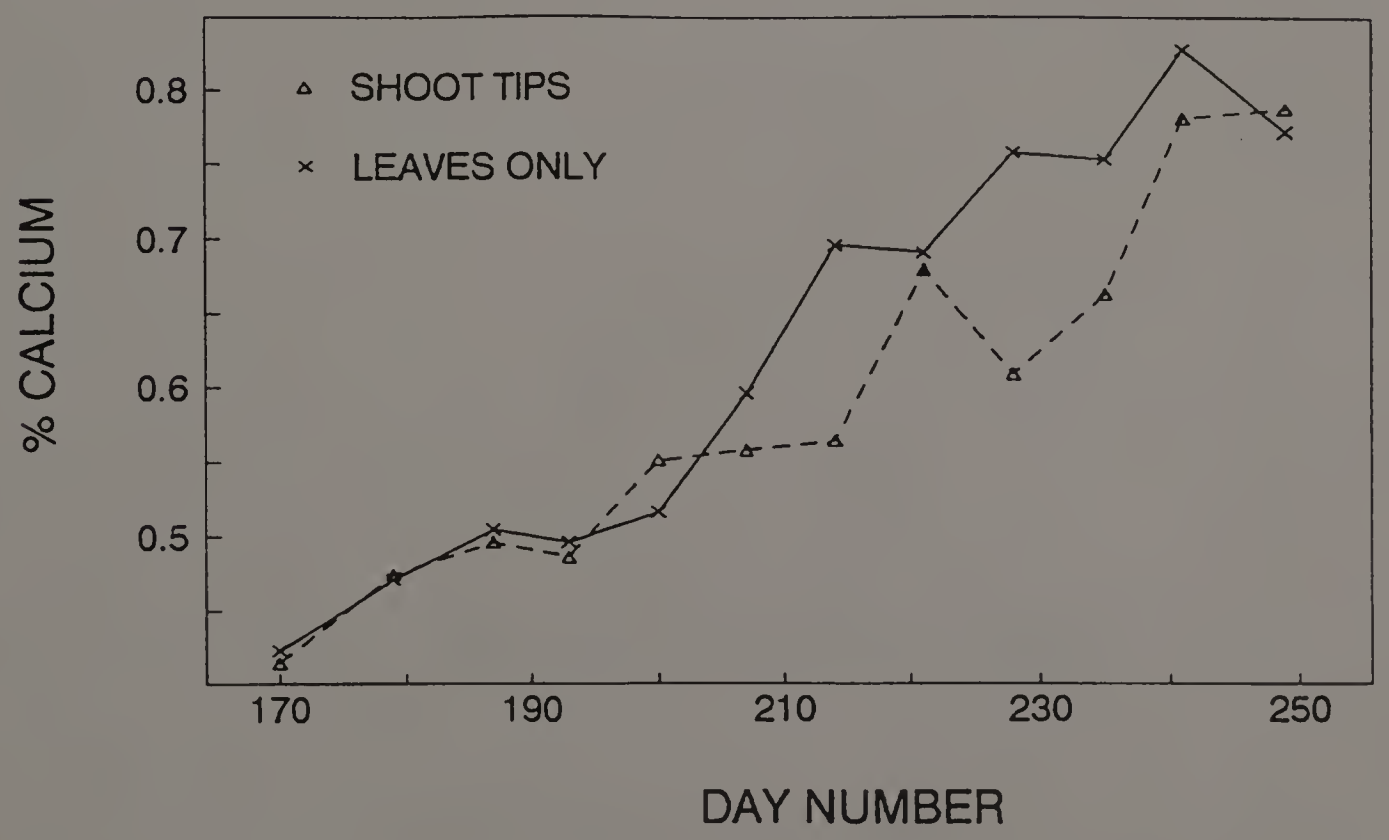

Figure 9.20 Ca concentration (dry weight) in new shoot tissues of cranberry, mixed vegetative and flowering uprights. Data points are the mean of 6 cultivars, 1989. Solid line = leaves only.

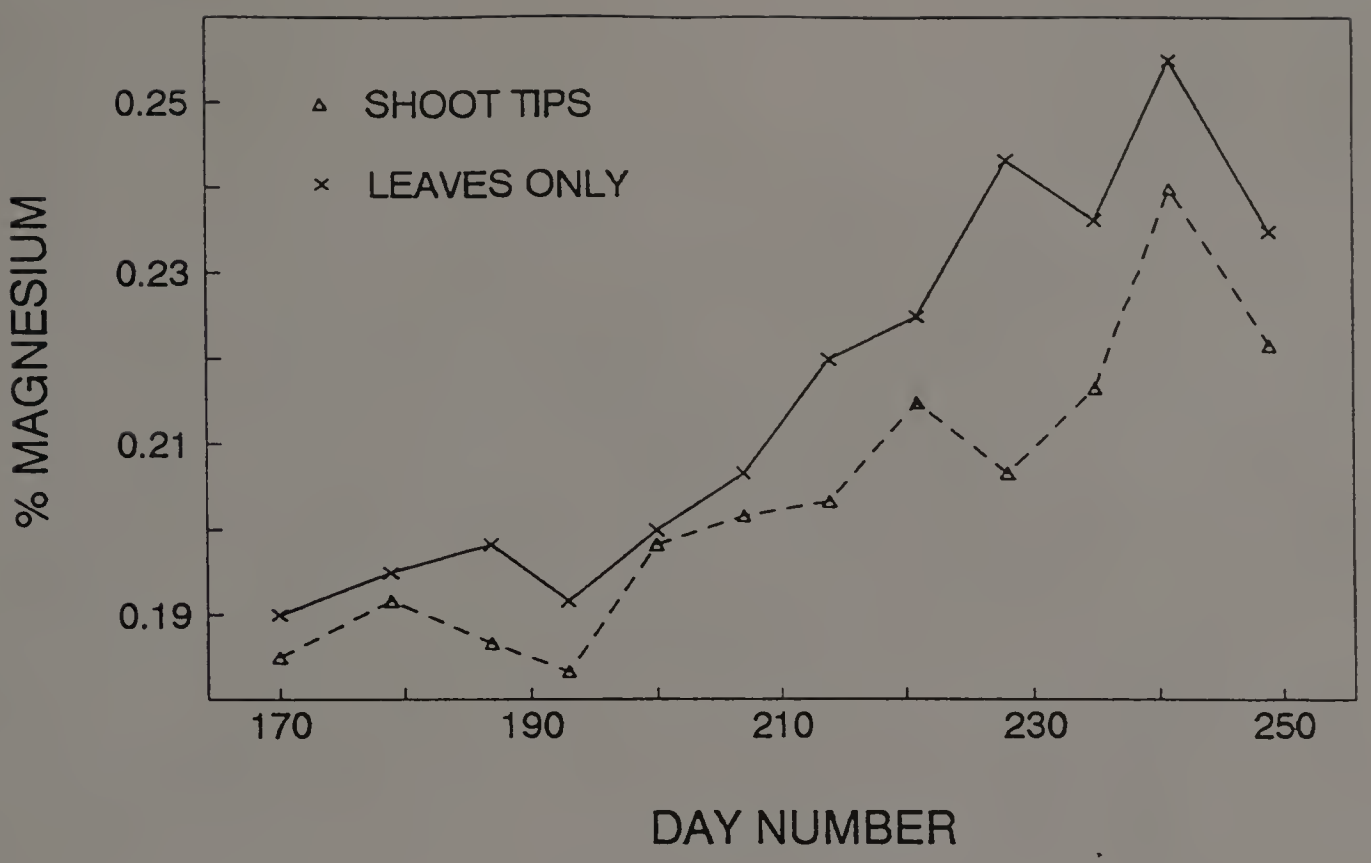

Figure 9.21 Mg concentration (dry weight) in new shoot tissues of cranberry, mixed vegetative and flowering uprights. Data points are the mean of 6 cultivars, 1989. Solid line = leaves only.

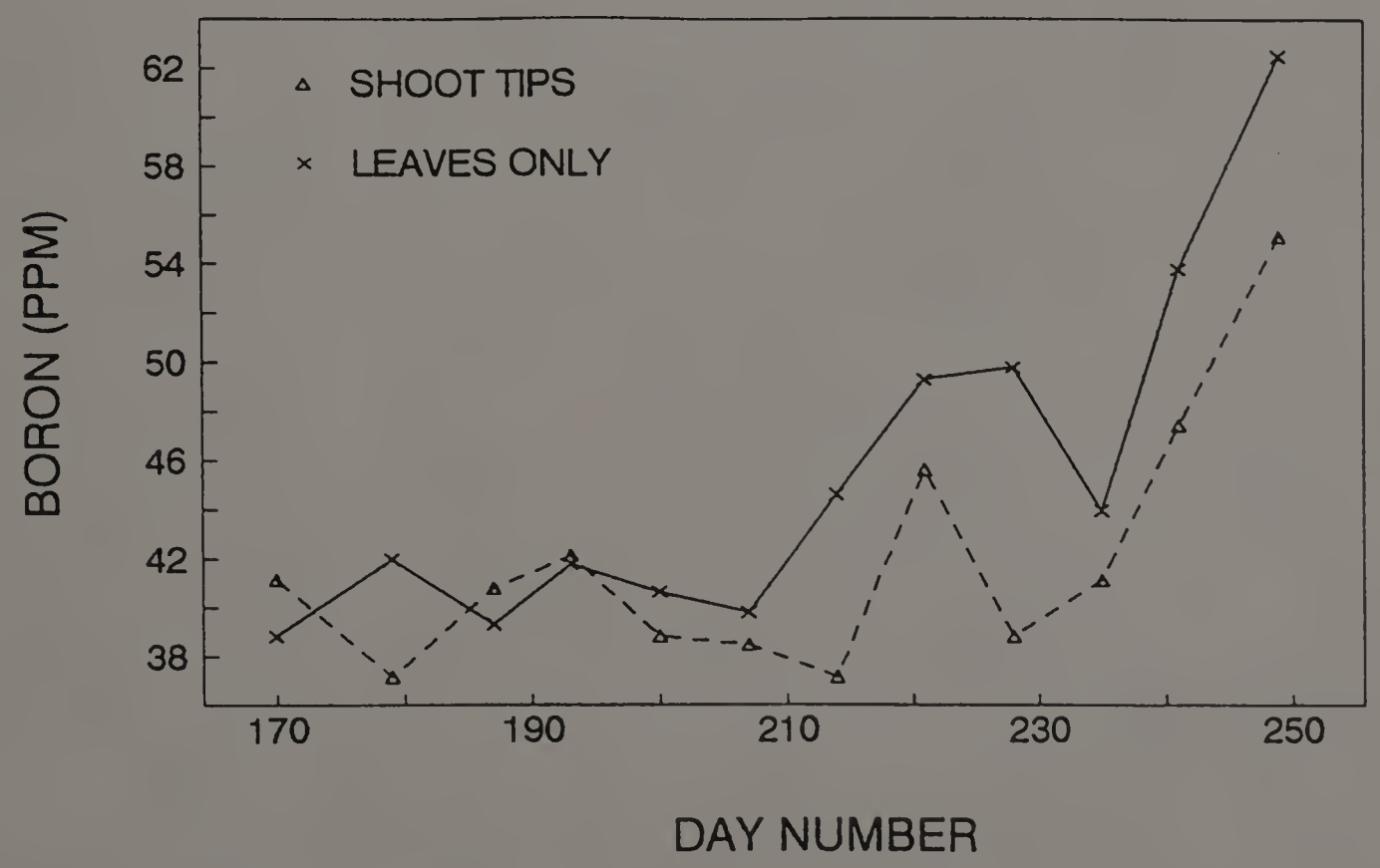

Figure 9.22 B concentration (dry weight) in new shoot tissues of cranberry, mixed vegetative and flowering uprights. Data points are the mean of 6 cultivars, 1989. Solid line = leaves only.

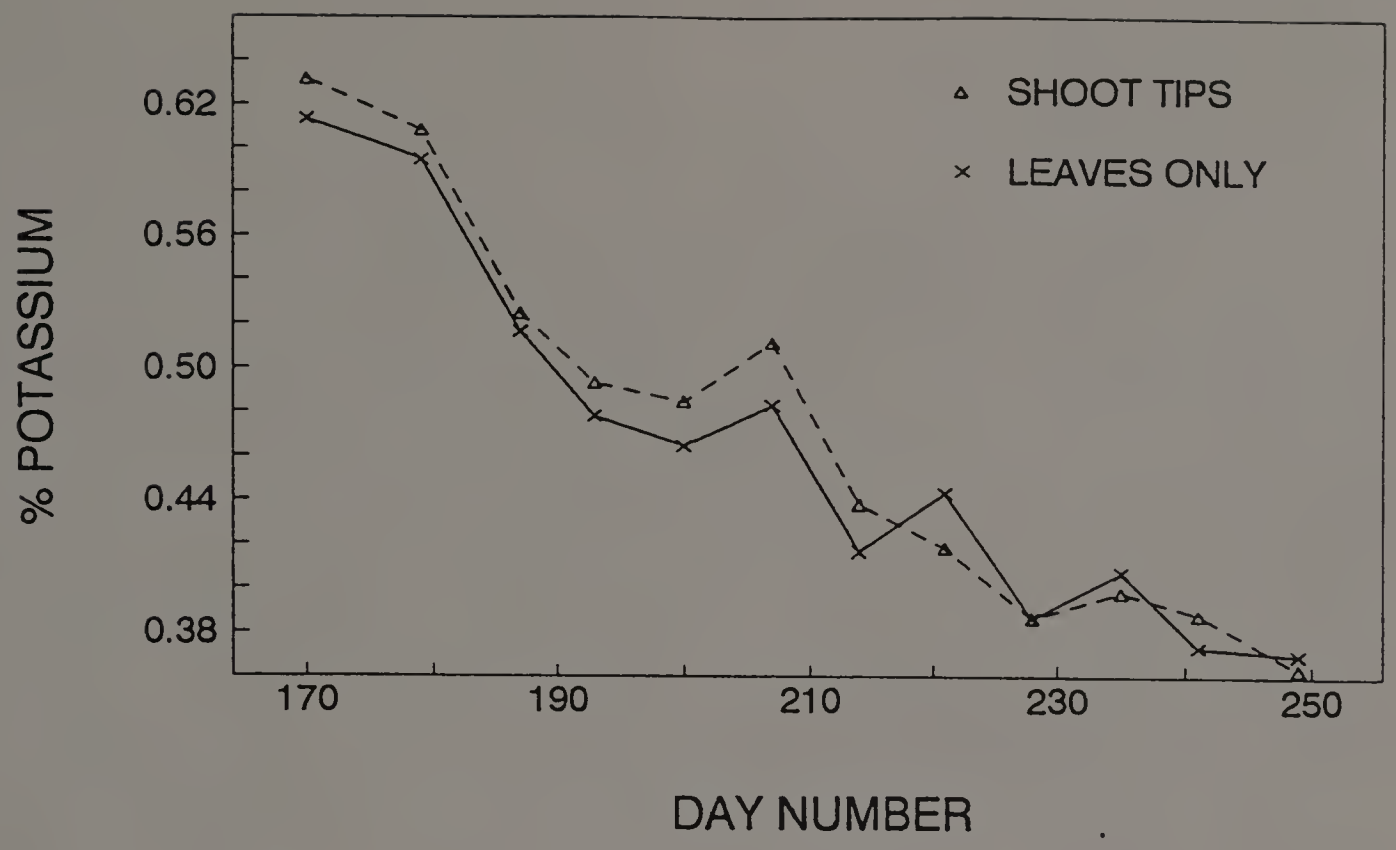

Figure 9.23 K concentration (dry weight) in new shoot tissues of cranberry, mixed vegetative and flowering uprights. Data points are the mean of 6 cultivars, 1989. Solid line = leaves only.

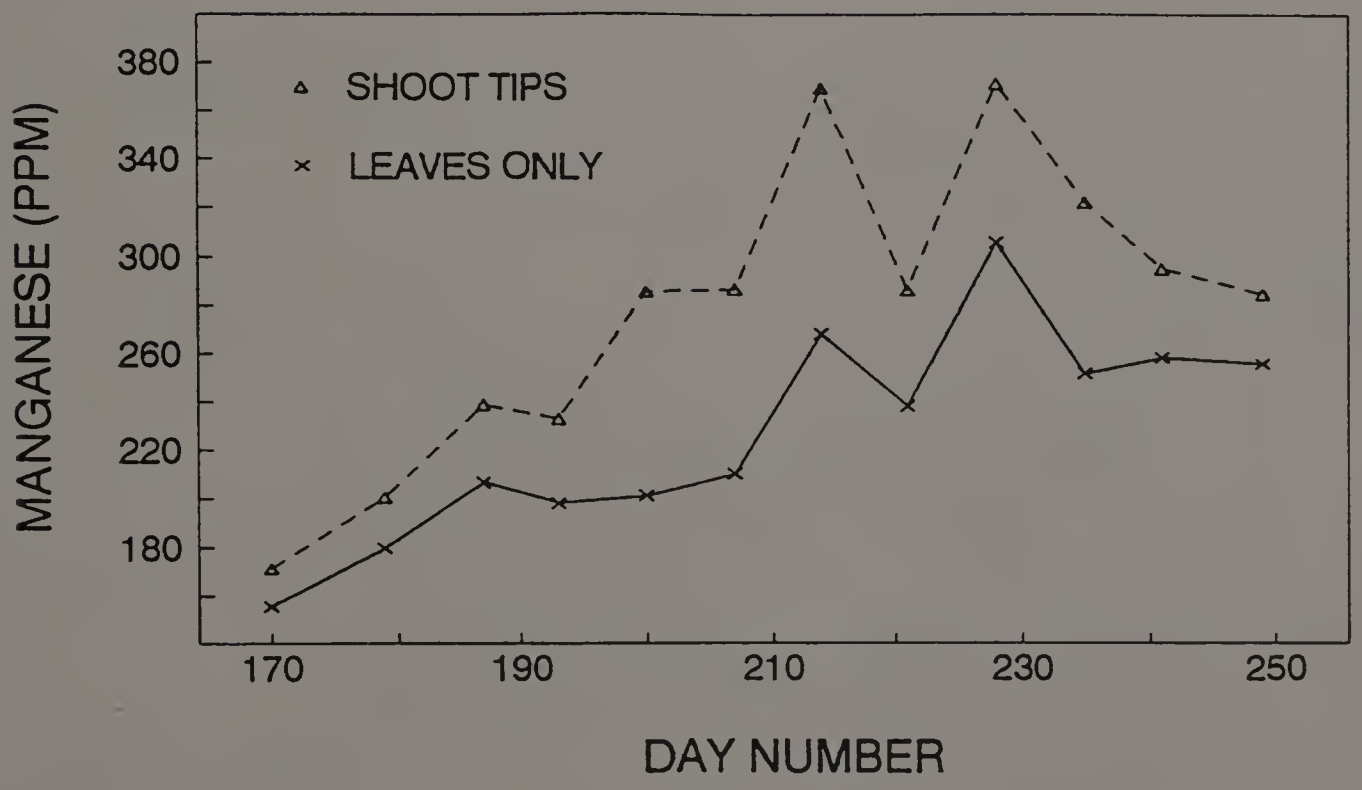

Figure 9.24 Mn concentration (dry weight) in new shoot tissues of cranberry, mixed vegetative and flowering uprights. Data points are the mean of 6 cultivars, 1989. Solid line = leaves only.

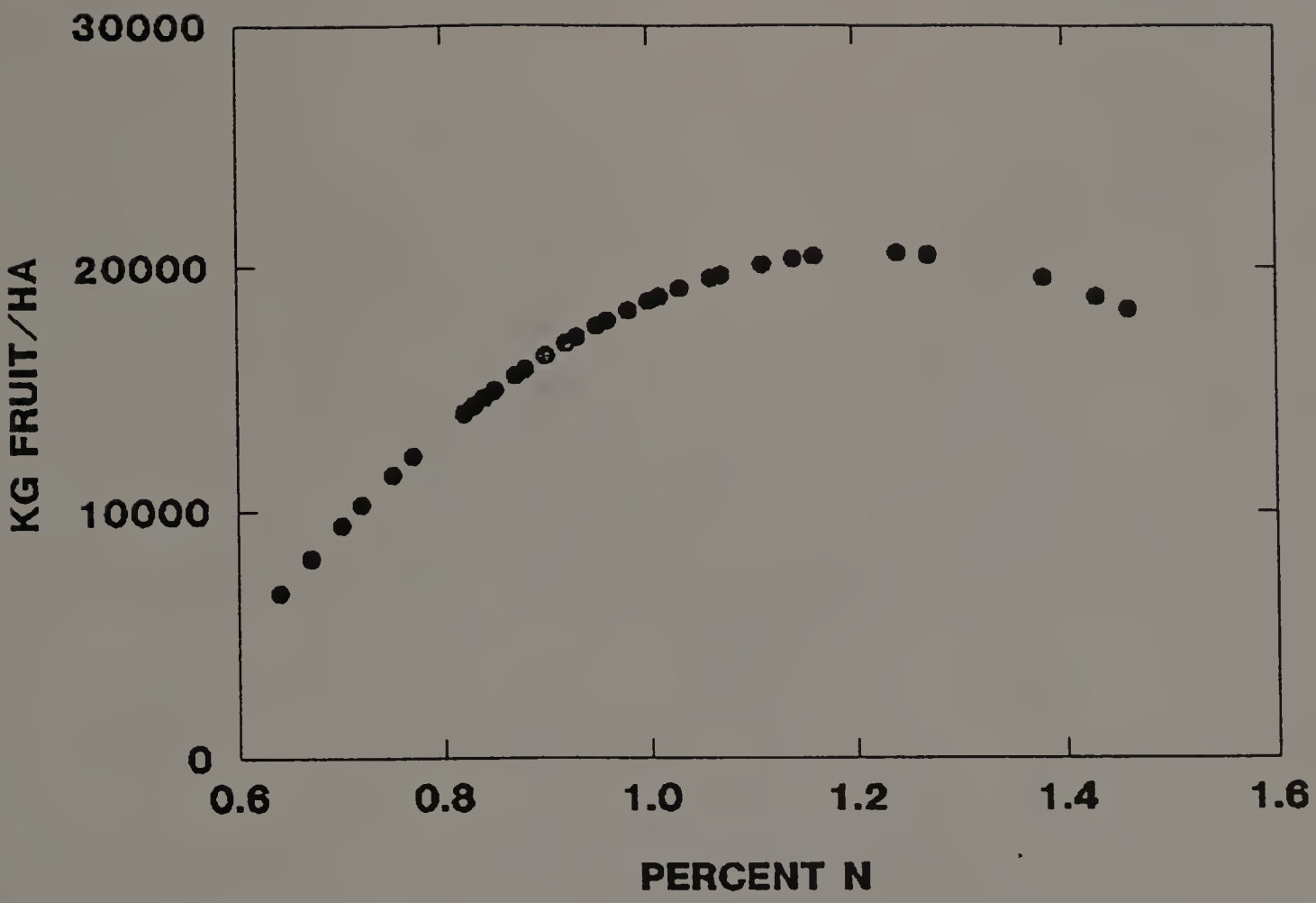

Figure 9.25 Curvilinear relationship between yield of 'Early Black' cranberry and %N in new shoots (mid-August sample).

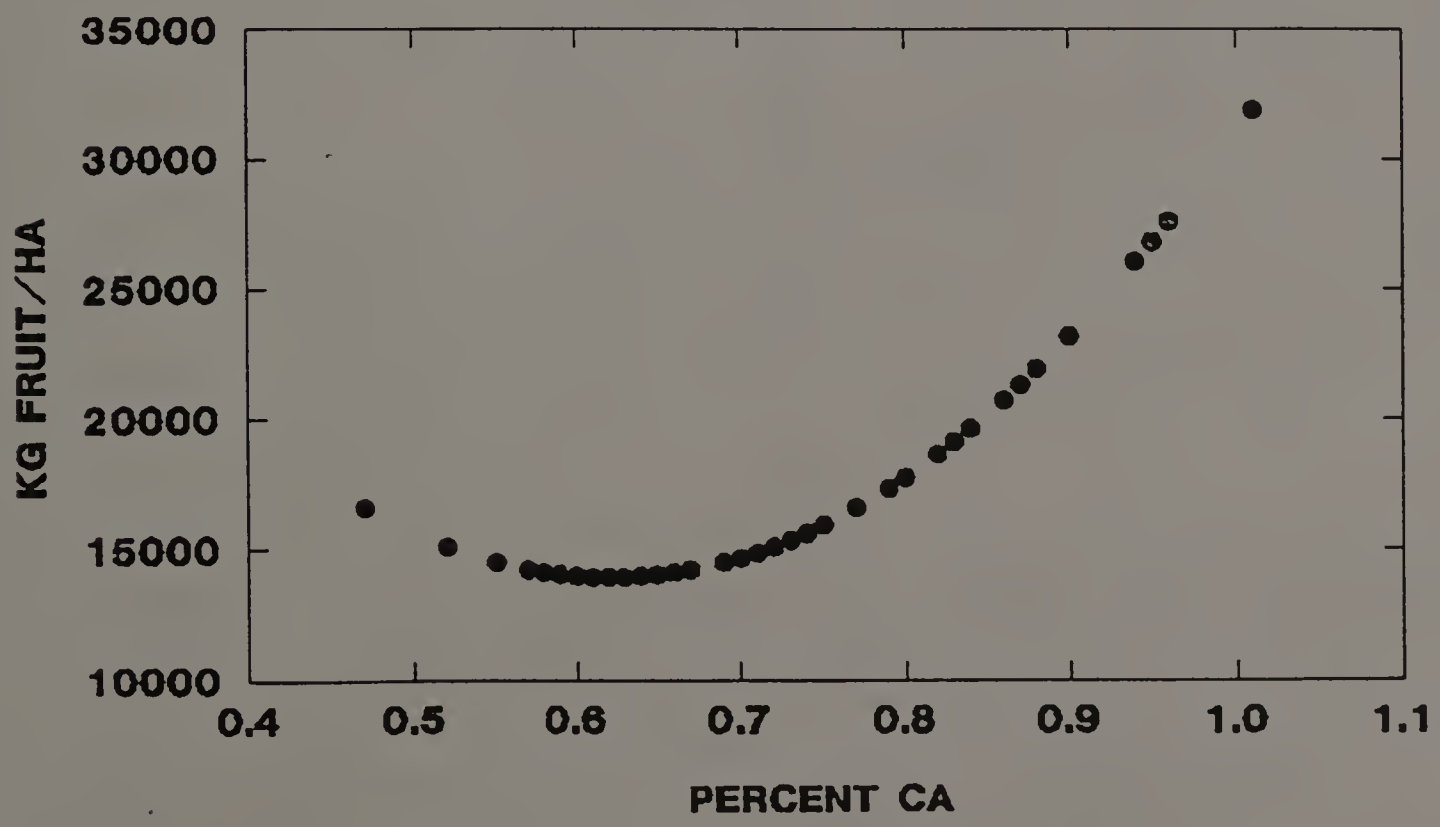

Figure 9.26 Curvilinear relationship between yield of 'Early Black' cranberry and %Ca in new shoots (mid-August sample).

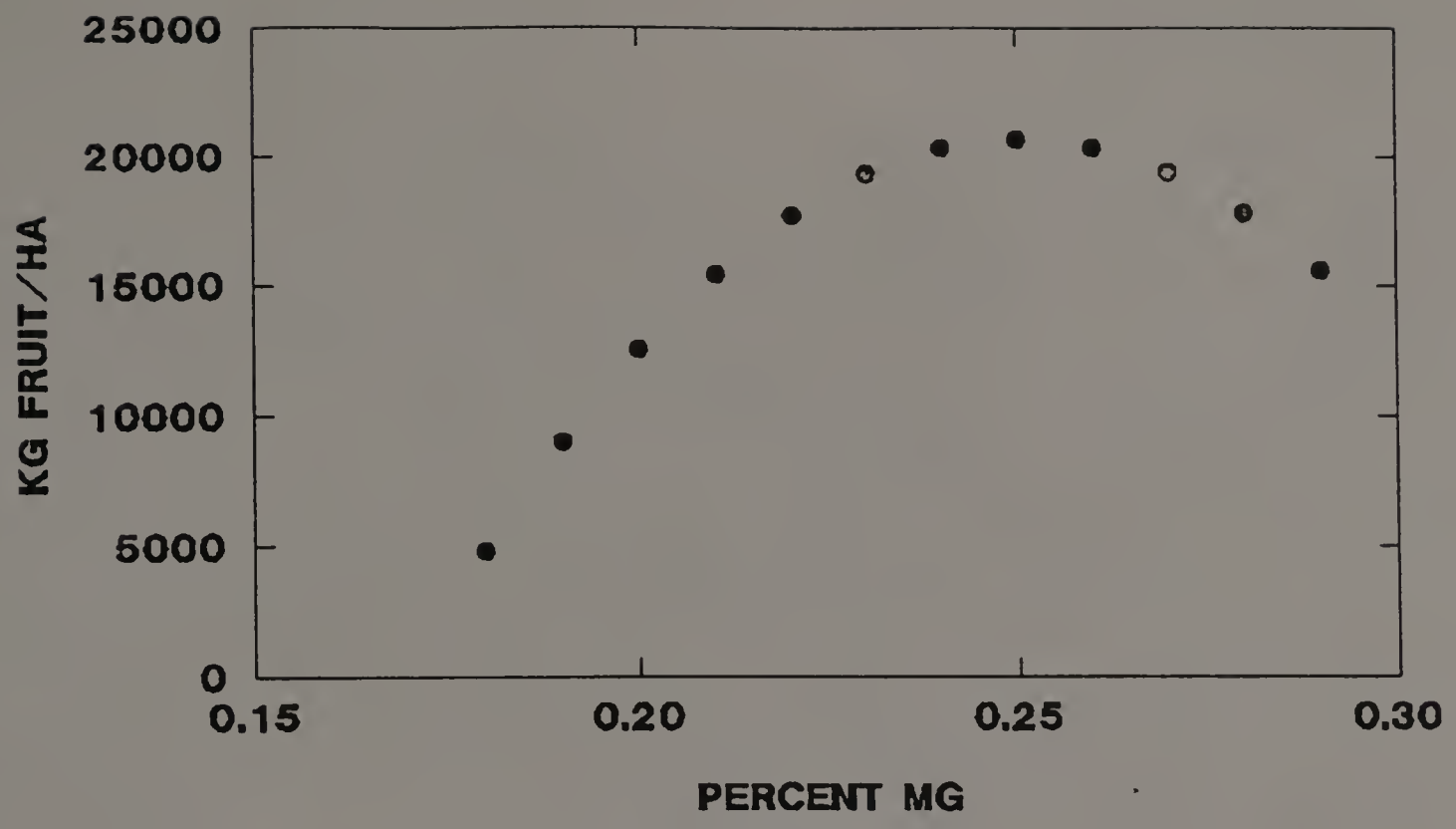

Figure 9.27 Curvilinear relationship between yield of 'Early Black' cranberry and %Mg in new shoots (mid-August sample).

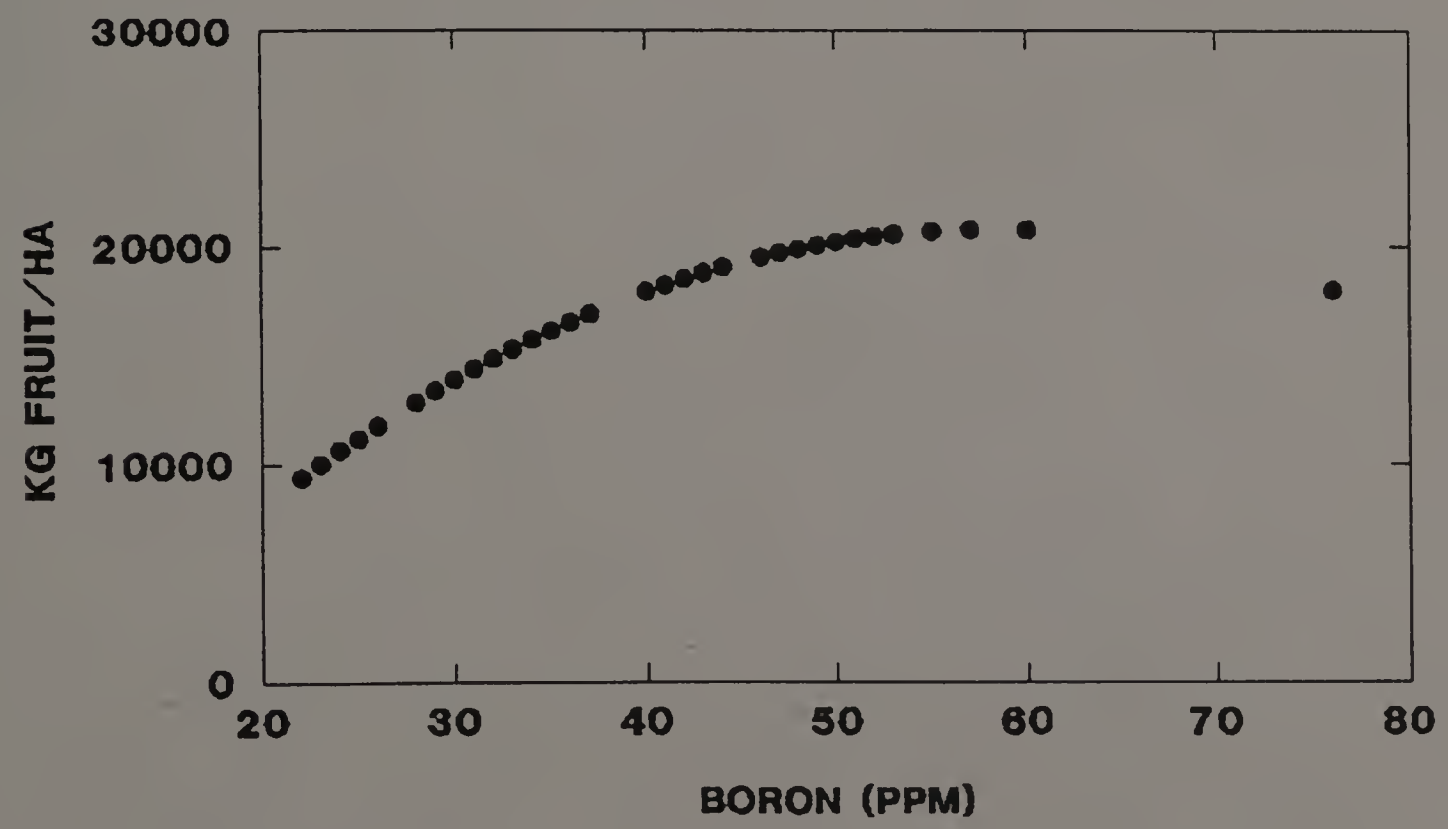

Figure 9.28 Curvilinear relationship between yield of 'Early Black' cranberry and B (ppm) in new shoots (mid-August sample).

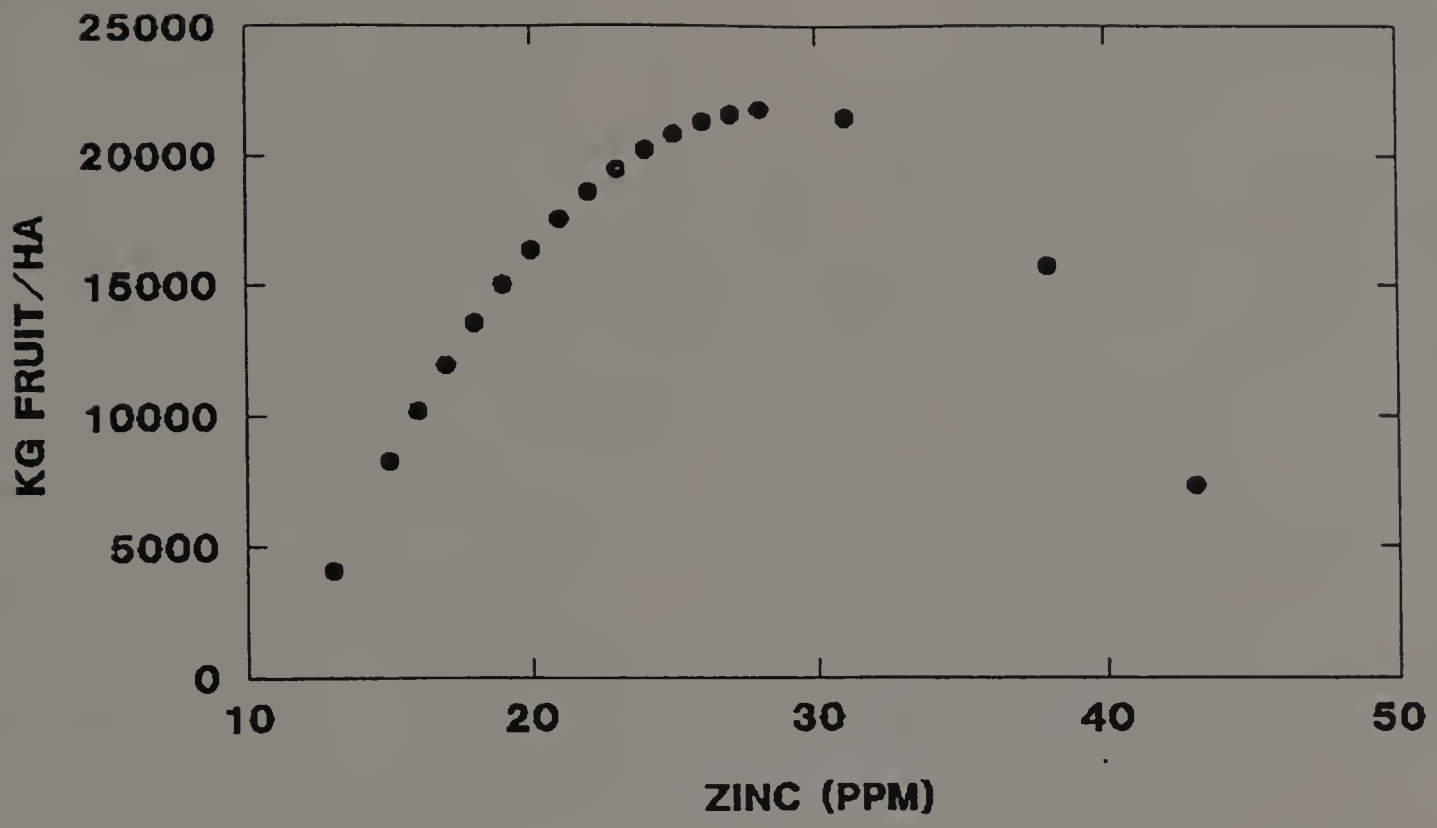

Figure 9.29 Curvilinear relationship between yield of 'Early Black' cranberry and Zn (ppm) in new shoots (mid-August sample).

CHAPTER 10

CRANBERRY NUTRITION, PHENOLOGY, AND N-P-K FERTILIZER: A SUMMARY

10.1 The Use of N-P-K Fertilizer: Effects on Tissue Nutrients, Growth, and Productivity

In this study, 'Early Black' cranberries were treated with four levels of N-P-K fertilizer -- 0, 170, 335, and 505 kg N-P-K/ha. These levels included the fertilizer doses commonly used on that cultivar in commercial production in Massachusetts as well as higher and lower doses. In order to properly interpret tissue analyses from commercial cranberry bogs, it was necessary to find out how fertilizer use could affect the element concentrations in the cranberry tissues.

As the N-P-K level increased, N, P, and K concentrations in cranberry new shoot tissue rose. After three years of treatment, the underfertilized (0 and 170 kg N-P-K/ha) plants could be separated from those receiving adequate (335 kg N-P-K/ha) and excess (505 kg N-P-K/ha) fertilizer on the basis of the N, P, and K content of new shoots. However, the overfertilized plants showed extremely high N concentrations in the new shoots only in the 1987 season when yields were lowest in all treatments. That season, vegetative growth also was retarded by frost so that there could be no dilution of excess N by increased new shoot tissue production. Based on these findings, it seemed likely that tissue testing would not necessarily detect N fertilizer excesses.

There was no antagonistic effect of N-P-K on Ca or Mg levels in new shoots, but both elements declined in old leaves as N-P-K level

increased. Additionally, Ca content in fruit tissues declined with increased N-P-K fertilization. This Ca decline may explain the tendency for fruit quality to decline with excess N-P-K fertilizer use. There was an interaction of tissue B levels with N-P-K fertilizer levels. In underfertilized plants, B concentrations were significantly higher than in those receiving adequate or excess N-P-K fertilizer. The higher concentrations may have been due to preferential accumulation in leaf tissues, failure of B concentrations to be diluted by growth in underfertilized plants, or increased uptake of B by those plants. Although the total root biomass of the cranberry plants in the different N-P-K treatments did not differ statistically, the underfertilized plants did tend to have more roots in the second year of treatment and in all years had higher root/shoot ratios than fertilized plants due to decreased production of above-ground biomass. If root activity increased in those plants for uptake of adequate amounts of N, P, and K, B uptake may have increased coincidentally. An alternative explanation involving changes in minor element availability due to N-P-K fertilizer modification of soil chemistry was less likely. No changes in soil pH or organic matter were found during the study and no other minor elements accumulated in the tissues of underfertilized plants.

Based on this study, tissue tests of cranberries should be interpreted with caution. These tests may not detect N overuse if high N availability leads to excess growth and subsequent dilution of the N content of the tissue. High tissue test levels of B may indicate too little fertilizer was used. Calcium and Mg concentrations in new tissues did not decline in response to

fertilizer overuse, but the levels in old leaves were lower. This may mean that over a longer time period (more than the three years studied here) induced deficiencies of those elements could occur. Overuse of N-P-K was associated with lower Ca in cranberry fruit. Testing just new shoots for mineral concentration was of limited value unless the results were interpreted in light of fertilizer use and other cultural practices.

The lowest and highest N-P-K levels were associated with the poorest crops, with the highest yields at 335 kg N-P-K/ha. The differences were mainly due to effects on the numbers of fruit produced, with only a minor effect on the size of individual fruit. The lack of effect of N-P-K on fruit size has implications in the use of N-P-K fertilizer as an agent to promote cranberry fruit sizing. Based on dry weight accumulations, the size of the individual fruit did not respond to N-P-K fertilizer.

Vegetative growth was most responsive to N-P-K application. The density of uprights, the weight of uprights, the total weight of new growth, and the length of uprights each were positively correlated with N-P-K level. The length of the uprights was the most sensitive variable with the most significant separation of the treatment means. The growth response of uprights was a much better indicator of response to N-P-K fertilizer than were tissue test N values. This result has implications for commercial cranberry growers. Monitoring length of uprights is a simple and inexpensive way to monitor response to added fertilizer. Use of this method could allow the grower to use tissue analyses less frequently, although testing for other elements would still be of value. For research, the use of upright length as

an experimental variable would be more costly than using tissue analyses, due to the need to collect accurate, replicated data (in comparison, growers would just use visual estimates). A possible alternative would be the use of upright weights. This variable is not quite as sensitive as upright length, but the labor involved in counting and weighing a set of uprights to get average weight would be much less than that needed to measure the lengths of those uprights. One drawback to the use of upright weight was the increase in weight late in the season due to lignification of the stem portion. That weight increase was not accompanied by further increase in length. Therefore, by late August, the correlation between the length of uprights and their weight was not as good. Regardless of the choice of variable, the inclusion of a determinant of vegetative response is desirable, especially in experiments with N fertilizers.

In this study, upright density was an important determinant of yield. This had implications in terms of data collection methods in cranberry field experiments. There was inherent variability in vine stand in cranberry bogs due to the method use in planting and due to subsequent affects of weed and mechanical injuries (eg. during harvest). In order to filter out the effect of stand variability, density counts should be included in data collection from cranberry field experiments if yield determination is required.

Other important determinants of 'Early Black' cranberry yield were percent of uprights flowering and percent fruit set. In field experiments, knowledge of effects of the treatments on these variables could be important. Data collection for percent flowering uprights would require little extra effort if upright density is going to

assessed in the experiment. Percent fruit set determinations were much more time consuming. A comparison of fruit numbers to the number of uprights flowering could be an alternative to collecting fruit set data in experiments where the dominant effect is not expected to be on fruit set.

During the course of this study, information regarding methods of data collection was shared with other researchers working with cranberry. As a result, an effort has been made to standardize the methods of data collection in cranberry fertility experiments in the various growing areas.

10.2 Cranberry Plant Development

Biomass accumulated in roots, new shoots, and fruit during the season. The pattern of root growth was cyclical with periods of dry weight accumulation alternating with periods of dry weight loss. Early in the season, root dry weight declined, likely due to movement of carbohydrate reserves into growing shoots. The earliest increases in root biomass followed the first flush of new shoot growth. Root biomass also increased at the time of fruit development (in response to high nutrient demand of developing fruit) and after harvest (most likely mobilization of carbohydrates into root tissue in preparation for dormancy). The two earlier periods of root increase were most likely associated with production of new root tissue. Therefore, adequate nutritional support should be present in the soil in June and August.

Budbreak occurred in mid-May and by the end of May new shoots were elongating rapidly. New shoots continued to accumulate dry weight until July. High concentrations of nutrients accumulated in the juvenile new shoots. Some dilution in concentration occurred during the early flush of vegetative growth but the total element content in new shoots continued to rise. This indicated a continuing demand for nutrients throughout the growth period. Late in the summer, dry weight of shoots rose as the stem portions became lignified. The early growth period of the new shoots was critical in order to have enough photosynthetic area present for mobilization of carbohydrates into developing fruits. Fruits gained dry weight rapidly from fruit set (mid-July) until mid-August. Most of the mineral content in the fruits was acquired during the earliest stages of fruit enlargement. After the initial acquisition of nutrients subsequent to fruit set, the element concentrations in fruits declined due to dilution by growth. Availability of mineral elements in July was critical.

The earliest stages of fruit development were the most critical in defining large vs. small fruit. The early growth rates and ultimate fruit weights of fruit from 'Stevens' and 'Pilgrim' were highest among the six cultivars studied. Again, this stresses the importance of adequate nutritional support during that period.

At the end of the season, almost 50% of the standing above-ground biomass of the cranberry plants was fruit. With so much of the plants resources going into the production of crop, any variable which affected photosynthetic capacity could be expected to have an effect on fruit production. However, overfertilization and longer uprights

(more photosynthetic area) was associated with a lower crop, perhaps due to diversion of resources to vegetation at the expense of reproduction, indicating that a balance between the two must be maintained to maximize cropping.

In the study of six cultivars, percent of uprights flowering and percent fruit set again were the most important determinants of yield. Upright density also was important but not always as a positive influence. For 'Howes' high upright density was correlated with decreased flowering uprights. Weight per fruit was important in determining yield for the large-fruited 'Stevens' and 'Pilgrim'. The differences in yield determinants among the cultivars may explain cultivar effects in cranberry field experiments. As Massachusetts moves away from a two cultivar cranberry industry, knowledge of the differences in cultivar response will become more important.

In this study, all six cultivars received the same N-P-K dose. Too much fertilizer could explain why 'Howes' and 'Franklin' showed compensation between variables defining vegetative response (eg. upright density) and those defining reproduction (eg. percent flowering and fruit set). Too little fertilizer could explain the negative correlations among reproductive variables in 'Pilgrim' (compensation). The shoot and fruit tissues of 'Pilgrim' had among the highest nutrient concentrations in the study. If 'Pilgrim' was not receiving enough fertilizer, its tissue concentration requirements must be greater than those of the other cultivars. 'Stevens' also had high concentrations of elements in its new shoot tissue. Both of those cultivars bore the largest fruit and had the most robust vines

(thicker stems, larger leaves). The normal tissue element levels for 'Stevens' and 'Pilgrim' may be higher than for the other cultivars.

In an attempt to predict nutrient concentration and developmental changes in cranberry, modelling vs. day number and growing degree days (GDD) was attempted. Changes in 'Early Black' cranberry development and nutrition at a single location were best defined by day number when comparing one year with another. The possibility existed that GDD could be a useful predictor for differences among locations within a single year.

10.3 Nutrient Requirements of Cranberry Bogs

Based on the nutrient concentrations in 'Early Black' cranberry tissues and biomass production during the season (3 years averaged), the amounts of the elements used to produce a season's biomass were calculated. For production of root and shoots, the amounts needed in kg/ha were N - 48, P - 5, K - 21, Ca - 33, Mg - 10, B - 2, Cu - 0.3, Fe - 3, Mn - 10, and Zn - 1. The high values for the minor elements reflected accumulation in stems and roots and were not necessarily requirements.

The removal of elements from an 'Early Black' cranberry bog in fallen leaves and fruit (150 bbl/A crop) also was calculated. The removal per ha was N - 24 kg, P - 4 kg, K - 19 kg, Ca - 17 kg, Mg - 5 kg, B - 117 g, Cu - 21 g, Fe - 215 g, Mn - 634 g, and Zn - 61 g.

The removal of elements from a bog in fruit only was calculated for six cultivars based on 100 bbl/A of fruit. The cultivars were roughly similar, with about 5 kg N/ha, 1 kg P/ha, 8 kg K/ha, 0.8 kg

Ca/ha, and 0.6 kg Mg/ha removed in a 100 bbl/A crop. Removal of minor elements amounted to less than 35 g/ha each.

Taken together, these removal calculations indicated that cranberries had a low nutrient requirement. The elements required in the highest amounts were N and K. The plants requirements should be met with the N-P-K fertilizers currently being used. In fact, it would appear that much more P is being used than should be based on the requirements of the plants. Minor element supplements should not be required generally.

10.4 Using Cranberry Tissue Analyses

In order for growers and researchers to interpret and compare cranberry tissue analyses, sampling techniques needed to be standardized. The best time to collect a tissue sample would be when the tissue is not rapidly growing or senescing (remobilization of nutrients, lignification, carbohydrate loading) so that biomass and internal nutrient concentrations would be stable. By using various statistical techniques, periods during which the element concentrations in new shoot tissues of cranberry were stable (statistically similar) were defined. The stable period for 'Early Black' was 5 August to 15 September. A common stable period for element concentrations in new shoots of six cranberry cultivars occurred from 10 August to 15 September. Sampling in the third week of August was preferred due to maximum numbers of elements being stable at that time. The wider time ranges represent a more realistic

recommendation for field situations when many samples at many locations need to be collected.

The tissue to sample chosen was whole shoot tips from new uprights, vegetative and flowering mixed. The minor differences found when just the leaves from this tissue were analyzed did not justify the increased time needed in sample preparation. Vegetative and flowering uprights had different element concentrations. For that reason, a sample consisting of just one upright type could under- or overestimate the nutrient requirements of the cranberries. The mixed samples reflected the total nutritional picture for the bog.

Standard (normal) values for element concentrations in 'Early Black' new shoot tissue were proposed. These values were in agreement with those published for 'Searles' cranberry in Wisconsin (Dana, 1981c) for some of the elements. However, Ca and K values were quite different reflecting the differences in the levels of those elements commonly found in cranberry tissues in samples collected from the two different areas.

When the mean element levels in the tissues from other cultivars were compared to the proposed standards for 'Early Black', the correspondence was quite high. Levels of Fe and Mn in some of the other cultivars were outside the range proposed. However, this might not be too meaningful considering the fact that cranberries can accumulate Mn and Fe depending on soil levels of those elements and soil pH.

10.5 Future Directions

Tissue analysis standards for cultivars other than 'Early Black' in Massachusetts need to be studied further. Values proposed for 'Howes' (DeMoranville and Deubert, 1986), were based on samples collected from mixed old and new leaves, leading to inflated values for N and Ca. 'Stevens' are being planted preferentially in Massachusetts. Beyond the limited information on 'Stevens' presented here, little is known about their nutritional requirements under Massachusetts conditions. The 'Stevens' planting used in this study produced lower than average yields. Information regarding nutrient levels in higher yielding 'Stevens' plantings remains to be gathered.

Future fertilizer studies should include the collection of data on the effects of the treatments on yield components, particularly in cross cultivar experiments. Fertilizer timing studies should focus on the period prior to bloom when photosynthetic area to support fruit is produced. The early fruit development period also merits further study.

Phosphorus bears further study in cranberries. Growers routinely use high assay P fertilizers on a crop which, based on this study, has a very low P requirement. Furthermore, soil tests (Bray method) of cranberry bogs show high P levels in many cases. It seems that applying large doses of P in N-P-K fertilizer may not be the most effective means to deliver P to this crop. A field trial with P applied separately from N and K and in different forms (besides triple superphoshate) has been initiated.

APPENDIX A

SEASONAL NUTRIENT LEVELS IN TISSUES OF 'EARLY BLACK' CRANBERRY, PROFILE ANALYSES

Repeated measures ANOVA was performed on the 'Early Black' cranberry nutrient data for each of the 10 elements, in each of the 3 years, for each of the 5 tissues. Post hoc profile analyses contrasting adjacent dates were then run. The results are given in Tables A.1 to A.50. The stable periods for all years combined, defined in the analyses are shown graphically in Figures 6.1 to 6.50 (p. 114-138) as horizontal lines.

Table A.1 Seasonal nitrogen concentrations (%) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987	2.41	1.69	1.62	1.36	1.04	1.16	1.06	1.13	1.11	1.13	0.92		0.94
1988	2.12		1.45		1.12		0.93	0.82	0.92	0.99	1.02	1.01	1.02
1989	1.77		1.38		1.07	1.01	1.03	0.92	0.89	0.84	0.91		0.99

Table A.2 Seasonal phosphorus concentrations (%) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		0.20	0.15	0.14	0.14	0.14	0.13	0.13	0.14	0.15	0.14		0.14
1988	0.34		0.23		0.18		0.16	0.12	0.13	0.12	0.12	0.11	0.11
1989	0.25		0.19		0.14	0.13	0.13	0.12	0.12	0.11	0.07		0.13

Table A.3 Seasonal potassium concentrations (%) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		0.79	0.71	0.75	0.70	0.63	0.65	0.60	0.63	0.68	0.58		0.45
1988	1.11		0.95		0.86		0.66	0.55	0.53	0.44	0.41	0.38	0.46
1989	0.88		0.70		0.66	0.60	0.60	0.54	0.49	0.44	0.45		0.41

Table A.4 Seasonal calcium concentrations (%) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		0.31	0.36	0.36	0.37	.038	0.42	0.54	0.61	0.69	0.70		0.55
1988	0.44		0.45		0.45		0.46	0.59	0.64	0.83	0.86	0.85	0.88
1989	0.40		0.42		0.40	0.46	0.50	0.49	0.62	0.68	0.75		0.93

Table A.5 Seasonal magnesium concentrations (%) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		0.14	0.15	0.14	0.15	0.14	0.16	0.19	0.20	0.26	0.24		0.20
1988	0.18		0.19		0.19		0.18	0.20	0.21	0.24	0.26	0.25	0.23
1989	0.19		0.18		0.16	0.18	0.18	0.18	0.20	0.20	0.22		0.23

Table A.6 Seasonal boron concentrations (ppm) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		21.7	15.9	19.7	23.9	29.3	28.6	37.3	42.0	47.2	64.3		41.2
1988	34.9		27.1		27.0		27.8	33.4	33.1	44.5	46.5	50.6	47.1
1989	34.4		26.2		22.4	28.4	31.2	27.4	28.1	29.6	33.1		44.3

Table A.7 Seasonal copper concentrations (ppm) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		8.0	7.1	3.4	3.1	6.1	5.5	5.8	7.2	6.3	4.9		15.0
1988	13.9		10.9		9.3		8.4	6.9	6.7	4.7	4.7	5.2	5.0
1989	10.5		8.4		9.3	6.4	6.2	7.4	7.3	5.2	5.0		4.7

Table A.8 Seasonal iron concentrations (ppm) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		37	28	60	34	91	41	34	60	70	34		47
1988	67		50		56		67	72	65	61	60	64	52
1989	85		66		73	62	70	62	68	61	73		59

Table A.9 Seasonal manganese concentrations (ppm) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		62	76	81	78	98	107	102	128	137	149		192
1988	64		75		118		151	153	187	213	215	206	245
1989	81		117		133	144	190	229	225	239	249		308

Table A.10 Seasonal zinc concentrations (ppm) in new shoots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	145	150	160	165	175	180	190	205	220	235	245	260	275
1987		18.1	17.0	13.2	15.6	18.3	18.3	17.6	20.4	21.9	18.8		21.2
1988	32.9		25.8		23.5		25.7	23.5	24.3	23.9	24.4	22.4	20.9
1989	34.1		27.2		47.7	22.1	28.4	22.8	22.1	21.5	22.6		28.4

Table A.11 Seasonal nitrogen concentrations (%) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	1.06	0.95	0.95	1.13	1.04	1.03	1.00	0.95	0.78	0.76	0.77	0.73	0.75	0.63
1988	0.99	0.95	0.95			0.87	0.78		0.73		0.63		0.70	
1989						0.86	0.73		0.71	0.67	0.59	0.62		

Table A.12 Seasonal phosphorus concentrations (%) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	0.14	0.13	0.13	0.10	0.10	0.10	0.13	0.10	0.12	0.11	0.12	0.11	0.13	0.12
1988	0.15	0.15	0.15			0.14	0.15		0.14		0.13		0.13	
1989						0.13	0.12		0.11	0.11	0.11	0.10		

Table A.13 Seasonal potassium concentrations (%) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	0.47	0.49	0.52	0.49	0.46	0.40	0.48	0.38	0.39	0.25	0.42	0.35	0.38	0.40
1988	0.52	0.54	0.59			0.53	0.45		0.39		0.33		0.34	
1989						0.37	0.30		0.32	0.28	0.28	0.27		

Table A.14 Seasonal calcium concentrations (%) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	0.59	0.63	0.61	0.66	0.56	0.62	0.67	0.66	0.75	0.37	0.85	0.79	0.95	0.92
1988	0.70	0.73	0.72			0.69	0.83		0.83		0.80		0.93	
1989						0.77	0.79		0.81	0.87	0.88	0.91		

Table A.15 Seasonal magnesium concentrations (%) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	0.14	0.17	0.15	0.16	0.14	0.15	0.16	0.16	0.17	0.10	0.18	0.17	0.19	0.19
1988	0.21	0.22	0.21			0.21	0.22		0.22		0.20		0.22	
1989						0.21	0.21		0.23	0.20	0.20	0.20		

Table A.16 Seasonal boron concentrations (ppm) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	33	14	25	30	30	40	33	42	46	46	58	55		
1988	32	34	36			34	42		40		43		52	
1989						41	39		49	53	44	41		

Table A.17 Seasonal copper concentrations (ppm) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	2.1	1.8	1.1	3.6	2.8	1.9	3.5	2.5	2.9	2.7	5.4	2.7		
1988	4.6	3.9	4.1			6.8	4.3		4.0		3.3		2.9	
1989						5.1	8.2		3.5	3.2	3.8	4.1		

Table A.18 Seasonal iron concentrations (ppm) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	66	65	55	46	38	48	49	46	49	56	53	93	74	
1988	180	163	128			163	124		139		129		147	
1989						315	316		289	274	260	250		

Table A.19 Seasonal manganese concentrations (ppm) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	198	206	201	202	186	194	213	211	221	281	232	322	295	
1988	237	251	221			241	236		262		258		311	
1989						237	269		290	335	345	350		

Table A.20 Seasonal zinc concentrations (ppm) in old leaves (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	165	175	180	190	205	220	235
1987	15	15	16	15	13	15	13	14	15	29	17	16	23	20
1988	20	22	21			22	21		21		20		23	
1989						26	29		27	22	25	24		

Table A.21 Seasonal nitrogen concentrations (%) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	0.69	0.64	0.58	0.58	0.56	0.66	0.63	0.56	0.45	0.68	0.55		
1988	0.66	0.66	0.65		0.52		0.50		0.48		0.48	0.45	0.55
1989						0.52	0.46	0.52		0.44	0.59	0.49	0.49

Table A.22 Seasonal phosphorus concentrations (%) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	0.10	0.09	0.08	0.09	0.08	0.08	0.06	0.07	0.09	0.10	0.10		
1988	0.11	0.10	0.10		0.10		0.11		0.09		0.11	0.10	0.11
1989						0.08	0.08	0.09		0.10	0.10	0.08	0.10

Table A.23 Seasonal potassium concentrations (%) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	0.28	0.30	0.28	0.28	0.27	0.30	0.30	0.27	0.33	0.36	0.32		
1988	0.33	0.32	0.36		0.34		0.40		0.32		0.31	0.30	0.36
1989						0.30	0.34	0.33		0.37	0.37	0.36	0.36

Table A.24 Seasonal calcium concentrations (%) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	0.18	0.20	0.17	0.19	0.21	0.22	0.19	0.20	0.22	0.18	0.18		
1988	0.27	0.26	0.27		0.25		0.31		0.24		0.22	0.25	0.25
1989						0.25	0.24	0.33		0.29	0.32	0.27	0.27

Table A.25 Seasonal magnesium concentrations (%) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	0.06	0.07	0.06	0.07	0.08	0.08	0.07	0.07	0.08	0.07	0.07		
1988	0.10	0.10	0.10		0.10		0.11		0.08		0.08	0.09	0.09
1989						0.11	0.08	0.15		0.10	0.13	0.14	0.12

Table A.26 Seasonal boron concentrations (ppm) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	12	11	11	11	7	9	14	14	17				
1988	12	15	15		13		17		15		16	19	17
1989						18	19	17		23	31	18	15

Table A.27 Seasonal copper concentrations (ppm) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	9.7	8.9	8.3	9.3	12.0	11.3	10.3	4.7	8.1	10.8	10.9		
1988	13.2	11.7	12.4		13.5		11.6		12.5		11.2	11.9	10.8
1989						13.0	14.9	13.9		13.1	11.3	12.3	13.0

Table A.28 Seasonal iron concentrations (ppm) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	253	293	265	290	267	270	270	326	314	286	376		
1988	472	435	542		449		416		487		559	690	569
1989						816	964	1083		1009	1104	891	858

Table A.29 Seasonal manganese concentrations (ppm) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	318	434	396	485	548	530	509	524	526	501	499		
1988	629	650	608		647		578		660		609	644	648
1989						589	593	483		457	538	569	546

Table A.30 Seasonal zinc concentrations (ppm) in woody stems (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220
1987	20	22	18	20	22	22	20	16	23	21	21		
1988	31	29	29		30		27		28		34	35	35
1989						34	32	51		32	41	32	40

Table A.31 Seasonal nitrogen concentrations (%) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	0.70	0.58	0.65	0.70	0.63	0.76	0.64	0.58	0.55	0.60	0.56	0.61	0.64	0.61	0.55		
1988	0.66	0.82	0.56			0.55	0.59		0.63		0.66	0.71	0.73	0.71	0.69	0.77	0.69
1989						0.74	0.73		0.62	0.75	0.70	0.67	0.57	0.67	0.65		

Table A.32 Seasonal phosphorus concentrations (%) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	0.10	0.10	0.11	0.10	0.09	0.09	0.10	0.11	0.10	0.12	0.11	0.13	0.12	0.02	0.12		
1988	0.11	0.12	0.11			0.12	0.12		0.12		0.13	0.14	0.14	0.14	0.13	0.12	0.12
1989						0.12	0.13		0.11	0.11	0.13	0.14	0.14	0.15	0.13		

Table A.33 Seasonal potassium concentrations (%) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	0.11	0.13	0.11	0.12	0.11	0.10	0.08	0.13	0.05	0.11	0.11	0.12	0.13	0.08	0.11		
1988	0.13	0.17	0.17			0.17	0.14		0.12		0.14	0.17	0.17	0.16	0.18	0.16	0.15
1989						0.15	0.19		0.13	0.16	0.12	0.12	0.13	0.14	0.15		

Table A.34 Seasonal calcium concentrations (%) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	0.18	0.12	0.10	0.09	0.10	0.09	0.09	0.09	0.09	0.10	0.11	0.10	0.10	0.06	0.10		
1988	0.13	0.15	0.13			0.11	0.12		0.12		0.14	0.11	0.13	0.12	0.13	0.11	0.11
1989						0.15	0.17		0.13	0.12	0.13	0.14	0.13	0.13	0.13		

Table A.35 Seasonal magnesium concentrations (%) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	0.07	0.08	0.06	0.05	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.07	0.03	0.05		
1988	0.07	0.09	0.07			0.07	0.07		0.07		0.07	0.08	0.08	0.08	0.08	0.08	0.07
1989						0.09	0.12		0.07	0.06	0.07	0.07	0.07	0.07	0.07		

Table A.36 Seasonal boron concentrations (ppm) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	11	5	9	6	11	8	9	10	11	7	15	6	7				
1988	12	15	13			12	14		14		23	18	13	16	15	18	16
1989						17	15		18	13	10	28	12	17	15		

Table A.37 Seasonal copper concentrations (ppm) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	188	149	105	192	184	156	153	158	189	163	183	166	331	246			
1988	250	166	87			126	149		182		280	190	169	139	278	170	219
1989						196	144		116	140	164	193	268	310	254		

Table A.38 Seasonal iron concentrations (ppm) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	3999	4738	4385	3470	4063	3950	4869	4430	4287	4240	4677	4020	5670	4851			
1988	5285	6208	4682			4875	5041		5833		5147	6399	6726	6370	6373	5820	5219
1989						6359	6344		6135	5616	6170	6252	5749	6010	6063		

Table A.39 Seasonal manganese concentrations (ppm) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	167	157	163	157	164	135	144	120	152	120	144	140	135	138			
1988	182	151	182			178	203		124		151	123	161	147	138	141	125
1989						143	159		93	109	149	134	155	173	160		

Table A.40 Seasonal zinc concentrations (ppm) in roots (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	105	120	135	140	145	150	160	170	175	180	190	205	220	230	245	260	275
1987	51	49	43	37	36	38	41	50	41	48	41	53	64	54			
1988	49	59	50			45	54		62		63	59	61	66	71	57	63
1989						65	75		51	47	74	57	73	68	59		

Table A.41 Seasonal nitrogen concentrations (%) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				0.51	0.53		0.52
1988			0.61	0.43	0.40	0.39	0.51
1989	0.98	0.67	0.46	0.34	0.33		0.30

Table A.42 Seasonal phosphorus concentrations (%) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				0.10	0.09		0.08
1988			0.12	0.10	0.10	0.09	0.10
1989	0.17	0.13	0.11	0.08	0.07		0.07

Table A.43 Seasonal potassium concentrations (%) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				0.74	0.69		0.63
1988			0.94	0.89	0.87	0.78	0.77
1989	0.85	0.84	0.87	0.76	0.73		0.67

Table A.44 Seasonal calcium concentrations (%) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				0.18	0.07		0.07
1988			0.13	0.12	0.10	0.08	0.13
1989	0.16	0.13	0.11	0.08	0.07		0.07

Table A.45 Seasonal magnesium concentrations (%) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				0.05	0.05		0.06
1988			0.09	0.08	0.07	0.06	0.07
1989	0.13	0.10	0.12	0.06	0.05		0.05

Table A.46 Seasonal boron concentrations (ppm) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				18	17		12
1988			20	18	13	13	15
1989	24	19	10	11	21		18

Table A.47 Seasonal copper concentrations (ppm) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				5.2	4.5		5.6
1988			6.7	6.4	4.9	6.2	7.0
1989	8.4	9.5	7.3	6.4	5.1		7.9

Table A.48 Seasonal iron concentrations (ppm) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				12.5	12.3		13.4
1988			21.3	19.0	28.4	32.6	37.9
1989	25.9	25.7	32.0	18.0	36.1		40.1

Table A.49 Seasonal manganese concentrations (ppm) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				20.6	21.0		18.4
1988			25.9	27.5	23.2	19.6	30.9
1989	35.9	34.1	31.1	22.6	20.8		20.5

Table A.50 Seasonal zinc concentrations (ppm) in fruit (all treatments combined). Values joined by underline do not differ significantly (5% level) as determined by profile analysis.

Day	190	205	220	235	245	260	275
1987				7.9	7.7		7.5
1988			11.6	9.7	9.3	8.2	9.8
1989	18.6	13.0	12.9	7.4	10.7		11.6

APPENDIX B

NUTRIENT CONTENT IN TISSUES OF 'EARLY BLACK' CRANBERRY

The content of N, P, K, Ca, Mg, B, Cu, Fe, Mn, and Zn in the plants on a cranberry bog (kg/ha basis) during the season was determined for three years. The results for 1987 are shown in Chapter 6 in Figures 6.51 to 6.60 (p. 139-143). The results for 1988 and 1989 are shown in the following Figures (B.1 to B.20).

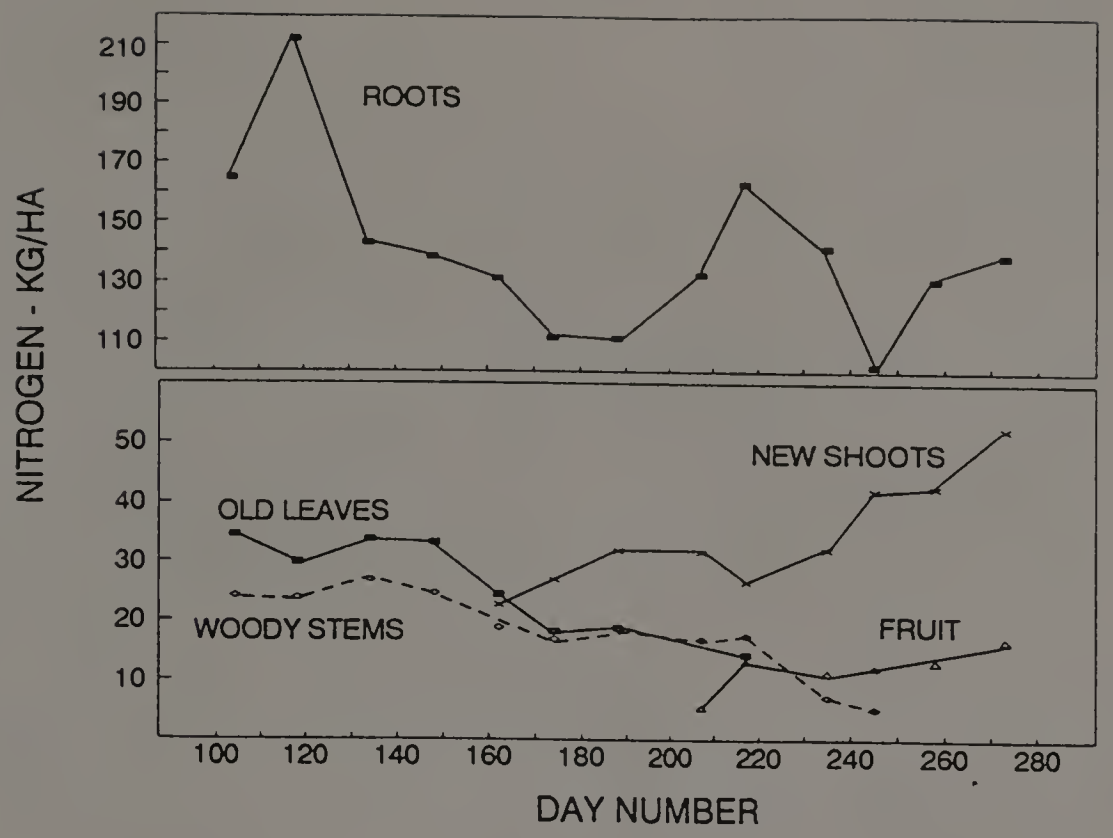

Figure B.1 Seasonal N content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

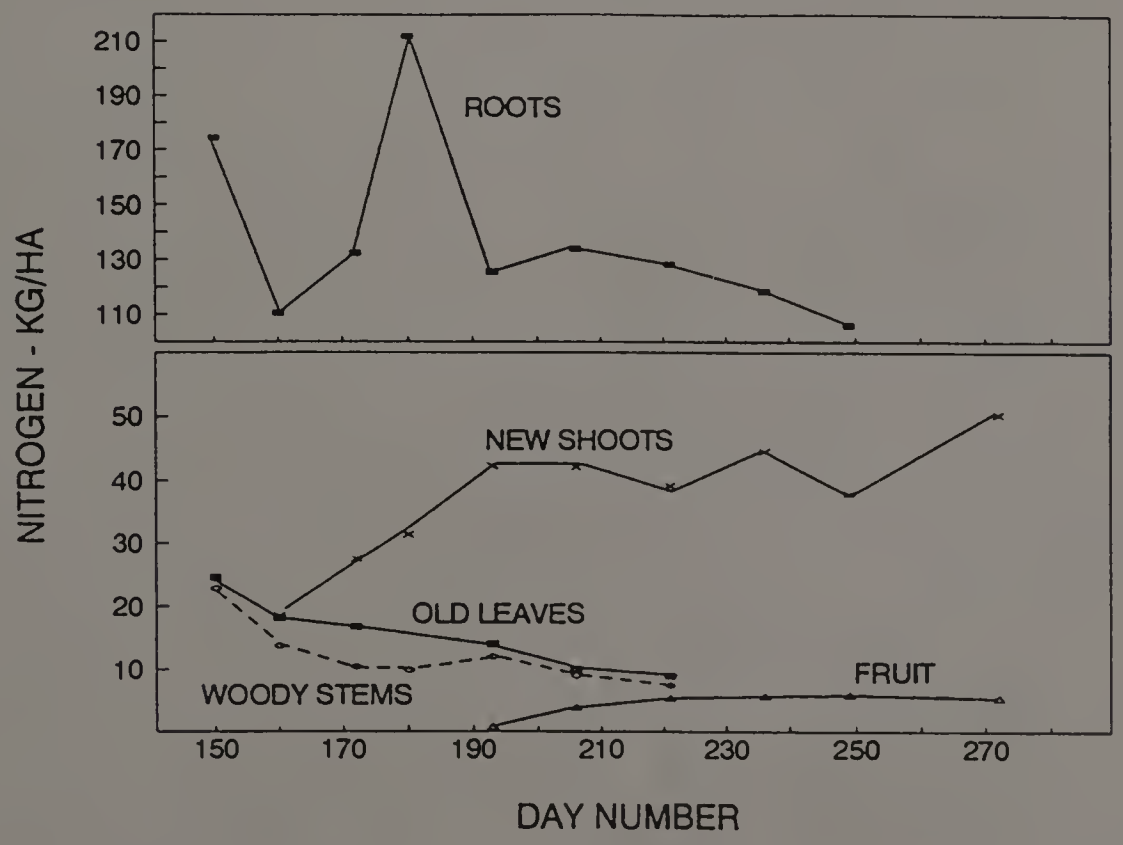

Figure B.2 Seasonal N content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

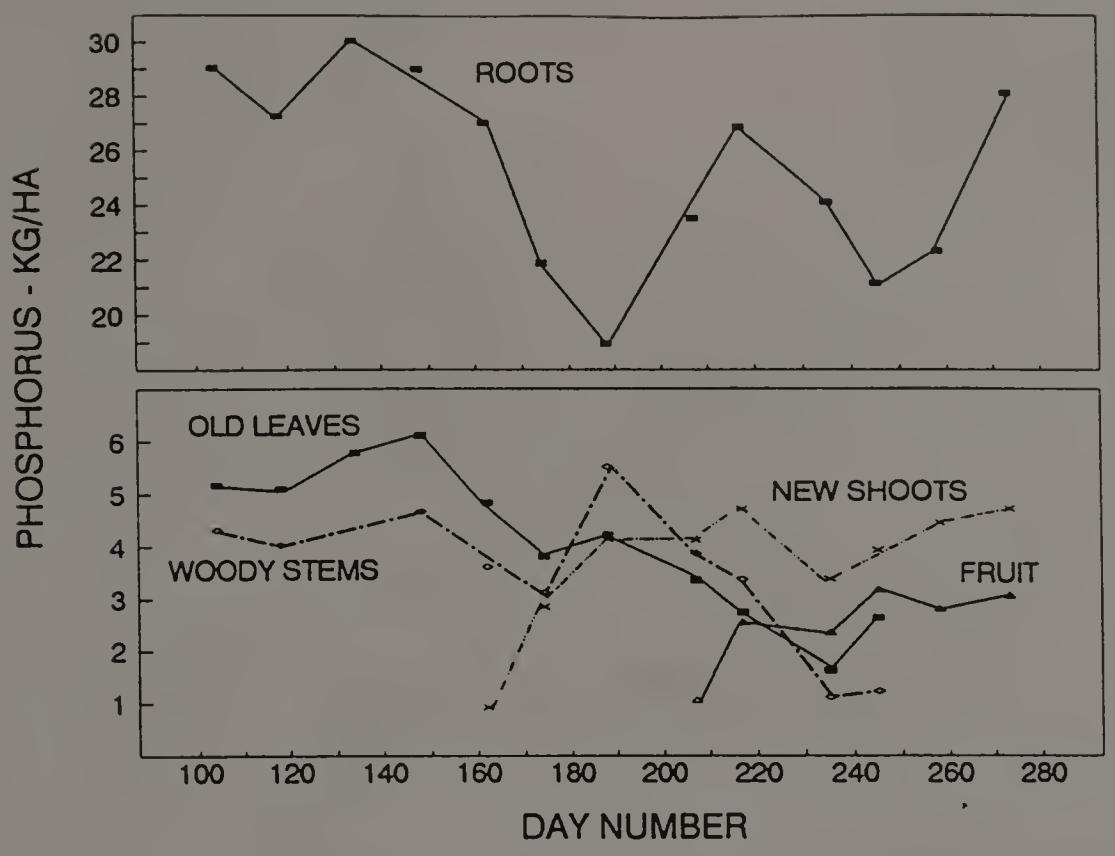

Figure B.3 Seasonal P content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

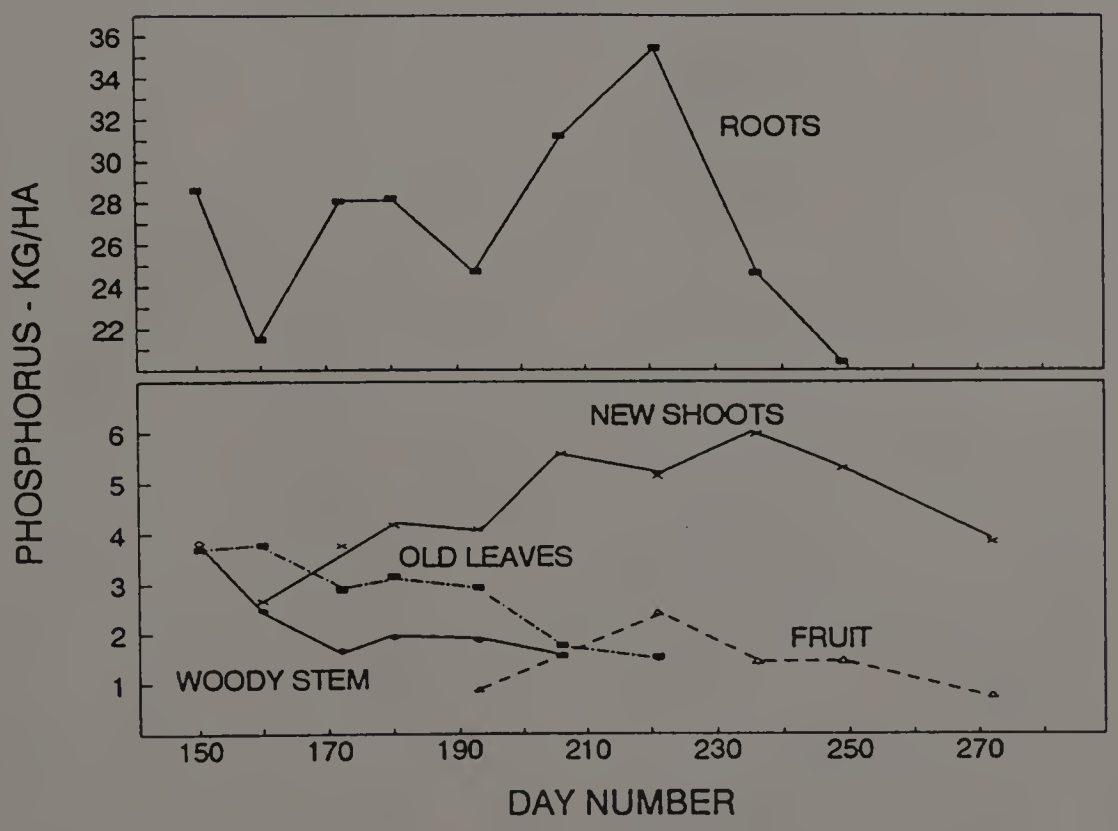

Figure B.4 Seasonal P content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

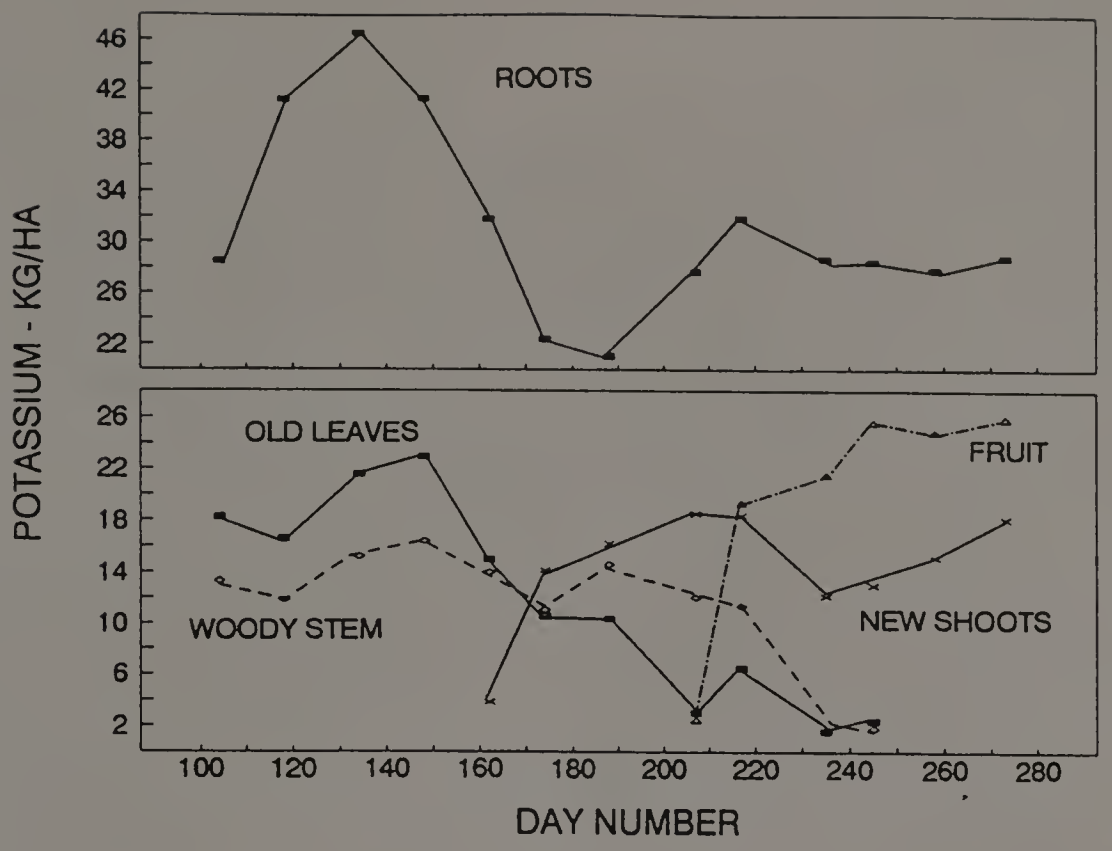

Figure B.5 Seasonal K content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

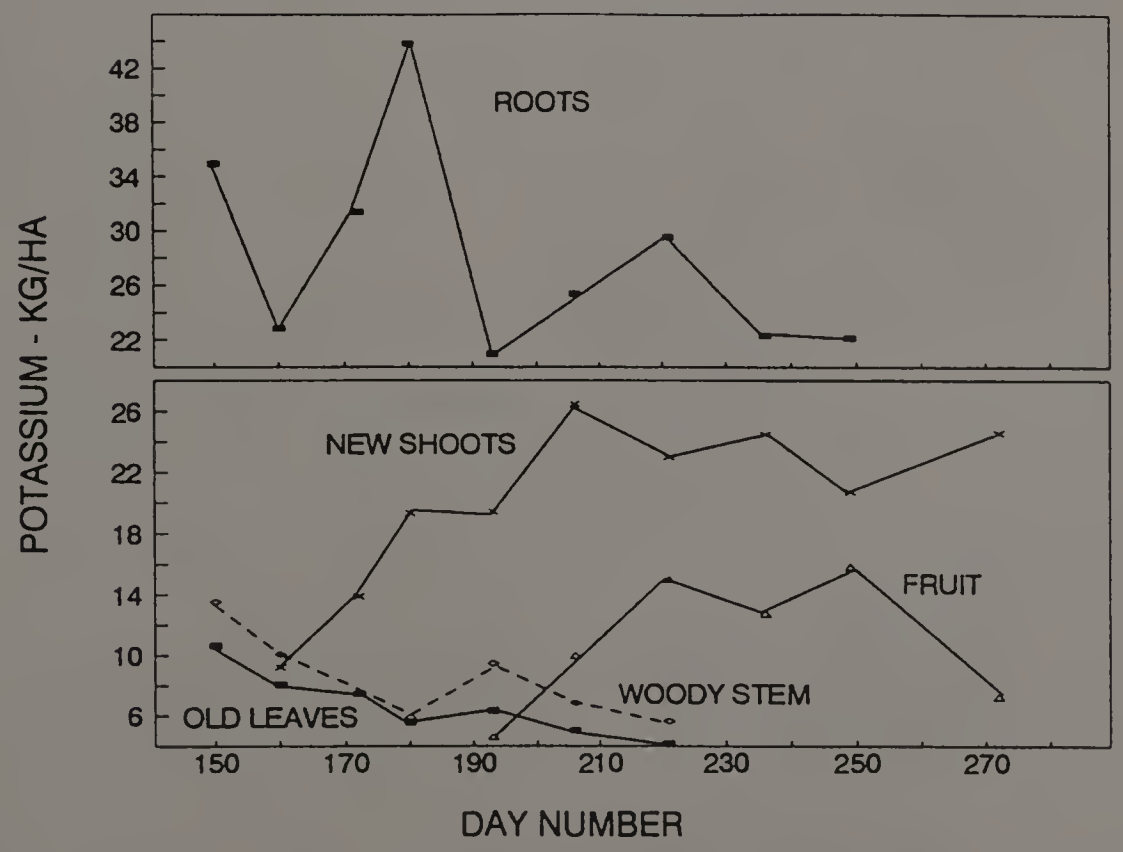

Figure B.6 Seasonal K content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

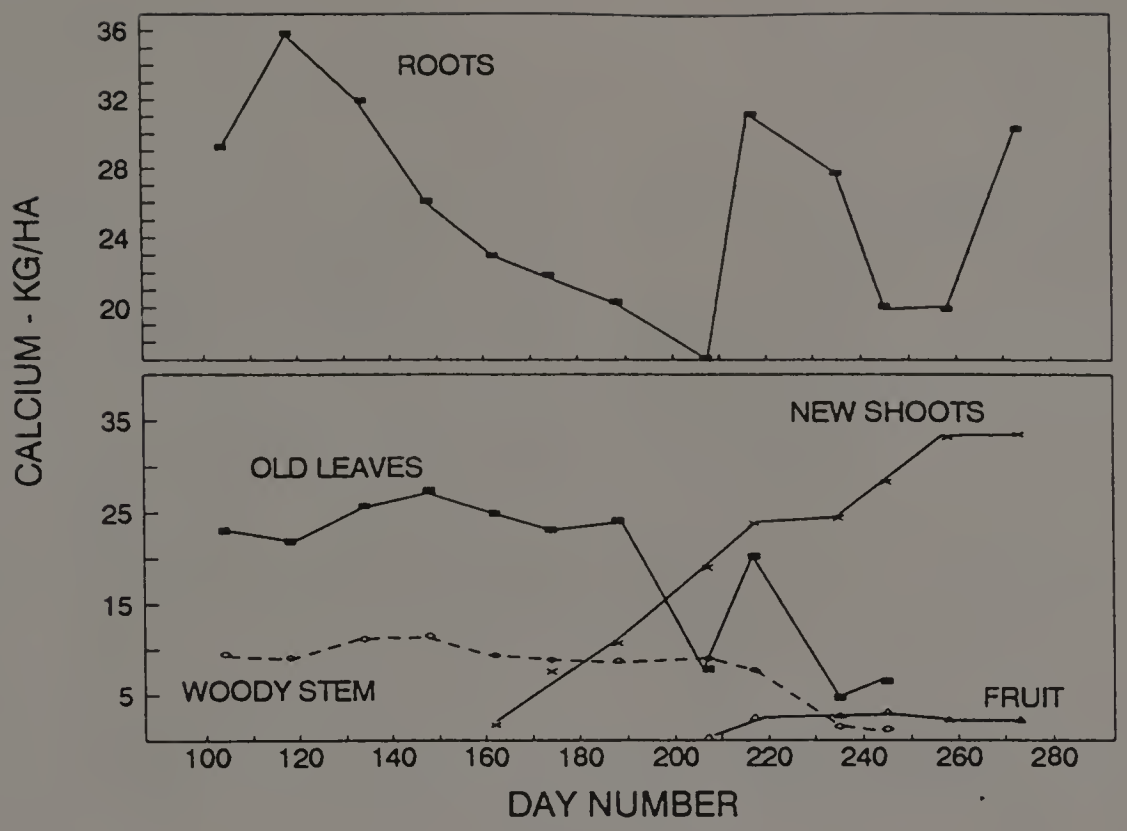

Figure B.7 Seasonal Ca content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

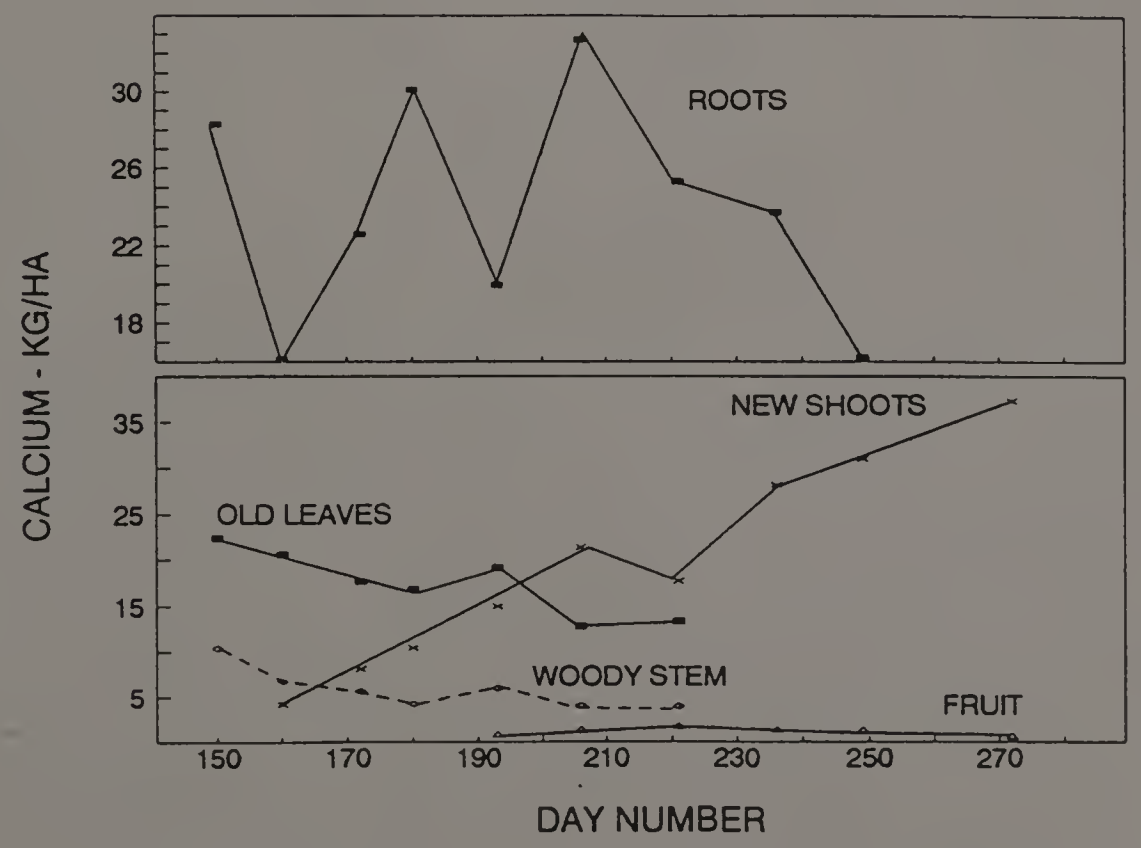

Figure B.8 Seasonal Ca content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

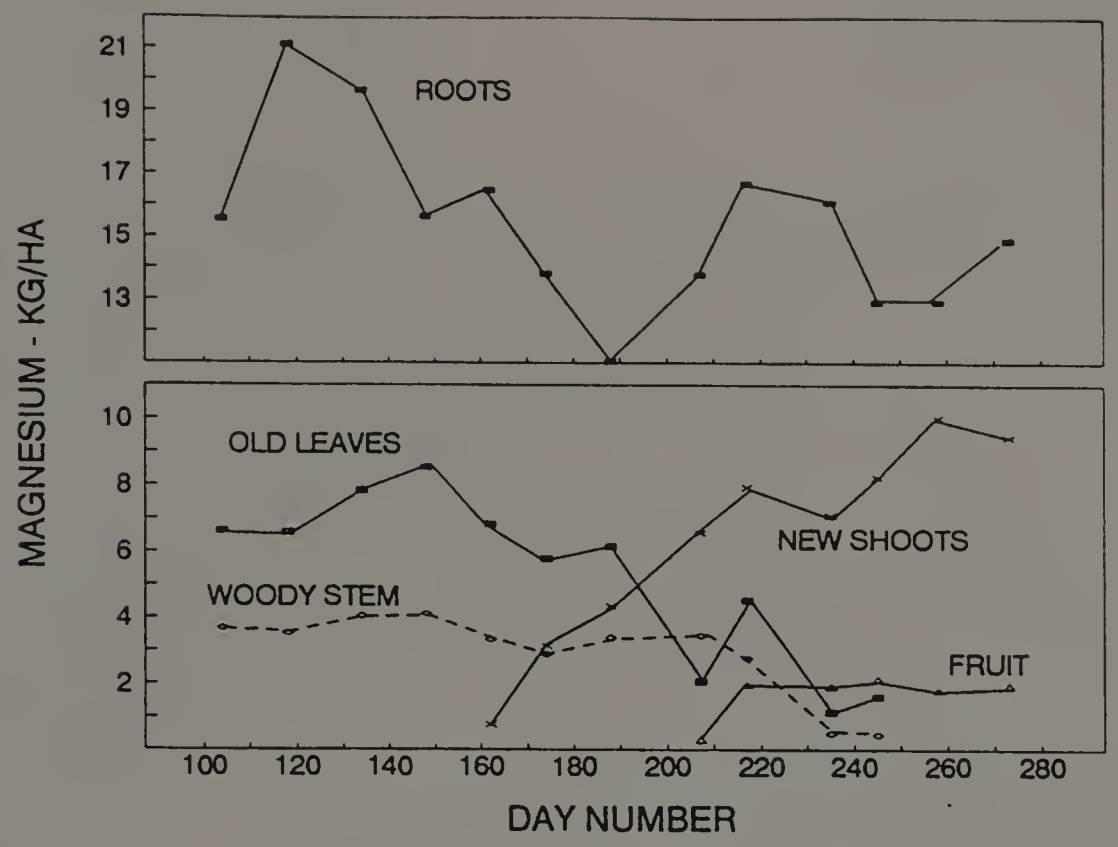

Figure B.9 Seasonal Mg content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

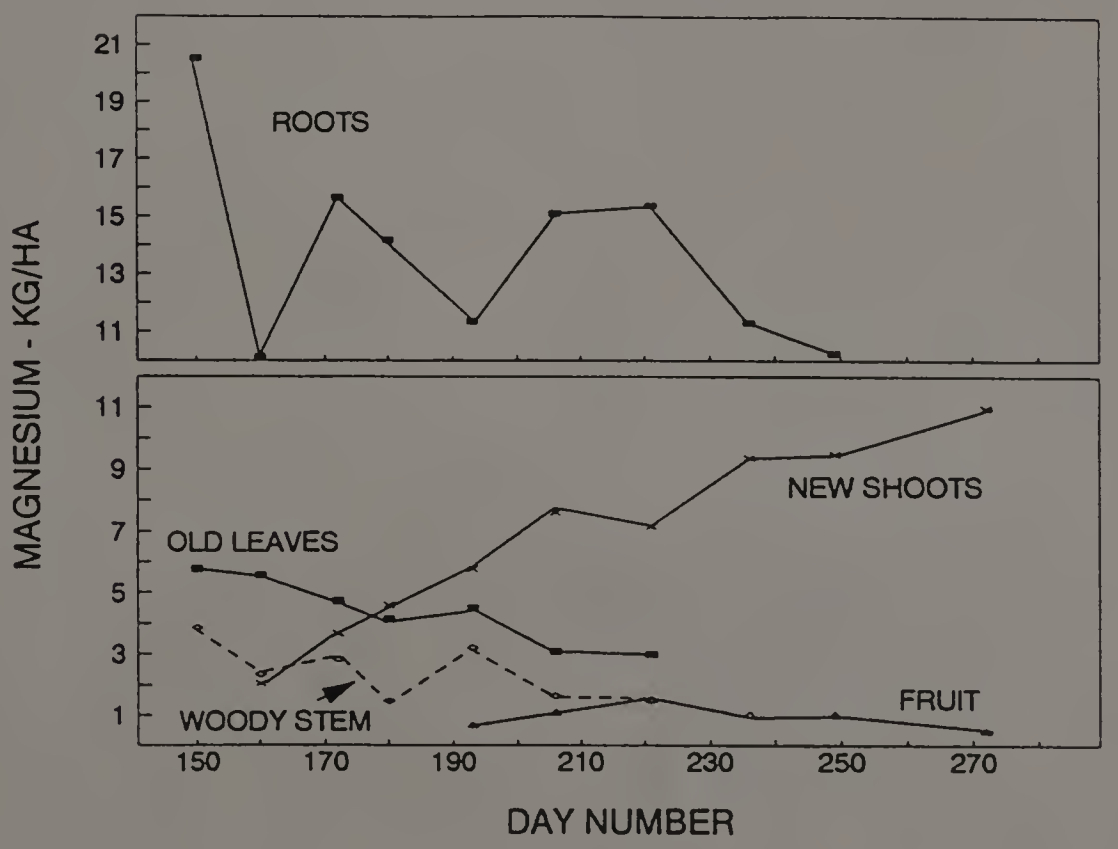

Figure B.10 Seasonal Mg content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

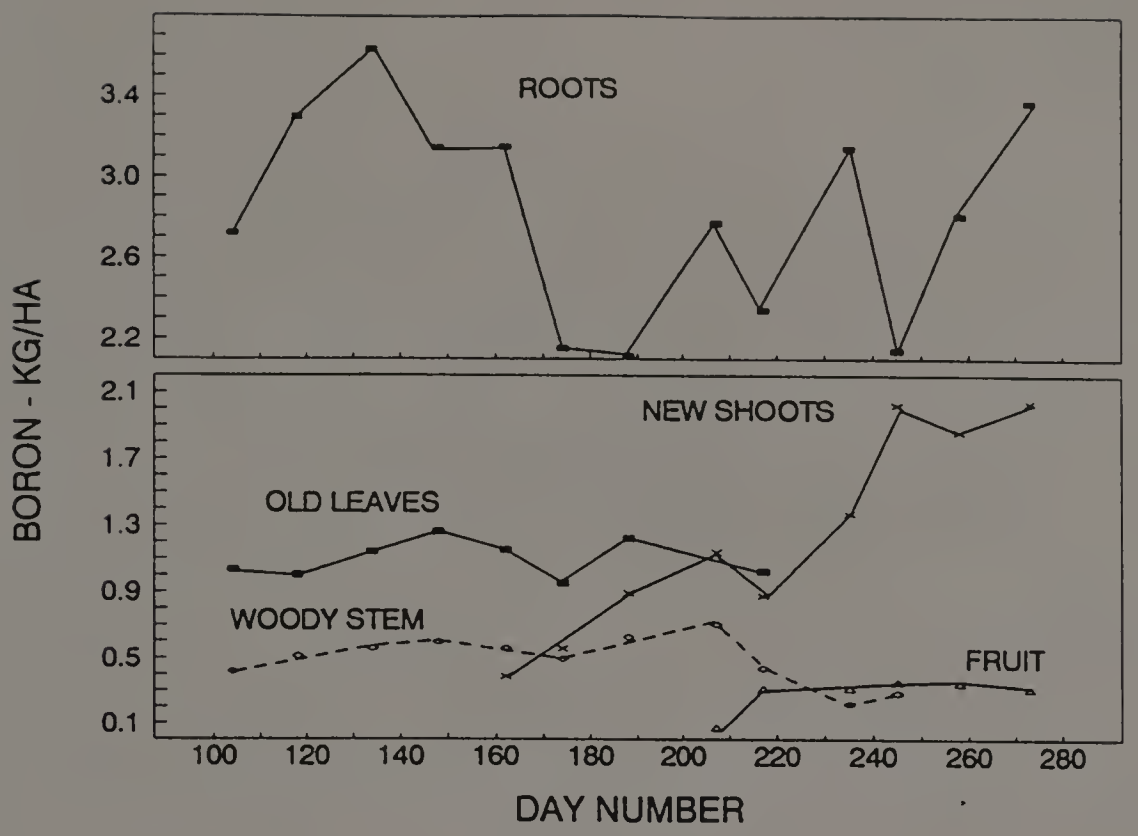

Figure B.11 Seasonal B content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

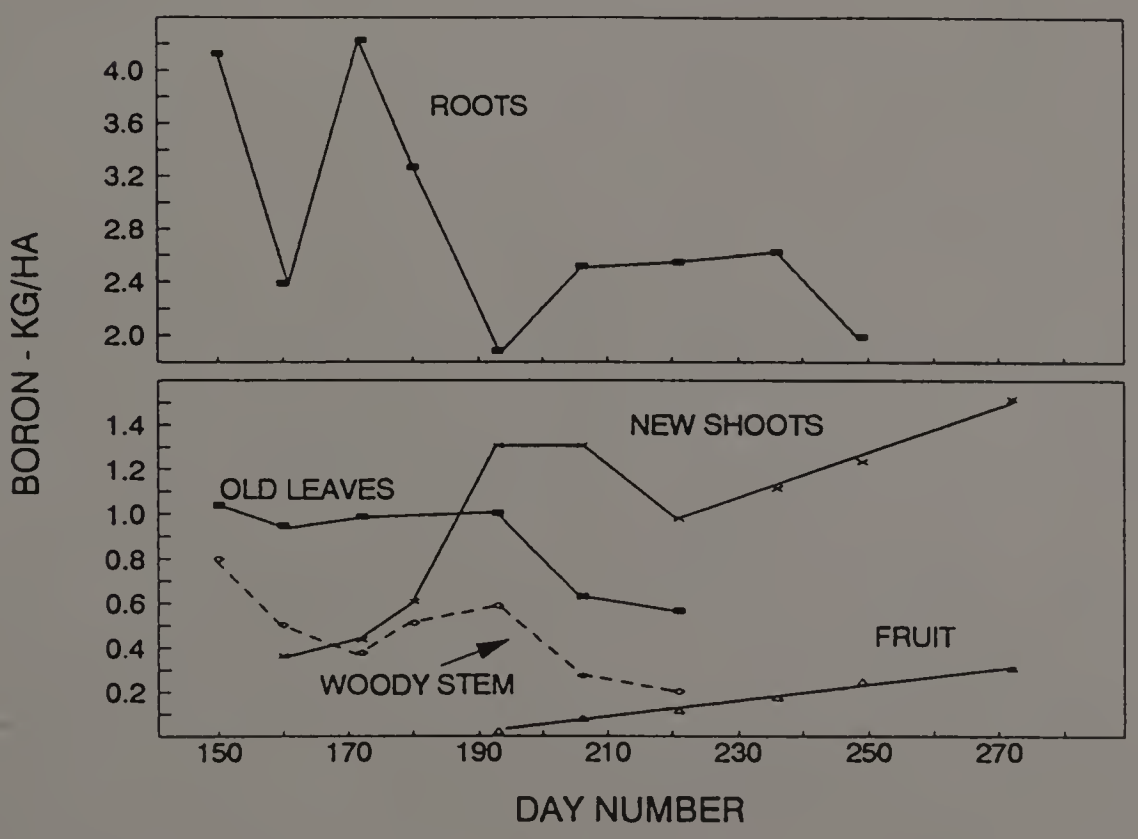

Figure B.12 Seasonal B content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

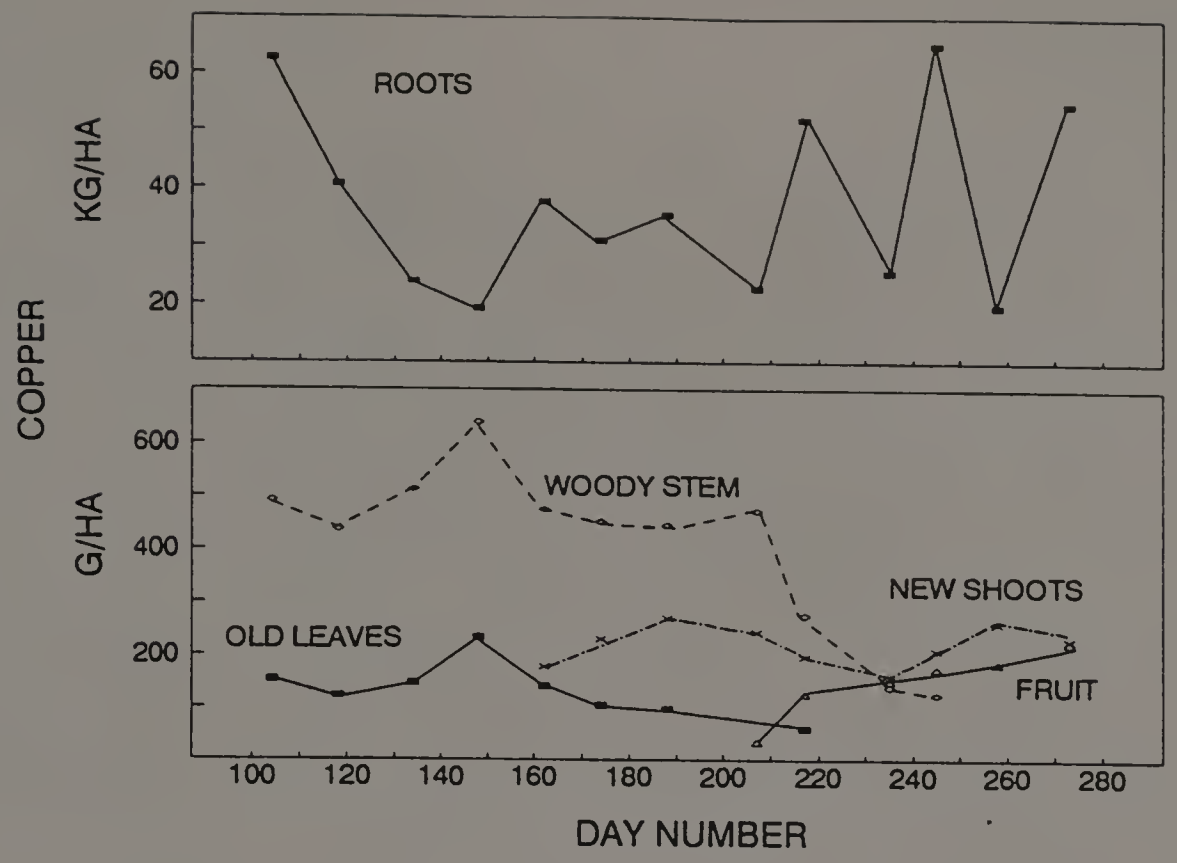

Figure B.13 Seasonal Cu content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

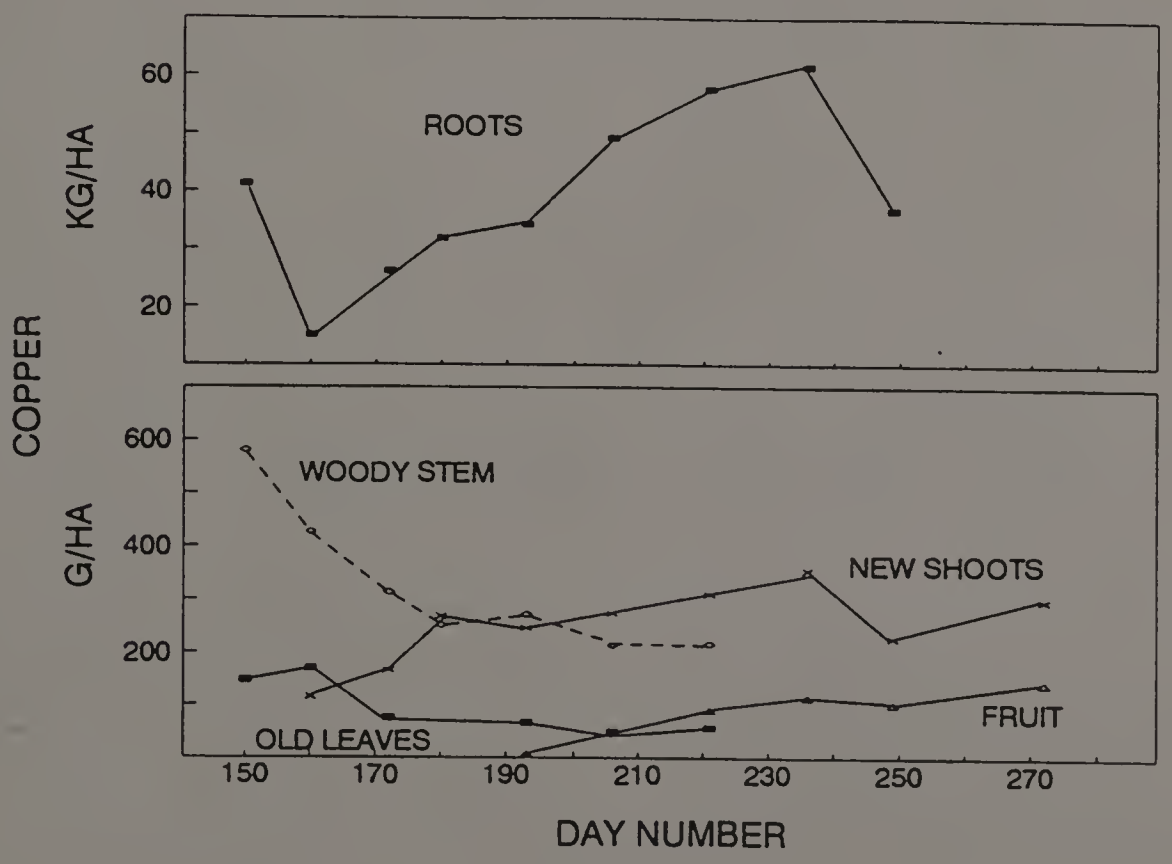

Figure B.14 Seasonal Cu content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

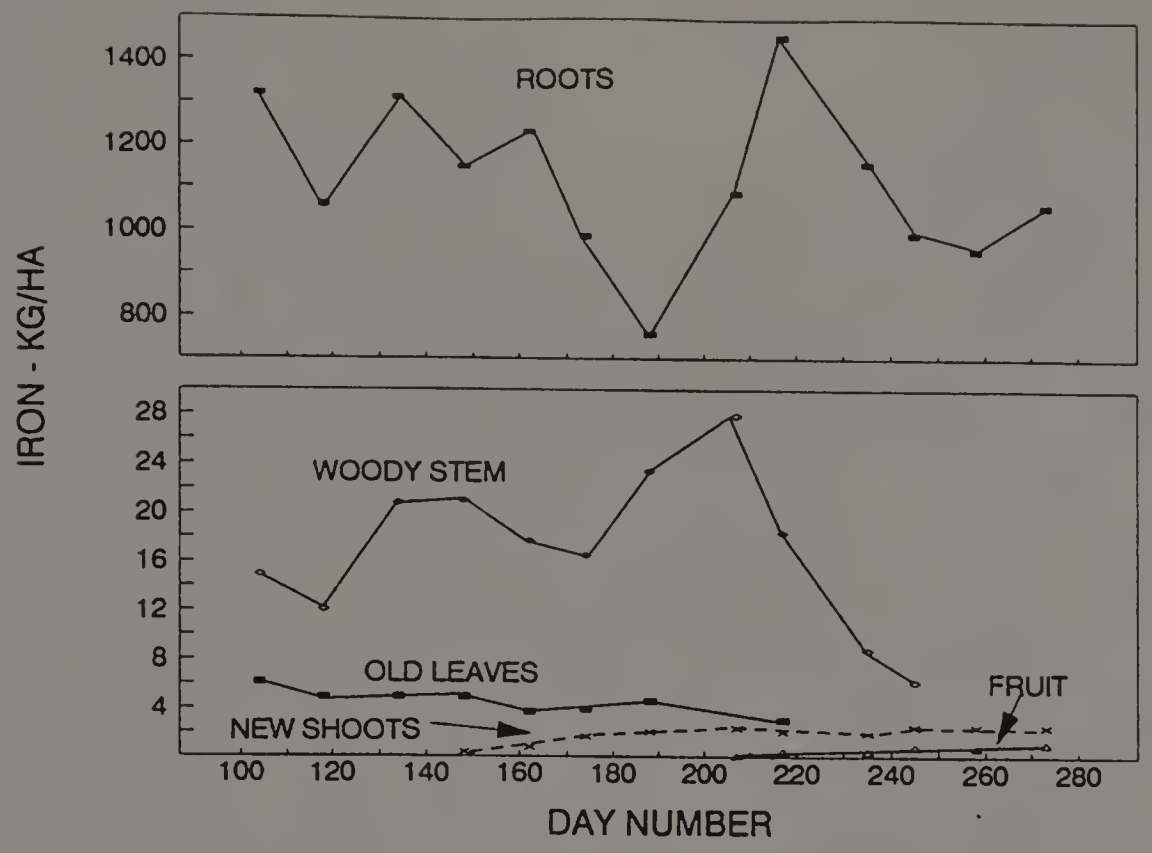

Figure B.15 Seasonal Fe content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

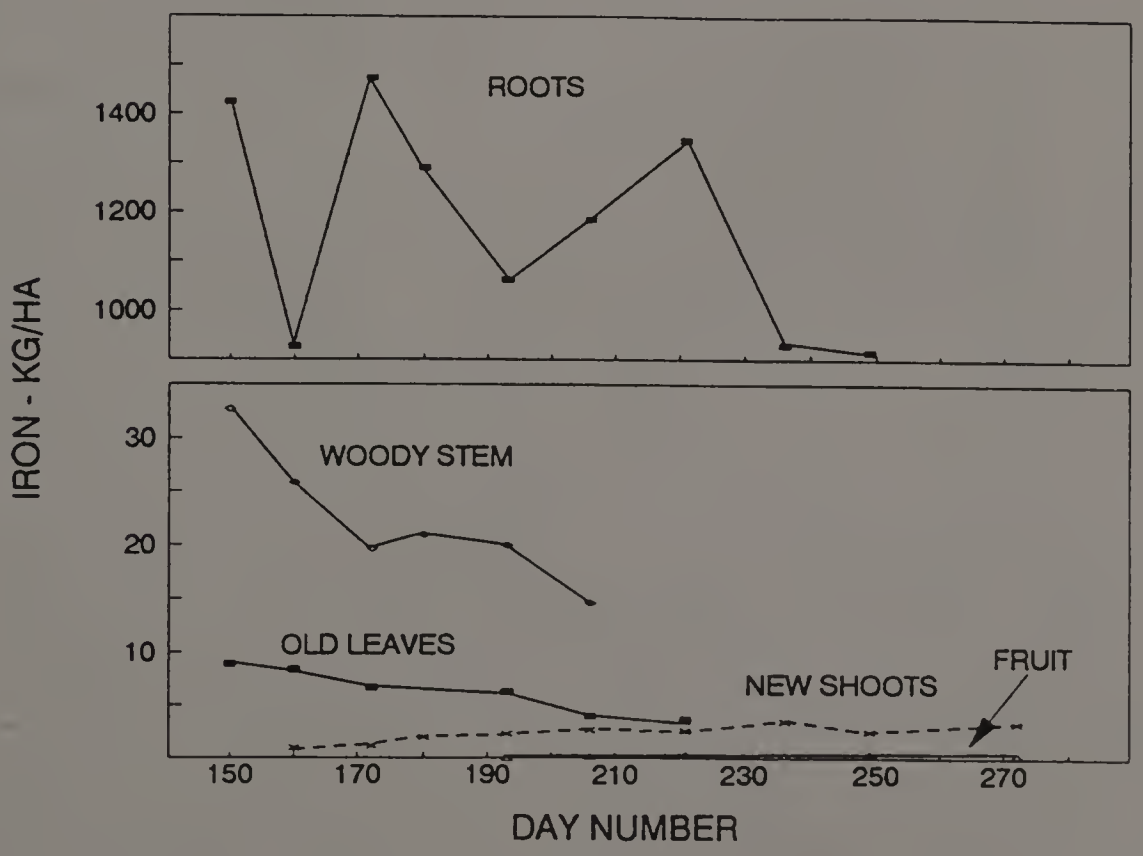

Figure B.16 Seasonal Fe content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

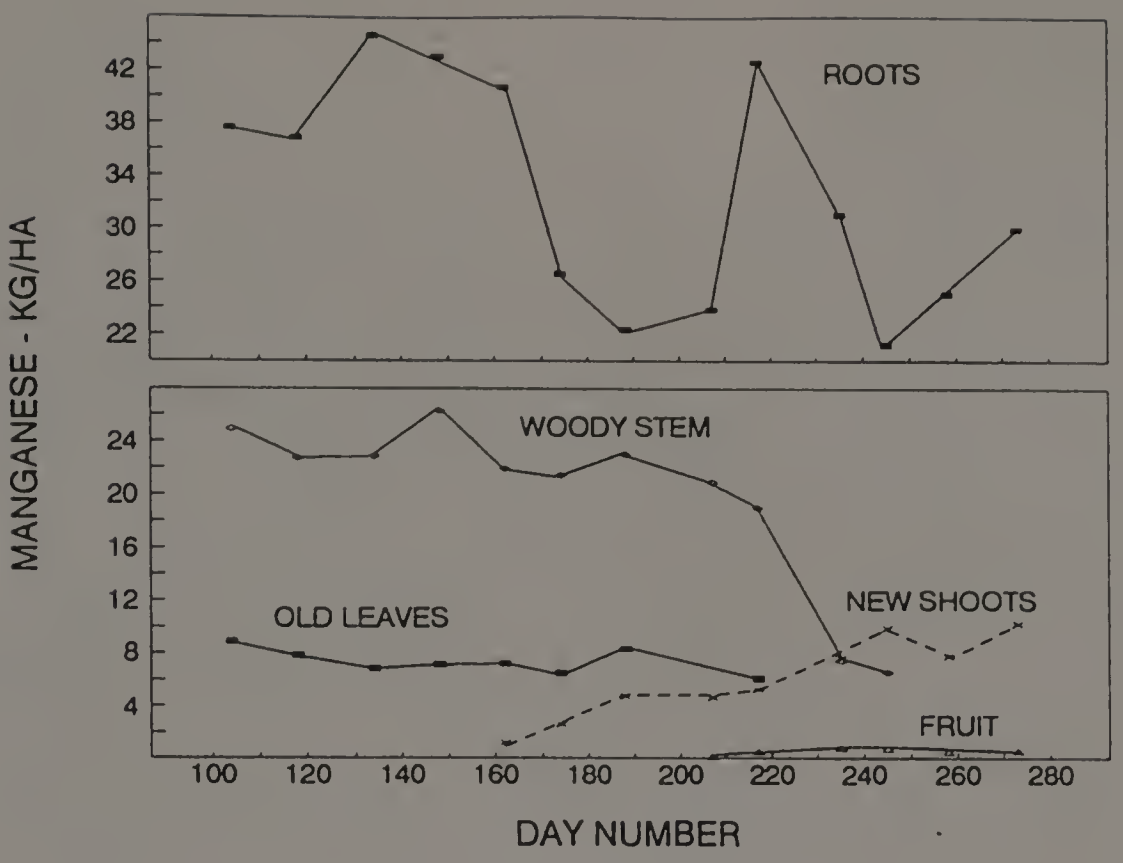

Figure B.17 Seasonal Mn content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

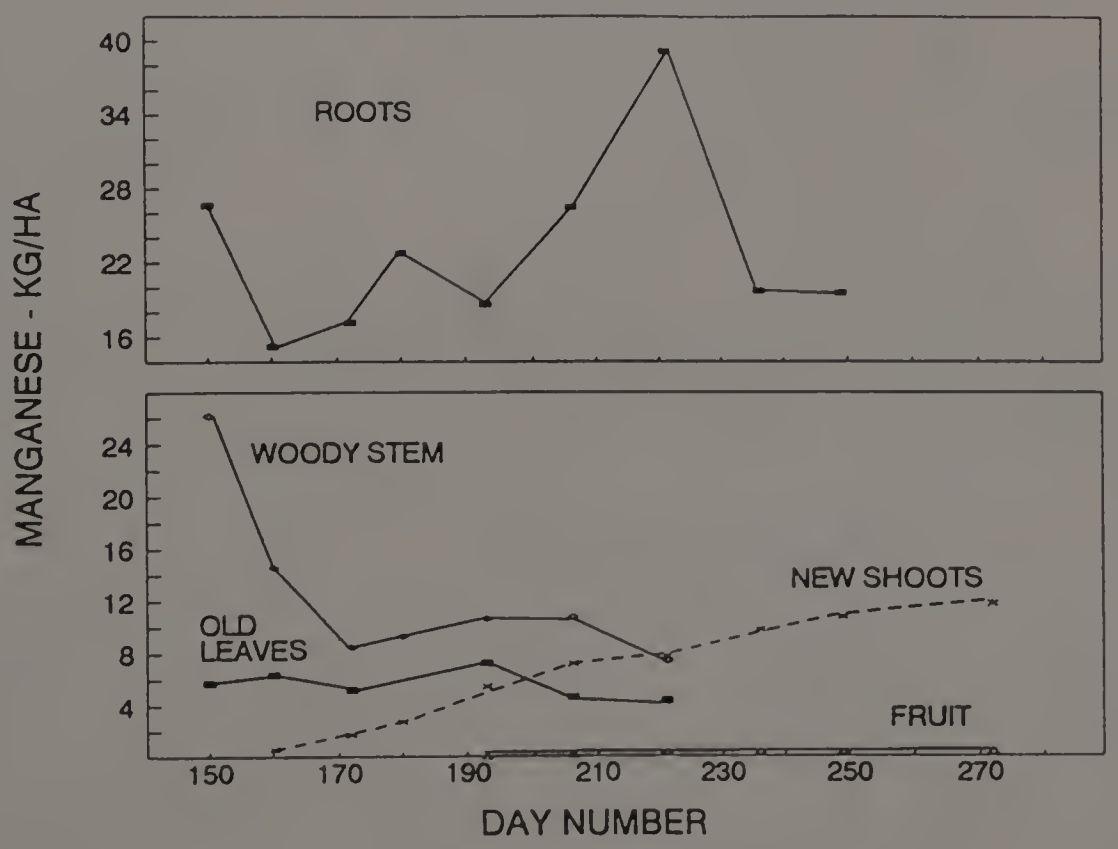

Figure B.18 Seasonal Mn content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

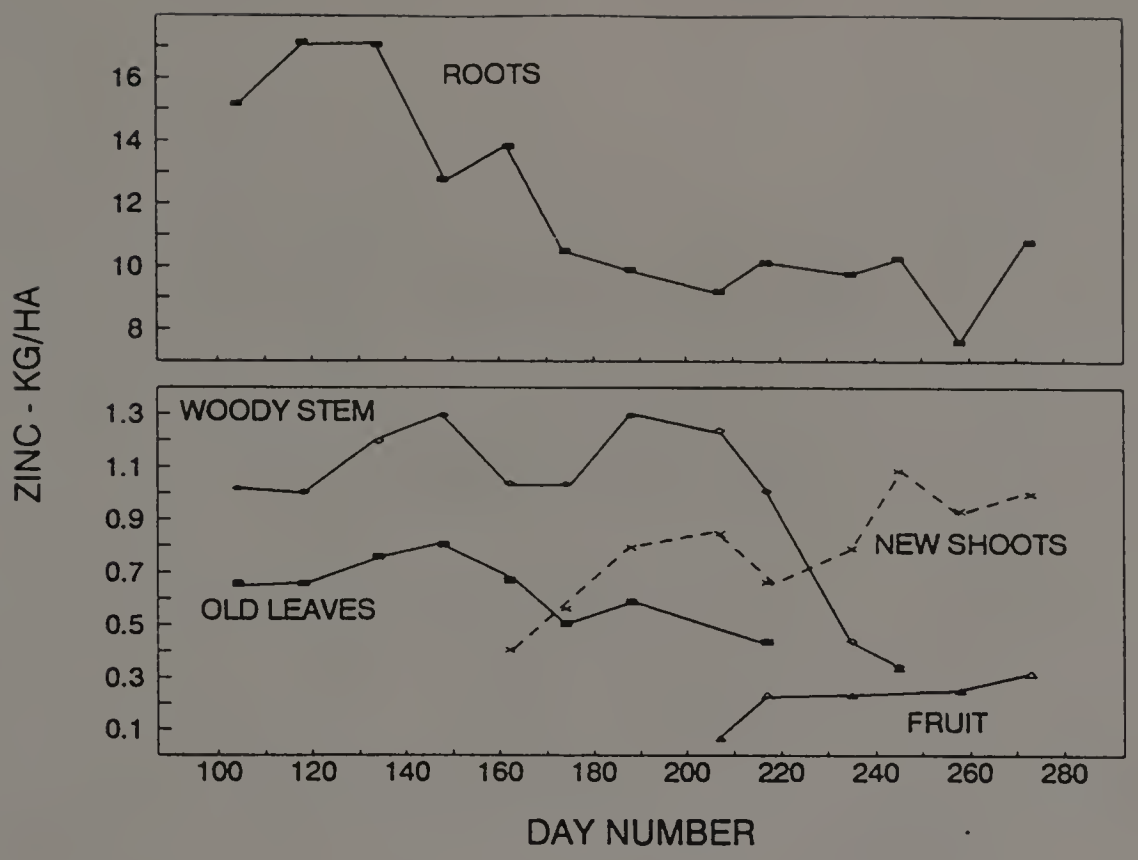

Figure B.19 Seasonal Zn content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1988 plots, means of 5 replicates.

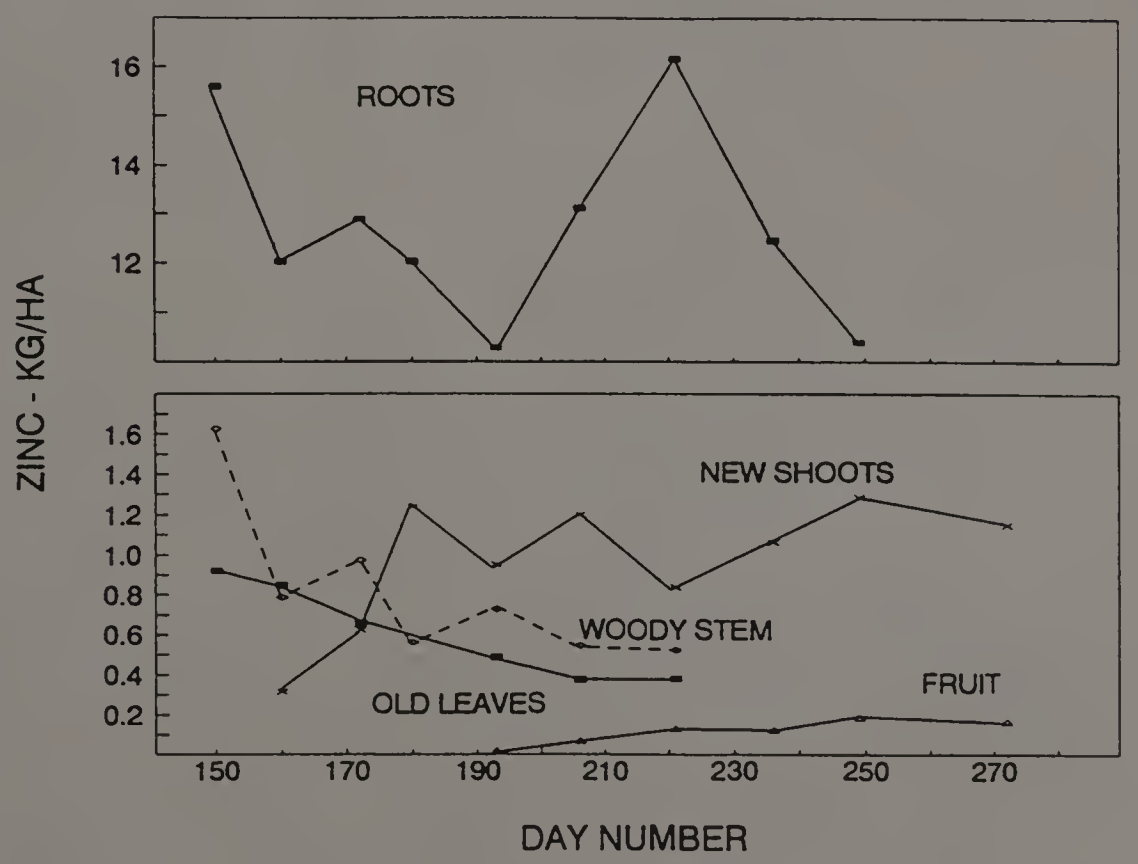

Figure B.20 Seasonal Zn content in tissues of cranberry receiving 335 kg N-P-K/ha. Data shown are from 1989 plots, means of 5 replicates.

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