AN ABSTRACT OF THE THESIS OF

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Title: ROOTSTOCK, K, AND N FERTILIZER EFFECTS IN A HIGH DENSITY ORCHARD ON SEASONAL MINERAL ELEMENTS, ENDOGENOUS ETHYLENE, MATURATION AND STORAGE QUALITY OF 'STARKSPUR GOLDEN DELICIOUS' APPLES

Abstract Approved:
Dr. Daryl G. Richardson

Leaf and fruit seasonal mineral fluctuations, fruit endogenous ethylene, maturity and quality of 'Starkspur Golden Delicious' apple (*Malus domestica* Borkh.) on six rootstocks: Seedling, Malling (M)1, M7, M26, Malling Merton (MM)106, OAR-1, in a high density orchard with two levels of each of the soil applied potassium (K_2SO_4) and nitrogen (urea) fertilizers were studied in 1980-1982.

Leaf concentrations of N, P, and K decreased but Mg and Ca increased, while fruit concentrations of all elements generally decreased as the growing season progressed. Lighter fruit crops resulted in higher concentrations of K in the leaf and lower Ca in the fruit.

Scion leaves on OAR-1 rootstock had significantly less Ca

than those on M7, MM106 and M1 and less Mg than those on M26. Fruit concentrations of N, K, P, Mg, Fe, and Cu on OAR-1 were lower as a result of a higher percentage of carbohydrates contributing to fruit dry weight. However, B concentrations of both leaf and fruit on OAR-1 were higher than all rootstocks. Rootstock M26 induced significantly more leaf Mg than those on M1, MM106 and OAR-1 and had lower fruit B concentrations than most of the tested rootstocks. Trees on M7 occasionally showed higher fruit N, K, P, Fe and Cu concentrations than most other rootstocks. Scion fruits on OAR-1 had the lowest content of all minerals (except B) partially due to their smaller size compared to other rootstocks. Higher potassium fertilizer significantly decreased leaf Ca and Mg concentrations while higher nitrogen increased leaf N and Mg and fruit N, but decreased P and K levels in both leaves and fruits.

Fruits from trees on OAR-1 produced endogenous and evolved ethylene later but had lighter color and higher soluble solids both at harvest and after storage and were firmer at harvest compared to fruits on other rootstocks. Fruits on MM106 produced low ethylene and had less storage breakdown. Fruits on M7 had lower soluble solids and dry matter than most other rootstocks. Fruits with higher minerals usually had lower soluble solids.

Higher nitrogen induced significantly greater evolved ethylene after storage and retained more green color in the fruit.

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Esmaeil Fallahi

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Professor of Horticulture in Charge of Major

Head of Department of Horticulture

Dean of Graduate School

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Typed by Bonnie J. Hummel and Deann Thompson for:

ESMAEIL FALLAHI

DEDICATION

This thesis is dedicated to my kind and devoted mother, Mrs. Ozra Naderi (Fallahi), to whom I am indebted for my education and development. She has been both my father and mother since I was 12 when my father died. Words are so inadequate to express my deep feelings and love for her and her compassion, wisdom, and elegant grace. I shall always be proud to be her son.

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PREFACE

This dissertation is presented as a series of five papers written in the format required by the Journal of the American Society for Horticultural Science.

CONTRIBUTIONS OF AUTHORS

Dr. Daryl G. Richardson served as major professor for my Ph.D. program. He and I cooperatively developed the design and analytical procedures for the maturation, post harvest physiology studies and quality evaluations of the fruit as well as the sampling procedures for fruit analysis. He furnished chemicals, laboratory and cold storage facilities and provided funds for the major part of these studies. He also substantially edited and aided in data evaluation and the review of the thesis.

Dr. Melvin N. Westwood and Dr. Michael H. Chaplin established the experimental orchard and the rootstock and fertilizer trials. Dr. Westwood also provided valuable guidance and comments in the interpretation of some of the results. Dr. Chaplin was responsible for determining the fertilizer treatments and provided laboratory facilities for mineral analysis.

ROOTSTOCK, K, AND N FERTILIZER EFFECTS IN A HIGH DENSITY ORCHARD ON SEASONAL MINERAL ELEMENTS, ENDOGENOUS ETHYLENE, MATURATION AND STORAGE QUALITY OF 'STARKSPUR GOLDEN DELICIOUS' APPLES

CHAPTER 1

INTRODUCTION

Apples have the greatest annual production of all deciduous fruit trees in the world, and the United States with annual production of 3,724,885 metric tons in 1982 was the leading producer (244). A large portion of the world's annual production is lost due to pests, mishandling and also due to deficient or imbalanced fruit mineral compositions that leads to storage disorders and diseases. A great portion of sound fruits have only limited uses due to poor maturity or poor eating quality. On the other hand, applications of various chemicals to control pests and diseases is not only costly (due to the increased costs of petroleum and chemical manufacturing) but also has generated several problems such as development of resistant pests and pollution of soil and environment causing dangerous consequences for man and wildlife. These considerations have increased the tendency of biological and horticultural scientists to develop pest and disease resistant varieties and rootstocks. At the same time, the increasing trend of the world population necessitates better handling and storage facilities for perishable horticultural commodities and dictates increased production every year. The concept of high density orchards would definitely be an important step toward increasing the supply on existing land area to satisfy the world's increasing demand. Use of dwarf rootstock enables establishment of these close spaced orchards. Thus, the nature of plant-to-plant competition at these close spacings requires an analysis of the interactions between fertilizer treatments and rootstock efficiencies under high density conditions. Such analysis in the trend of mineral accumulations, maturity and quality, would help to resolve problems in production such as mineral-related disorders, fertilizer needs, maturity and quality of fruits and possible solution of these through the appropriate choices of rootstocks and fertilizer combinations.

The purpose of this thesis is to study various responses of 'Starkspur Golden Delicious' apples on six rootstocks: Malling (M)1, M7, M26, Seedling, OAR-1, and Malling Merton (MM)106 and two levels of soil applied K (as K_2SO_4) and N (as urea) fertilizers in a high density orchard. This goal is accomplished through five objectives, each presented as a paper. However, all of these objectives are interrelated and these relations will be explored within each objective. These objectives are:

1) Studying the seasonal leaf mineral nutrient responses of various rootstocks. This study would increase not only our knowledge of rootstock and fertilizer effects on leaf mineral

fluctuation and seasonal mineral movement for a spur type apple, but may also clarify several nutrient needs, uses, and limitations of leaf tissue analysis as an estimator of nutrient need. Thus, this part of the study would be complemented by the second part of this series of studies (fruit minerals).

2) Study of the effects of various rootstocks and K and N fertilizers on the seasonal mineral accumulation of fruits. This study would determine the seasonal mineral accumulation of fruits. It would also determine the seasonal mineral concentrations, total content, percent fresh weight mineral content, fresh weight and dry matter accumulation in the fruit. This study also would clarify the advantages and disadvantages of the tested rootstocks and fertilization received from the standpoint of mineral uptake in a high density system. With this knowledge, one might be able to predict mineral-related keeping quality and storage disorders prior to havest. Since fruit sampling in this research was done together with leaf sampling, some trends in mineral translocations between leaf and fruit and vice versa might be obtained at several periods of the growing season in various rootstocks. A study of the relationship of the mineral composition of fruit with storage quality as a result of rootstock and fertilizer at early stages of fruit maturity might help to improve or at least estimate storage keeping quality ahead of time through various cultural practices.

3) Assessing effects of rootstock and K and N fertilizers

on fruit maturation as measured by the new method using quantification of internal ethylene from attached and detached fruits. Results of this study will not only determine the influence of each treatment on ethylene onset, but also it will evaluate how well this new method can correspond with other traditional maturity and quality factors which will be studied in Objective Four.

4) Studying the traditional fruit quality factors such as days from full bloom, color, soluble solids, firmness, bitterpit, storage rot, and titratable acidity at harvest and after storage from three harvest dates for rootstock and fertilizer combinations. This study might identify superior rootstocks and level of fertilizer and improved quality and storability.

5) Determining all possible correlations among various pre-harvest nutritional factors and maturity and post-harvest quality of 'Starkspur Golden Delicious' as influenced by six rootstocks. In this objective, basic goals of objectives 1, 2, 3, and 4 are integrated and their interrelationships will be studied.

One rootstock, OAR-1, is of special interest since it has been recently selected by Dr. M.N. Westwood and Dr. A.N. Roberts at Oregon State University. Except for vigor and growth habit of 'Gravenstein' apple trees, no information on this rootstock is known. In a large domestic seedling trial, 'Gravenstein' apple trees on OAR-1 rootstock had smaller trunk cross sectional area than trees on other seedling rootstocks, and thus were selected and propagated as a clonal rootstock for 'Starkspur Golden Delicious' apple in these studies.

CHAPTER 2

REVIEW OF THE LITERATURE

Leaf Mineral Nutrition

General Background of Leaf Minerals

Shear et al. (219) stated that plant growth and mineral nutrition deficiency or toxicity symptom expressions are functions of two variables of nutrition: intensity and balance. At any given level of nutritional intensity (total equivalent concentrations of all functional nutrient elements in the leaf) there exists an optimum balance or proportion among these elements at which maximum growth for that intensity level will result. They suggested that the maximum potential growth and yield for any given plant will be obtained only when the proper balance between all of the nutrient elements occur in combination with their optimum intensity. Kenworthy (112) presented a table showing the high, low and average values of several minerals for leaves of various kinds of fruits and found distinct differences between varieties and kinds of fruit. Potassium was the only mineral element which did not show any characteristic differences between varieties or kinds of fruits.

Westwood and Bjornstad (261) compared leaf nutrient concentrations of various *Malus* species grown at the same location and reported that Asiatic apple species tended to have highest K, Ca and Mg, whereas North American species had lowest levels of these elements. However, minor cations (Mn, Fe, Cu, Zn) were highest in European types and lowest in those of North American origin.

Vang-Petersen (247) studied the interactions between Ca, Mg and K in leaves of 'Cox's Orange' apples in a pot experiment by soil and spray applications of different levels of Ca, Mg and K. He found that high application of Ca drastically increased leaf concentrations of Ca and Mg while decreased leaf K suggesting that Ca, Mg and K accumulations in the leaf is a mutual relationship. Ford et al. (74) and Vang-Petersen (245) reported that symptoms of Mg deficiency were more dependent on the ratio between soil available K and Mg than the actual Mg concentration in the leaves. Levitt (125) noted that a very non-specific role of Ca is that of a pH-regulator which under Ca deficiency might be replaced by Mg. Replacement of Mg for Ca in the Ca deficient leaves of 'Cox's Orange' apples was demonstrated by Vang-Petersen (247). Mason (153) indicated that since Mg is in soil competition with K, concentration of K in the plant depends on the K:Mg ratio in the growth media.

Schneider et al. (204) reported that tree spacing did not affect N, Fe, Zn, or Cu concentrations of 'Goldspur Golden Delicious' leaves, but leaves from the widest spaced trees had more P and K than those from the closest spaced trees. This suggested that there was more competition for K and P among the more closely spaced trees.

Seasonal Changes of Leaf Minerals

Cain and Boynton (48) noted that Ca concentrations of 'McIntosh' apple leaves increased but N, K and P decreased as the growing season progressed. Rogers and Batjer (197) confirmed that with Red Delicious apple leaves. A seasonal decline in 'McIntosh' apple leaf K concentration was reported by Reuther and Boynton (190), and Boynton et al.(28) reported a seasonal decline in leaf K and P, but an increase in Ca, particularly at the beginning and again at the end of the season. Himerlrick and Pollard (99) reported that concentrations of N, P, K, B and Cu decreased in leaves of 'McIntosh' apple as the growing season progressed, while concentrations of Ca, Mg, Mn, Fe, Zn, Sr, and Mo increased. They also noted that treatment with 2,2 dimethyl hydrazide (daminozide, SADH) significantly increased foliar Ca concentrations in August, while Fe was decreased.

Rowe (200)showed that seasonal uptake of N, P, and K, in the whole tree, had a similar trend linearly related to the growth of the permanent tree structure in 'Cox' apple trees, while Ca and Mg uptake differed from this with maximum uptake taking place during the period of greatest white root production as found by Head (96). Magnesium concentration has been reported to show the minor fluctuations during the growing season (28,197).

Rootstocks and Scion Leaf Minerals

Tukey et al. (241) observed significant differences in the scion leaf nutrient content depending upon the rootstock, the scion variety and the orchard location. However, these differences were not always consistent. They observed that leaves of 'Jonathan' with various East Malling rootstocks (M1,M2,M7,M13) showed significant differences in N, P, and Mg but not in K or Ca, while leaves of 'Rome Beauty' in combination with the same rootstocks showed significant differences in all nutrients tested including K and Ca. They also reproted (241) significantly higher K in the leaves of 'Rome Beauty' on M1 than on Western Seedling. In addition to the differences among the rootstocks, interstocks and bodystocks had significant influences on scion leaf mineral composition.

Sistrunk and Campbell (222) found higher Ca concentrations in the leaves of 'Winesap', 'Rome' and 'Jonathan' apple cultivars on Hiberna as compared to those on French crab. They also noted that soil applications of lime and foliar sprays of Ca nitrate and Ca acetate resulted in higher Ca accumulation in the leaves of all tested cultivars on Hiberna rootstock but had no effect on the leaves of these cultivars on French crab.

Lockard (139) in a greenhouse experiment, reported lower Ca in the leaves of Red Delicious apples on MM111 rootstock than on MM106 or M 9. The level of K in the scion leaves was lower with M9 than with MM106 rootstocks or with Red Delicious interstock. He also noted that nutrient levels of leaves from rootstocks and three interstocks (Red Delicious, MM106, M9) were similar. Rootstock treatments (MM111, MM106, M9) differentially affected the leaf levels of N and Ca over a four-year period. However, Lockard (139) found no differential effect of rootstocks on the scion leaf Mg concentration as found by Hoblyn (100) and Awad and Kenworthy (8). However, M7 which was considered as the most susceptible to Mg deficiency in other reports (8,100), was not included by Lockard (139).

Whitfield (264) reported significantly higher Ca but lower K and P in the leaves of 'Jonathan' than those of 'Cox's Orange Pippin.' In this report, leaves of trees on M9 rootstock had higher Ca and Mg than those on M7, and trees on M2 showed higher P, Ca and Mg values than those on M16. Whitfield has also reported (264) very low leaf Mg concentration on M7 rootstock. On the other hand, Dzamic et al. (63) did not report any pronounced differences in 'Golden Delicious' leaf mineral content in relation to rootstock (M4,M7,Seedling of *M. sylvestris*) vigour.

Eaton and Robinson (64) used four cultivars of apples as scions in 16 combinations of interstocks, reported higher leaf accumulations of P and Fe of 'Delicious' apples than those in the leaves of 'Golden Delicious', 'McIntosh', or 'Spartan.' However, they concluded that interstock did not influence the scion leaf mineral concentrations.

Bould and Campbell (25) studied three apple rootstocks (MM104, MM111, MM106) infected by four different viruses and reported that scion leaf-N on MM111 was reduced more by the viruses compared to other rootstocks. In the presence of viruses, trees on MM106 had higher leaf-Mg and Ca than on other rootstocks.

Several researchers have found year to year variation in the mineral compositions of apple leaves on the same rootstock (64, 88,111). Kennedy et al. (111) noted that year-to-year differences in nitrogen and phosphorus leaf concentrations were greater than the rootstock differences, whereas significant influences of rootstocks were seen for leaf K, Mg and Ca. Whitfield (264) suggested that fertilizer requirements should be varied according to the rootstock used every year.

Jones (108) showed that xylem sap collected from various apple rootstocks contained different concentrations of minerals suggesting that major genetic variation exists in rootstocks with respect to their ability for uptake and translocation of minerals from the soil.

Fertilizers and Leaf Minerals

Cain and Boynton (48) reported that high levels of nitrogen applications tended to decrease K and P and increase Mg and Ca concentrations in the leaves of 'McIntosh' apples. This result was later confirmed by other researchers on the same variety (26,256). Weeks et al. (256) noted that the decrease in the foliage P concentrations due to high N application was greater for light crop years than for heavy crop years.

Slowik and Swietlik (223) applied ^{15}N-labeled urea as a ground application in a 4% solution, and 8% solution spray to 'Golden Delicious' trees in greenhouse pots in September. In the following February, about 42% and 44% of the applied nitrogen was found in the trees following leaf application of urea in 4% and 8% solutions, respectively, while ground applications result in a 43% recovery of nitrogen fertilizer. So the method of urea application did not appear to make a difference as used in that study.

Vang and Petersen (247) reported that 'Cox's Orange' apple trees low in Ca supply were strongly dependent on Mg supply. Also, during Ca deficiency, application of K aggravated the deficiency. In that report, application of K reduced the Ca concentrations in the leaves and Mg application depressed it further. Rogers and Batjer (197) reported that ten years of phosphorus and potassium fertilizer applications did not significantly change the leaf compositions of these elements. They suggested that the reason could be due to the fact that soil in their experimental orchard was inherently high in these elements.

Effect of Cropping on Leaf Minerals

Cain and Boynton (48) reported that changes in the concentration of each mineral nutrient in the 'McIntosh' leaf as affected by fruit crop were in the same direction as those by increasing ammonium sulfate as N fertilizer source. That was, both an increase in fruit crop and nitrogen fertilizer decreased K and P but increased Ca and Mg concentrations of the leaves. Weeks et al. (256)

noted that the 'McIntosh' leaf N, Ca, and Mg increased as yield increased while K and P decreased.

Fruit Mineral Nutrition

General Background

Most of the studies concerning fruit mineral nutrition are done in relation to the storage disorders such as: bitterpit, cork spot, breakdown, etc. (See "Quality" section). However, there are some studies directly related to fruit nutrition per se.

Faust et al. (70) reported that the concentration gradients of K, Ca, Mg and Mn were highest in skin of 'York Imperial' apples and lowest in the flesh, and intermediate in the core. Concentrations of K, P, B and Cu were higher in calyx half than in the stem half of the apple, whereas Ca concentration was lower. They also suggested that the calyx half of the fruit should be preferentially sampled for determining the lowest Ca concentrations in the fruit.

Rogers and Batjer (198) reported a seasonal decline in 'Winesap' apple fruit concentrations of N, P, K, Ca, B, and Mg but an increase in the content (total amounts) per fruit. Wilkinson and Perring (272) proposed that the final level (i.e., at harvest) of Ca in the fruit is probably determined early during its development. Vang-Petersen (246) stated that it is difficult to establish sufficient concentrations of Ca in the fruit due to the competition between Ca and both K and Mg.

Perring (180) showed that fruit nitrogen could be increased as a result of nitrogen fertilizer and an even greater response resulted from both potassium and nitrogen applications. Fruit trees receiving higher K applications showed higher flesh concentrations. Applications of K supply alone has been reported (247) to decrease 'Cox's Orange' fruit Ca concentrations. But, Mg supply, together with K increased fruit Ca (247).

Translocation of Minerals into the Fruits

Translocation Through Xylem and Phloem of Trees

Batjer and Rogers (14) suggested that the roots and tops of apple trees serve as storage organs for different amounts of certain minerals which are available for transfer and re-utilization. They also noted that N and P particularly are stored in sufficient amount to provide a substantial portion of the yearly requirement of these minerals, rather than requiring annual uptake for elemental needs.

Several researchers have studied the physiology of Ca translocation in tree fruits. Wilkinson (269) proposed that Ca may be translocated to the apple fruit for a short time only at the beginning of the fruit growth. He also stated that Ca may even decrease in the fruit, perhaps being transported back into the trees, but provided no vigorous evidence for his speculation.

The concept of Ca translocation in the plants by ion exchange reaction in the conducting tissue was first proposed by Bell and Biddulph (15), and was later supported by several studies (18, 106, 220). This exchange is not specific and Ca ions can be released for ascent by other divalent cations such as Sr, Mg, Mn and Zn (15, 165, 166, 220). Shear and Faust (220) suggested that the exchange reactions may be a property of lignin of various genotypes of apple seedlings. Water and K can not release Ca from the exchange sites (15,166,167). The association of Ca with lignin (103) and with protein of protoplasmic membranes (231) were reported to be the possible exchange sites. Shear and Faust (220) indicated that the water-soluble Ca in living tissue is held in compartments not readily available for exchange.

It has been reported that most of the Ca is translocated in the xylem (18, 155, 192). However, Biddulph et al. (18) indicated that the cortex of beans may also serve as a channel for ascent of Ca. The concept of Ca translocation through phloem has also been suggested by others (165,167,192,228,239). Stebbins and Dewey (228) suggested that in young apple trees, Ca moved in the phloem, but leaks into the xylem at increasing rates in the younger stem and near the growing apex.

Stebbins et al. (229) found single crytals and clusters of crystals or druses containing Ca in cells adjacent to the vascular tissue near the pedicel in mature apple fruits and in dormant flower buds, stems, petioles, shoot apices, root and callus tissue. They proposed that when the formation of these crystals (presumably co-oxalate) is stimulated by environmental or metabolic conditions, Ca concentration is reduced in the fruit flesh resulting in internal breakdown of fruits.

Soderlund and Hanger (225) grew 'Granny Smith' seedlings in water solution, Ca free solution, and complete solution. Cessation of root formation and typical Ca-deficiency symptoms were more apparent in the solution containing all minerals except Ca than those in the water solution suggesting that the presence of cations in the external media caused much of the root Ca to be leached into the surrounding media. Green and Bukovac (82) reported the mobilization of Ca in the bean roots when the roots were subjected to Ca applications.

Translocation Through the Leaf

It has been suggested that once Ca is deposited in the leaves, it becomes immobile (117,183,193) and can be translocated to other parts of the plant only under special conditions. Other reports show that Ca could be translocated from senescent leaves (72) and from petioles when cations were injected into the midrib of the leaf (165,166,173). It was also mobilized by treating the plant with diethylether (17,38), triiodobenzoic acid (37,113), EDTA (165) citric acid or malic acid (165,167), Hcl (165) or by dehydrating the plant (17). Shear and Faust (220) reported that spraying 'York Imperial' apple seedlings with kinetin, boron and benzyladenine increased Ca movement from roots to the developing leaves. They also noted that application of NO_3^- as nitrogen source increased Ca movement and accumulation of Ca into mature leaves, while NH_4^+

increased Ca movement into new leaves.

Amount of root adsorbed ^{45}Ca deposited in a leaf was reported to be proportional to the transpiration rate of leaves in apples, (228,265). Tromp (240) reported that reduced transpiration reduces xylem movement of water, the principle route of Ca movement to the fruit, while permitting phloem movement of N,K, Mg and P. Mix and Marshner (168) found that under conditions of high transpiration and low soil moisture, some xylem movement of water from bean and pepper fruits may occur which can carry small amounts of Ca. Shear(218) suggested that a proper leaf/fruit ratio must be maintained to prevent an excessive vegetative sink from competing with the fruit for Ca. If leaf/fruit ratio is too high, it tends to increase fruit size, further diluting the Ca that is able to reach the fruit. Shear (218) also noted that severe winter pruning stimulates vegetative growth just at the time when most Ca should be moving into the fruit. On the other hand, Perring and Preston (182) found that late summer shoot pruning increases fruit Ca but decreases fruit K, P, N, and dry matter.

Fruit Weight, Fruit Shape and Yield

Fruit Size and Dry Weight

It has been reported that volume and fresh weight of 'Winesap' apple increased as the season progressed (94,95,198) but both volume and fresh weight curves although still increasing showed a slow down in rate between 150 and 169 days after full bloom.

However, the decline in volume was greater than the decline in fresh weight of the same fruits (94).

Forshey and Elfving (75) reported a positive relationship between fruit number and yield but a negative relationship between fruit size and yield. Westwood et al. (259) found that apple fruits from light cropping trees were larger due to an increased number of cells and in some cases larger cells than from heavy cropping trees. Small fruits had smaller and fewer cells than large ones. Harley (94) noted that the seasonal accumulation for dry weight per fruit of 'Winesap' apple showed total solids accumulation at an increasing rate as the fruit grew in volume. After 97 days from fullbloom there was an acceleration of deposition reaching a maximum rate during the last 19 days before harvest. He also noted that dry matter per 100 grams of fresh cortical tissue did not vary during the growing season. These results were mostly confirmed later by other researchers (21,197,198).

Westwood (257) reported a seasonal decline in the specific gravity of several kinds and varieties of fruits including apples. This was later confirmed in apples (21). Westwood (257) also indicated that small fruits were denser than larger ones.

Barden and Ferree (11) noted that M9, M26, M7A, MM106 and seedling rootstocks did not show any significant differences in net photosynthesis, dark respiration, specific leaf weight, and transpiration of 'Delicious' apple leaves.

Rogers and Thompson (199) reported that higher applications of nitrogen fertilizer did not affect fruit size. But Fisher et al.

(73) noted that mid summer sprays of urea increased fruit size. Vang-Petersen (247) observed that lack of Ca supply decreased yield, number of fruits and fruit size in 'Cox's orange' apple. Fruit size increased by application of Ca or of K alone to the growth media or by foliar spray of Mg and water supplied K combined (247).

Fruit Shape or Length-to-Diameter Ratio (L/D)

General Background. Westwood (257) found that the length-to-diameter ratio (L/D) of various cultivars of apples and pears declined as the growing season progressed. This decline of L/D in apples was rapid between 30 and 70 days after full bloom. After which it leveled off for the rest of the season. Westwood and Blaney (262) found that the length of center-bloom fruit of Red and 'Golden Delicious' apples was longer than side-bloom suggesting that the center-bloom (or King bloom) fruit has a position comparable to that of a primary shoot arising from a terminal bud. A side-bloom fruit is analogous to a shoot arising from a lateral bud.

Westwood and Bjornstad (260) demonstrated that pre-bloom applications of GA_3 increased the L/D ratio of 'Rome Beauty' apples. After fullbloom treatments of GA_{4+7} and cytokinins alone or in combination were later reported to increase the L/D ratio of 'Delicious' apples, (273). Cytokinins caused 'Delicious' apple fruits to have well developed calyx lobes, but GA_{4+7} did not appreciably affect the development of the calyx lobes (273). Miller (164) could increase weight and L/D ratio of 'Delicious' apples at both a cool mountain location and at a lower warm elevation by application of 25 ppm Promalin, which is a mixture of GA_3 and kinetin.

Shaw (214) reported that cool temperatures during the cell division and early developmental period cause 'Delicious' apple fruits to be more elongated, whereas warm temperatures induce round flattened fruits.

Effect of Rootstock on the Fruit Shape. Westwood and Blaney (262) found that trees of Red Delicious apple produced more elongated fruits on vigorous rootstocks (Seedling, M16, M1, M2). They noted that relative fruit length varied with rootstock in the same way as shoot growth, suggesting that the rootstock somehow affects the hormonal balances (GA's and cytokinins) which affect fruit development in particular planes.

Yield

Seeley et al. (208) reported that spur-type 'Delicious' strain ('Miller spur') apple produced more fruit per tree on all tested rootstock (seedling, MM106, M7, MM111, MM104, M26) than the regular type strain ('Red Prince') on the same rootstocks. While trees of non-spur 'Golden Delicious' produced as much or more yield per tree than the spur type strain 'Goldspur' on the same rootstocks even in the early years. Schneider et al. (204) reported that yield (both MT/ha and Kg/tree) of 'Goldspur' and 'Redspur' were highest on MM106 and were lowest on seedling rootstocks in a high density orchard. They suggested that small size of trees on MM106 could be related to their higher production. Schneider et al. (204) also reported no significant differences in the total yield per tree as a result of spacing. However, yield per hectare was significantly decreased when the in-row spacings of trees were increased from 1.8m to 3.0m or from 3.0m to 4.3m. Westwood et al. (263) in a long term study of yield (18 years) in a high density orchard reported higher yield per hectare with 1.22m in-row spacing than 1.83m or 2.44m spacings. In that report, trees of 'Golden Delicious' and 'Starking' apples were grown on M9 rootstock and yield of 'Golden Delicious' was higher than 'Starking' apples.

Heinicke (97) proposed that the yield efficiency of apple trees on M9 rootstock in comparison to more vigorous rootstocks could be due to the ability of better light utilization by small trees. However, yield efficiency varied with rootstocks even with similar ultimate tree size (71,186,187). It has been proposed (6,7) that reserved photosyntate of various tree parts particularly roots, may be utilized for fruit set in the dwarfing rootstocks to induce higher yield efficiency.

Hansen (72) noted that high levels of potassium application increased the tendency of apple trees toward biennial bearing by increasing yield in the 'on year.' He found higher N and Ca but lower K (due to the high content of Ca in the fruit) in the leaves of cropping trees, while total N, P, Ca and Mg were greater in trees without fruits. Other researchers attributed differences in fruit responses between years on alternate bearing trees to differences in carry over reserves or differences in the level of competition between vegetative growth and fruit (152). Rogers and Thompson (199) did not find a meaningful influence of higher N fertilizer on the yield of 'York Imperial' apples.

Ethylene

Ethylene Biosynthesis

Physiological and biochemical studies of ethylene biosynthesis and mode of action have been reviewed periodically (1,39,129,130, 185,283). Meigh et al. (159) reported that fruits such as apples and tomatoes which are able to produce ethylene, produce no ethylene under the homogenized to a cell-free state condition. There have been several research projects attemtping to obtain physiological cell-free production of ethylene (2,81,121,146,237). However, Matoo and Lieberman (158) suggested that the natural ethylene forming system is highly structured and very delicately poised in the intact cells. Various older models had been advised for the system of ethylene production such as: conversion of bound linolenate to active linolenate in the presence of oxygen and finally to ethylene in the presence of a Cu enzyme (136,137); conversion of methionine (134); conversion of methional or -keto-y-methylthiobutyrate (133,284), and conversion of propanol to ethylene in the presence of metal catalysts or free radical generating systems (132).

Methionine is presently believed to be the common precursor of ethylene in higher plants (283) including apple fruits (45). There is now good evidence that S-adenosylmethionine (SadoMet), formed from methionine and ATP, is an intermediate between methionine and ethylene (41). Adams and Yang (4) have illustrated that 5'-methylthioadenosine and its hydrolysis product, 5-methylthioribose are derived from the CH_3S group of methionine during its conversion to ethylene. The same researcher later reported (3) that 1-aminocyclopropane-1-carboxylic acid (ACC) is an intermediate in the conversion of methionine to ethylene and suggested the following pathway for ethylene biosynthesis in apple tissue: Methionine → S-adenosylmethionine → ACC → ethylene.

Ethylene and Ripening

Kidd and West (116) used the term 'Climacteric' for the onset of respiration in 'Bramley's seedling' apples for the first time and Biale (16) later classified the edible fruits as climacteric and non-climacteric on the basis of type of response obtained with ethylene applications and described the physiological difference between these two groups. Hansen (89) suggested three progressive stages of ripening: a) preclimacteric stage following harvest, b) an initiation period required for stimulation or organization of the ripening mechanism, followed by, c) the actual chemical changes involved in the fruit acquiring an edible condition.

During the preclimacteric period, there are conditions associated with resistance to ripening. Kidd and West (116) suggest that ripening of fruits does not occur until the endogenous ethylene reaches a stimulatory level and found that the concentration of ethylene required for stimulation decreased with age. Burg (39) found ethylene at physiologically active concentrations prior to the initiation of ripening in various fruits. He suggests that due to the wide spread occurrence of ethylene in all different plant parts, there could be a universal ethylene producing mechanism in plants. It was denoted that because fruit ripening can be stimulated at the immature stages by application of ethylene, ethylene might gradually accumulate in the fruit tissue to reach a stimulatory level, and that threshold levels of ethylene for stimulation of ripening are associated with the synthesis of particular ripening enzymes and proteins (89). Lieberman (130) proposed the enzymatic system in the process of ripening can be unique in that it includes a well-controlled free radical generating system and its activation may be regulated by ethylene utilization and by other hormones, particularly auxin.

Ethylene has been considered the triggering ripening agent or the fruit ripening hormone (42) that sets in motion reactions in the ripening process (147). However, the lack of correlation between ethylene production and ripening of grape berry (55) and also suppression of ripening by auxin despite increased ethylene production (76,77,249) have raised questions about the triggering actions of ethylene and the possibility of other hormonal involvement in ripening (130). In grape berry ABA is proposed to be the triggering agent (55).

Lieberman et al. (131) found that in apple tissue, ethylene production was suppressed by treatment with cytokinins in both early climacteric rise and the post climacteric tissue. In their experiment, auxin suppressed ethylene in early climacteric but stimulated it in post climacteric slices, and GA_3 had minor effect on ethylene production at any stage; abscisic acid stimulated ethylene production in the early climacteric rise in tissue slices. Premature ethylene production and ripening of 'Bartlett' pears, which is associated with cool temperatures, was counteracted by treating the fruit on the tree with GA_3 (255).

Measurement of Internal Ethylene.

Ethylene evolution was found to increase within 30 minutes of wounding in pea, tomato, corn and cucumber as well as a number of woody plants (105,202). Walsh and Kender (254) suggested that the rapid wound response complicates the study of endogenous ethylene in plants, as it is difficult to harvest and sample within such a short time period. Other researchers have indicated that use of excised plant materials could lead to large sample variability of endogenous ethylene (196).

Several methods have been used to measure internal ethylene (22,35,42,58,143,227). However, the most common method is to withdraw internal gas samples with a hypodermic syringe while the fruit is momentarily submerged in water (42,141,142). Sfakiotakis and Dilley (209) presented a method for internal ethylene sampling from Red Delicious apples. In this method, the internal ethylene was collected from the fruit calyx end by insertion of a 22 gauge 3.8 cm hypodermic needle fitted with two serum stoppers. They noted that the results of this method were similar to those in fruits measured by submerging in the water immediately after harvest. Walsh (253) estimated the changes in ethylene concentration of attached, horticulturally mature 'Lodi', 'McIntosh' and 'Golden Delicious' apples by measuring the ethylene present in a tube sealed over the calyx, and observed a direct proportion between ethylene measured by this method and the internal ethylene concentration of the same fruit. The internal ethylene in this research (253) was measured as described by Sfakiotakis and Dilley (209).

Internal Ethylene in Wood and Fruits.

Walsh and Kender (254) detected seasonal patterns of ethylene evolution in the two year wood of spur and non-spur strains of 'Delicious' and 'McIntosh' apples and found high concentrations of ethylene early in the season which subsequently declined. It has been reported that the length of time to abscission after increase in the fruit internal ethylene was negatively correlated with daily mean temperature in 'McIntosh' while no such relation was found in 'Golden Delicious' apples (253). Both the respiratory CO_2 climacteric (224) and high levels of endogenous ethylene (23) have been correlated with fruit abscission. Both of these processes are proposed to occur over a wide time span among individual fruits on the same tree (189,209,253).

Sfakiotakis and Dilley (209) hastened the increase in internal ethylene of fruits by one month by isolating Red Delicious fruit from leaves by girdling plus defoliation of spur leaves. By this experiment, they (209) confirmed the concept that fruits receive a ripening inhibitor from the leaves. This concept was previously hypothesized by several researchers (40,43,44,79,145). Burg (40) and Burg and Burg (43) by girdling avocados, mangos and other fruits suggested that the inhibitor is translocated from the leaves to fruits via the phloem. Other researchers suggested that this inhibitor either inhibits ethylene production or increases the threshold value at which ethylene becomes physiologically active for ripening (145).

Farhoomand et al. (68) observed considerable variations in the ethylene production of 'HiEarly Red Delicious' apples both between and within branches of a tree. They noted a linear trend between ethylene production of fruits in primary branches from base to apex of the tree. Fruits near the end of the primary leaders and the top of the central leaders had lower ethylene production than fruits within the canopy. They also found a delayed ethylene production in the fruits below terminal shoots suggesting that ripening regulators in shoot tissue interact to delay ethylene synthesis.

It has been observed that small fruits and those with greenish appearance had much greater ethylene than well developed fruits suggesting that green or immature appearing fruits could be physiologically more mature in other aspects than fruits which would be considered mature or ripe based on appearance (color) alone (68).

Applications of Ethylene

It has been reported that chemicals which release ethylene or increase ethylene evolution can decrease shoot growth, crop load, firmness and abscission of mature fruits and can increase flowering of young trees and the red color of 'McIntosh' apples (47,65,110). Paiva and Robitaille (179) reported that neither ethylene releasing chemicals nor silver ion or cobalt had any influence on bud break of 'Golden Delicious' apples when applied to shoots at two dates during the rest period. Edgerton and Blanpied (65) found that both ethylene evolution and respiration rate of 'McIntosh' apples receiving pre-harvest applications of Alar at 2000 ppm were lower than those treated with 250 ppm ethephon at harvest time. Pre-harvest sprays of ethephon also shortened the interval between harvest and the beginning of the climacteric rise.

It was reported that summer pruning, shoot bending, and ethephon applications all increased concentrations of ethylene in apple wood (118,122,194,196) and stimulated flowering.

Fruit Quality

Definitions

Based on the definition of the U.S. standards for Grades of Apples (243), "Mature means that the apples have reached the stage of development which will insure the proper completion of the ripening process." Some researchers have stated that maturation is physiologically complete when endogenous ethylene exceeds the threshold value required to initiate ripening (59,84). "Physiological maturity is the attainment, after full development of the stage just prior to the start of ripening" while "horticultural maturity is the stage at which growth or development is optimum for a particular use," (258). For a simple definition, "mature" means ready to harvest, but "ripe" means ready to eat or process (258). Excessive boron in fruit has been reported to be a cause for earlier maturation (29,33).

Date of Harvest

Haller and Magness (85) found minimum amounts of disorders due to immaturity or over-maturity when 'Golden Delicious' apple fruits were harvested at 145 to 150 days after full bloom whereas, 'Golden Delicious' fruit quality for fresh market and storage was obtained when harvested 150 to 160 days from full bloom. Haller and Smith (86) reported best dessert quality for

'Golden Delicious' apples when they were harvested 142 to 152 days from full bloom. That report was in close agreement with Bittner et al. (19). Bartram (12) recommended 'Golden Delicious' apple fruits be harvested 135 to 150 days after full bloom and above 12% soluble solids for optimum storage quality.

Soluble Solids

Haller and Magness (85) found that soluble solids of 'Golden Delicious' apples varied greatly depending upon moisture supply and climatic conditions and concluded that days from full bloom was the most reliable harvest index. Olsen et al. (178) reported slight increase in the soluble solids content of 'Golden Delicious' apples after storage. Delayed bloom of 'Starking Delicious' apples as a result of modified tree temperature in cages had less soluble solids than fruits from earlier or normal bloom dates (177). Sullivan (234) reported that fruit from early pollinated blossoms had more soluble solids than the normal time pollinated fruits.

Fruits from an in-row spacing of 2.44m in a hedgerow system of apples had significantly higher soluble solids than fruits from the 1.22m spacing in the same system (263).

Color

Magness et al. (144) noted that higher concentrations of leaf nitrogen in'Rome Beauty'apples led to more green (less red) color on the fruit surface. Other reporters (27) suggested that in addition to high leaf nitrogen, orchard factors such as cultivation, heavy pruning and heavy mulching were associated with poorer color development of apple fruits, but no effect of potassium fertilizer or fruit color was observed. A proper balance between the color and yield can be maintained by various combinations of soil management and fertilizer applications (27). The timing, and therefore effectiveness of N application is an important factor in the development of fruit color so that application of nitrogen in the fall may result in brighter (less green) apples due to more nitrogen leaching in winter (13). Weeks et al. (256) found that increasing the potassium fertilizer could offset the depressing effect of high nitrogen on fruit color. Fisher et al. (73) found that early spring foliar applications of urea resulted in better fruit color in 'McIntosh' apples as compared to those with soil applications. While mid-summer spray of urea induced poorer color suggesting that factors of timing and dosage of urea must be taken into account for better fruit color before applications.

Miller (163) found that ethephon disappeared from ethephon treated 'McIntosh' fruit, without color development after the fruit was harvested, and concluded that ethephon treated apples must be on the tree in an active state of metabolism in order to obtain either a color response or fruit softening.

Olsen and Martin (177) found that green color of 'Golden Delicious' fruit was associated with warm night temperatures before harvest rather than with length of growing season.

Firmness

High nitrogen fruit was reported to be softer after storage (29). However, Ystaas (285) did not find differences of firmness due to nitrogen supply in 'Moltke' pears. Sharples (213) noted a positive correlation between fruit P and firmness in 'Cox's orange pippin' apples.

Titratable Acidity

Most of the acids in apple fruit exist in the vacuole of the pulp cells and a large part of the organic acids are translocated from leaves or roots to the fruits (242). Perring (180) suggested that the titratable acidity is used up more rapidly than the sugars during storage and a time is reached when the apple fruit tastes overly sweet.

Acidity of 'Golden Delicious' fruit has been reported to decrease as days from full bloom and as duration of storage increases (178). Hammett et al. (87) noted a highly positive correlation between the ratio of soluble solids to percent acid content of 'Golden Delicious' fruits and days from full bloom.

Wilkinson (267) reported that apple fruit K concentration was directly proportional to its titratable acidity. However, no other fruit mineral element has been correlated with titratable acidity.

Overall Quality

Southwick (226) found that 'McIntosh' fruit from trees grown under a medium soil applied nitrogen condition were softer, lower in red color and respired at a higher rate than similar fruits at lower nitrogen level. In that report, applications of 2, 4, 5-TP hastened the rate of ripening, red color, and respiration of fruits from the medium nitrogen trees to a greater degree than a similar treatment on low nitrogen trees. The medium nitrogen plus 2,4,5-TP fruits had almost reached their climacteric at harvest.

Westwood et al. (263) reported that mechanical shearing of tops and sides of apple trees on M9 rootstock in a hedgerow system resulted in adequate fruit size, color and quality. They also reported that size, firmness, soluble solids and general quality of these fruits were satisfactory for fresh market and processing. However, Hennerty (98) reported that multi-row and bed systems of high density orchards of apple trees on M9 rootstock had unsatisfactory fruit size and quality as the trees ages under conditions in Ireland.

Research on the effect of rootstocks on the eating quality of apples is limited. Sharples (211) reported that the rate of respiration in 'Cox's orange pippin' apples on M26 at harvest indicated a more advanced maturity of these fruits compared to those on M9, MM106, and M7. Fruits on M9 rootstock also appeared to be slightly in advance of fruit from MM106 and M7.

Nichol and Mack (172) found that mealiness, color, and acidity of 'McIntosh' apples were positively correlated with flesh Mn concentrations, while negatively correlated with Fe and Cu.

Bitterpit

Fruit minerals and bitterpit: Tomkins (238) suggested the need for more mineral analysis of fruit so that a direct comparison with storage characteristics might be made. Perring (180) concluded that an apple of good quality must have high concentrations of all mineral elements, correctly balanced one to another and also to the organic constituents.

Since the relationship between mineral nutrition balance and bitterpit was earlier proposed by Garman and Mathis (78), many studies have been done on the relationship between Ca, Mg, N, K and bitterpit (5,174,211,212,213,236,266,271). De Long (56,57) was one of the first to find that sound apples had higher concentrations of Ca than pitted fruits from the same source. It has been found that high fruit N (29,126), high K (213) and high Mg (218) all increase the incidence of bitterpit in apple fruit. Contradicting others, Brown (36) noted that high concentrations of K in apple fruit reduced bitterpit. He also noted that high fruit P reduced bitterpit. High levels of Mn have also been reported to reduce bitterpit (172).

It has been suggested that leaf Ca concentration does not necessarily indicate the functional Ca status of the tree nor the Ca content of fruit (52,221). However, negative correlations between leaf or fruit Ca level and the incidence of bitterpit, cork spot and related disorders have been reported (69,215).

Shear (216) suggested the use of leaf N/Ca ratios as an indication of nutritional status of apple trees and incidence of bitterpit and cork spot in the fruit. K and Mg ratios to Ca have often been correlated with apple fruit disorders (218). Sharples (213) found that high fruit K/Ca or Mg/Ca ratios were associated with increased wastage of apples due to bitterpit in storage. He also noted a high negative correlation between August leaf Ca concentration and bitterpit.

Terblanche et al. (236) observed more bitterpit in 1978 than in 1977, although the fruit Ca levels showed the opposite pattern suggesting that higher Ca concentrations are required in years of high bitterpit incidence to prevent bitterpit. They did not find any relationship between fruit size and bitterpit.

Rootstock and Bitterpit: Quinn (188) found less bitterpit in the apples from trees on more dwarfing rootstocks than those grown on 'Northern Spy' stock. Jackson (104) confirmed Quinn's report by noting less incidence of bitterpit in fruit from trees on 'Northern Spy' stock than those grown on the more vigorous M12 and M16 rootstocks. Van Zyl et al. (248) noted less incidence of bitterpit in 'Golden Delicious' on M7, MM106 and MM109 than on Merton 793 which in turn had less bitterpit than those on MM104. Sharples (211) observed less bitterpit in 'Cox's

Orange Pippin' apples from trees on M9 than those on M7, M26 and MM106 grown in a low Ca soil orchard. However, no effect of these rootstocks was observed in a high Ca soil orchard. O'Loughlin and Jotic (175) found that 'Cox's Orange' apples developed significantly higher incidence of bitterpit on M16 and MM115 rootstocks than on MM104, MM114, MM112 and MM106. Fruits from trees on M16 also had more pit than those on MM109, 'Northern Spy' and M7 in the first year of their experiment. However, no effect of rootstock was observed in the following year. Their (175) observations agree with the view of Sharples (211) that differences among rootstocks can be overridden by other factors such as sufficient supply of orchard Ca which controls general susceptibility to bitterpit in 'Golden Delicious' apples was not affected by eight rootstocks (M2, M7, Merton 793, MM104, MM105, MM106, MM109, MM111). They concluded that incidence of bitterpit was not affected by vigour of rootstocks.

Fertilizer Spraying and Bitterpit: Sharples (211) noted that increases in the rates of nitrogen fertilizer induced less incidence of bitterpit in 'Cox's Orange Pippins.' There have been some attempts to use boron as well as other elements to decrease bitterpit (149). Marsh and Shive (148) showed that boron could help to maintain more plant Ca in soluble form. Other researchers could reduce corkspot of 'York Imperial' apples by increasing B when Ca was in marginal supply, although increasing fruit boron did not affect incidence of corkspot (221). Dixon, Sagar and Shorrocks (61) could increase fruit Ca levels with foliar sprays of boron. The increase in fruit Ca, however, was not associated with a reduction in storage bitterpit.

Breakdown and Rotting

Fruit Minerals and Breakdown: Wilkinson and Fidler (270) described that the low temperature breakdown often has a moist appearance and originates in the outer cortex, whereas senescent breakdown usually begins just below the hypodermis, often at the calyx end, and the texture is mealy. Other researchers have noted that these two types of breakdown do not always conform to their classical descriptions and visual descriptions alone can be misleading (107). Symptoms of 'Spartan' apple breakdown as described by Lidster et al. (128) were not similar to that in 'Jonathan' as reported by Wills and Scott (277), and 'Delicious' as described by Bramlage and Shipway (32). Several researchers have reported apple fruit breakdown in storage due to the low Ca content in the fruit (128,156,180,181,213).

Montgomery and Wilkinson (170) reported that high concentrations of P, K and Mg in the fruit caused less low temperature breakdown. Confirming this report, Perring (180) suggested that in addition to high P, K, and Mg, high content of sugar in the apple fruit was essential to prevent low temperature breakdown. Lidster et al. (128) noted that K, B, fruit size, soluble solids, and tree vigor were positively correlated to 'Spartan' breakdown. Some reports have indicated that low fruit P content is associated with low temperature breakdown (124,170), and Johnson and Yogaratman(107) reduced severity of low temperature breakdown by foliar (i.e. fruit) spray of monopotassium dihydrogen phosphate.

Sharples (213) noted that high fruit K/Ca or Mg/Ca ratios were associated with storage rotting. Excessive boron in the fruit has also been reported to increase water core and 'Jonathan' spot at harvest, and high incidences of decay and breakdown after storage (29,33).

Rootstocks and Breakdown: Keijer and Dijksterhuis (109) did not see any effect of rootstocks (M1 and M4) on scaled incidence of 'Golden Delicious' apples. However susceptibility of 'Bramley's' seedlings to storage breakdown varied with different rootstocks (115,205,252). O'Loughlin and Jotic (176) noted that 'Lalla Red Delicious' apples had significantly more internal breakdown on M16 than those on M1,M13,M25,MM107, and MM110. Wallace (252) found less incidence of low temperature breakdown in 'Bramley's seedling' on M4 rootstock than M9. That report was confirmed by Schubert (205) in the cultivar 'Erwin Baur' on the same rootstocks. Wallace (252) also noted that 'Bramley's seedling' fruit grown on trees on M1 were more susceptible to breakdown and core flush than those from trees on M5. Kidd and West (115) reported that 'Bramley's seedling' and 'Lane's Prince Albert' apples from trees on M2 were more susceptible to low temperature breakdown and rotting, respectively, than apples from trees on M1 or M9.

O'Loughlin and Jotic (175) reported that in a high breakdown year, 'Cox's Orange Pippin' from trees on M16, MM115 and MM104 had significantly more internal breakdown than similar fruits on MM106, MM112 and MM114, while no significant effect of rootstocks were observed in the following year. Sharples (211) noted that M9, MM106, M26 and M7 rootstocks did not show significant differences in storage rot and breakdown of 'Cox's Orange Pippin' from trees on M16, MM115 and MM104 had significantly more internal breakdown than similar fruits on MM106, MM112 and MM114 while no significant effect on rootstocks was observed in the following year. Sharples (211) noted that M9, MM106, M26 and M7 rootstocks did not show significant differences in storage rot and breakdown of 'Cox's Orange Pippin' apples grown in a low Ca soil orchard.

Effect of Fertilizer and Sprays on Breakdown: Wilkinson (268) reported that application of potassium fertilizer in the orchard increased the incidence of core flush in apples, and Montgomery and Wilkinson (170) reported that nitrogen and potash treatments increased *Gloeosporium* rot in storage, while none of these incidences were seen in similar studies by Perring (180). It has been reported that application of nitrogen fertilizer increased the susceptibility of the apple fruit to breakdown, while phosphorus application reduced this disorder (212,268,278). Sharples (211) reported that 'Worcester' apples treated with high levels of Mg fertilizer showed less shrivel during air storage at 35°F than those with low Mg applied. He also noted, that storage breakdown and *Gloeosporium* rot incidences were lower in fruits grown in the irrigated plots, particularly where

N had been applied in spring rather than in fall. In this report, increasing the rate of nitrogen fertilizer decreased core flush in apples stored at 37°F.

Several researchers have found that applied Ca reduces storage breakdown of apples (10,20,107,154,157,176,217). Lidster (127) noted that both pre-harvest spray and post harvest dipping of 'Spartan' apples at different times and in different concentrations of $CaCl_2$ increased the Ca content of fruits and decreased the incidence of storage internal breakdown. But, most post-harvest dip of fruits was more effective than pre-harvest spray in control of breakdown. Combinations of pre-harvest sprays and post-harvest dips resulted in even more reduction in the breakdown than either of the treatments by themselves.

<u>Other Factors Involved in Breakdown:</u> Perring (180) reported that senescent breakdown was associated with prolonged storage and was worsened by late picking date. Knee and Bubb (120) reported that late harvested 'Bramley Seedling' apples had more breakdown in storage than early harvested ones. However, date of picking and storage temperature had little effect on the final incidence of superficial scald or stem browning (120).

Various researchers have found that increase in the volatiles of apples in storage resulted in internal breakdown of fruits (274,275,276,278,279), other researchers have noted that volatiles produced by apples in the cold storage were increased with applications of nitrogen fertilizer (278).

Theory of Dwarfing Mechanism

Hypotheses Which Have Been Proposed

Sachs (201) and Gersani et al. (80) proposed that the auxin synthesized in leaves and shoots is the messenger from these organs to the roots. The auxin moves basipetally through the cambial cells and phloem to the roots. Leopold and Kriedemann (123) reported that some of the auxin is degraded in the bark by IAA oxidase, peroxidase, and phenols and perhaps other compounds. The amounts of degrading compounds vary among species and cultivars of plants; for example, dwarf rootstocks have thick barks with more starch but low levels of auxin (140).

Lockard and Schneider (140) suggested that the amount of auxin transported from the shoot to the roots will control the extent of root growth which in turn will control the amount of cytokinin synthesis by the root. Cytokinin is transported from the roots to the top of tree through the xylem and controls auxin synthesis in the shoots. Therefore, genetic characteristics of both scion and rootstock would determine the final growth of a tree. Both interstock and rootstock can control growth through the flow of hormonal messages; however, applications of neither cytokinin to the roots nor auxins to the tops could change the trend of growth in dwarf or non-dwarf systems (140).

Both direct (83,162) and indirect (207,250) influences of auxin in dwarfing of apple trees have been reported. However, callus cultures deprived from both dwarfing (M9) and vigorous

(M13) apple rootstocks achieved maximum growth at the same concentration of NAA and kinetin and required both growth regulators for growth. But the cultures of M13 displayed a higher growth rate than those of M9 at the optimum concentrations of growth regulators (160).

Martin and Stahly (151) found less growth promoting activity and more growth inhibiting activity in the bark of a dwarf compared to a vigorous rootstock. Similarly, Yadava and Dayton (281) found progressively lower levels of an ABA-like inhibitor in extracts of scions on M9 M7, M1 and M16. Ibrahim and Dana (102) reported that extracted exudate from M9 rootstock could not expand the apple leaf discs in a growing media. In the same report, exudate of three rootstocks (M1, M25, M9) was used to conduct a bioassay on two dwarf cultivars and exudate of M1 caused highest growth of pea stems while that of M9 caused least growth suggesting the presence of a GA-like compound in the exudate of M1 rootstock. Because of the lower GA-like activity in the root xylem exudate from the dwarfing rootstock (M9) than from the vigorous rootstock (M1), the dwarfing response could be due to a lower production or more rapid metabolism of GA's (102). Robitaille and Carlson (195) found higher ABA-like activity in the dwarfing ('Jonathan'/M8 interstock/Alnarp-2) than vigorous trees ('Jonathan'/seedling) at full bloom, and remained higher until after the onset of summer dormancy. They (195) also noted higher GA-like activity in the dwarfing rootstock at the tight flower cluster stage. ABA was able to inhibit shoot elongation and this inhibition was reduced by applications of GA_3 (195).

CHAPTER 3

EFFECTS OF ROOTSTOCKS, K, AND N FERTILIZERS IN A HIGH DENSITY ORCHARD OF 'STARKSPUR GOLDEN DELICIOUS' APPLES ON SEASONAL LEAF MINERAL ELEMENTS AND YIELD[1]

Esmaeil Fallahi[2], D.G. Richardson[3], M.H. Chaplin[4] and M.N. Westwood[5]

Department of Horticulture, Oregon State University, Corvallis, OR 97331

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Abstract. Leaf mineral composition of 'Starkspur Golden Delicious' apple (*Malus domestica* Borkh.) on six rootstocks: Seedling, Malling (M)1, M7, M26, Malling Merton (MM)106, OAR-1 in a high density orchard with two levels of K (K_2SO_4) and two levels of N (urea) soil fertilization were studied in August 1980 and over

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[2] Graduate Research Assistant, partially supported by Ferdowsi University, Mashhad, Iran.

[3] Associate Professor, to whom reprint requests are to be made.

[4] Former professor, now Associate Dean, School of Agriculture, Pennsylvania State University.

[5] Professor, now National Technical Advisor for Clonal Germplasm.

the growing season of 1981. Foliar N, P, and K concentrations decreased seasonally while Mg and Ca increased in scion leaves on all rootstocks in the 1981 growing season. A higher demand for K and P was observed in fruit tissue as fruit cropping increased in some rootstocks leading to less leaf concentrations of these elements. Scion leaves on OAR-1 had significantly lower Ca than on M7, MM106 and M1 and lower Mg than on M26. Those on MM106 had the highest levels of Ca in both years. OAR-1 had higher B in the scion leaves compared to all other rootstocks. Scion leaves on M26 had significantly higher Mg than those on M1, MM106 and OAR-1. Leaves on M7 had more Cu than other rootstocks in both years. Greater soil applications of K significantly decreased Ca and Mg concentrations while higher N significantly increased leaf N and Mg but decreased K and P.

Introduction

The influence of rootstocks on scion leaf mineral concentrations has been reported for cherry (1), prunes (6), pears (5,8, 22), and apples (7,12,15,19,21). While seasonal trends of mineral elements in 'McIntosh' and 'Delicious' apple leaves have been reported (3,9,16) no report has been found in the seasonal trends of minerals in the leaves of spur-type strains of apple as influenced by rootstocks or fertilizers. Since the use of dwarfing rootstocks has increased the trend toward high density plantings, the nature of the plant-to-plant competition at these close spacings necessitates an analysis of the interactions between fertilizer treatments and rootstock efficiencies under higher density conditions. The aim of this research is to study the interactions of six rootstocks ranging from vigorous to dwarfing, in combination with low and high levels of K and N fertilizer applications on the seasonal changes of macro (N,P,K,Ca,Mg) and microelements (Fe,Cu,B) in the scion leaf tissue of 'Starkspur Golden Delicious' apples. One of the rootstocks in this research is OAR-1 which is a new rootstock and the observations on its influence on the mineral composition of the scion leaf were unknown.

Materials and Methods

The experimental orchard was established in 1972 at Oregon State University's Lewis Brown Research Farm near Corvallis, Oregon. The eight year old high density orchard was planted 0.61m apart within rows and 2.43 between rows. 'Starkspur Golden Delicious' apple was grafted on Seedling, M1, MM106, M7, OAR-1 and M26 rootstocks. Oregon Apple Rootstock (OAR) has been selected at Oregon State University. In a large domestic seedling trial, a 'Gravenstein' tree on OAR-1 had smaller trunk cross sectional area than trees on other seedling rootstocks, and thus was selected and propagated as a clonal rootstock for 'Starkspur Golden Delicious' apples in this study. Since planting, two different levels of potassium (K_2SO_4) and two levels of nitrogen (urea) fertilizers hve been applied to this orchard in late March of every year. The amounts of these fertilizers applied were based on the previous August leaf analysis for each year. From 1975 through 1981, zero and 68 g of actual K/4-tree unit area (256 kg/ha K_2SO_4) and in 1975, 1976, 1979, and 1980, 34 and 68 g of actual N/4-tree unit (126 kg/ha and 252 Kg/ha of urea) were applied as the low and high levels of potassium and nitrogen fertilizers respectively. But in each spring of 1977 and 1978, zero and 34 g of actual N/4-tree unit and in 1981 zero and 68 g of actual N/4-tree unit were applied.

The experimental design for 1980 was a randomized block split-split plot design with six blocks, six rootstocks as main (whole) plots, two levels of K as split (sub) plots and two levels of N as split-split (sub-sub) plots with four trees each per treatment. In 1981, the K treatment was eliminated as no major effect of K application was found in 1980, and statistical evaluation was reduced to a randomized block split plot design with six blocks, six rootstocks, as main (whole) plots and two levels of N as split (sub) plots with four trees each per treatment.

A summer pruning was done during August 1980 and 1981 by hand shearing of sides and tops to maintain the height at 2.4 m. Chemical thinning of fruits was done by dinitro-o-cresol (DNOC) followed by a hand thinning if needed to regulate biennial bearing and to adjust the yield for rootstock studies.

Areas around the tree hedgerows were annually sprayed with herbicide N-(phosphonomethyl) glycine (glyphosate). The orchard soil is Chehalis silty clay loam and the trees were irrigated by drip irriation.

Leaves were sampled August 27, 1980 and on July 27, August 27 and September 27, 1981. At each leaf sampling date, a composite sample of 40 leaves per 4-tree plot unit (10 leaves per tree) was taken from all sides of hedgerows from the mid-shoot area of current season's growth. Leaf samples were washed with a solution of 0.05% EDTA and 0.05% Alconox detergent and rinsed with distilled water. Washed leaf samples were dried to a constant weight in a forced air oven at 70°C and ground to pass a 40-mesh screen. These ground samples were stored in air tight plastic bags and redried before weighing for analysis.

Nitrogen was analyzed by an automated Kjeldahl technique (17) and K, P, Ca, Mg, Fe, Cu, and B by spark emission spectroscopy (4).

Analysis of variance was computed for the designs described earlier and separations of rootstock means was calculated based on Duncan's Multiple Range Test at 5% and significant or nonsignificant differences between low and high levels of each fertilizer were determined by F test at 5% and 1%.

Results and Discussion

General Trends: Results of leaf mineral analysis are presented in Figures 3.1 to 3.14. In general, concentrations of N decreased from 2.07 (percent dry weight) to 2.0%, K decreased from 1.40% to 0.97% and Cu decreased from 6.6 ppm (dry weight) to 5.9 ppm, while Ca increased from 1.44% to 2.17%, Mg increased from 0.30% to 0.34%, and B increased from 37.8 ppm to 41.0 ppm between July and September 1981 (Figs. 3.1-3.14). These trends are generally similar to the report by Rogers and Batjer (16) in 'Delicious' apple leaves.

Effect of Cropping: Comparison of August leaf mineral concentrations of trees on each given rootstock in 1980 and 1981 showed some variations from year to year. Although year to year variations have been reported in the leaves of other cultivars (7,11,12), the cause of these variations from the standpoint of physiology of mineral translocation is not yet clear, as many cumulative factors interact to change the physiology of the tree. However, this variation is partially due to the fruit cropping differences from year to year (Table 3.1).

Leaves of trees on M26 had 5% lower levels of K and 5% lower P in August 1980 than in August 1981 (Figs. 3.3-3.6) whereas, fruit concentrations of these elements with the same rootstock were higher in August 1980 than August 1981 (Appendix Tables B.1 and B.2). As trees on M26 had 39.3 MT/ha higher yield in 1980 (Table 3.1), it is possible that higher levels of K and P are demanded by the fruits of heavy cropping trees. Thus less amounts of these minerals reach to the leaf as a result of weaker leaf-fruit competition. Alternatively, smaller individual fruit size in 1980 (Appendix Table B.3) may have meant less mineral dilution by accumulationg carbohydrates.

Rootstock Effect: Leaves from trees on M26 rootstock had significantly higher (at least 7%) concentration of N than those from Seedling, M1 and OAR_1 in 1980. However, no significant effect of rootstock on scion leaf N concentration was found in 1981 (Figs. 3.1-3.2). Rootstock M26 induced relatively lower P in scion leaves while OAR-1 caused the highest leaf P in both 1980 and 1981 as compared to other rootstocks (Figs. 3.5-3.6).

Although leaves from trees on OAR-1 had the lowest level of Ca in August 1980 and during the growing season of 1981 (Figs. 3.7-3.8), fruits on this rootstock had relatively lower Ca in 1980 and higher Ca in 1981 as compared to other rootstocks (Appendix Tables B.1 and B.2). Also, leaves from MM106 had always the highest concentrations of leaf Ca (Figs. 3.7-3.8) while this was not always the case in fruits (Appendix Tables B.1 and B.2). This supports other studies (18) that leaf analysis poorly indicates fruit Ca status ($-0.09 \leq r \leq 0.26$ in all rootstocks). Scion leaves on M26 had the highest concentrations of Mg in August 1980 and at all sampling dates for 1981 (Figs. 3.9-3.10).

Fruits on M26 had very low incidence (about 2.5%) of bitterpit in 1980 but relatively high levels (about 12%) in 1981 (Chapter 6, Table 6.5). Therefore, one cannot predict the incidence of this disorder just by the high levels of leaf Mg although this implication has been suggested in the fruit tissue (10). Unlike a previous report on the leaves of 'Cox's Orange Pippin' and 'Jonathan' apples (21), we did not particularly find lower leaf Mg concentration as a result of M7 rootstock influence, perhaps because difrerent groups of rootstocks were used in our research. No significant effect of rootstock was found in the Fe concentrations of the scion leaves (Figs. 3.11-3.12).

Scion leaves on M7 stock showed the highest concentration of Cu in both years. This high level of leaf Cu corresponded to high levels of fruit Cu (r = 0.37). Leaves on OAR-1 had relatively (at least 5 ppm B) higher concentrations of B than all other rootstocks in 1980 and significantly (at least 7 ppm B) higher in 1981 (Figs. 3.13 and 3.14).

Effect of Fertilizers: Two different levels of soil applied potassium exhibited no significant differences in concentrations of N, P, K, Fe, Cu or B in the leaves (Figs. 3.1, 3.3, 3.5, 3.11, 3.13). This is due to the cross feeding and perhaps root grafting between trees from plots receiving zero potassium and those with high potassium application as a result of close spacing. The lower level of potassium fertilizer resulted in a significant increase in Ca (5% increase) and Mg (7% increase) in 1980 (Figs. 3.7 and

3.9). Both Ca and Mg compete with K in the plant (13, 20). Lower applications of potassium reduces K:Mg and K:Ca ratios in the site of absorption, leading to a higher accumulation of Mg and Ca in the leaves.

Compared to the lower N treatment, the higher soil N treatment induced lower concentrations of leaf K, P, Ca and B but higher concentrations of N and Mg in August 1980 and at all sampling dates in 1981 (Figs. 3.1, 3.9, 3.13, 3.14). The differences in mineral concentrations as a result of low and high N application were statistically significant in most cases. This agrees in part with Cain and Boynton (3) but contrasts with Bould and Campbell (2) on other cultivars of apples. When urea is applied to the soil as N source, it is hydrolyzed to NH_4^+ and CO_2 by the enzyme urease, and NH_4^+ is strongly absorbed to negatively charged clay minerals due to its cationic properties. Therefore, higher applications of urea have led to a stronger competition between NH_4^+ and Ca^{++} and K^+ on the site of absorption resulting in lower Ca and K accumulation and their translocation to the leaves. Higher (about 11%) accumulation of foliar Mg associated with higher applications of urea in our research contrasts with Mulder's report (14) on potatoes as he found lower Mg as a reult of higher NH_4^+ application. The relationship between NH_4^+ and Mg uptake has not been clearly investigated in fruit trees and the exact mechanism of their antagonism or synergism is not clear. However, higher Mg accumulations as a result of higher urea applications could originate from the lower absorption and uptake of Ca which is considered to be a competitive cation for Mg (20).

Correlation between scion leaf elements in all rootstocks in both years (August samplings) showed negative r-values for N vs. K, N vs. P, K vs. Mg, P vs. Mg, and Mg vs. B, although the latter 3 r -values were less than -0.60 which were significant at $p > 0.05$. Positive r-values for K vs. P, B and P vs. Ca, Fe, Cu, and B, and Ca vs. B, and Cu vs. Fe, B, were observed with K vs. P, K vs. B, and P vs. B having significant "r" values ($r > 0.60$) at $P > 0.05$ in all rootstocks.

As a general conclusion, leaf analysis alone seems to be insufficient for determination of fruit mineral status particularly fruit Ca. Both rootstock and crop load can alter mineral concentrations of scion leaf. Based on results of this research, rootstock OAR-1 can be recommended for 'Starkspur Golden Delicious' apple in the areas with B and P deficiency problem as this rootstock is able to accumulate higher levels of these elements in the leaf tissue. While M26 could be desirable to solve the Mg deficiency problem. However, the influence of these rootstocks on other scion cultivars and soil conditions should be further investigated.

Figure 3.1. N concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by **(1%).

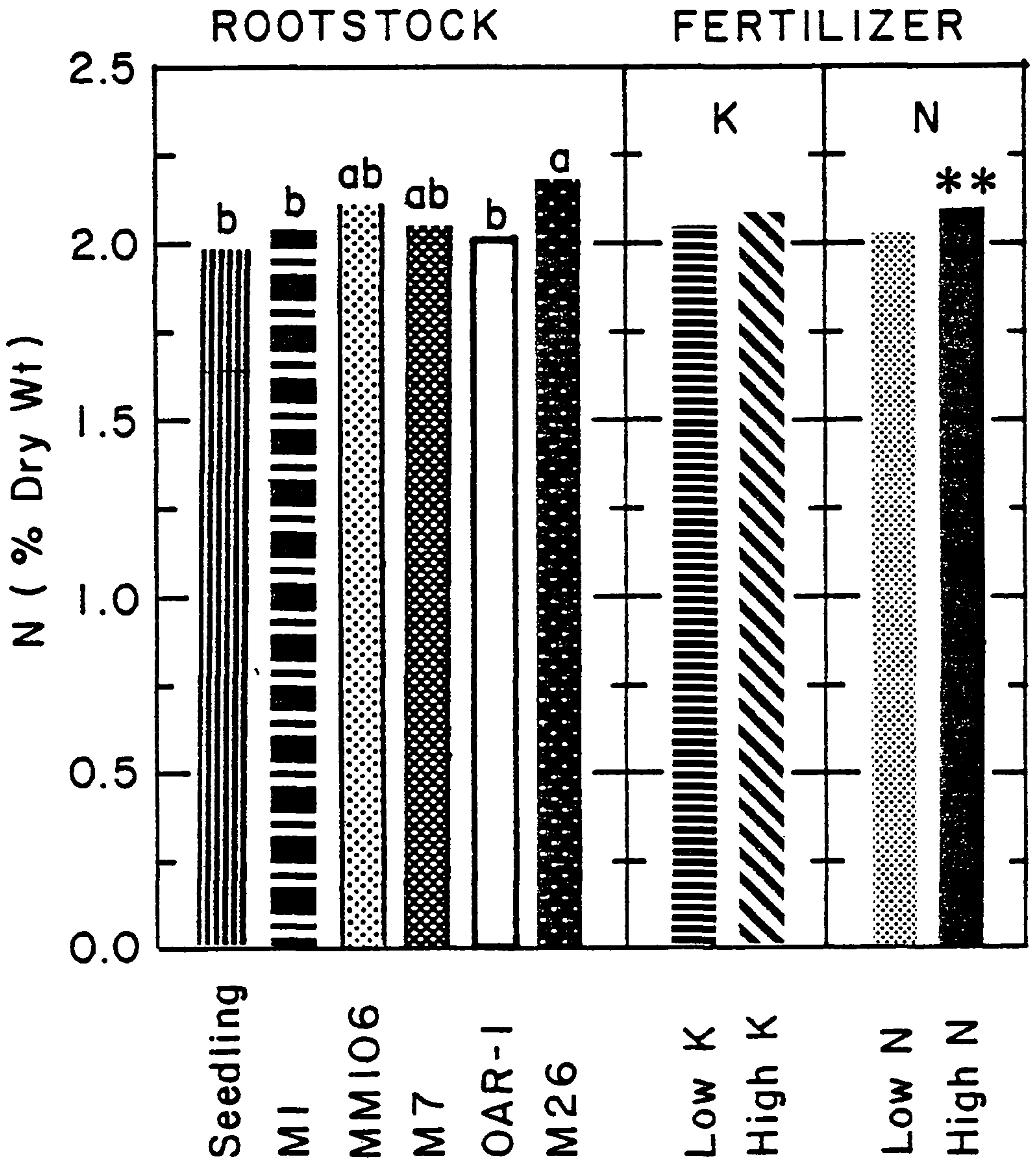
ROOTSTOCK
FERTILIZER
K
N
N (% Dry Wt)
2.5
2.0
1.5
1.0
0.5
0.0
b
b
ab
ab
b
a
**
Seedling
MI
MM106
M7
OAR-1
M26
Low K
High K
Low N
High N

Figure 3.1

Figure 3.2. N concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range tests, 5% level. Low levels of K or N are significantly different from high levels within dates if shown by *(5%) or by ** (1%).

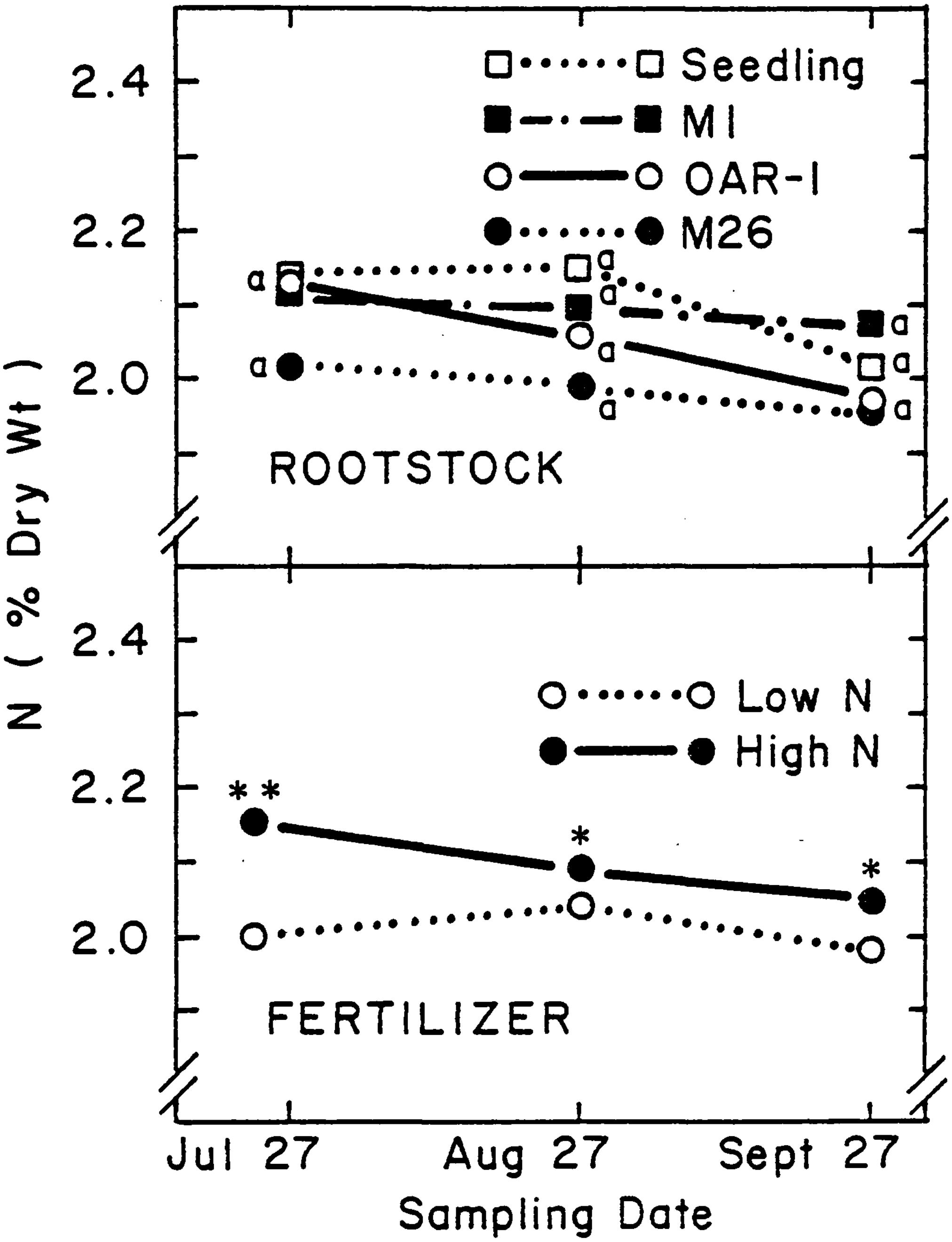
N (% Dry Wt)
2.4
2.2
2.0
Seedling
M1
OAR-1
M26
a
ROOTSTOCK
2.4
2.2
2.0
Low N
High N
**
*
*
FERTILIZER
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.2

Figure 3.3. K concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by ** (1%).

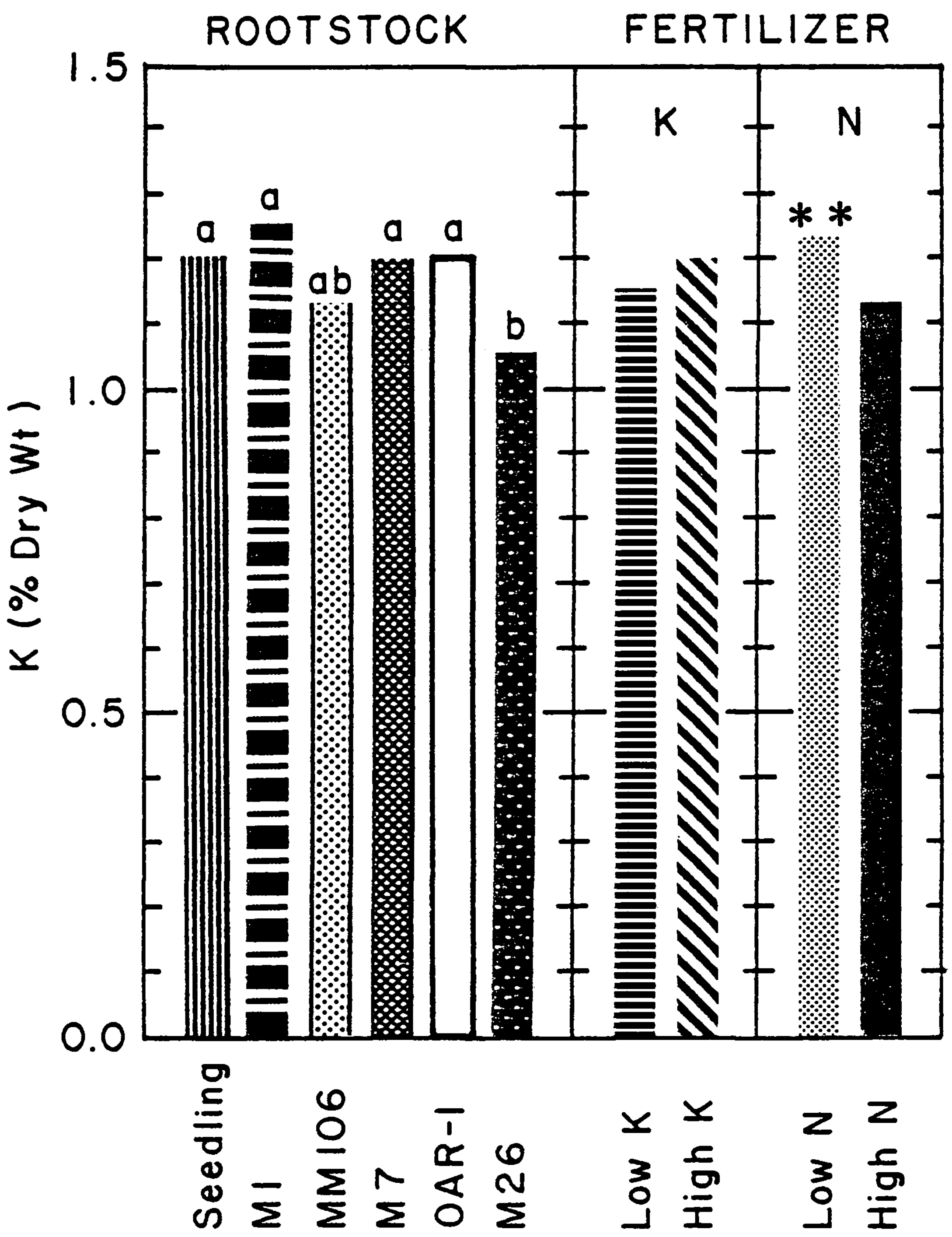
ROOTSTOCK
FERTILIZER
K
N
K (% Dry Wt)
1.5
1.0
0.5
0.0
a
a
ab
a
a
b
**
Seedling
MI
MM106
M7
OAR-I
M26
Low K
High K
Low N
High N

Figure 3.3

Figure 3.4. K concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range tests, 5% level. Low levels of K or N are significantly different from high levels within dates if shown by *(5%) or by ** (1%).

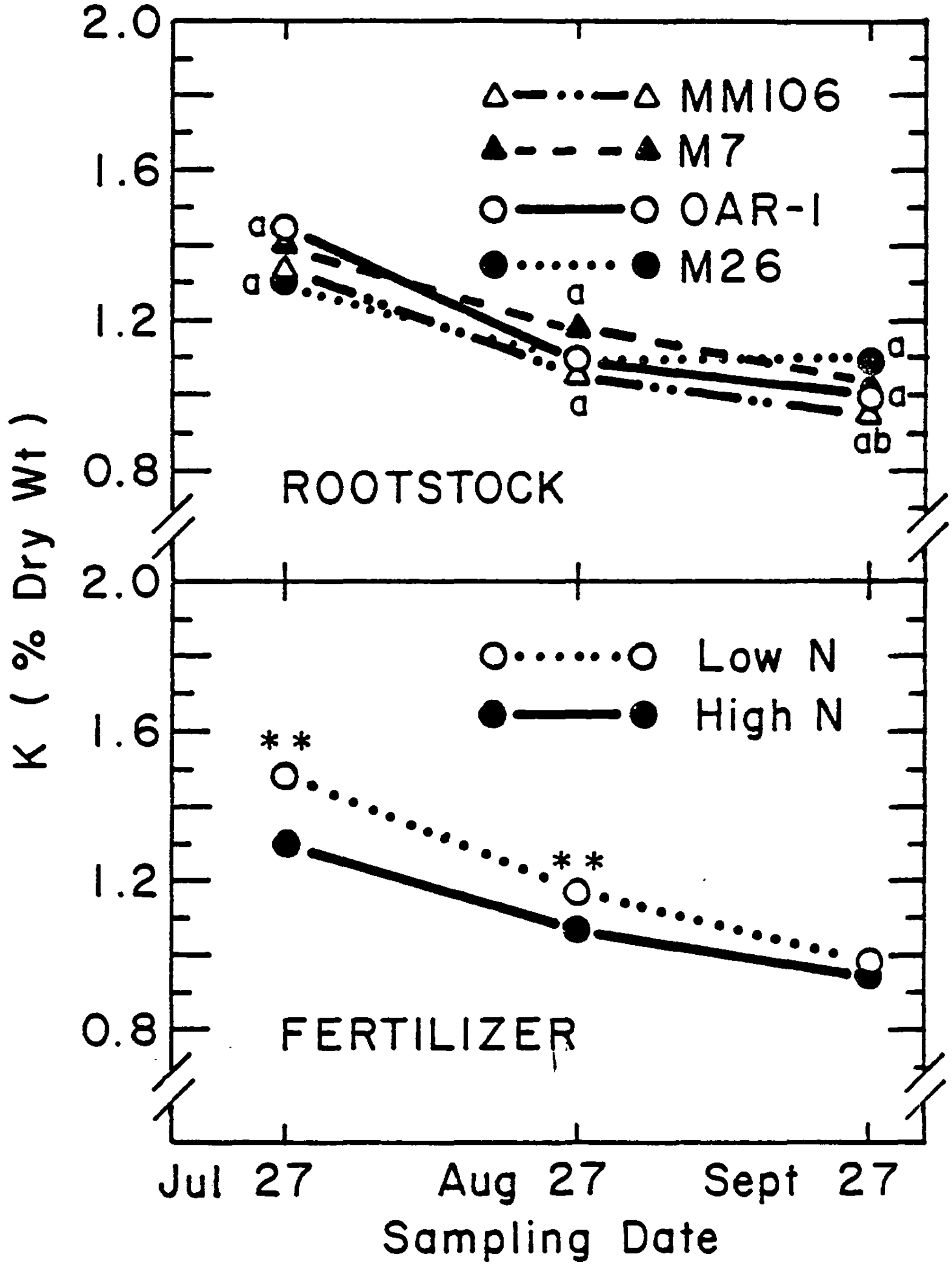
2.0
1.6
1.2
0.8
MM106
M7
OAR-1
M26
a
a
a
a
a
a
ab
ROOTSTOCK
K (% Dry Wt)
2.0
1.6
1.2
0.8
Low N
High N
* *
* *
FERTILIZER
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.4

Figure 3.5. P concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by (1%).

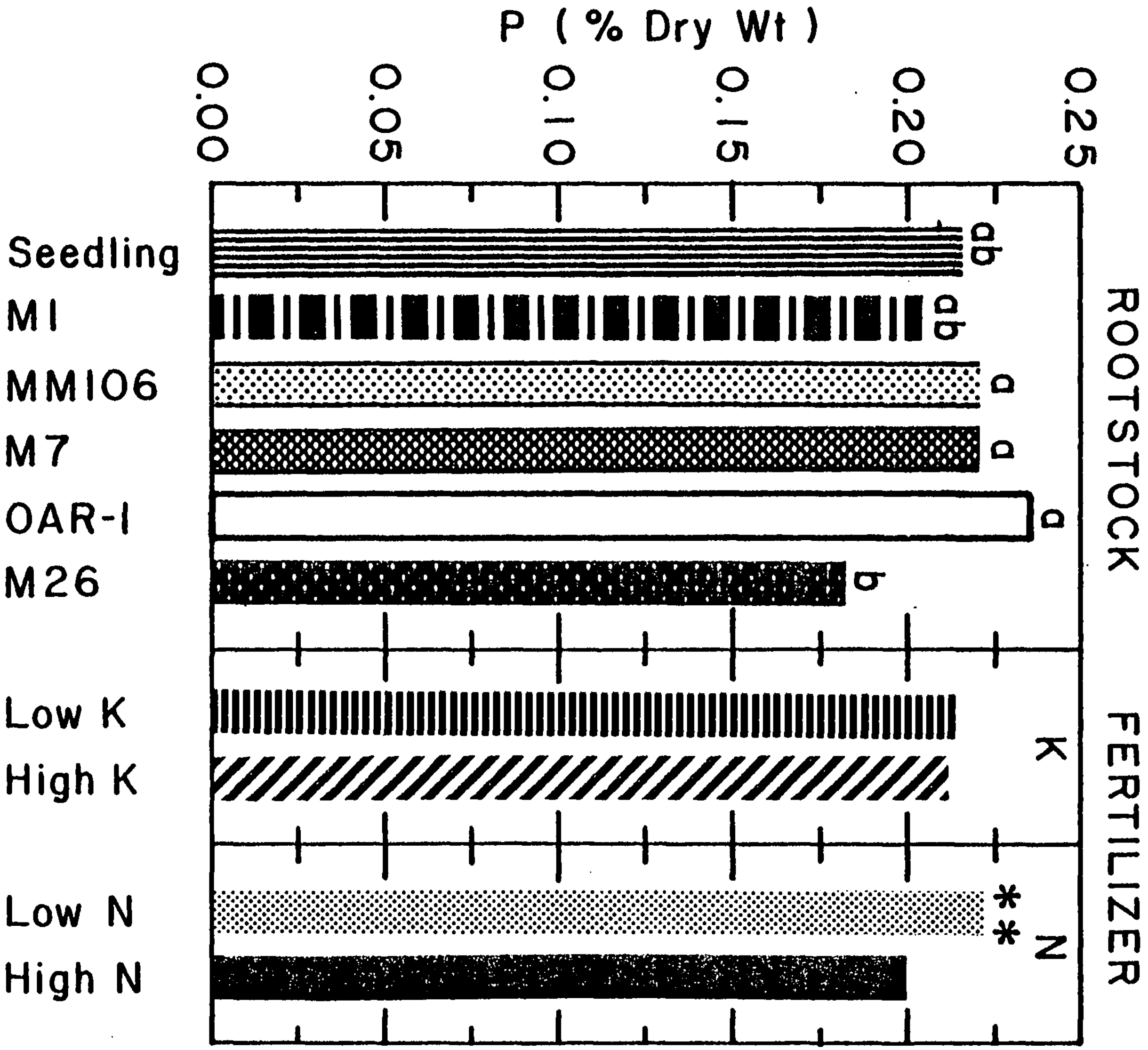
P (% Dry Wt)
0.00
0.05
0.10
0.15
0.20
0.25
ROOTSTOCK
FERTILIZER
K
N
Seedling
M1
MM106
M7
OAR-1
M26
Low K
High K
Low N
High N
ab
ab
a
a
a
b
**

Figure 3.5

Figure 3.6. P concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range tests, 5% level. Low levels of K or N are significantly different from high levels within dates if shown by *(5%) or by ** (1%).

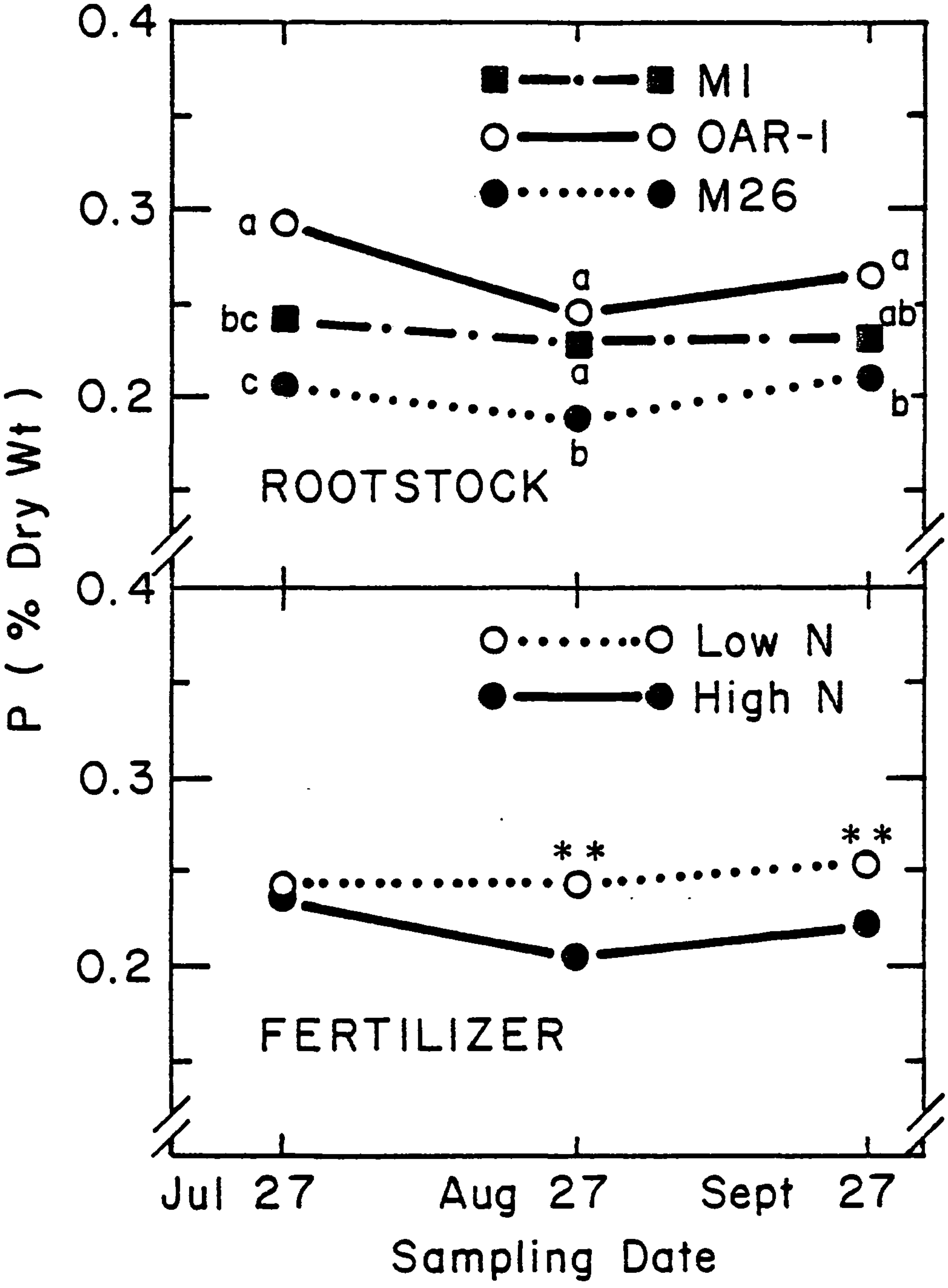
0.4
0.3
0.2
0.4
0.3
0.2
P (% Dry Wt)
M1
OAR-1
M26
a
a
a
bc
a
ab
c
b
b
ROOTSTOCK
Low N
High N
* *
* *
FERTILIZER
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.6

Figure 3.7. Ca concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by **(1%).

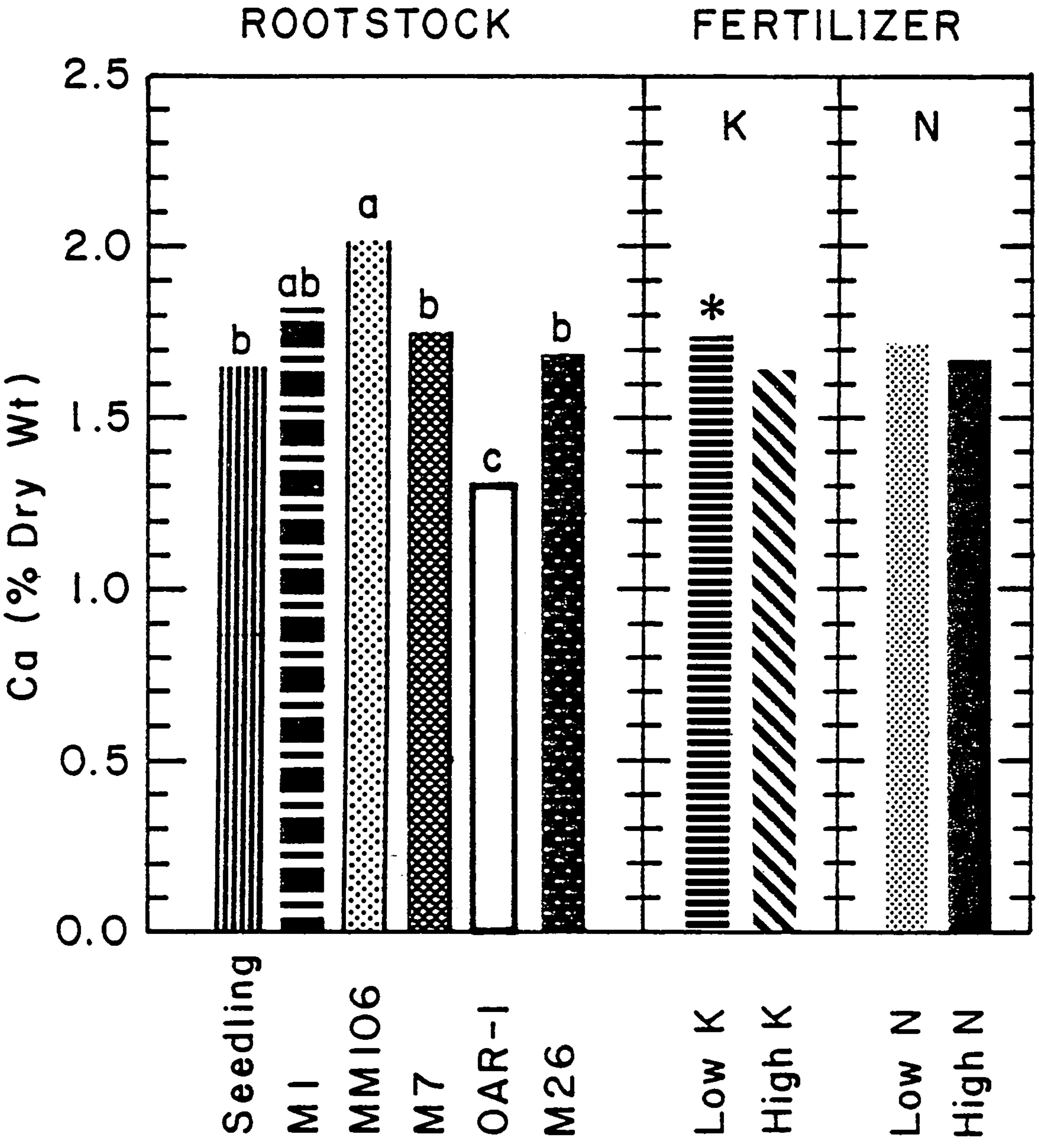
ROOTSTOCK
FERTILIZER
K
N
Ca (% Dry Wt)
2.5
2.0
1.5
1.0
0.5
0.0
a
ab
b
b
b
c
*
Seedling
M1
MM106
M7
OAR-1
M26
Low K
High K
Low N
High N

Figure 3.7

Figure 3.8. Ca concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range tests, 5% level. Low levels of K or N are significantly different from high levels within dates if shown by *(5%) or by ** (1%).

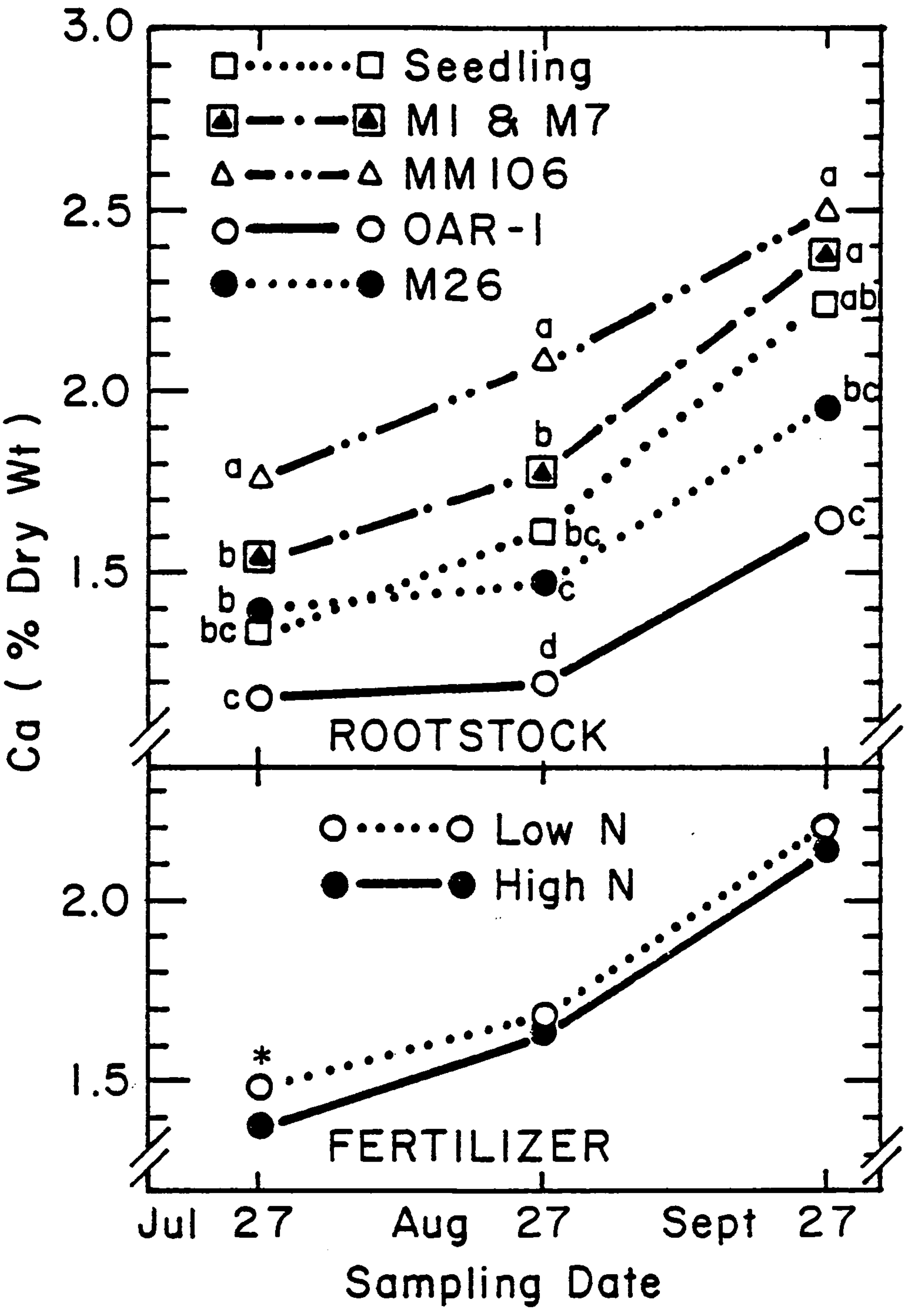
3.0
2.5
2.0
1.5
Ca (% Dry Wt)
Seedling
M1 & M7
MM106
OAR-1
M26
a
b
b
bc
c
a
b
bc
c
d
a
a
ab
bc
c
ROOTSTOCK
Low N
High N
2.0
1.5
*
FERTILIZER
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.8

Figure 3.9. Mg concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by **(1%).

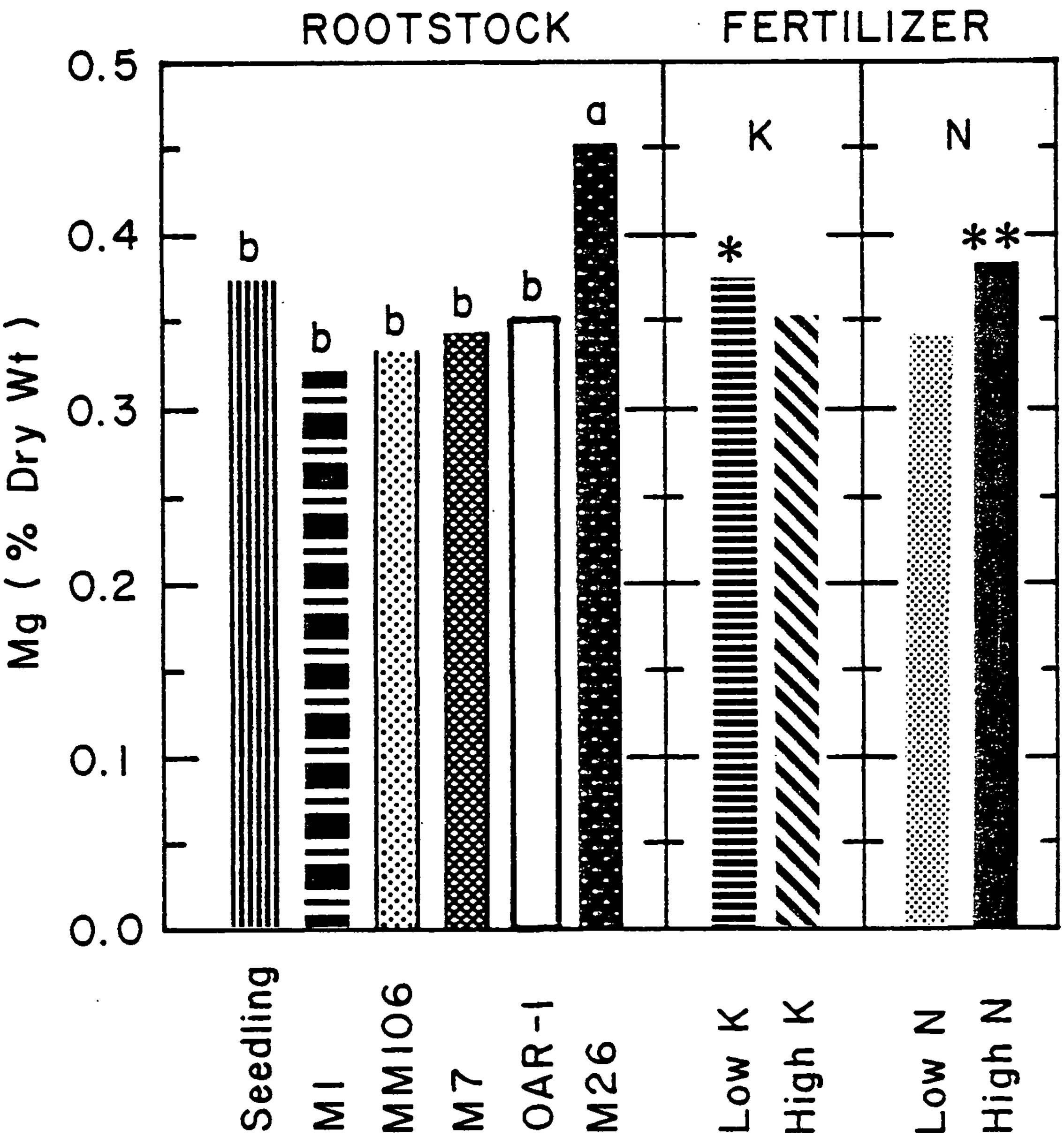
ROOTSTOCK
FERTILIZER
K
N
Mg (% Dry Wt)
0.0
0.1
0.2
0.3
0.4
0.5
b
b
b
b
b
a
*
**
Seedling
MI
MM106
M7
OAR-1
M26
Low K
High K
Low N
High N

Figure 3.9

Figure 3.10. Mg concentration (% dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range tests, 5% level. Low levels of K or N are significantly different from high levels within dates if shown by *(5%) or by ** (1%).

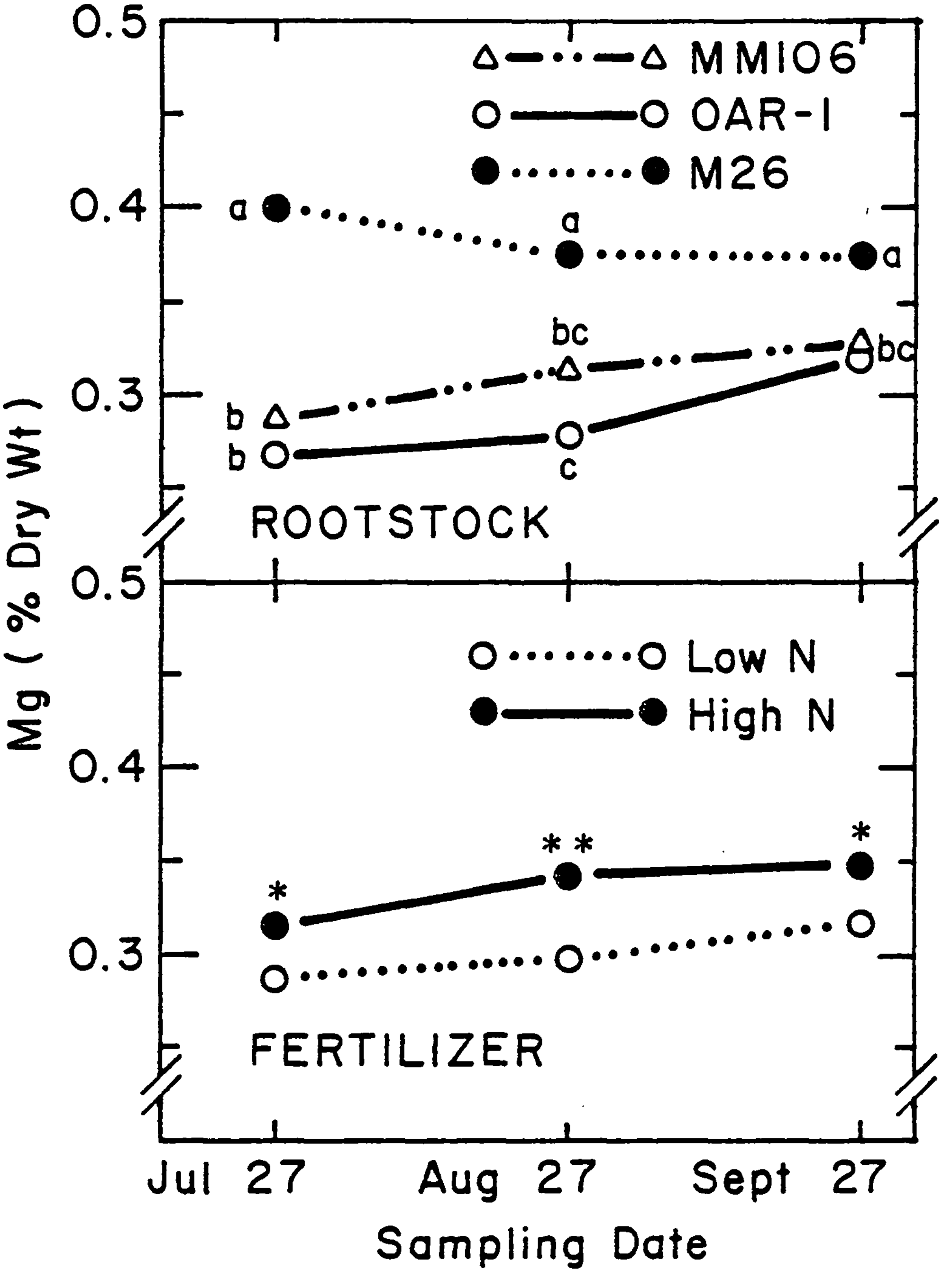
Mg (% Dry Wt)
0.5
0.4
0.3
MM106
OAR-1
M26
a
a
a
bc
bc
b
b
c
ROOTSTOCK
0.5
0.4
0.3
Low N
High N
*
* *
*
FERTILIZER
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.10

Figure 3.11. Fe and Cu concentrations (PPm dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level.

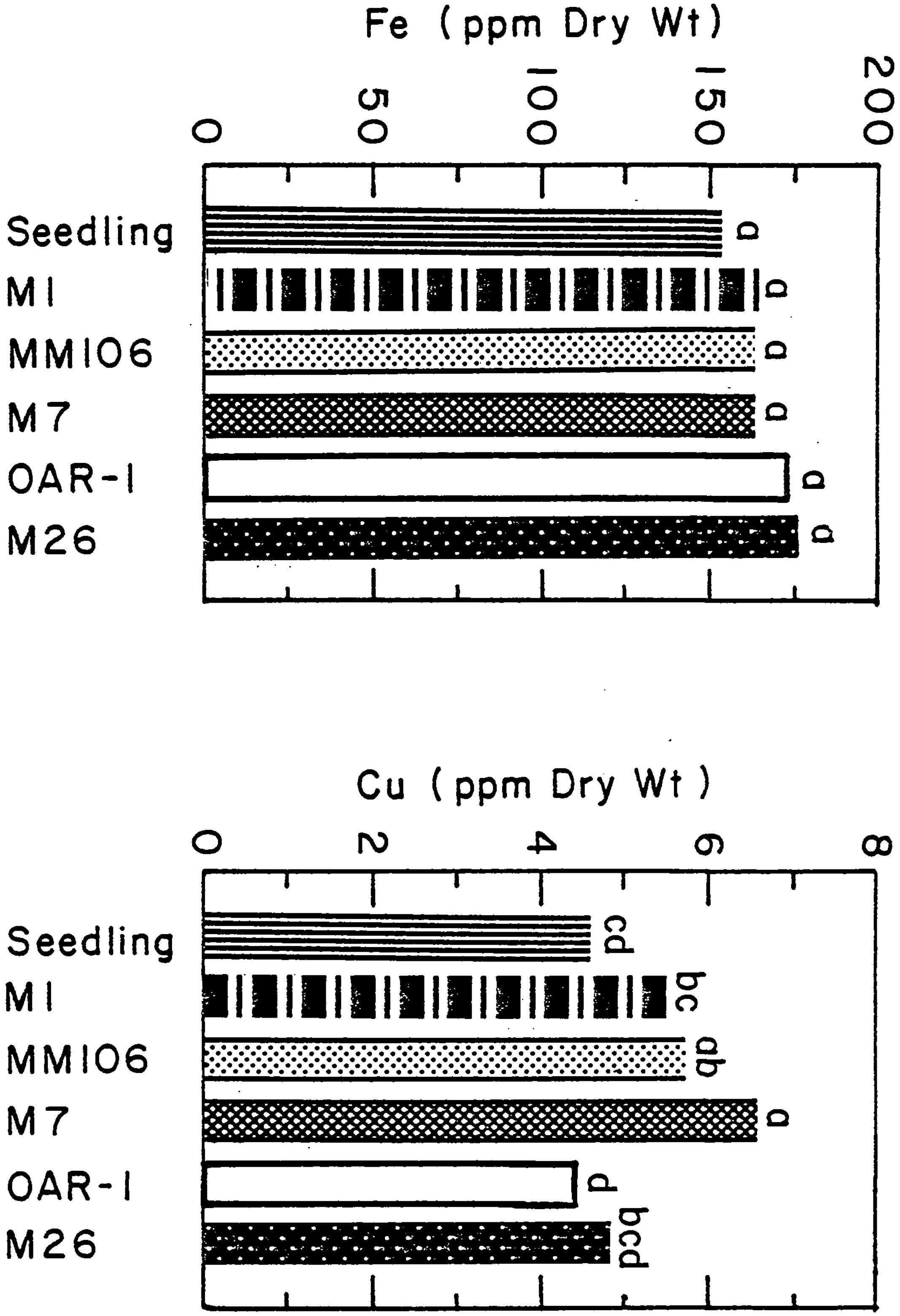
Fe (ppm Dry Wt)
0
50
100
150
200
Seedling
M1
MM106
M7
OAR-1
M26
a
a
a
a
a
a
Cu (ppm Dry Wt)
0
2
4
6
8
Seedling
M1
MM106
M7
OAR-1
M26
cd
bc
ab
a
d
bcd

Figure 3.11

Figure 3.12. Fe and Cu concentrations (PPm dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

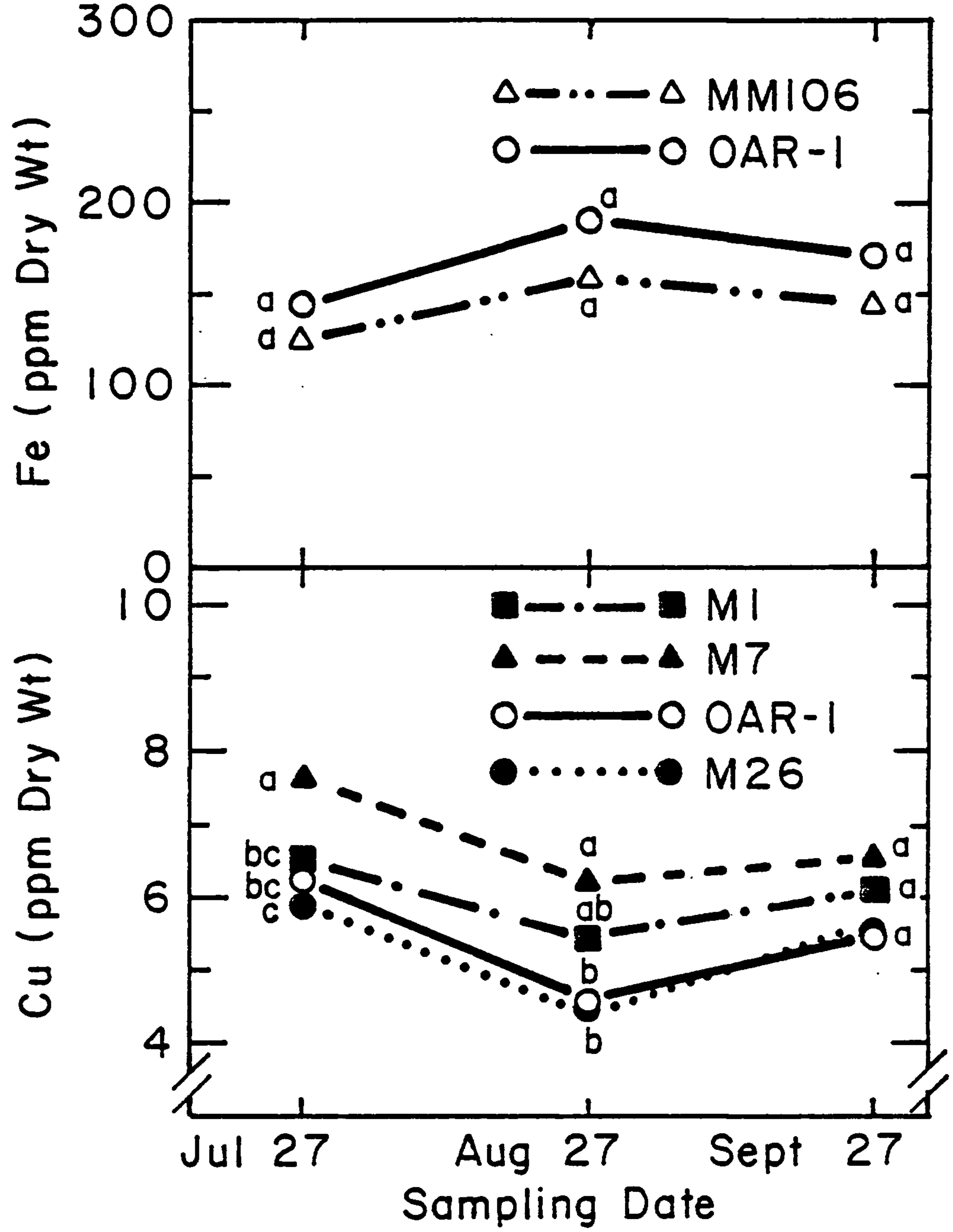
Fe (ppm Dry Wt)
300
200
100
0
MM106
OAR-1
a
a
a
a
a
a
Cu (ppm Dry Wt)
10
8
6
4
M1
M7
OAR-1
M26
a
bc
bc
c
a
ab
b
b
a
a
a
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.12

Figure 3.13. B concentration (PPm dry weight) of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and fertilizer in August 1980. Rootstock mean separation by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by **(1%).

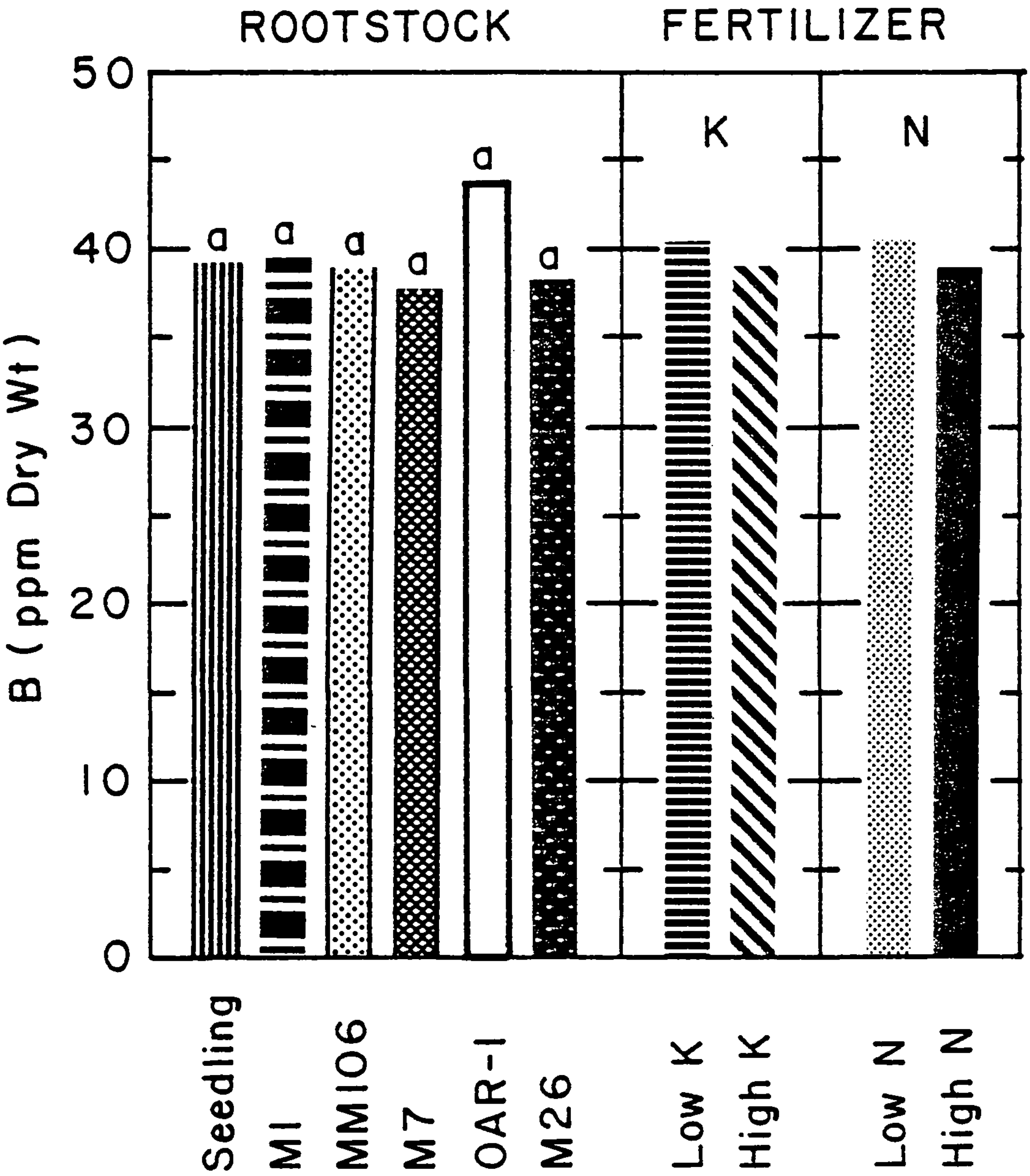
ROOTSTOCK
FERTILIZER
K
N
B (ppm Dry Wt)
50
40
30
20
10
0
a
a
a
a
a
a
Seedling
MI
MM106
M7
OAR-1
M26
Low K
High K
Low N
High N

Figure 3.13

Figure 3.14. B concentration (PPm dry weight) of 'Starkspur Golden Delicious' apple leaves during the growing season of 1981. Rootstock mean separation within dates by Duncan's multiple range test, 5% level. Low levels of K or N are significantly different from high levels if shown by *(5%) or by **(1%).

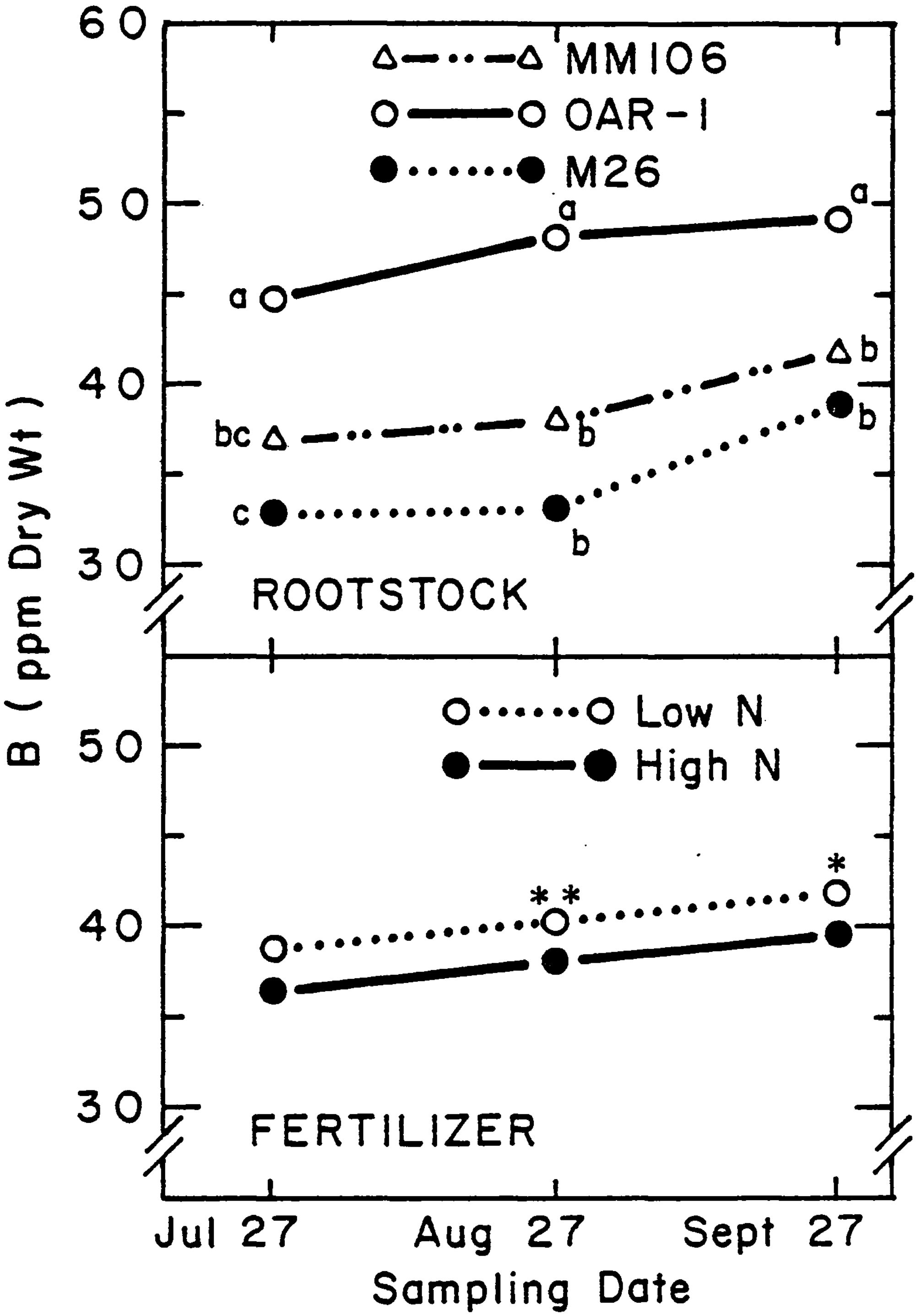
B (ppm Dry Wt)
60
50
40
30
MM106
OAR-I
M26
a
a
a
bc
b
b
c
b
b
ROOTSTOCK
50
40
30
Low N
High N
* *
*
FERTILIZER
Jul 27
Aug 27
Sept 27
Sampling Date

Figure 3.14

Table 3.1 Yields of 'Starkspur Golden Delicious' apples as influenced by rootstock, K and N fertilizers in a high density orchard. Values expressed in metric tons per hectare.

	Years					
	1976	1977	1978	1979	1980	1981
Seedling	6.3	30.7	19.3	3.4	43.5c^z	58.2bc
M1	21.0	48.4	33.2	6.3	86.5b	66.2ab
MM106	26.2	39.9	42.8	7.4	105.6a	89.8a
M7	25.1	34.1	36.8	4.9	89.2ab	76.0ab
OAR-1	44.8	9.4	16.6	5.2	45.1c	84.1a
M26	26.0	33.2	35.6	8.3	94.6ab	55.3c
Levels of K^y						
Low K	20.1	41.4	30.5	6.2	76.5	73.5
High K	19.6	40.9	28.2	6.0	78.2	69.7
Levels^y of N						
Low N	19.6	40.3	28.2	6.2	75.9	76.2
High N	20.1	42.0	30.5	6.0	79.4	66.9

[z] Rootstock mean separation within years 1980 and 1981 by Duncan's multiple range 5% level.

[y] In 1980, low K = zero K/4 trees, high K = 68g actual K as K2SO4/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees. In 1981, low K = zero g/4 trees, high K = 68g actual K as K2SO4/4 trees, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees. In 1980 and 1981, low levels of K or N is not significantly different than high levels within columns at 5% level.

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CHAPTER 4

ROOTSTOCK, K AND N FERTILIZERS INFLUENCES IN A HIGH DENSITY ORCHARD OF 'STARKSPUR GOLDEN DELICIOUS' APPLES ON SEASONAL FRUIT MINERAL ELEMENTS

Esmaeil Fallahi[2] and Daryl G. Richardson

Department of Horticulture, Oregon State University, Corvallis
Oregon 97331

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Abstract. Seasonal mineral composition of 'Starkspur Golden Delicious' apple fruits (*Malus domestica* Borkh.) grown on six rootstocks: Malling (M)1, M7, M26, Malling Merton (MM)106, OAR-1 and seedling rootstocks in a high density orchard with two levels of K (K_2SO_4) and two levels of N (urea) soil fertilization were studied over two seasons of 1980 and 1981. The concentrations of all minerals declined in fruits of all treatments as the season progressed. However, fruit from OAR-1 stock generally had about 15% lower N, P, K, Mg, Fe and Cu, but

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[2] Graduate Research Assistant, partially supported by Ferdowsi University, Mashhad, Iran.

[3] Associate Professor to whom reprint requests may be made.

about 17% higher B, whereas fruits from M7 had about 10% higher concentrations of N, K, Fe and Cu than most other rootstocks. Fruits on M26 had about 6% lower concentrations of B than most other stocks in both seasons. Scion fruits on OAR-1 had the lowest (about 16% lower than all other stocks) mineral content, except for B which was about 11% higher for this rootstock than most other rootstocks. Crop load was found to affect mineral contents particularly fruits of light cropping trees on M26 in which higher contents (up to about 20%) of N, P, K and Mg were observed due to the larger size of fruits. Higher K fertilizer decreased fruit B concentrations with little effect on other elements. Whereas higher applications of N increased fruit N concentrations, total N content per fruit and nitrogen on fresh weight basis but decreased fruit P and K concentrations. Discussions of the effects of rootstocks on mineral nutrition and how this relates to fruit quality at harvest and after cold storage are in a companion paper as part of the overall research.

Introduction

Establishment of high density orchards because of more yield per unit land area has become increasingly popular. Use of dwarfing rootstocks makes the establishment of these types of orchards more feasible. Therefore, the influence of various rootstocks and various fertilizers on the scion fruit mineral composition has special importance for study as the nature of the plant-to-plant competition would be expected to create differences in minerals and quality of scion fruits. This research attempts to characterize the influence of six rootstocks, low and high soil applied K and low and high soil applied N fertilizers on the seasonal changes of mineral concentrations and content in 'Starkspur Golden Delicious' apple fruits. No report has been found for these combinations, although the general seasonal trend for the mineral composition of elements in 'Winesap' and 'Delicious' fruits (15) and fruit mineral composition in relation to storage keeping quality and cropping have been reported (2,8,10,12,13,17). Fruit quality aspects from this research are reported in another paper (Chapter 6).

Materials and Methods

The experiment design and cultural practices of the high density orchard used in this research are described in the first paper of this research series (Chapter 3).

Fruit sampling for 1980 began on May 27, one month after full bloom, and continued on the 27th of each following month until September 27, 1980. An additional fruit sample was taken on October 15, 1980 which was considered to be commercial maturity. In 1981, fruit sampling began on July 27, 1981 and continued monthly through commercial maturity (October 10, 1980). At first sampling of 1980, a composite sample of 32 fruits was taken randomly from each treatment replication, eight fruits from each tree of the four tree sub-sub-plot unit. At each of the other samplings, in 1980 and 1981, a composite sample of eight fruits was taken from each of the four tree plot unit (two fruits per tree). Each treatment combination had six replications with four trees per each replication.

Fruit shape was determined by measuring length to diameter ratio with a vernier caliper during the growing season of 1980. In both seasons, average weight of fruits was measured.

Fruit samples were washed with a solution of 0.05% EDTA and 0.05% Alconox detergent and distilled water. Washed fruits were cored, sliced, freeze dried and ground to pass a 40-mesh screen. Ground samples were stored in air tight plastic bags and were redried before weighing for analysis. Nitrogen was analyzed by an automated Kjeldahl technique (16) and K, P, Ca, Mg, Fe, Cu and B by spark emission spectroscopy (3).

In 1981, fresh weight of the composite fruit sample after coring and dry weight of these composite samples, were recorded and mineral content per fruit and mineral concentration as a percent of fresh weight was calculated.

Results and Discussion

General Trends: There was a logarithmic decline in all fruit mineral concentrations of 'Starkspur Golden Delicious' on all rootstocks between May and June 1980 with a somewhat slower rate between June and July and a still slower decline in N, P, K, Ca and Fe between July and October. The same trend was observed in 1981 (Figs. 4.1-4.11). This decline was due to rapid carbohydrate or dry matter accumulation of the fruits during development (Figs. 4.12-4.14), thereby creating a dilution effect. However, concentrations of K, P, Ca and B in the fruits increased in the final October 1980 sampling (Figs. 4.2,4.3,4.4,4.8). Since fruits of October 1980 were analyzed after six months of storage, the increase of these elements at this time of sampling was possibly because of the mineral migration from the core to the flesh as reported by Bramlage et al. (1) for Ca or could have been due to actual high mineral absorption during October.

The differences of K, P, Ca, B and Fe concentrations of fruits on various rootstocks became more statistically significant as the growing season progressed.

Other than the reduction of total N, Mg and Fe per fruit (fruit content) between July and August and reduction of Cu between September and October, fruit content of all elements increased as the growing season progressed (Figs. 4.15-4.19). Slight reduction in some of the other mineral content per fruit between July and August was not significant. Overall, the increasing trend of fruit mineral content observed here agrees with those found in 'Winesap' and 'Delicious' apples (15).

Reduction of fruit N, Mg, and Fe contents between July and August 1981 (Figs. 4.15-4.19) could have been due to retranslocation of these elements from fruit to leaves or other organs during heavy transpirational demand during the very hot period of early August. Such re-translocation was reported previously for Ca^{45} from apple fruits (11). Although reduced Ca content of fruit at the August samples (Fig. 4.16) was not as dramatic, except for M26, it is of interest that fruit on OAR-1 did not exhibit a decreased Ca content, but rather a slight increase even during that stressful environmental period. M26 had about five times more bitterpit and core breakdown than did OAR-1 fruits after six months of storage at 0°C (Chapter 6; Table 6.5).

Increasing trends of fruit mineral content after August suggests a continuous inward movement of minerals in the fruit tissue throughout the growing season.

Mineral concentration based on fresh weight (mg or µg per 100 g fresh weight) declined between July and August for all rootstocks, thereafter, more or less stable levels were observed (Table 4.1). Ca concentration tended to decrease steadily and slowly in most rootstocks as the season progressed. This decline is due to faster fruit growth (Fig. 4.13) than Ca accumulation, beginning in July. It should be noted that the fruit on different rootstocks ranged from a calcium concentration of high 8.3 mg Ca/100g fresh weight for OAR-1 rootstock to a low of 4.3 mg Ca/100g fresh weight for M26 rootstock (Table 4.1). Therefore, OAR-1 fruit had low bitterpit (1.4%) compared to M26 fruit with 12% bitterpit after storage (Chapter 6; Table 6.5).

Effects of Rootstocks: Scion fruits on OAR-1 rootstock always had relatively (and sometimes significantly) lower concentrations of N, P, K, Mg, Fe and Cu, but the highest concentrations of B compared to all other rootstocks in both 1980 and 1981 (Figs. 4.1-4.8). Lower concentrations of most fruit minerals on OAR-1 is due to the high percent dry weight of these fruits which creates a dilution effect (Fig. 4.21). Higher soluble solids content of these fruits as found in another part of these studies (Chapter 6) corresponds with their relatively high dry weight. This might have been a result of higher scion leaf photosynthesis on this rootstock.

The concentrations of B in the fruits from the trees on OAR-1 apparently exceeded even the dilution effect of accumulating dry matter. The physiology of B uptake as a result of rootstock has not been clarified. However, several physiological characteristics of trees on OAR-1 might be linked to the high levels of B in the leaves and fruit. One way this might be expressed is in smaller size (Figs. 4.12-4.13) with lower length:diameter ratio (L/D) fruits from trees on OAR-1 rootstock (Fig. 4.20). Boron has been reported to protect the IAA oxidase system by making a complex with inhibitors of IAA oxidase (4). In the presence of higher IAA oxidase activity, less auxin would be translocated from the top into the roots resulting in less root development therefore less cytokinin synthesis. Thus, less synthesis of cytokinins by roots of OAR-1 might result in lower fruit L/D ratio throughout the growing season (Fig. 4.20). A greater L/D ratio of 'Delicious' apple was a result of early season cytokinin application as reported by Williams and Stahly (18).

In 1981, fruits on OAR-1 had higher Ca concentrations but those on M26 had lower Ca than other rootstocks, while the opposite situation occurred in 1980. This can be related to the 46% higher yield of trees on OAR-1 and 42% lower yield of trees on M26 in 1981 as compared to yield of these rootstocks in 1980. Higher yield would result in less parition of photosynthate in each fruit due to the lower leaf/fruit ratio. Thus the dilution effect of fruit dry matter will be less apparent in the concentration of fruit mineral particularly Ca. This explanation is supported by the significant correlations between fruit Ca and yield (r=0.46), and percent fruit dry matter and yield (r=-0.38), and percent fruit dry matter and fruit Ca (r=-0.67). However, low concentrations of B were observed in the fruits from trees grown on M26 in both 1980 and 1981 which is definitely a rootstock effect, and not a light or heavy cropping effect.

Rootstock M7 induced higher fruit concentrations of N, P, K, Fe and Cu than most other rootstocks, while Seedling, M1 and MM106 induced intermediate concentrations of these elements (Figs. 4.1, 4.2, 4.3, 4.6, 4.7). It has been suggested that efficiency of leaves with respect to transpiration and translocation in the fruiting trees is higher than non-fruiting trees (5,6,7). Since M7 was among the most consistently high yielding rootstocks (Chapter 3; Table 3.1) it is possible that the leaves of trees on this rootstock are more efficient in terms of transpiration. This leads to more ascent of N, K, Fe and Cu per unit water transpired which is mainly accomplished by means of mass flow movement.

Fruits from OAR-1 had the lowest fruit content of N, K, P, Fe and Cu (Figs. 4.15-4.18) not only because of the relatively (and in some cases significantly) lower concentrations of these elements but also because of the smaller size of these fruits (Figs. 4.12 and 4.13). However, B content of fruit on this rootstock was higher due to the high concentrations of this element (Fig. 4.18).

High fruit content of N, K, P, Mg, Fe, and B on M26 was observed (Figs. 4.15-4.18) and is related to the light cropping and subsequently, the large size of fruits on this rootstock (Fig. 4.13). However, Ca content per fruit on this rootstock was lower and incidence of bitterpit was higher than all other rootstocks (Chapter 6; Table 6.5). Among these minerals, N, K, P, and Mg, can be transported both through one way movement in xylem and bidirectional movement in phloem, while Ca basically follows the transpiration stream and moves through xylem. Due to the low cropping of these trees on M26, higher leaf/fruit ratio allowed for larger amounts of photosynthate to move from the leaf into the fruit through the phloem. Together with this photosynthate and water, N, K, P and Mg can move in organic forms. These elements also enter into the fruits in inorganic forms through the xylem while Ca gets into the fruit mostly through the xylem, leading to very low accumulation of Ca and higher accumulation of other elements. Based on this mechanism, B and Fe could have also moved through the phloem into the fruits leading to higher content of those elements in the fruits on M26 rootstock which contradicts the concept of B and Fe immobility in phloem as has been accepted. As an alternative, M26 may have more efficient uptake mechanism specific to B, Fe and other elements. Fruits on Seedling, M7, MM106 and M1 had intermediate content of minerals per fruit (Figs. 4.15-4.18).

No significant influence of rootstock was observed in the fruit N, P and Mg based on fresh weight concentrations, except OAR-1 induced relatively lower levels of N, K and Cu (Table 4.1). However, OAR-1 had the highest levels of B per 100g fresh weight on all sampling dates of 1981.

It has been suggested that low Ca threshold for bitterpit is about 5 mg/100 g fresh weight (17) and high threshold for Mg is 3.8-4.3 mg/100 g. Thus the critical ratio of Mg:Ca will be between 0.76 and 0.86. In this regard, the seasonal Mg:Ca ratios in the fruits on M26 were highest among all rootstocks and this ratio was 0.74 in July which is close to the critical ratio. Thus, fruits on M26 might have been predisposed to develop bitterpit as early as July. Therefore, fruit mineral analysis and determination of this ratio and other ratios such as N:Ca as early as July may allow adjustment of the balance of Mg, N and Ca by orchard Ca sprays to reduce the incidence of bitterpit and corking disorders (14).

Effects of K and N Fertilizer Treatments: The high level of K application did not significantly change the accumulation of various mineral elements in the fruit except in a few cases where the low K application had higher fruit concentrations of Ca and B (Fig. 4.9). This small or no difference, is because of cross feeding and probably root grafting between low and high K applied plots. However, high N fertilizer application increased fruit N concentration. This increase was statistically insignificant in 1980, but significant in 1981 (Fig. 4.10). As in the case of leaves (Chapter 3), high N application reduced fruit K and P (Fig. 4.11). Antagonism between N and K has probably started from the site of absorption because urea fertilizer converts to NH_4^+ and this ion can directly compete with K^+ ion. However, synergism between P and N is not clear, but it seems that mechanism of K^+ uptake is somehow closely related to P uptake ($r = 0.86$ in fruit tissue). Thus, reduced K uptake by high N applications has led to the low uptake of P or vice versa. Concentrations of other minerals were not affected by fertilizer.

High N applications significantly increased the fruit N content (total N/fruit; Fig. 4.19) and fruit N concentration based on fresh weight (mg N/100 fresh weight) at all sampling dates of 1981 (Table 4.1).

Somewhat to our surprise, no significant rootstock-fertilizer interaction was found in any part of this research. It appears that leaf analysis between mid-July to late August has only limited usefulness, if any, as an indication of fruit nutrient status, correlating with a few mineral elements, especially N and some microelements, but not for Ca. Fruit tissue analysis should be considered as the most important tool for the determination of Ca levels. Development of proper fruit standards with regard to the ideal eating and keeping quality will be an important part of fruit analysis and decision making for fertilizer applications. In addition, crop load must be taken into consideration as a major influence on the balance of N, K, and Ca in the fruit.

Rootstock can influence the seasonal trends of mineral content of scion fruits and in this research, rootstocks clearly had the dominant effects. It seems that the OAR-1 rootstock has very distinct properties which may influence the physiology of other scion cultivars as it did in this research on 'Starkspur Golden' and ultimately these special features of OAR-1 will be of interest to future studies.

Figure 4.1. 1980 and 1981 seasonal fruit N concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

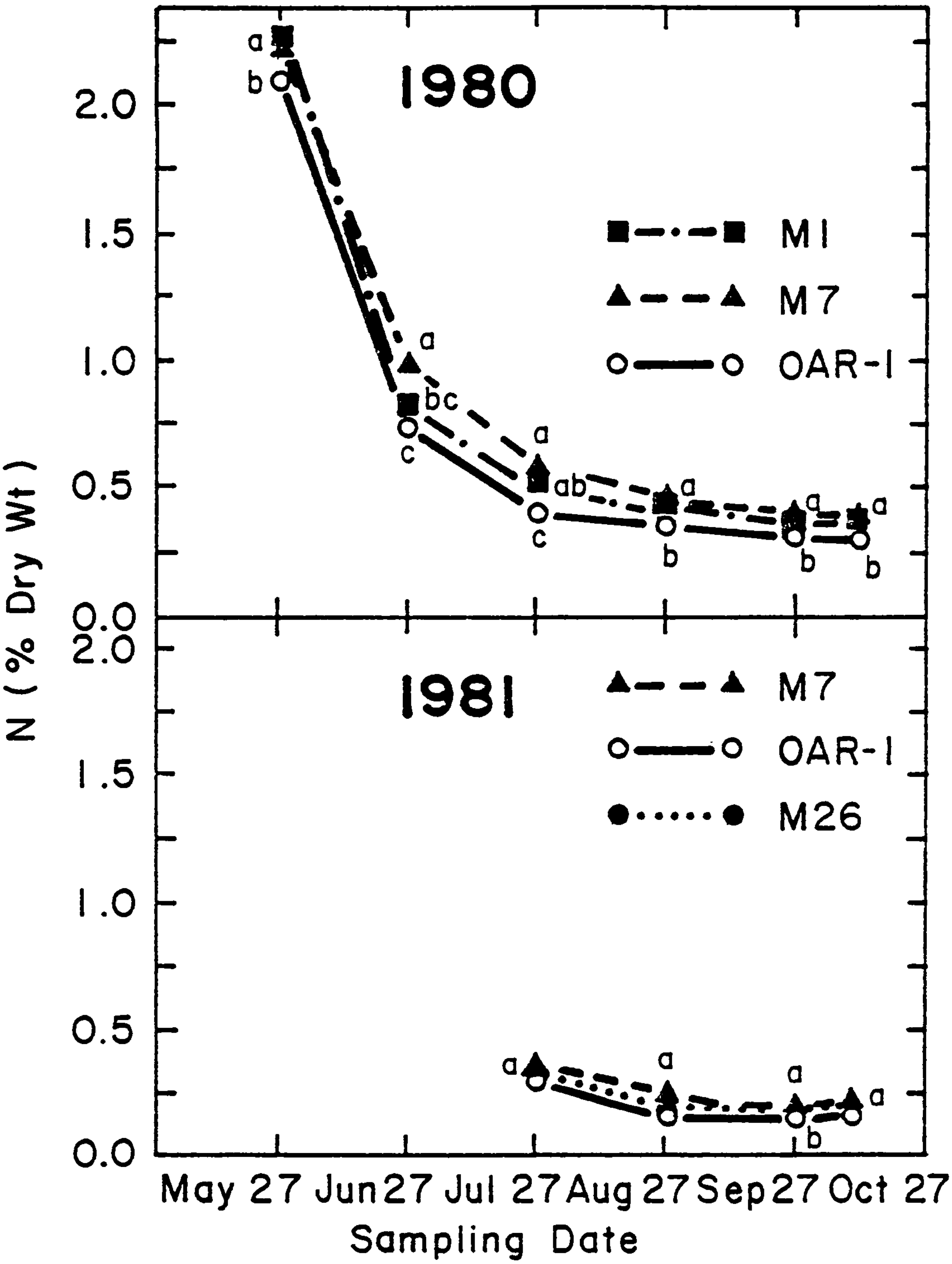
1980
■—·—■ M1
▲— —▲ M7
○——○ OAR-1
1981
▲— —▲ M7
○——○ OAR-1
●·····● M26
N (% Dry Wt)
2.0
1.5
1.0
0.5
0.0
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date
a
b
bc
c
ab

Figure 4.1

Figure 4.2. 1980 and 1981 seasonal fruit K concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

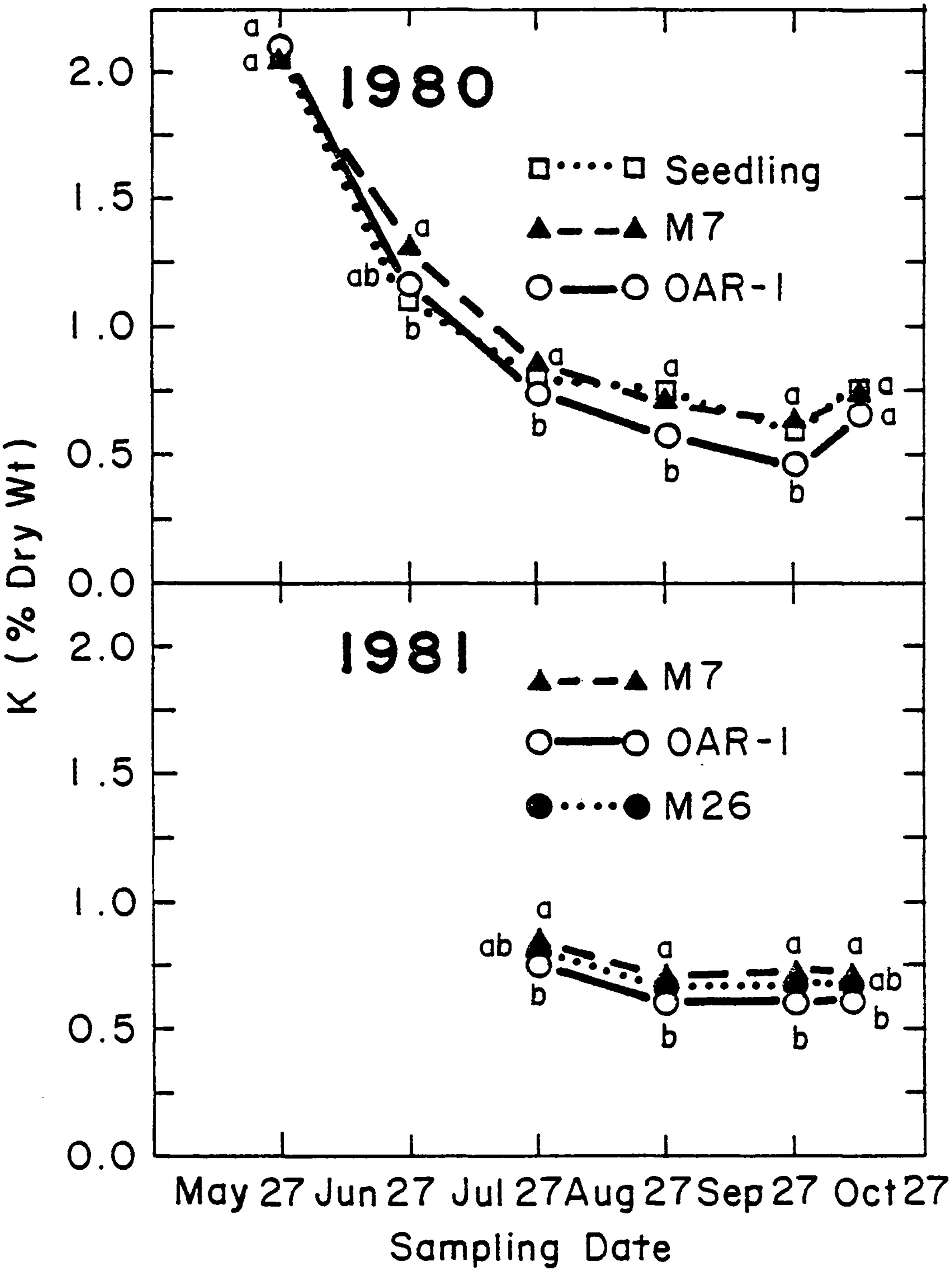
1980
□····□ Seedling
▲– – –▲ M7
○——○ OAR-1
1981
▲– – –▲ M7
○——○ OAR-1
●····● M26
K (% Dry Wt)
0.0
0.5
1.0
1.5
2.0
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date
a
ab
b

Figure 4.2

Figure 4.3. 1980 and 1981 seasonal fruit P concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

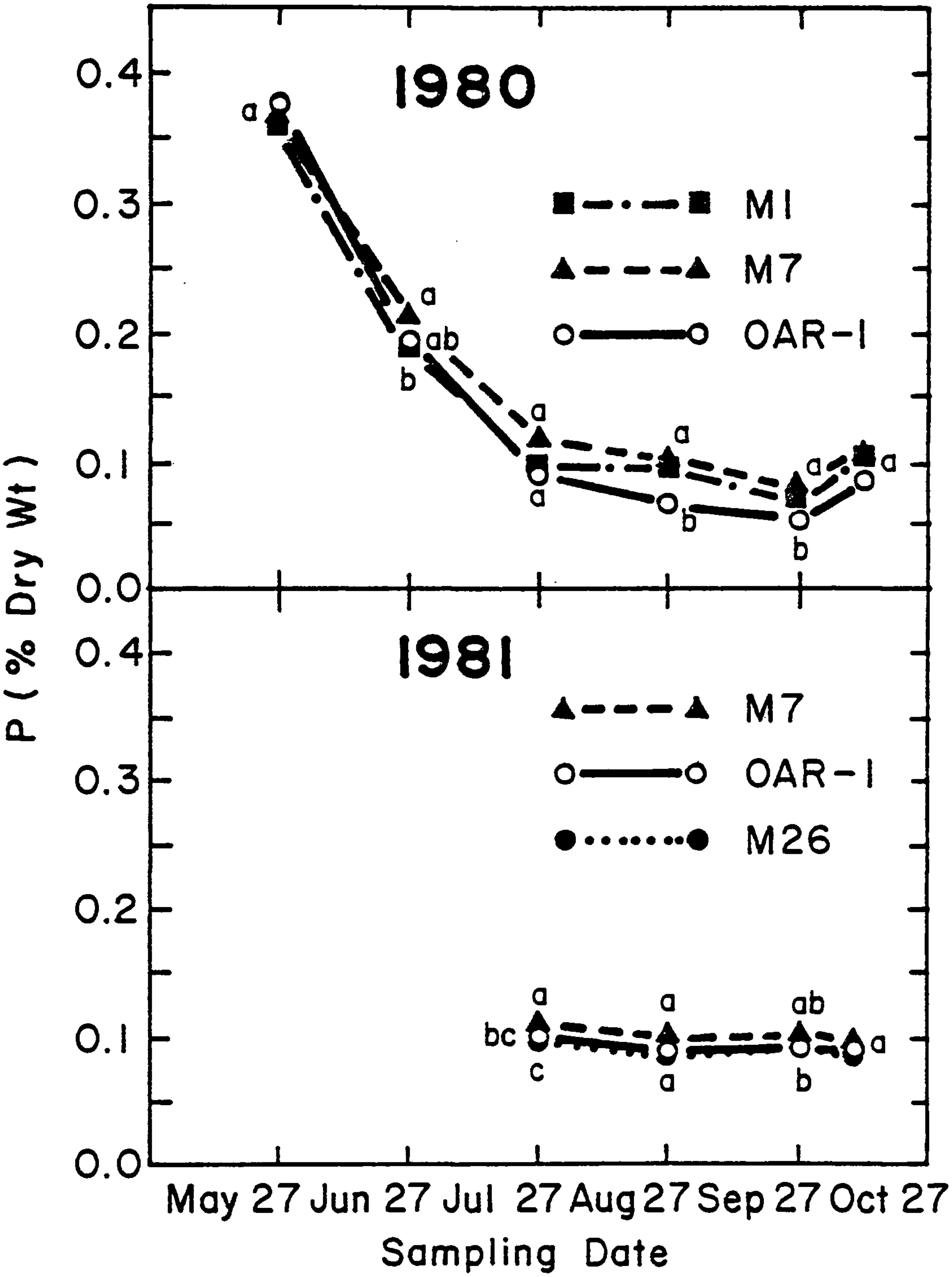
1980
M1
M7
OAR-1
1981
M7
OAR-1
M26
P (% Dry Wt)
0.0
0.1
0.2
0.3
0.4
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date
a
ab
b
bc
c

Figure 4.3

Figure 4.4. 1980 and 1981 seasonal fruit Ca concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

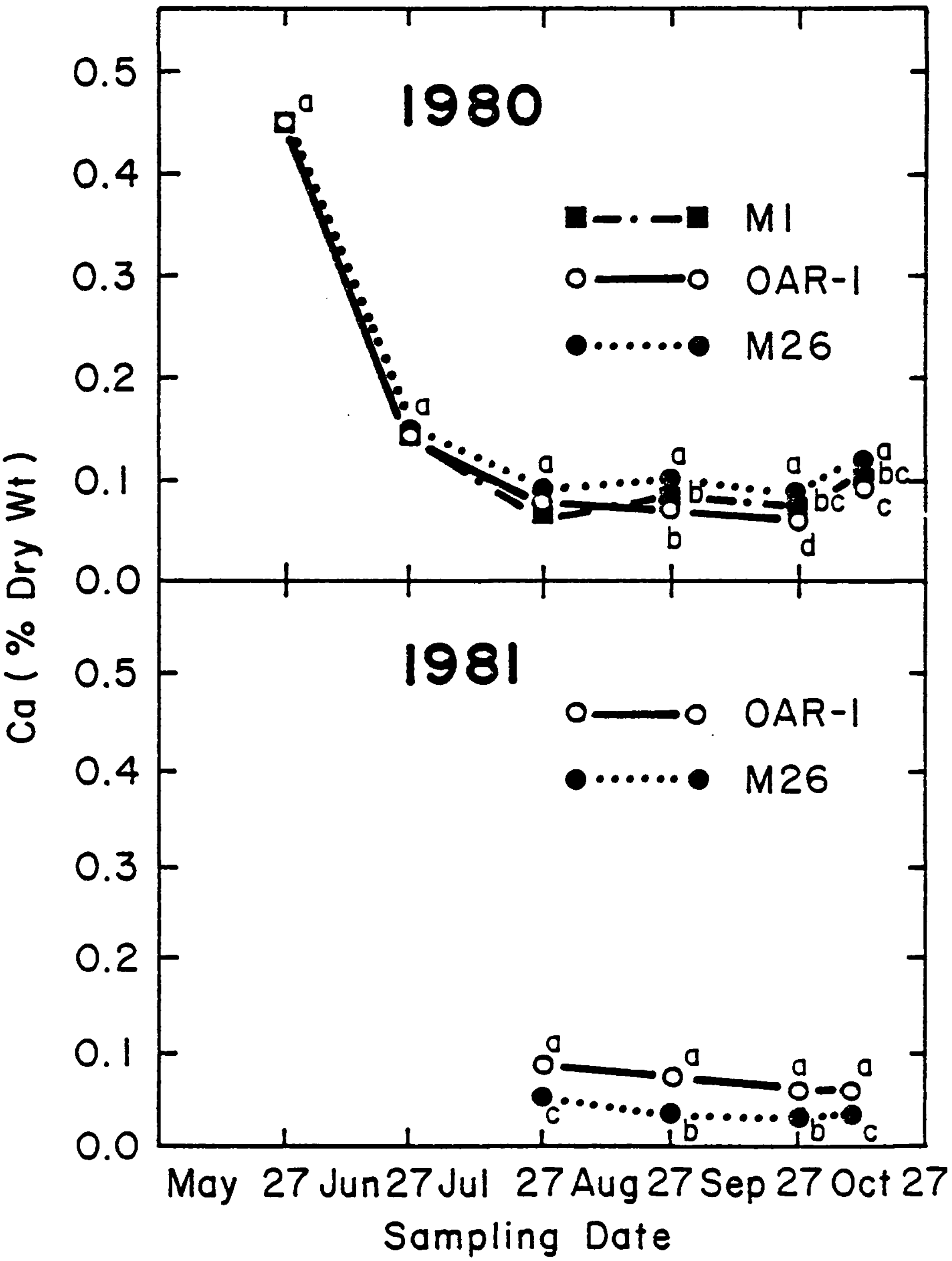
1980
1981
M1
OAR-1
M26
OAR-1
M26
Ca (% Dry Wt)
0.0
0.1
0.2
0.3
0.4
0.5
a
b
bc
c
d
May 27 Jun 27 Jul 27 Aug 27 Sep 27 Oct 27
Sampling Date

Figure 4.4

Figure 4.5. 1980 and 1981 seasonal fruit Mg concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

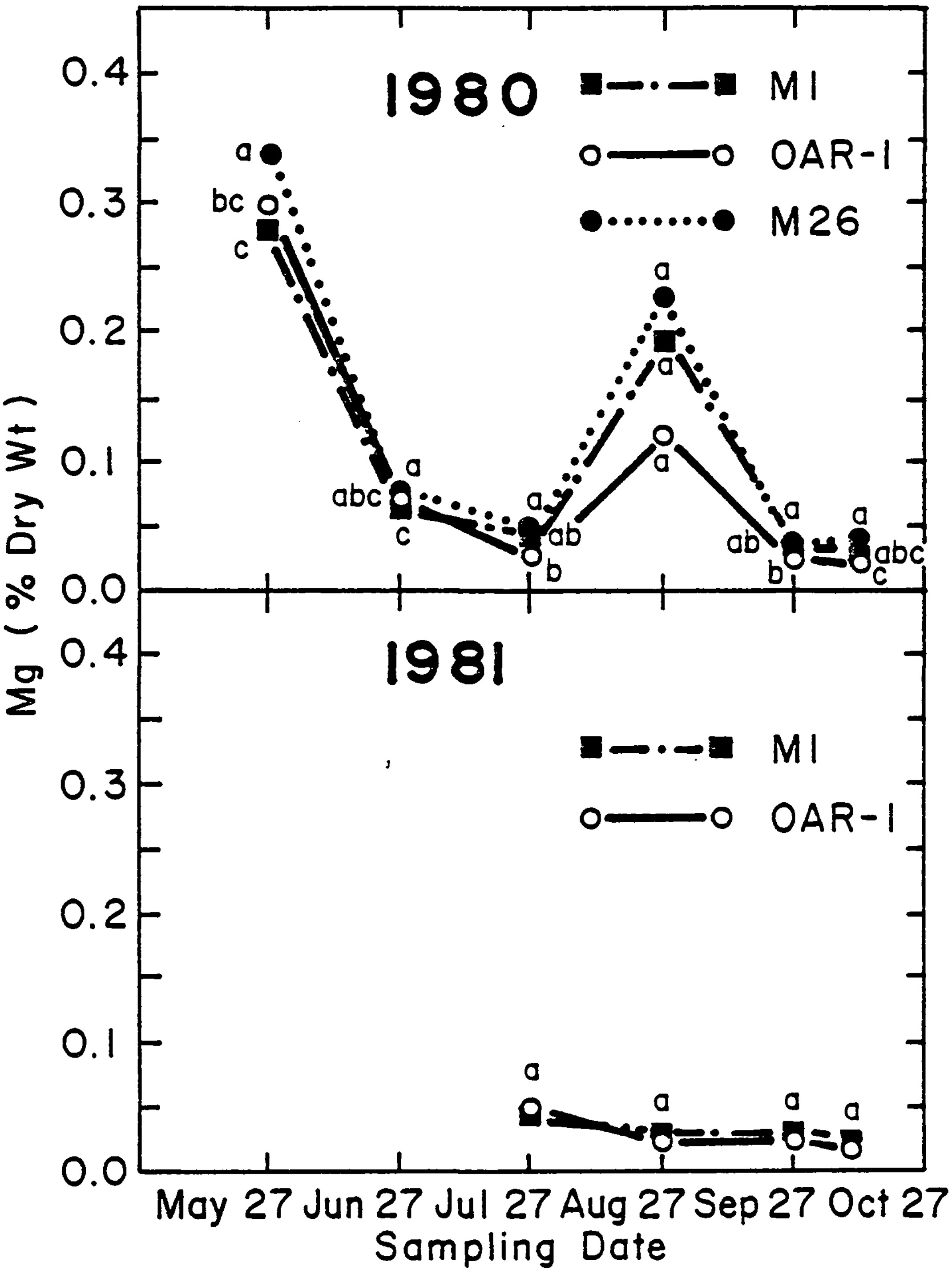
1980
1981
■—·—■ MI
○——○ OAR-I
●·····● M26
Mg (% Dry Wt)
0.0
0.1
0.2
0.3
0.4
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date
a
bc
c
a
abc
c
a
ab
b
a
a
a
a
ab
b
a
abc
c
a
a
a
a

Figure 4.5

Figure 4.6. 1980 and 1981 seasonal fruit Fe concentrations (expressed as PPm dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test. 5% level.

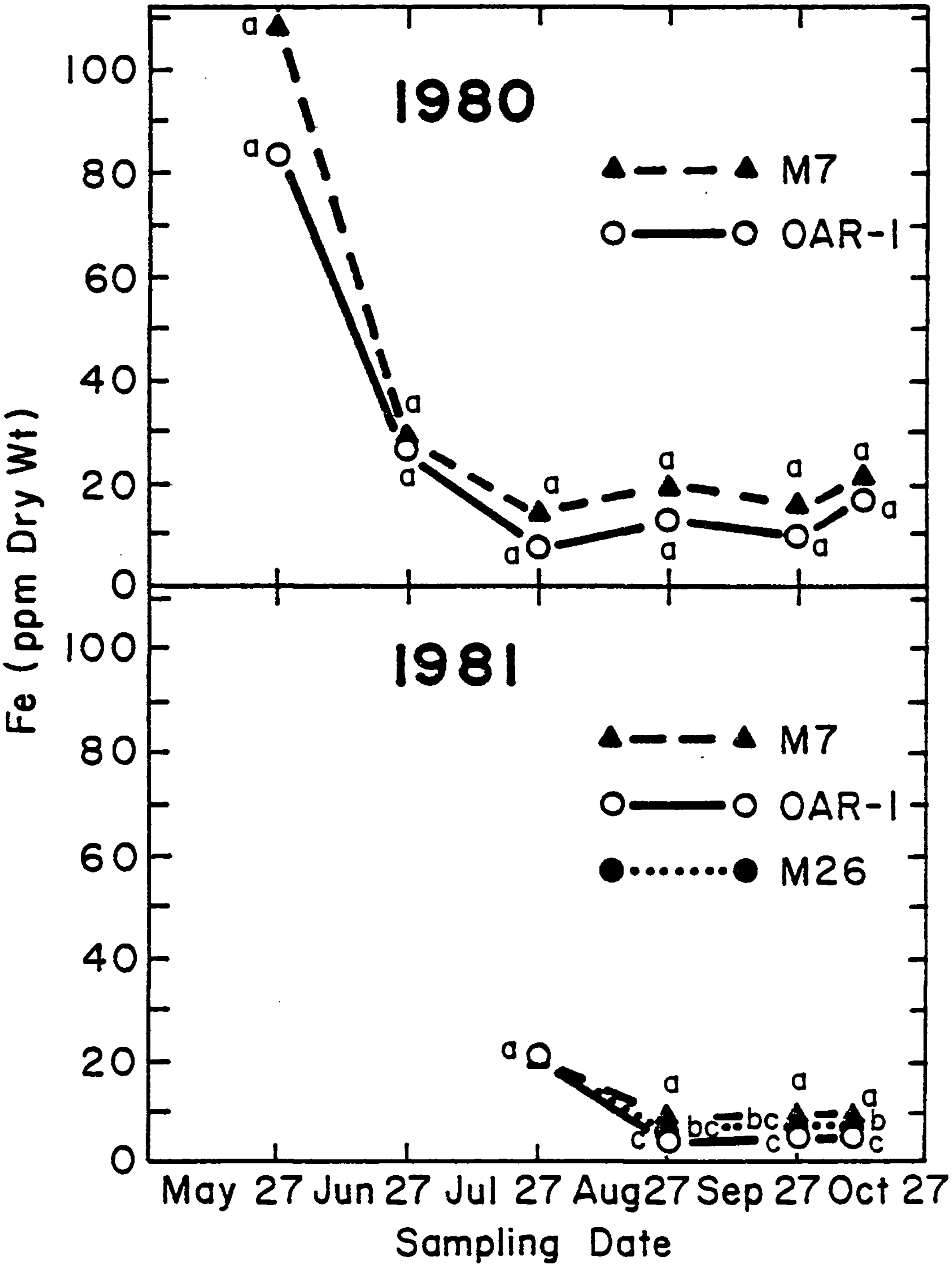
1980
1981
▲ – – ▲ M7
○——○ OAR-1
●••••● M26
Fe (ppm Dry Wt)
0
20
40
60
80
100
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date
a
b
bc
c

Figure 4.6

Figure 4.7. 1980 and 1981 seasonal fruit Cu concentrations (expressed as PPm dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

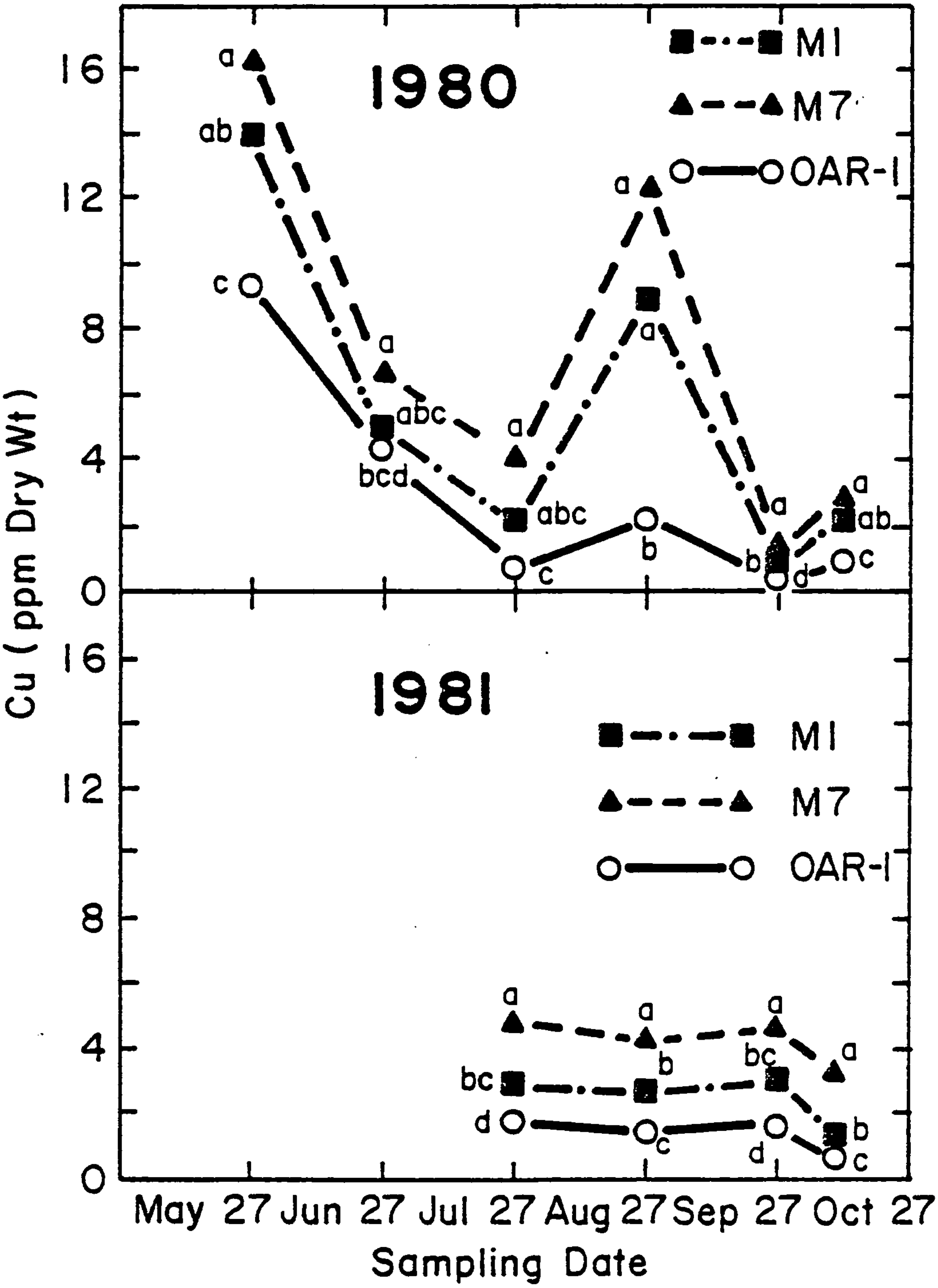
1980
1981
M1
M7
OAR-1
Cu (ppm Dry Wt)
0
4
8
12
16
May 27 Jun 27 Jul 27 Aug 27 Sep 27 Oct 27
Sampling Date
a
ab
c
abc
bcd
abc
b
d
ab
bc

Figure 4.7

Figure 4.8. 1980 and 1981 seasonal fruit B concentrations (expressed as PPm dry weight) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

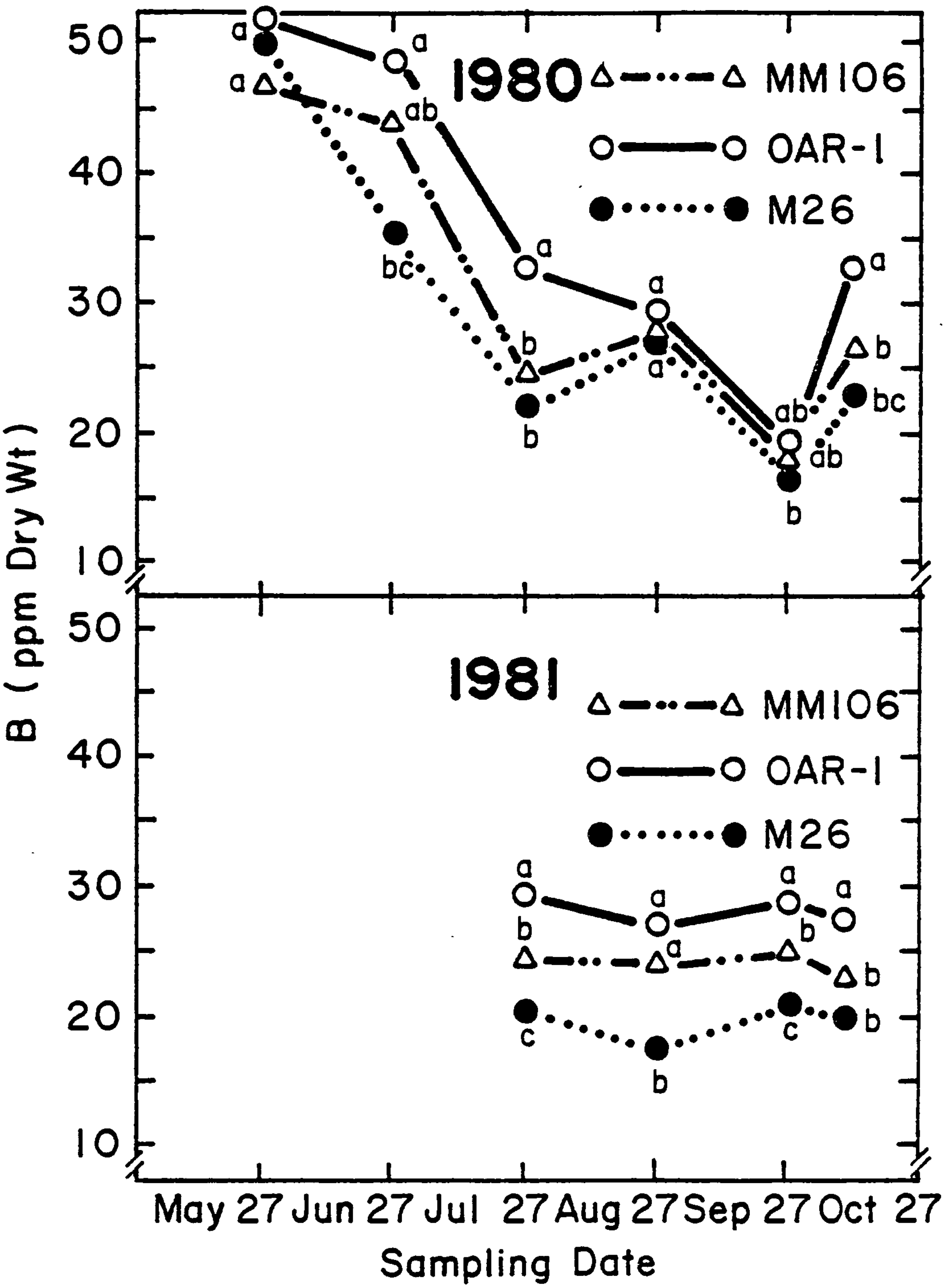
1980
MM106
OAR-1
M26
1981
MM106
OAR-1
M26
B (ppm Dry Wt)
50
40
30
20
10
May 27 Jun 27 Jul 27 Aug 27 Sep 27 Oct 27
Sampling Date
a
ab
bc
b
c

Figure 4.8

Figure 4.9. 1980 seasonal fruit Ca and B concentrations (expressed as % and PPm dry weight) of 'Starkspur Golden Delicious' apple as influenced by soil K applications. Low level of K is significantly different from high level within dates if shown by * (5%) or 1% (**).

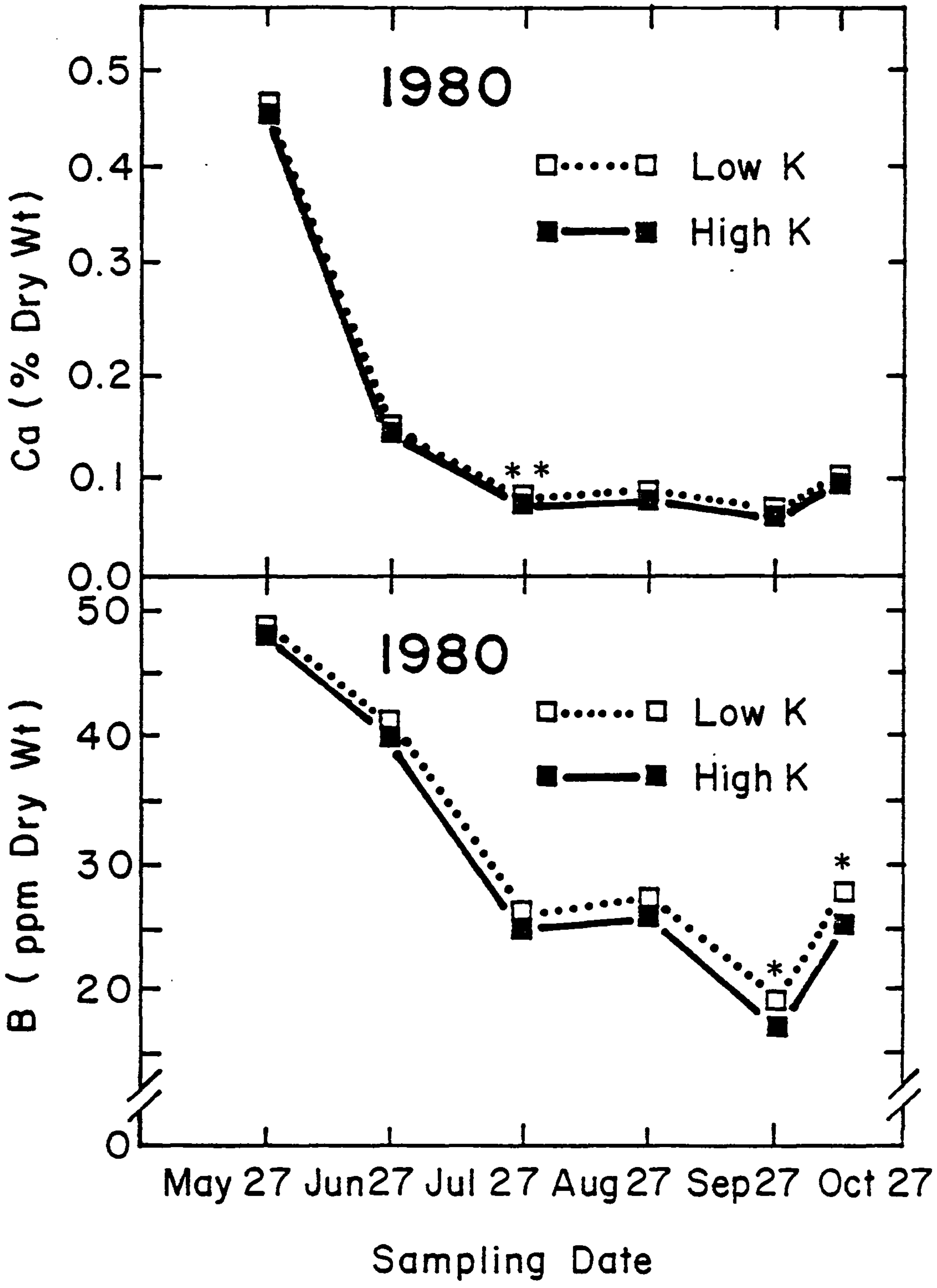
1980
□·····□ Low K
■——■ High K
Ca (% Dry Wt)
0.0
0.1
0.2
0.3
0.4
0.5
* *
1980
□·····□ Low K
■——■ High K
B (ppm Dry Wt)
0
20
30
40
50
*
*
May 27
Jun27
Jul 27
Aug 27
Sep27
Oct 27
Sampling Date

Figure 4.9

Figure 4.10. 1980 and 1981 seasonal fruit N concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influence by soil N applications. Low level of N is significantly different from high level within dates if shown by * (5%) or ** (1%).

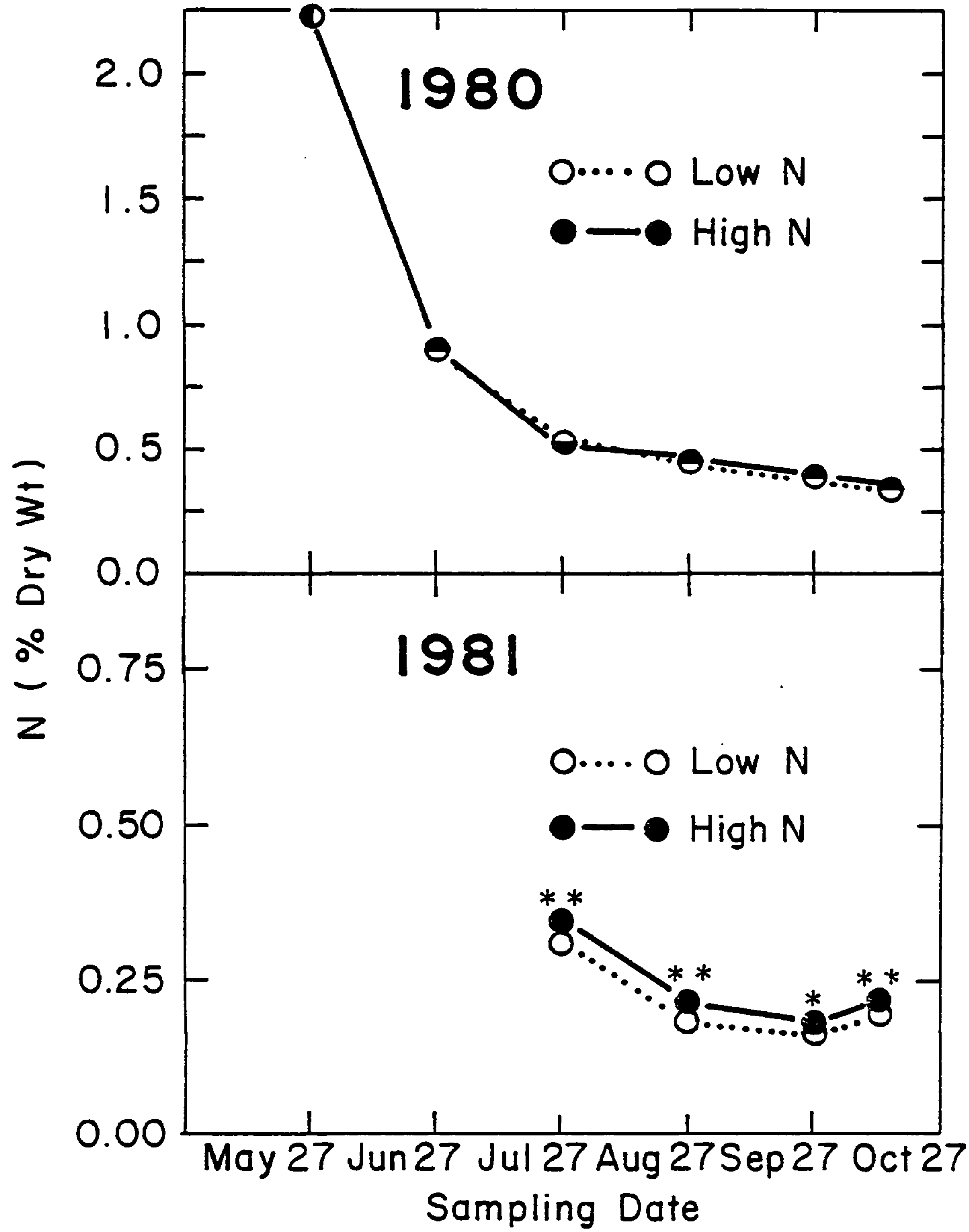
1980
○····○ Low N
●——● High N
2.0
1.5
1.0
0.5
0.0
N (% Dry Wt)
1981
○····○ Low N
●——● High N
0.75
0.50
0.25
0.00
* *
* *
*
* *
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date

Figure 4.10

Figure 4.11. 1980 and 1981 seasonal fruit P concentrations (expressed as % dry weight) of 'Starkspur Golden Delicious' apple as influenced by soil N applications. Low level of N is significantly different from high level within dates if shown by * (5%) or ** (1%).

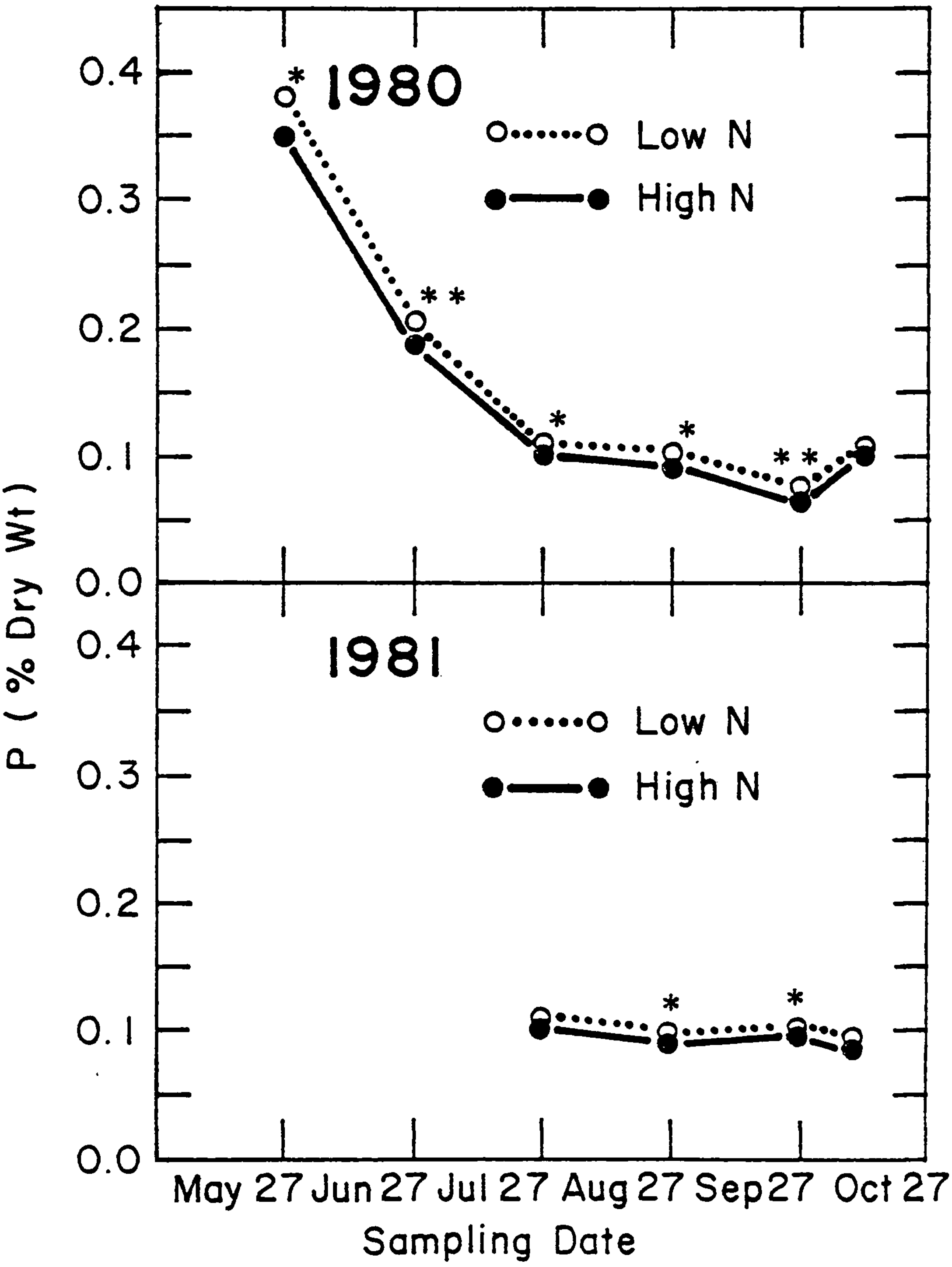
1980
Low N
High N
1981
Low N
High N
P (% Dry Wt)
0.4
0.3
0.2
0.1
0.0
May 27
Jun 27
Jul 27
Aug 27
Sep 27
Oct 27
Sampling Date
*
**
*
*
**
*
*

Figure 4.11

Figure 4.12. 1980 seasonal fresh weight changes during development of 'Starkspur Golden Delicious' apple fruit as influenced by rootstocks. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

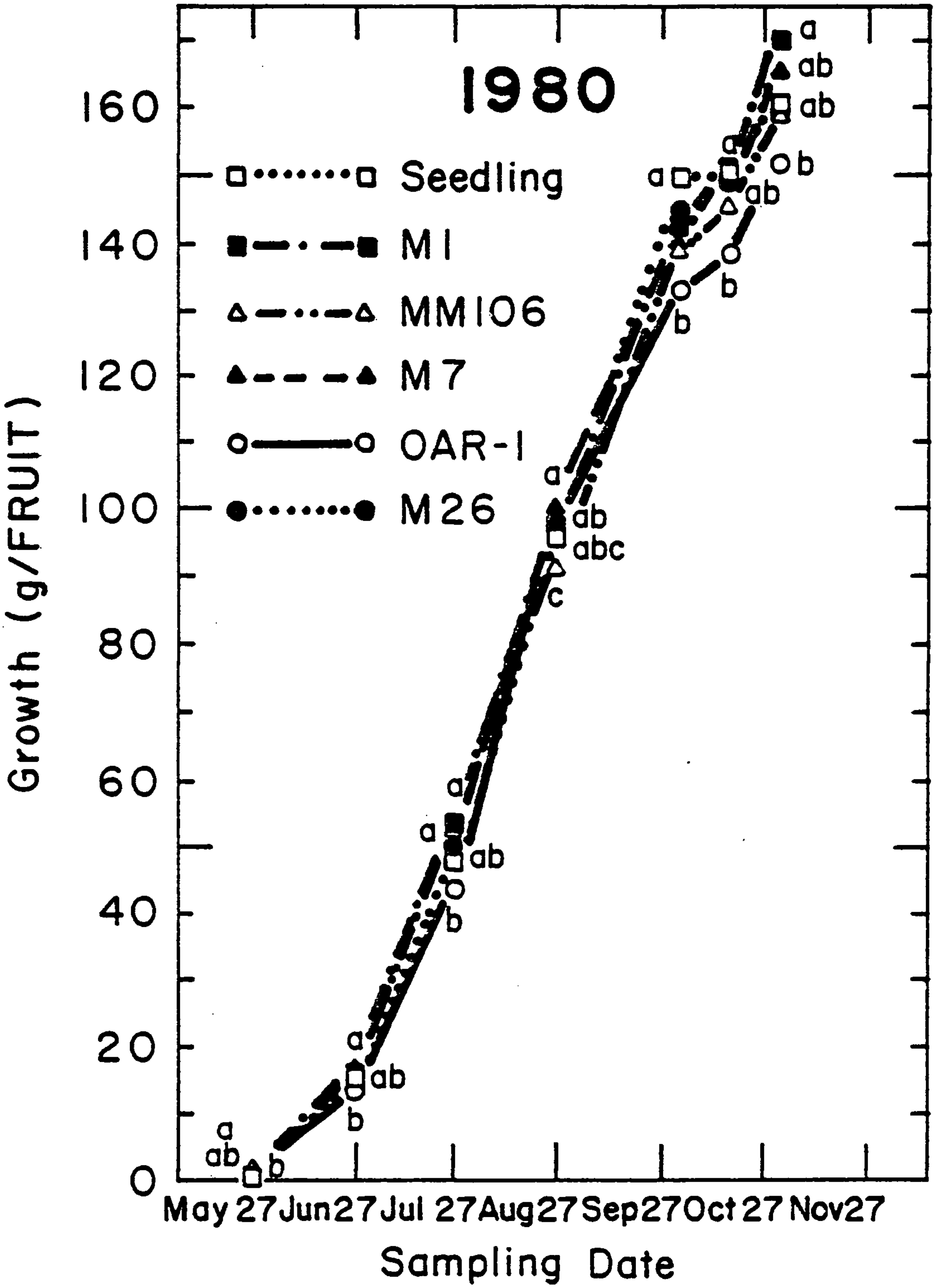
1980
Seedling
M1
MM106
M7
OAR-1
M26
Growth (g/FRUIT)
0
20
40
60
80
100
120
140
160
May 27
Jun27
Jul 27
Aug27
Sep27
Oct 27
Nov27
Sampling Date
a
ab
b
a
ab
b
a
ab
b
a
ab
a
ab
abc
c
a
b
b
a
ab
a
ab
ab
b

Figure 4.12.

Figure 4.13. 1981 seasonal fresh weight changes during development of 'Starkspur Golden Delicious' apple fruit as influenced by rootstocks. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

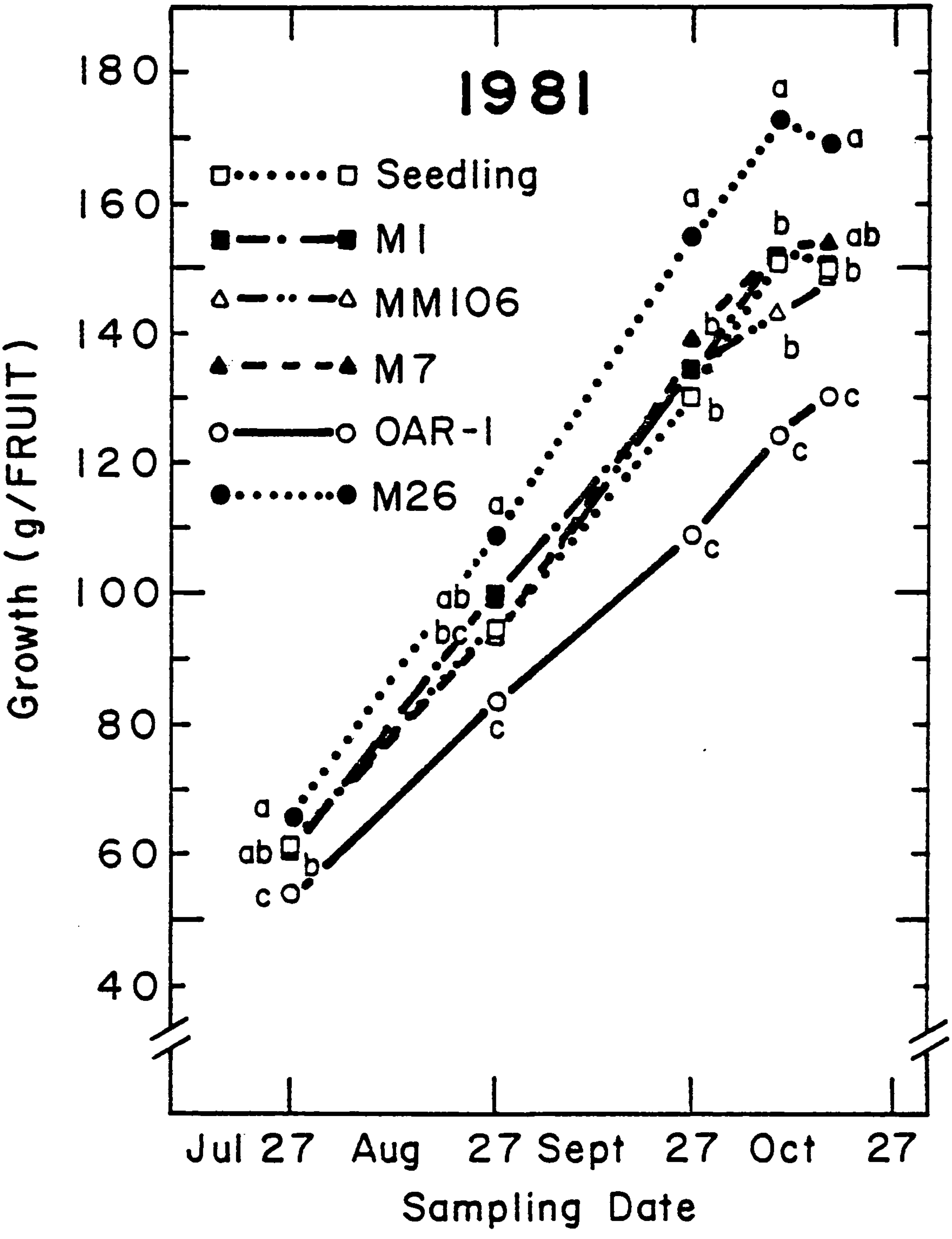
1981
Seedling
M1
MM106
M7
OAR-1
M26
Growth (g/FRUIT)
180
160
140
120
100
80
60
40
Jul 27
Aug
27
Sept
27
Oct
27
Sampling Date
a
ab
b
bc
c

Figure 4.13.

Figure 4.14. 1981 seasonal changes in dry matter content (grams/fruit) of 'Starkspur Golden Delicious' apple fruit as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

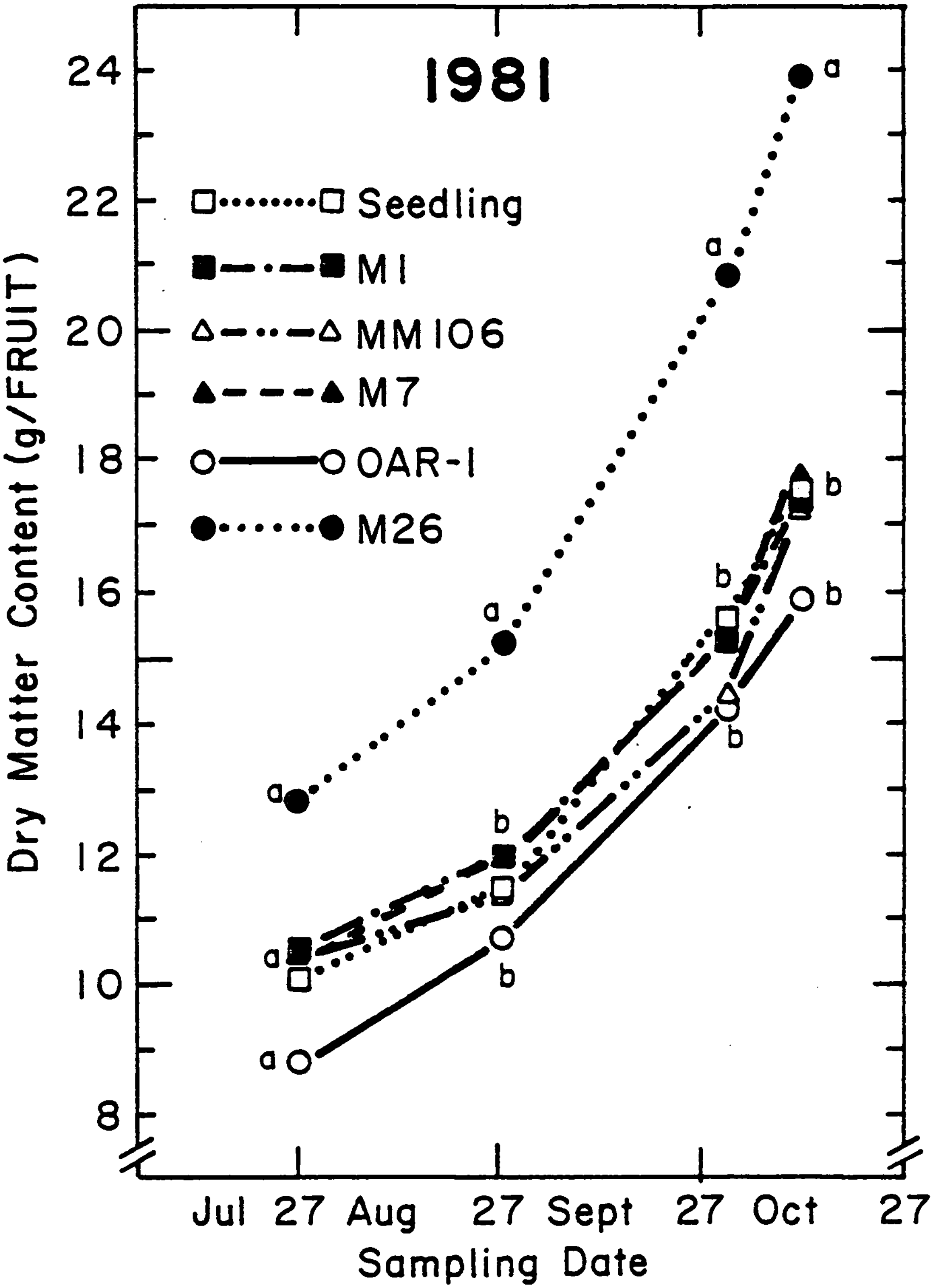
1981
□……□ Seedling
■—·—■ M1
△—··—△ MM106
▲– – –▲ M7
○——○ OAR-1
●……● M26
Dry Matter Content (g/FRUIT)
24
22
20
18
16
14
12
10
8
a
b
Jul
27
Aug
27
Sept
27
Oct
27
Sampling Date

Figure 4.14.

Figure 4.15. 1981 seasonal fruit N and K content (expressed as mg per fruit) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean seperation within dates by Duncan's multiple range test, 5% level.

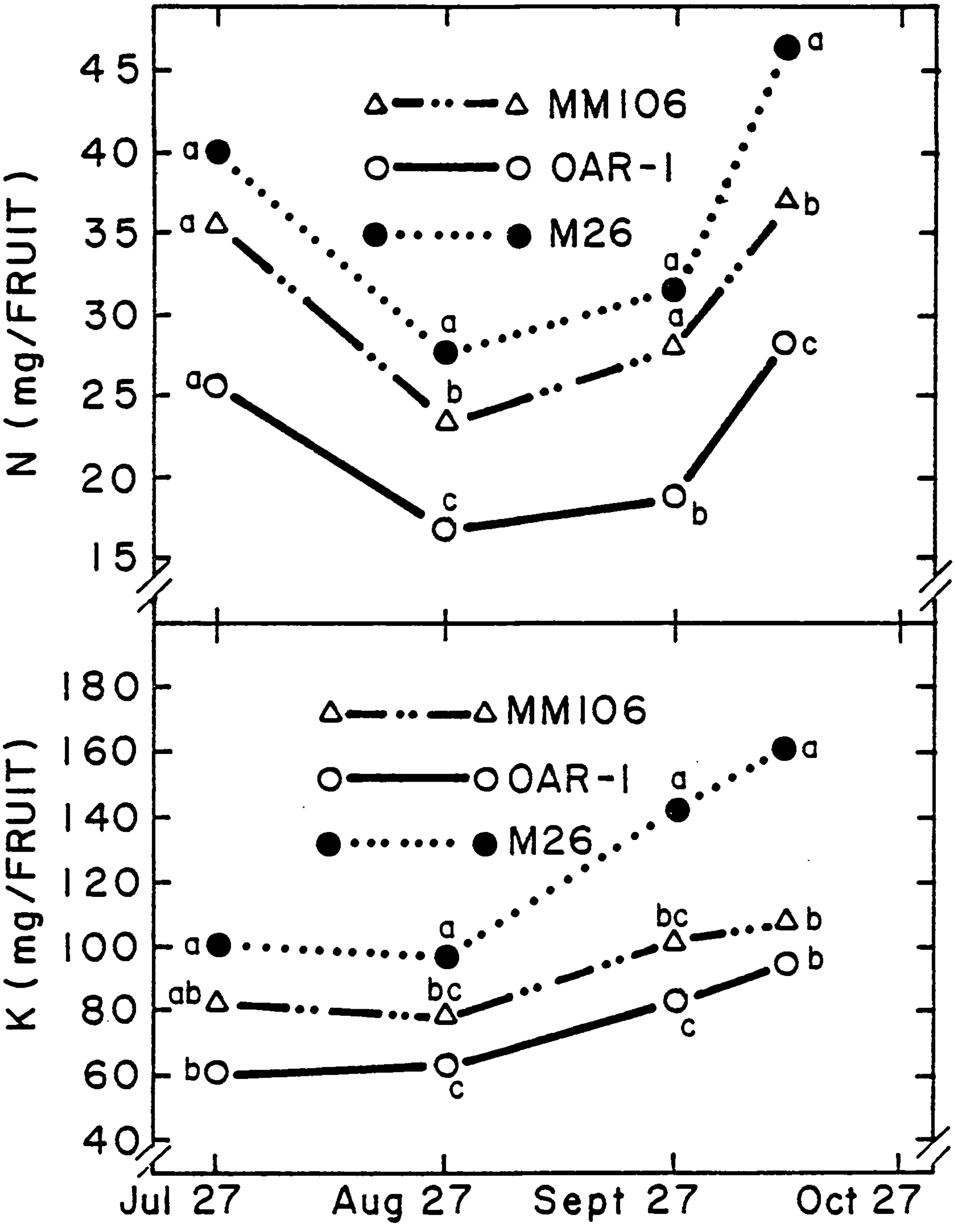
N (mg/FRUIT)
15
20
25
30
35
40
45
MM106
OAR-1
M26
a
b
c
K (mg/FRUIT)
40
60
80
100
120
140
160
180
ab
bc
Jul 27
Aug 27
Sept 27
Oct 27
Sampling Date

Figure 4.15.

Figure 4.16. 1981 seasonal fruit P and Ca content (expressed as mg per fruit) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean seperation within dates by Duncan's multiple range test, 5% level.

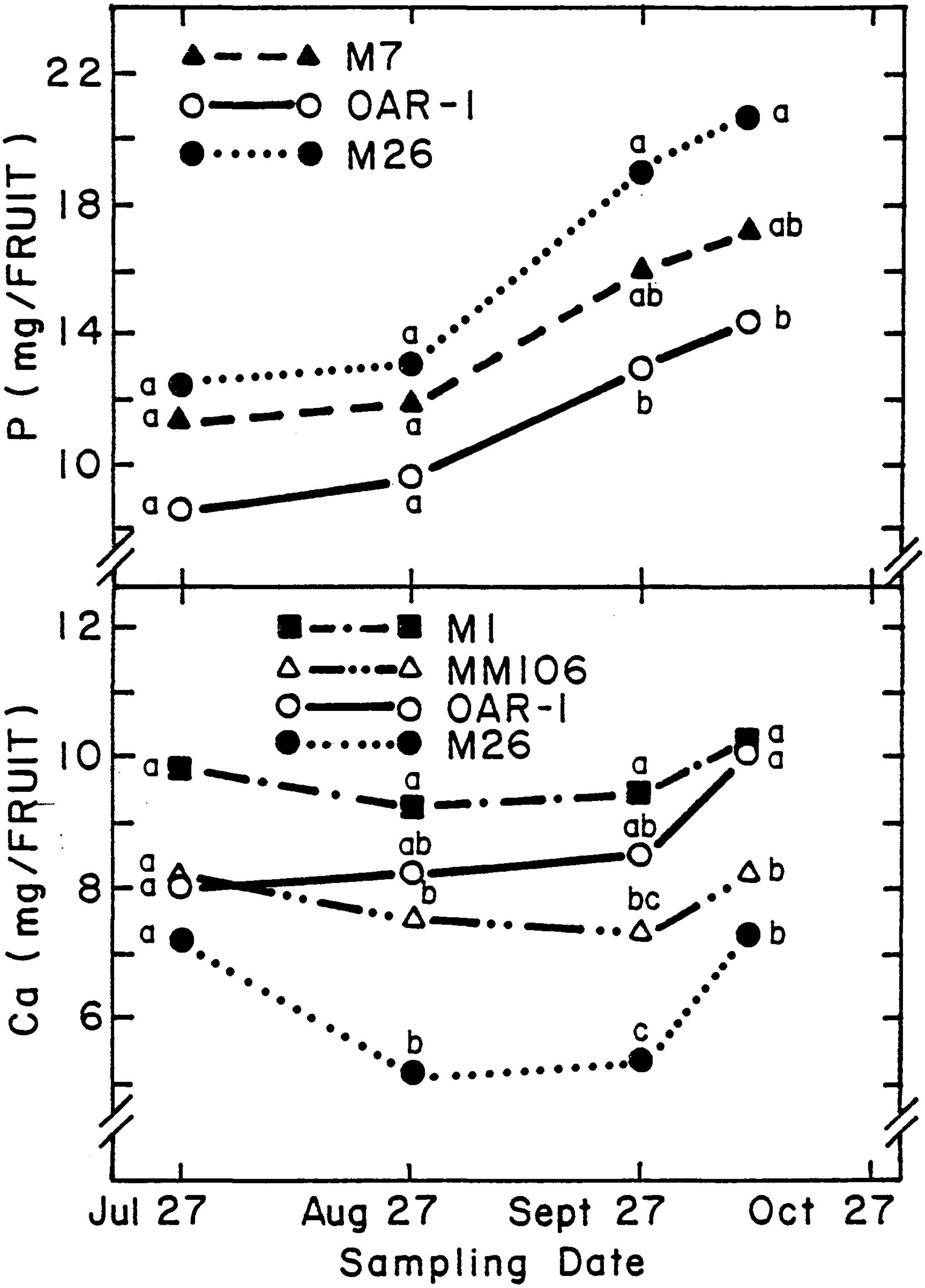
▲ M7
○ OAR-1
● M26
P (mg/FRUIT)
22
18
14
10
a
a
a
a
a
a
a
ab
b
a
ab
b
■ M1
△ MM106
○ OAR-1
● M26
Ca (mg/FRUIT)
12
10
8
6
a
a
a
a
a
ab
b
b
a
ab
bc
c
a
a
b
b
Jul 27
Aug 27
Sept 27
Oct 27
Sampling Date

Figure 4.16

Figure 4.17. 1981 seasonal fruit Mg content (mg per fruit) and Fe content (ug per fruit) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean seperation within dates by Duncan's multiple range test, 5% level.

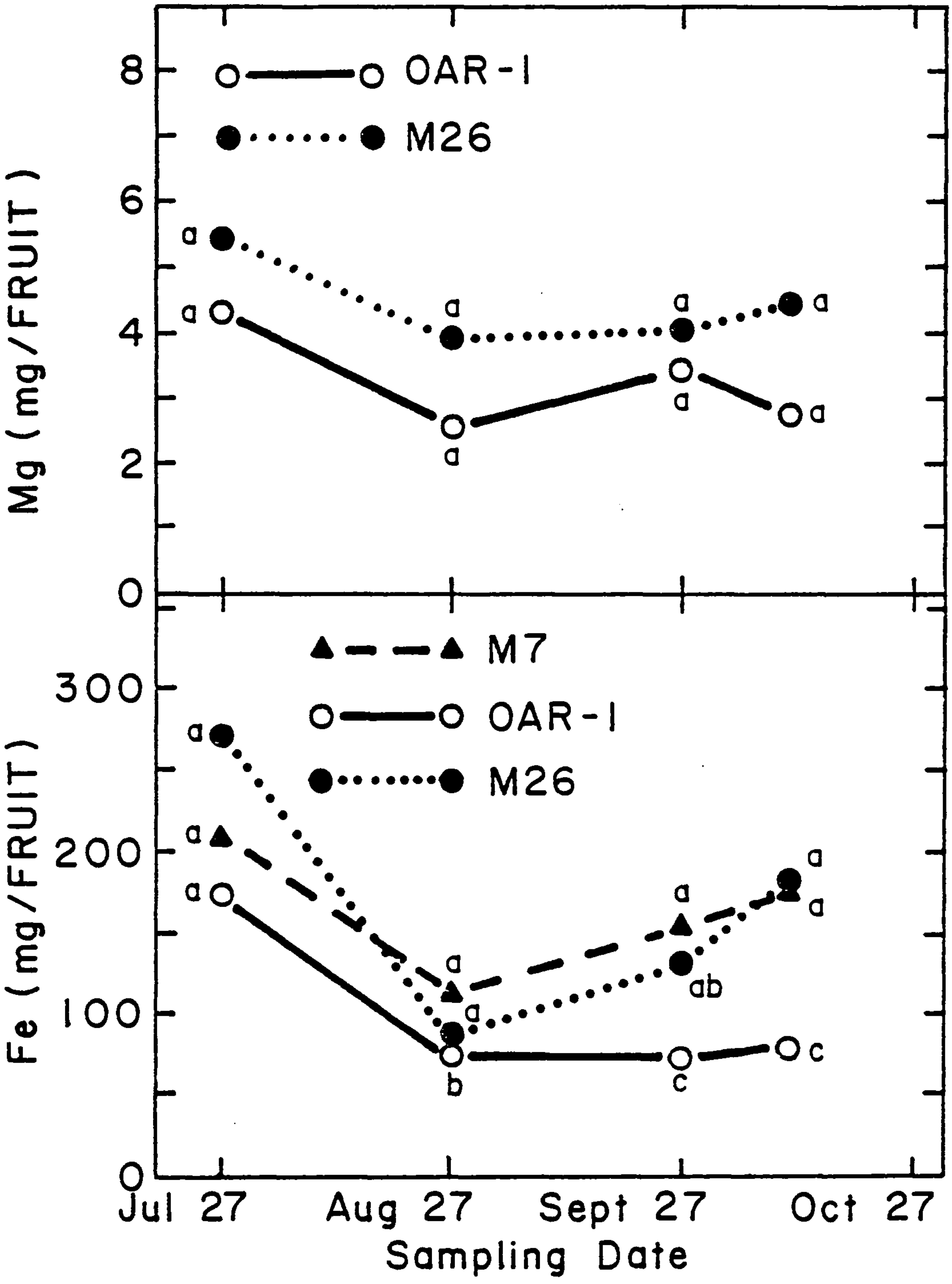
OAR-I
M26
Mg (mg/FRUIT)
8
6
4
2
0
a
a
a
a
a
a
a
a
M7
OAR-I
M26
Fe (mg/FRUIT)
300
200
100
0
a
a
a
a
a
a
b
a
ab
c
a
a
c
Jul 27
Aug 27
Sept 27
Oct 27
Sampling Date

Figure 4.17.

Figure 4.18. 1981 seasonal fruit Cu and B content (expressed as ug per fruit) of 'Starkspur Golden Delicious' apple as influenced by rootstock. Rootstock mean seperation within dates by Duncan's multiple range test, 5% level.

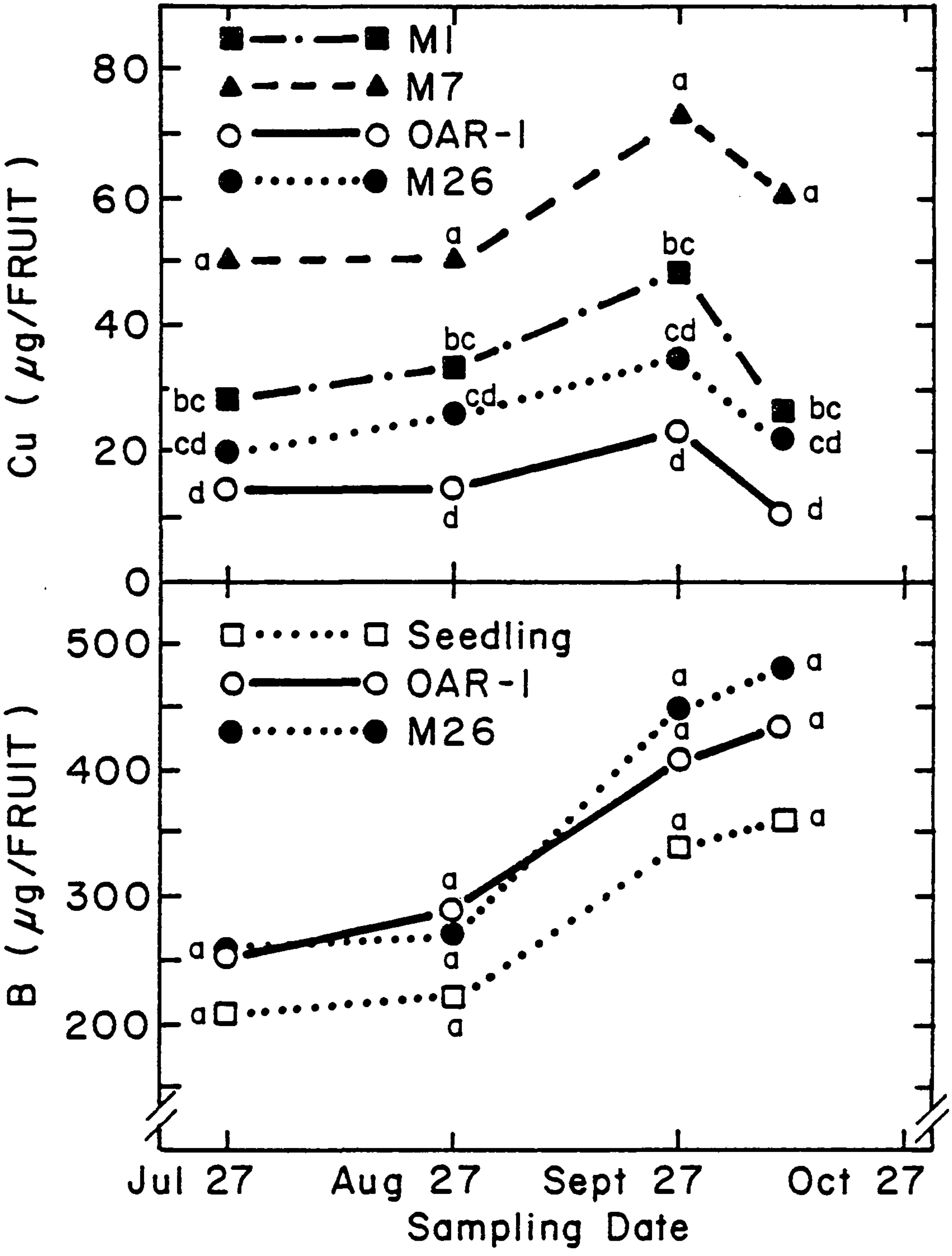
M1
M7
OAR-1
M26
Cu (µg/FRUIT)
0
20
40
60
80
a
bc
cd
d
Seedling
OAR-1
M26
B (µg/FRUIT)
200
300
400
500
Jul 27
Aug 27
Sept 27
Oct 27
Sampling Date

Figure 4.18

Figure 4.19. 1981 seasonal fruit N content (mg per fruit) of 'Starkspur Golden Delicious' apple as influenced by N fertilizer. Low level N is different than high level within dates if shown by *(5%) or **(1%).

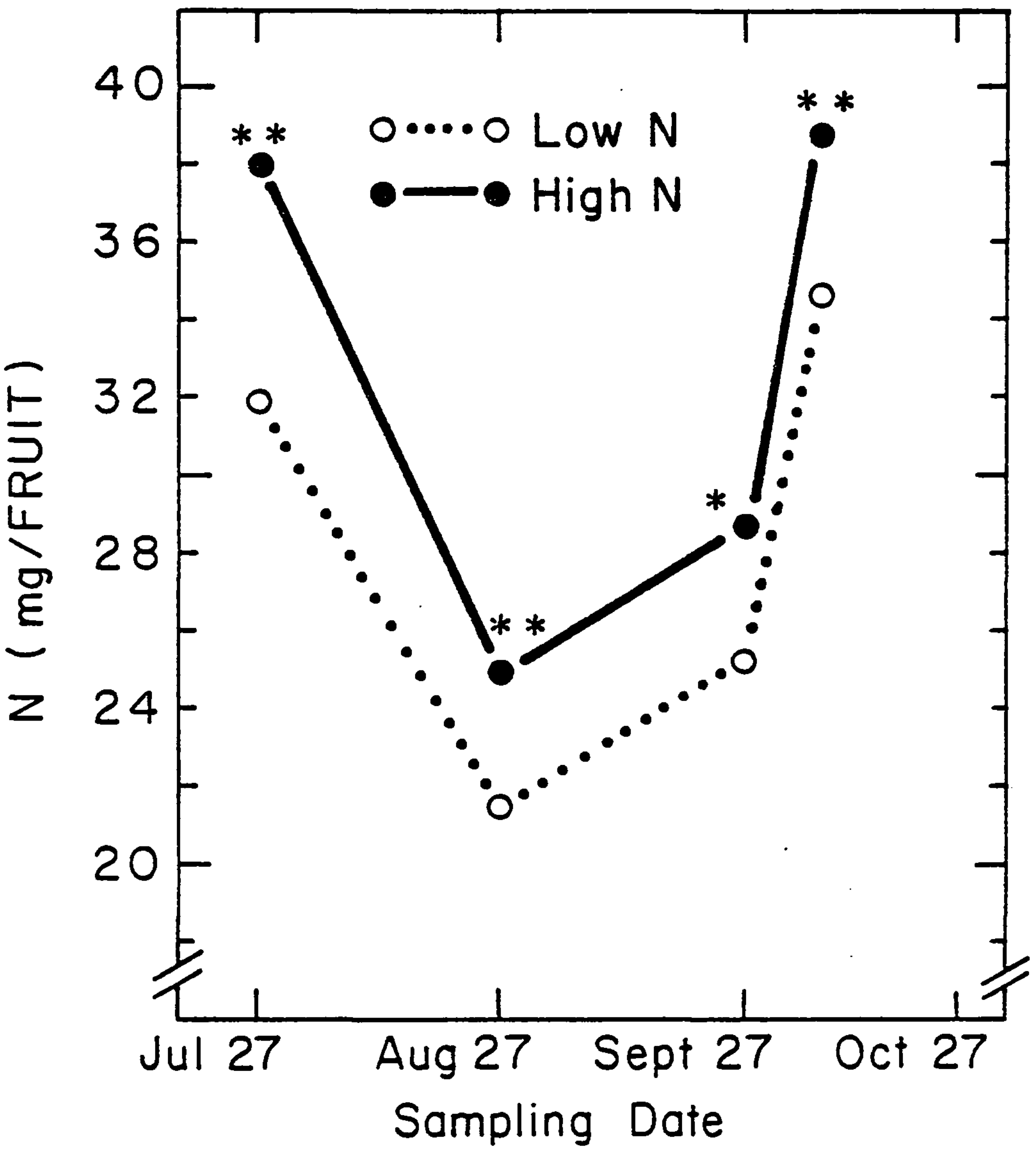
Low N
High N
40
36
32
28
24
20
N (mg/FRUIT)
Jul 27
Aug 27
Sept 27
Oct 27
Sampling Date
* *
* *
*
* *

Figure 4.19

Figure 4.20. 'Starkspur Golden Delicious' apple fruit shape (Length/Diameter ratio) changes during seasonal development as influenced by rootstock. Rootstock mean seperation within dates by Duncan's multiple range test, 5%.

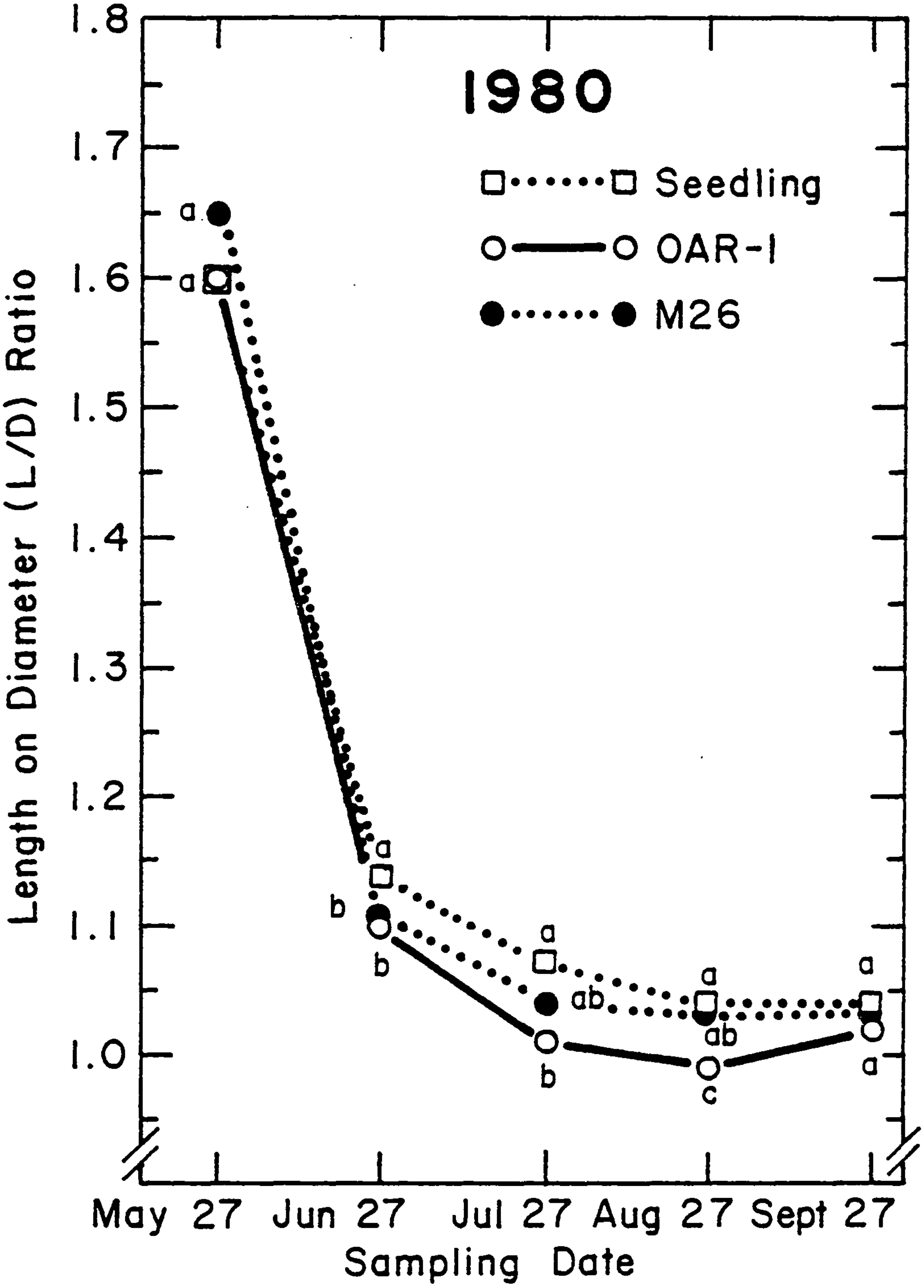
1980
Seedling
OAR-I
M26
Length on Diameter (L/D) Ratio
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
May 27
Jun 27
Jul 27
Aug 27
Sept 27
Sampling Date
a
a
a
b
b
a
ab
b
a
ab
c
a
a

Figure 4.20

Figure 4.21. 1981 seasonal changes in dry weight concentrations (expressed as % fresh weight) of 'Starkspur Golden Delicious' apple fruit as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

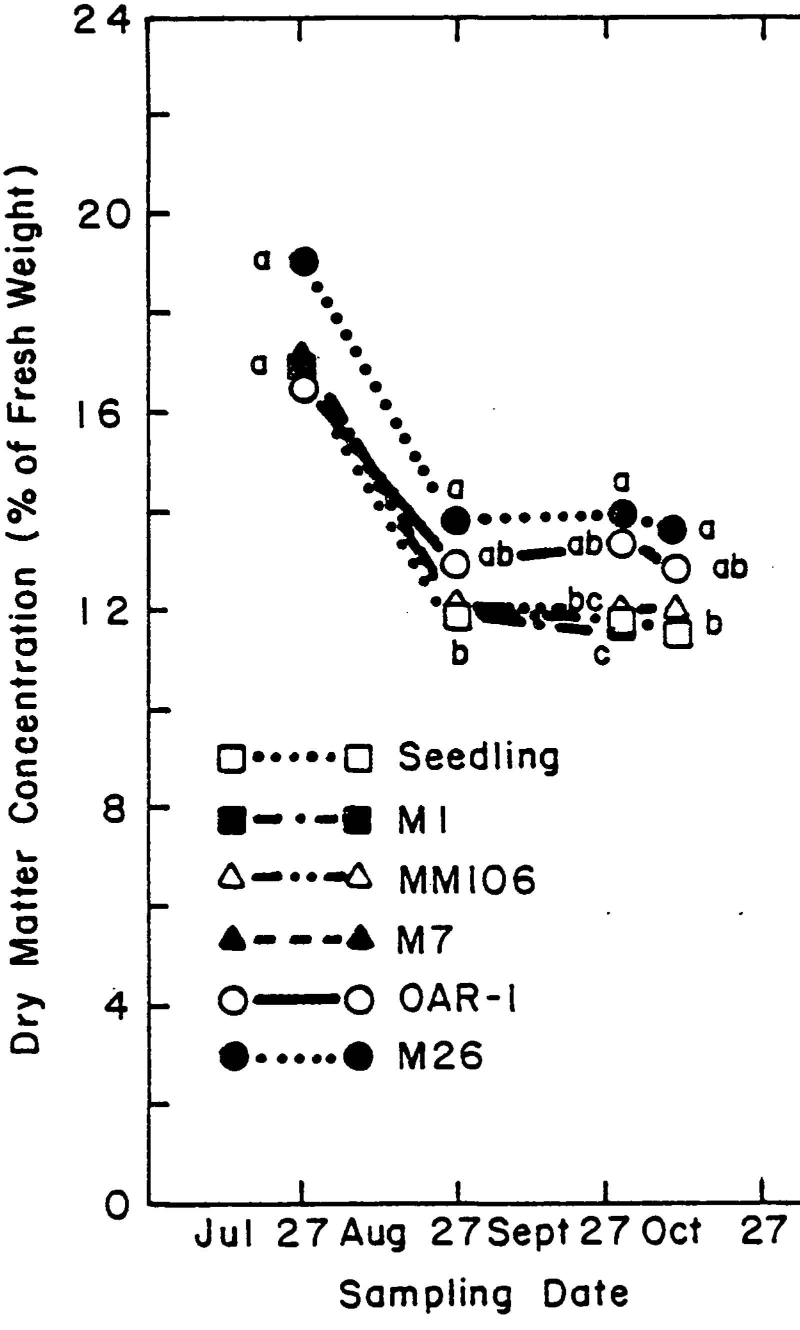
Dry Matter Concentration (% of Fresh Weight)
24
20
16
12
8
4
0
Jul 27
Aug 27
Sept 27
Oct 27
Sampling Date
a
a
a
ab
ab
b
a
ab
bc
c
a
ab
b
Seedling
M1
MM106
M7
OAR-1
M26

Figure 4.21

Table 4.1 1981 seasonal mineral concentration (expressed as mg or ug per 100g fresh weight) of 'Starkspur Golden Delicious' apple fruit as influenced by rootstocks and soil applied urea.

	N (mg/100g Fr. wt.)				K (mg/100g Fr. wt.)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	56.1a[z]	23.9a	21.2a	24.5a	127.5a	73.6a	75.8b	68.6b
M1	57.3a	22.4a	21.9a	24.6a	140.1a	79.6ab	84.8b	76.6b
MM106	57.6a	24.7a	23.3a	25.7a	134.4a	83.1ab	84.4b	75.2b
M7	61.5a	25.6a	22.0a	23.1a	143.0a	82.0ab	83.9b	80.3ab
OAR-1	47.7a	20.1a	17.5a	22.6a	115.2a	75.5b	77.0b	75.4b
M26	59.7a	25.4a	21.2a	26.6a	149.3a	88.1a	95.1a	91.7a
Levels[y] of N								
Low N	52.6[y]	22.0	20.1	23.1	134.3	80.7	84.5	77.1
High N	60.7**	25.3**	22.3**	25.9**	135.5	79.9	82.5	78.8

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of N (zero N/4 trees) is significantly different from high levels (68g actual N as urea/4 trees) if shown by *(5%) or by **(1%).

Table 4.1 continued

	P (mg/100g Fr. wt.)				Ca (mg/100g Fr. wt.)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	18.0a[z]	11.7a	12.6a	11.0a	12.7bc	8.3abc	7.1ab	6.8ab
M1	18.8a	11.1a	12.6a	11.3a	15.8a	9.2ab	7.3ab	6.7ab
MM106	18.2a	12.4a	12.7a	11.5a	13.2abc	8.0bc	6.2ab	5.7bc
M7	18.9a	11.8a	12.3a	11.2a	12.3bc	7.0c	5.5bc	5.7bc
OAR-1	16.1a	11.5a	12.0a	11.3a	15.0ab	9.8a	8.0a	8.2a
M26	18.4a	11.9a	12.6a	11.8a	10.9c	5.1d	4.0c	4.3c
Levels[y] of N								
Low N	17.9[y]	11.9	12.8	11.5	13.4	8.0	6.7	6.3
High N	18.2	11.5	12.2	11.2	13.3	7.7	6.0	6.1

Table 4.1 continued

	Mg (mg/100g Fr. wt.)				Fe (ug/100g Fr. wt.)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	7.0a^{z}	3.1a	2.5a	2.7a	316a	93a	89ab	91abc
M1	7.5a	3.5a	3.1a	2.4a	372a	88a	107a	84bcd
MM106	8.1a	2.7a	2.8a	2.0a	229a	86ab	93a	78cd
M7	7.8a	3.2a	2.8a	2.3a	336a	109a	114a	113a
OAR-1	7.9a	3.1a	3.2a	2.1a	329a	56b	67b	63d
M26	8.1a	3.6a	2.7a	2.5a	400a	79ab	88ab	104ab
Levels^{y} of N								
Low N	7.8^{y}	3.1	2.7	2.6*	322^{y}	79	94	84
High N	7.7	3.3	3.0	2.1	339	91	92	95

Table 4.1 continued

	Cu (ug/100g Fr. wt.)				B (ug/100g Fr. wt.)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	39cd^z	23d	30cd	17bcd	341a	229c	250c	233c
M1	46bc	32b	36bc	17bc	392a	244c	277bc	258bc
MM106	54b	36b	43b	23b	410a	292b	306b	282b
M7	81a	50a	56a	38a	364a	245c	259bc	255bc
OAR-1	27d	17d	21d	8d	470a	342a	382a	347a
M26	30d	24cd	23d	10cd	389a	247bc	296bc	275bc
Levels^y of N								
Low N	47^y	30	36	19	396	271	297	267
High N	46	31	34	18	393	262	293	283

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CHAPTER 5

EFFECTS OF ROOTSTOCK, K, AND N FERTILIZERS ON ENDOGENOUS ETHYLENE OF ATTACHED AND DETACHED FRUITS OF 'STARKSPUR GOLDEN DELICIOUS' APPLES DURING MATURATION[1]

Esmaeil Fallahi[2] and Daryl G. Richardson[3]

Department of Horticulture, Oregon State University, Corvallis,
Oregon 97331

Additional index words: *Malus domestica*, maturity indices, Seedling, M1, MM106, M7, OAR-1, M26, High density.

Abstract: Endogenous ethylene of attached and detached fruit of 'Starkspur Golden Delicious' apples as influenced by six rootstocks: Malling (M)1 M7, M26, Malling Merton (MM)106, OAR-1, Seedling, two levels of soil K applications and two levels of soil N applications were measured during maturation for two years (1980-81).

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[2] Graduate Research Assistant, partially supported by Ferdowsi University, Mashhad, Iran.

[3] Associate Professor, to whom reprint requests may be made.

Endogenous ethylene in the fruits was less than 0.1 ppm in late September and early October and began to rise between October 9 and October 15. Ethylene increased in all treatments almost at the same time in 1980. But in 1981, ethylene in the fruits on OAR-1 began to increase nine days later than all other rootstocks. However, concentration of ethylene in the fruits on OAR-1 was lower than in fruits on all other rootstocks in late October 1980, and during all storage sampling intervals of 1981. These fruits always had the lowest evolved ethylene. This low ethylene in relation to fruit chemical composition is further discussed. Scion fruits on MM106 had about 10% less internal ethylene than those on M26 and M7 after mid-October of both years. Fruits on M26 had at least 25% higher concentrations of internal ethylene than those on Seedling, OAR-1, MM106 and M1 in late season of 1980 and had the highest internal and evolved ethylene during maturation and after harvest of 1981. Thus, fruits on M26 could be considered more advanced in maturity although the highest ethylene in 1981 was related both to the lowest yield and rootstock influence. No consistent significant influence of K or N applications was found, however, high N applications resulted in significantly higher ethylene evolution after harvest than did low N treatments.

Introduction

Ethylene has been studied in the tissue of various higher plants and particular attention has been given to the role of ethylene relative to the onset of pome fruit climacteric physiology. Many researchers have studied the precursors and pathways of ethylene biosynthesis (1,2,10). Others have studied the action of ethylene on the physiology of fruit ripening (3,4,5,6,7,11,17) and the triggering ethylene concentration (6). Only recently has attention been paid to the determination of internal ethylene prior to harvest on the attached fruits as a maturity index (8). Dilley (8) has designated various ranges of internal ethylene and recommended appropriate storage duration and marketing strategies for the fruits having internal ethylene in each range. In this research, endogenous ethylene of attached and detached 'Starkspur Golden Delicious' apples on various rootstocks in combination with N and K fertilizer treatments from a high density orchard were studied to determine possible effects on maturity as determined by the rise in internal ethylene. Thus, such a study would add information about the effect of various rootstocks on the maturity and prediction of storage life relative to fruit ethylene concentrations and would help in the determination of harvesting time.

Materials and Methods

Details of the planting and the experimental design and statistical analysis were described in Chapter III.

One average size fruit from each tree (four trees per replication; six replications for each treatment) was selected and tagged for identification at about 1.65 m height from the ground (all fruits were located in a line on the south side of each hedgerow, in order to minimize the variations of fruit size and location in each tree).

A preliminary test showed no significant differences between the tagged and multiply punctured fruits from which endogenous ethylene samples were taken periodically and unpunctured fruits; nevertheless, the amount of multiply punctured fruits was slightly higher than unpunctured ones (0.81ppm ± 0.60 in punctured vs. 0.69 ppm ± 0.58 in unpunctured). Thus ethylene samples were taken several times from the same apple starting at mid-September in 1980 and early October in 1981 through early November of both years. In 1980 sample sizes for ethylene involved a total number of 96 fruits from the trees on each rootstock and 288 fruits from each level of K or N fertilizer. In 1981 a total of 48 fruits for each rootstock and 144 for each level of low or high N fertilizer was tested at each time of ethylene sampling.

Internal ethylene was sampled near the mid-line between stem and calyx each time and the needle puncture holes were marked.

The next sample was taken a few days later about 2 cm away from the previous mark on the same diameter. Needles were pushed down close to the core line (about 2cm) then pulled back about 0.75 cm and after five seconds the endogenous gas of the flesh intercellular space was collected in the 1cc plastic syringes. Needles were sealed by insertion into rubber septum material. Each syringe was identified as to location, treatment and tree number, and was immediately carried in a cooler to the laboratory where samples were injected in a gas chromatograph (Carle Analytical Gas Chromatograph Model 312). After every sampling, syringes and needles were washed, rinsed and vaccum treated overnight to remove any ethylene absorbed in the syringes and to prevent any growth of fungi due to residual flesh.

In addition to the regular analysis of variance, six ranges, based on Dilley's (8) recommendations were designated for the amount of ethylene produced, and number of fruits from each treatment which would fall in each of these ranges were calculated for four days of sampling when internal ethylene began to change. Dilley's (8) recommendations suggest suitable storage for fruits within each range of internal ethylene as follows:

No. of Fruits	Fruit Ethylene	Suggested Action
10 out of 10	Less than 0.1 ppm	May delay harvest for better size, color and quality.
3 out of 10	0.1 to 0.5 ppm	Suited for long-term CA. 'CO_2 treatment' maximally effective
3 out of 10	0.5 to 1 ppm	Suited for mid-term CA. 'CO_2 treatment' marginally effective
3 out of 10	1 to 5 ppm	Suited for short-term CA. 'CO_2 treatment' ineffective.
3 out of 10	5 to 10 ppm	Suited for up to 4 months of refrigerated or Ca storage.
3 out of 10	More than 10 ppm	Suited for short-term storage and processing.

Based on this recommendation (8) we should have had 29 fruits for each rootstock and 86 fruits for each level of K or N treatment at each sampling in 1980, and 14 fruits for each rootstock and 43 fruits for each level of N fertilizer in 1981. This would meet the 3/10 ratio in each of Dilley's (8) designated ranges.

In addition to internal ethylene, in December 1981, duplicate 9 fruit composites of each treatment at the commercial harvest date (October 10) were measured for evolved ethylene. Apple fruits were placed in four liter glass respirometer jars at 20°C with 200 ml/min air flow. One ml gas sample from the outlet tube was injected into a gas chromatograph equipped with a flame ionization detector to measure ethylene.

Results and Discussion

General Trends: The changes in endogenous ethylene during maturation of 'Starkspur Golden Delicious' apple fruits in 1980 and again in 1981, are shown in Figures 5.1 and 5.2. Ignoring the rootstock effects for the moment, it will be seen that internal ethylene began to rise between September 30 and October 12 in both years, and that the increase was logarithmic over time, at least during the maturation period. Figure 5.1 shows that prior to September 30, 1980, ethylene was less than 0.01 ppm and nearly constant at that low concentration. Although it is not shown in Figure 5.2, the same thing happened in 1981, but intensive sampling was begun only after a few samples started to show greater than .01 ppm ethylene. Fruits harvested at these early stages in both years (October 2, 1980; and September 30, 1981) were immature not only with respect to internal ethylene, but also the other desirable eating and marketing qualities were not yet fully developed (Chapter 6).

Prior to October 9 (in both 1980 and 1981), the internal ethylene concentration was so low that the fruits were all ranked as too immature for any storage condition (Tables 5.1 and 5.2). Furthermore, a substantial increase in the fruit weight (about 18g/fruit or 12% increase) between early and late October harvested fruits occurred (Chapter 4). This suggests that it would be possible to delay fruit harvest until later in order to gain higher yield at a time when eating quality is still improving.

After October 9, the fruits in 1980 were mature enough for long-term CA storage through October 22. However, in 1981, it was only after October 22 that scion fruits on M26 were the only fruits mature enough for long-term CA storage. Fruits on all other rootstocks were still too immature (Tables 5.1 and 5.2). In 1980, the progression from range 2 through range 3 and 4 occurred up to October 28, whereas during the same time in 1981, the fruit internal ethylene progressed rapidly from range 1 on October 21 well into range 6 on October 28, except for OAR-1 rootstock which only progressed to range 4. Furthermore, Tables 5.1 and 5.2 show that the proportion of fruits with higher ranges of ethylene compared to range 1 (low range) ethylene after mid-October of 1981, was generally higher than that of 1980. Thus, at the same calendar date of October 28, more advanced maturity of fruits existed in 1981 than in 1980. It is possible that higher overall temperature particularly after mid-October 1981 (Fig. 5.3) stimulated endogenous ethylene synthesis compared to 1980.

After storage at 0°C for three months, then ripening at 20°C, evolved ethylene increased to a maximum after one week, then decline for fruits from most rootstocks (Fig. 5.4) and fertilizer treatments (Fig. 5.5) in 1981.

Effects of Weather: Some irregularities in the internal ethylene curves for both 1980 (Fig. 5.1) and 1981 (Fig. 5.2) are worth pointing out. In both years, the internal ethylene samples drawn on October 15, showed a decrease or at least a slowdown in rate compared to previous and subsequent samples. It appears that this was related to low temperatures prevailing in the orchard between October 11 and October 15 (Figure 5.3) in both years. If this effect of prevailing temperatures on internal ethylene is genuine, this implies that some caution must be exercised in assigning fruit to certain storage strategies based exclusively on internal ethylene in the 0.1 ppm range as the fruit could in fact be in a more advanced physiologic maturity state than is indicated by internal ethylene. Further attention should be directed at this possible effect of temperature in future studies utilizing internal ethylene as a basis for characterizing fruit maturation. A similar effect of temperature was observed by Walsh and Kender (18) in the internal ethylene of 'McIntosh' apple shoot and spur.

Effects of Rootstocks: Internal ethylene was very low (< 0.01 ppm) in fruits from all rootstocks in early October and no significant rootstock differences were observed up to October 10, 1980 and October 12, 1981 (Figures 5.1 and 5.2). Considerable variation was found between the fruits on the same rootstock, although a large number of samples were used for each rootstock at each sampling in 1980-81 and despite the fact that we attempted to reduce the variability by sampling only in certain positions of the tree and by sampling only a narrow size range of fruits for ethylene. Had we not sampled in this manner, fruit positional effects of the tree as reported by Farhoomand and Patterson (9) would have been a major factor in ethylene variability. Despite variations, the differences between rootstocks was great enough that it was apparent in the statistical analysis for most sampling dates (Figs. 5.1 and 5.2).

The rise in fruit internal ethylene on OAR-1 rootstock was not as rapid as for the other rootstocks in either 1980 (Fig. 5.1 or 1981 (Fig. 5.2). In 1981, the slower rise in internal ethylene of fruits on OAR-1 was most dramatically shown (Fig. 5.2). Internal ethylene of these fruits rose nine days later than other rootstocks in 1981. Furthermore, fruits on OAR-1 consistently had the highest number of fruits with range 2 ethylene in 1980 and with range 1 ethylene in 1981 until October 28 (Tables 5.1 and 5.2) and were thus suited for long term CA storage. After October 28, these fruits were still suited for long-term storage in 1980 (ranked at range 2) and short-term storage in 1981 (ranked at range 4). This indicates the delay in internal ethylene onset as a maturity index for scion fruits on OAR-1 rootstock. In terms of other maturity indices, scion fruits on OAR-1 usually had the highest soluble solids and yellowest skin color, yet had the firmest flesh values at different harvest times (Chapter 6). It has been suggested that B forms polyhydroxy compounds with cell wall components, which raise the stability of the cell wall (12). Therefore, high concentrations of B in the fruits on OAR-1 (Chapter 4) could be responsible for the greater firmness (r=0.31) of these fruits at harvest (Chapter 6). Thus, there may be some relationship between these firmer cell wall structures with the ethylene producing enzyme systems, as has been implicated by the studies of Strand and Mussell (15) and Strand et al. (16) and as we found a correlation coefficient of -0.47 between fruit B and endogenous ethylene in OAR-1 rootstock.

Fruits on MM106 usually had lower internal ethylene than most other rootstocks except OAR-1 (Figs. 5.1-5.2). Positive correlations were found between fruit size and ethylene production most of the time, although these correlations were not always very high. Thus, relatively small scion fruits (Chapter 4) seem to somehow be related to the low internal ethylene production in OAR-1 (r=0.18) and MM106 (r=0.53).

Fruits from seedling and M26 fruits generally were among the highest in internal ethylene compared to other rootstocks (Figs. 5.1 and 5.2). At the October 28, 1980 sampling, scion fruits on seedling, M1 and MM106 were ranked midway between range 3 and 4 in internal ethylene, whereas M7 and M26 were classed as range 4. Thus fruits on these rootstocks would have been suited for mid-term to short-term Ca storage. On October 28, 1981, internal ethylene of fruits on all rootstocks, except OAR-1, ranked at range 6 (more than 10 ppm), thus were suitable for short-term storage and processing or immediate marketing (Tables 5.1 and 5.2).

Scion fruits on M26 had higher endogenous ethylene and more fruits with the higher range of ethylene than those on M1, MM106, Seedling and OAR-1 after October 22, 1980 and had the highest ethylene in 1981 (Figs. 5.1 and 5.2). Therefore, it could be concluded that M26 enhances maturity of 'Starkspur Golden Delicious' apples. However, a lighter crop (larger fruits) from trees on M26 in 1981 was definitely responsible in part for the earlier maturity of the scion fruits. Thus, high levels of internal ethylene in scion fruits on M26, had a positive correlation with the fruit size ($r > 0.69$). In addition, low concentrations of Ca in these fruits in 1981 had always significantly negative correlations with endogenous ethylene ($r < -0.60$). In addition to the case in the scion fruits on M26, a small negative correlation was found between fruit Ca and internal ethylene of fruits on all other rootstocks and fertilizer treatments in both 1980 and 1981. One might speculate that higher Ca interacts in some way to restrict ethylene synthesis, but the mechanism by which this might occur is not yet characterized. Whether higher Ca means tighter control on membrane permeabilities, or is tying up (binding) ethylene precursors such as methionine, S-adenosylmethionine, or ACC or whether there are direct effects on the enzymes synthesizing ethylene, are some interesting questions and alternative possibilities that need to be researched in the future.

Evolved ethylene after three months of storage (from the incubated fruits in the jars) confirmed the field endogenous sampling. Thus, fruits on OAR-1 had always the lowest evolved ethylene while those on M26 were the highest (Fig. 5.4). Other rootstocks had intermediate concentrations of evolved ethylene. Decline of ethylene in fruits on all rootstocks occurred after one week except those on M7 and M1 in which decline started after nine days (Fig. 5.4). Relatively higher nitrogen levels of fruits of M7 and M1 (Chapter 4) could mean a higher concentration of cytokinin in these fruits resulting in later senescence of fruit tissue.

Effects of Fertilizers. As soon as ethylene started to rise, fruits receiving higher soil applications of K always had higher production of endogenous ethylene during maturation and this difference in comparison with the fruits of low K treatment was statistically significant at the end of the season (Appendix Table C.1). Had we prevented the cross feeding and probable root grafting between low and high K applied plots, we could have seen more increase in endogenous ethylene as a result of high K application. No significant influence of nitrogen fertilizer was found in 1980, but in 1981, attached fruits with higher application of nitrogen occasionally had relatively higher concentrations of endogenous ethylene. High N treated fruits always had significantly higher concentrations of evolved ethylene as compared to the fruits with low N application (Fig. 5.5). Slightly higher respiration was found in the fruits with higher applications of nitrogen as compared to those with lower N application at most harvest times of 1980 and 1981, although the differences were never statistically significant (Appendix Table D.1). A much higher rate of respiration as a result of higher nitrogen application was found by Southwick (14). Higher ethylene production as a result of higher nitrogen in this study is the factor which is most likely to have stimulated respiration. However, the mechanism by which increased nitrogen enhances ethylene is not known at this time. It is possible that nitrogen by itself does not affect ethylene but it may have some influence by interacting with the concentrations of other mineral elements in the fruits. Another possibility is that nitrogen enhances auxin concentrations in the fruits and thereby increases the auxin-induced ethylene production. Still another possibility is that higher N may generally elevate enzyme concentrations thus magnifying their effects.

General Discussion: Results of preliminary tests showed that accumulation of ethylene in the flesh occurs at the same time as in the core cavity but concentrations of ethylene in the core were about 30% higher than flesh. Recommendations of Dilley (8) were based on the core ethylene concentrations; therefore, we could have expected somewhat higher ranges of ethylene if we had taken our samples from the core instead of flesh. The timing for ethylene rise would not be different by either method. Thus, we can expect that internal ethylene of flesh increased paralleling that of the core cavity, but at slightly lower concentrations which might have established some fruits in higher ranges than we have reported. Therefore, the results of this research can be compared with recommendations of Dilley (8) if the factor of lower concentrations of ethylene in the flesh as compared to ethylene of core cavity is taken into account.

It will be of interest to look at the simultaneous seasonal changes in the roots, wood, spurs and fruits from trees on several rootstocks and to find the pattern and distribution of ethylene in the tree before and during the fruit maturation. Research in this area is new and limited. Walsh and Kender (18) observed high internal ethylene in two year wood of spur and non-spur strains of 'Delicious' and 'McIntosh' early in the season which subsequently declined. It is possible that there is a translocation of ethylene precursors or stimulators of enzymes from the shoots in to the fruits. By the time spur internal ethylene declines, fruits start to produce ethylene. If such a translocation system could be shown to exist, the ripening of attached fruits from trees on each rootstock would depend on the interactions between ripening inhibitors in the scion leaves (13) and the translocated systems which stimulate ethylene in the fruit.

Future research in the physiology and ethylene producing system of fruits on OAR-1 rootstock and mechanism of nitrogen fertilizer interactions would be of interest.

Lighter cropping enhances earliness and the earlier ethylene rise must be taken into account when determining the optimum harvest time. Fertilizer, particularly nitrogen, applications and mineral content of fruit affect ethylene evolution particularly after storage. Thus applications of nitrogen only as much as is needed (perhaps about 2% of dry weight leaf N) is a very important factor in keeping quality of apples and warrants further investigation.

Figure 5.1. 1980 Endogenous ethylene (PPm) during maturation of 'Starkspur Golden Delicious' apple fruit as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

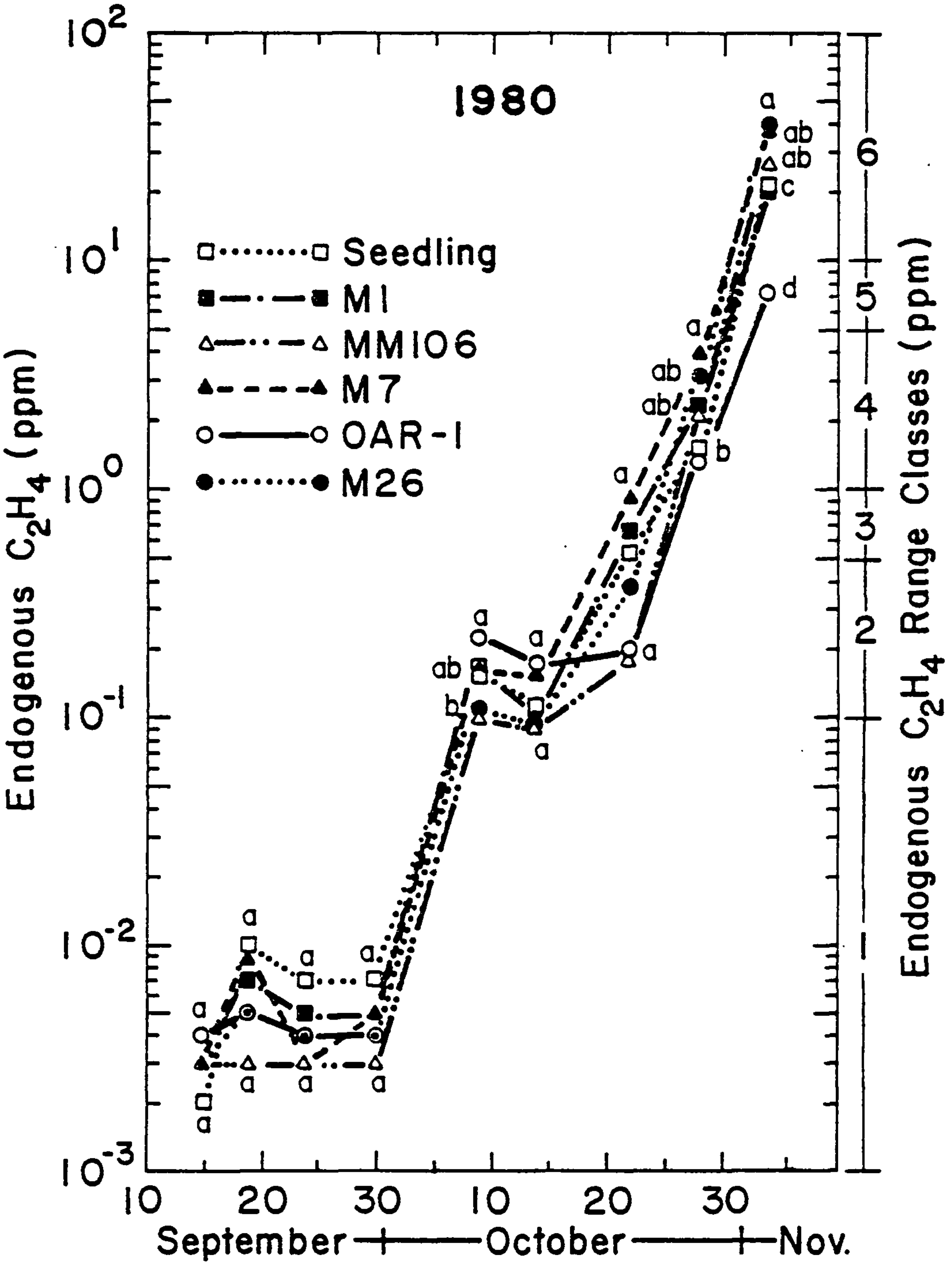

1980
Seedling
M1
MM106
M7
OAR-1
M26
Endogenous C_2H_4 (ppm)
Endogenous C_2H_4 Range Classes (ppm)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
10
20
30
10
20
30
September
October
Nov.
a
ab
ab
c
d
a
ab
ab
b
a
a
a
a
ab
b
a
a
a
a
a
a
a
a
a
a

Figure 5.1

Figure 5.2. 1981 endogenous ethylene (PPm) during maturation of 'Starkspur Golden Delicious' apple fruit as influenced by rootstock. Rootstock mean separation within dates by Duncan's multiple range test, 5% level.

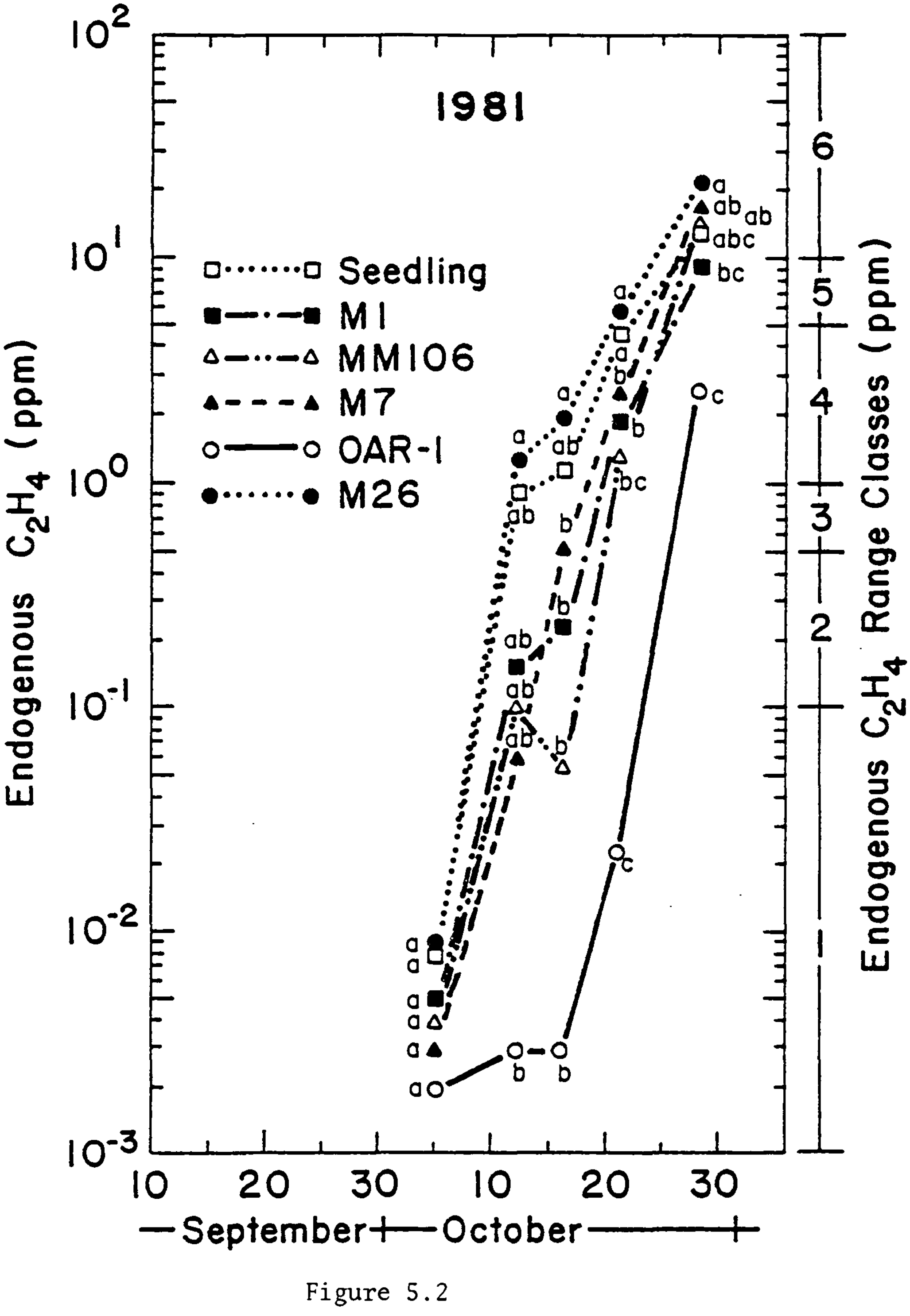
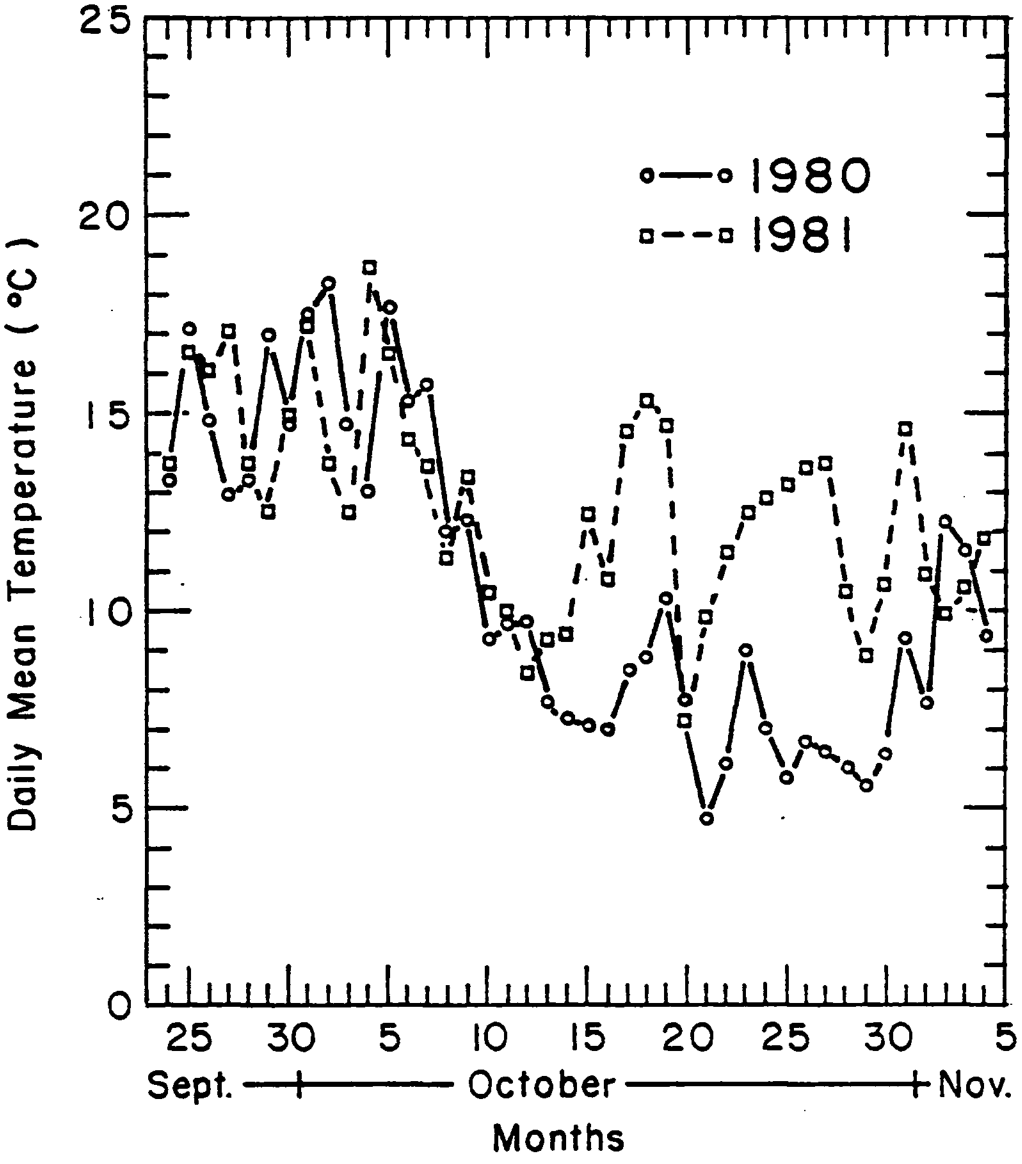

1981
Seedling
M1
MM106
M7
OAR-1
M26
Endogenous C_2H_4 (ppm)
Endogenous C_2H_4 Range Classes (ppm)
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10
20
30
10
20
30
September
October
1
2
3
4
5
6

Figure 5.2

Figure 5.3. Temperature fluctuations in September, October and November 1980 and 1981 (°C).



Daily Mean Temperature (°C)
25
20
15
10
5
0
1980
1981
25
30
5
10
15
20
25
30
5
Sept.
October
Nov.
Months

Figure 5.3

Figure 5.4. Evolved ethylene (uℓ C_2H_4/Kg fruit/hr.) during 20°C ripening of 'Starkspur Golden Delicious' apple fruit harvested October 10, 1981 and stored at 0°C until late December 1981 as influenced by rootstock. Rootstock mean seperation within dates by Duncan's multiple range test, 5% level.

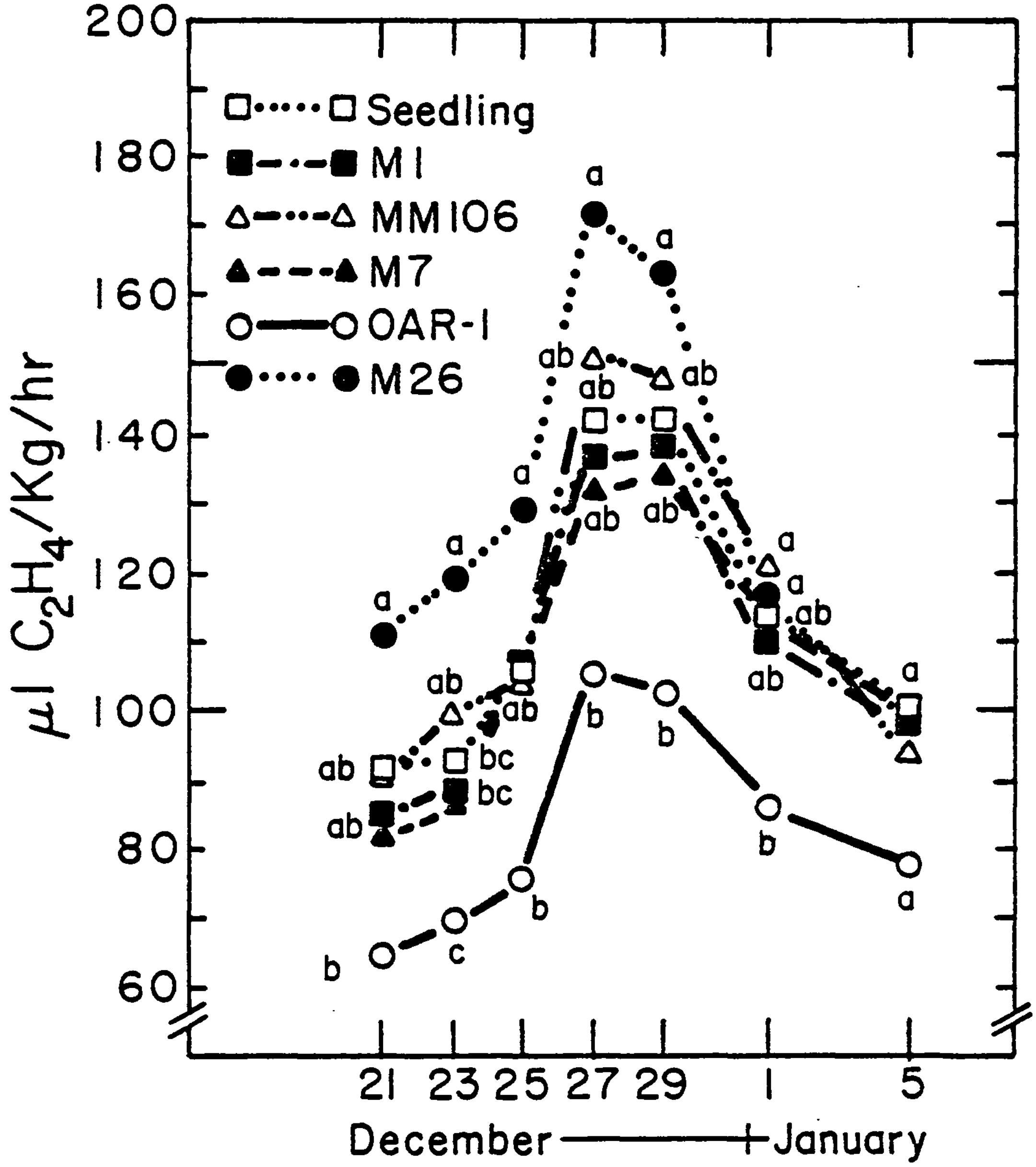

Seedling
M1
MM106
M7
OAR-1
M26
$\mu l\ C_2H_4/Kg/hr$
200
180
160
140
120
100
80
60
21
23
25
27
29
1
5
December
January
a
ab
bc
b
c

Figure 5.4

Figure 5.5. Evolved ethylene (μℓ/Kg fruit/hr.) during 20°C ripening of 'Starkspur Golden Delicious' apple fruit harvested October 10, 1981 and stored at 0°C until late December 1981 as influenced by N fertilizer. Low level of N is significantly different from high level within dates at 1%.

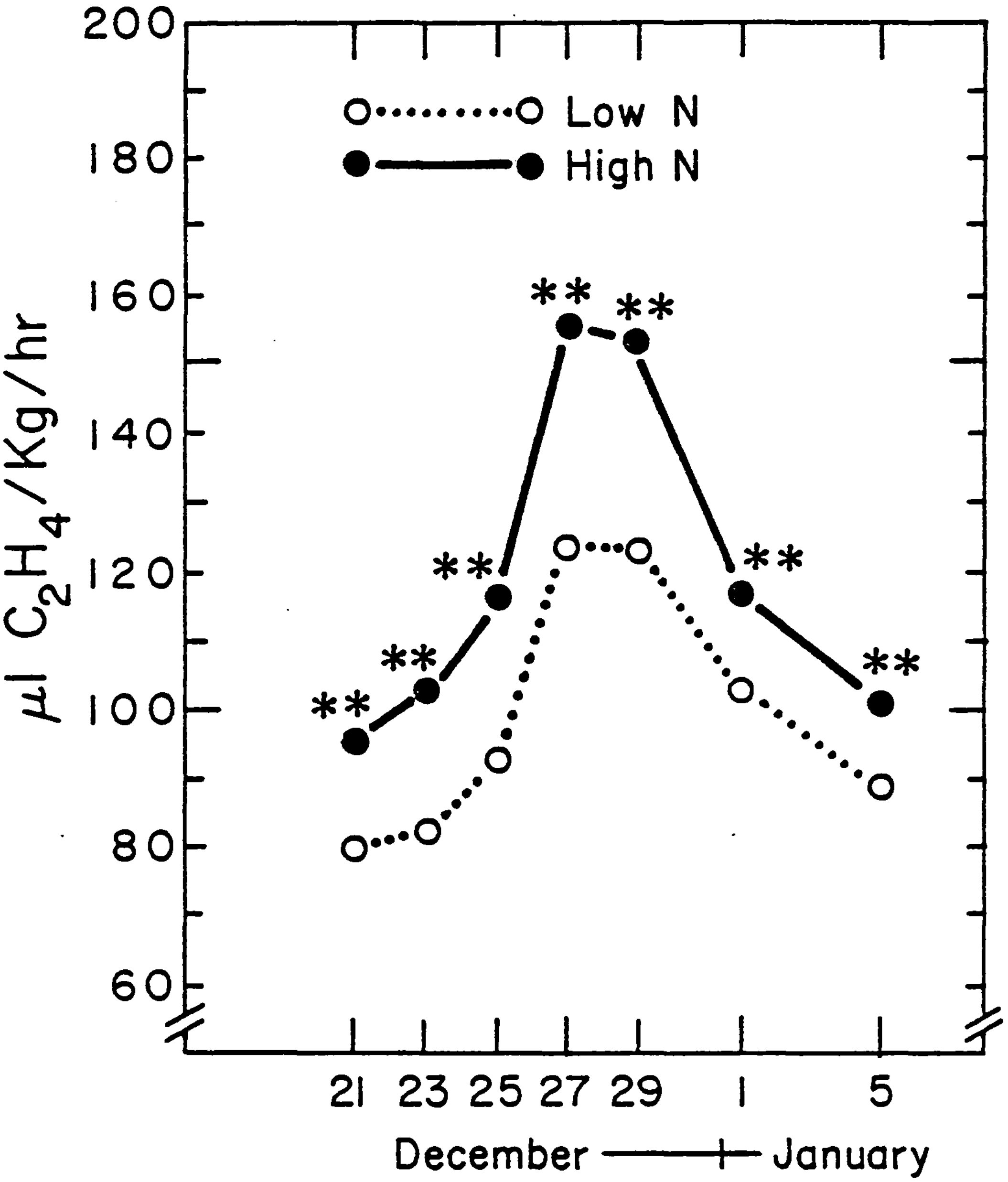

μl C_2H_4/Kg/hr
200
180
160
140
120
100
80
60
Low N
High N
**
21
23
25
27
29
1
5
December
January

Figure 5.5

Table 5.1 Distribution of 'Starkspur Golden Delicious' apple fruits grouped by internal ethylene at four maturity dates (1980) as influenced by rootstock and soil applied K and N. At each sampling date, n = 36 for each rootstock and n = 288 for each level of K or N. R_1 through R_6 refers to internal ethylene ranges (ppm): $R_1<0.1$, $R_2 = 0.1-0.5$, $R_3 = 0.5-1.0$, $R_4 = 1.0-5.0$, $R_5 = 5.0-10$, $R_6>10$. Values in table are numbers of fruit in each range.

	Oct. 9 ethylene ranges						Oct. 4 ethylene ranges						Oct. 22 ethylene ranges					
Rootstock	R_1	R_2	R_3	R_4	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
Seedling	55	39	0	0	1	1	74	22	0	0	0	0	64	27	3	0	0	2
M1	48	45	2	1	0	0	66	29	0	1	0	0	47	42	3	2	1	1
MM106	63	33	0	0	0	0	72	24	0	0	0	0	58	37	0	0	0	1
M7	51	42	1	2	0	0	75	18	0	3	0	0	44	41	5	1	1	4
OAR-1	30	59	6	1	0	0	51	41	3	0	0	1	37	54	4	0	0	1
M26	63	33	0	0	0	0	79	16	0	0	0	1	57	30	7	0	1	1
Levels^z of K																		
Low K	159	114	3	0	12	0	210	72	3	3	0	0	150	120	12	3	0	3
High K	147	129	3	0	6	3	207	78	0	3	0	0	156	111	9	6	0	6
Levels^z of N																		
Low N	150	126	9	0	3	0	204	75	3	6	0	0	141	120	18	6	0	3
High N	162	126	0	0	0	0	213	75	0	0	0	0	165	111	6	0	0	6

^{z}Low K = 0g K/4 trees, high K = 68g actual K as K2SO4/4 trees, Low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees (applied in the soil).

Table 5.1 continued

	Oct. 28 ethylene ranges					
Rootstock	R_1	R_2	R_3	R_4	R_5	R_6
Seedling	32	25	12	22	3	2
M1	32	33	9	13	4	5
MM106	32	25	15	19	3	2
M7	21	19	15	21	9	11
OAR-1	29	43	14	6	1	3
M26	17	20	15	30	7	7
Levels^z of K						
Low K	81	96	36	48	12	15
High K	84	69	42	60	15	18
Levels^z of N						
Low N	72	78	33	66	18	21
High N	90	87	45	45	9	12

Table 5.2 Distribution of 'Starkspur Golden Delicious' apple fruits grouped by internal ethylene at four maturity dates (1981) as influenced by rootstocks and soil N application. At each sampling date, n = 48 for each rootstock and n = 144 for each nitrogen level. R_1 through R_6 refers to internal ethylene ranges (ppm): $R_1<0.1$, R_2 = 0.1-0.5, R_3 = 0.5-1.0, R_4 = 1-5, R_5 = 5-10, $R_6>10$. Values in table are numbers of fruit in each range.

	Oct. 12 ethylene ranges						Oct. 16 ethylene ranges						Oct. 21 ethylene ranges					
Rootstock	R_1	R_2	R_3	R_4	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
Seedling	43	0	0	3	0	2	43	0	0	1	0	4	40	2	0	0	2	4
M1	46	1	0	0	1	0	47	0	0	0	0	1	38	0	0	5	2	3
MM106	46	0	0	2	0	0	46	0	0	1	1	0	43	0	0	3	1	1
M7	46	0	1	1	0	0	43	1	0	1	3	0	35	1	0	2	5	5
OAR-1	48	0	0	0	0	0	48	0	0	0	0	0	47	0	1	0	0	0
M26	40	0	1	4	1	2	37	0	1	4	2	4	33	1	0	3	2	9
Levels[z] of N																		
Low N	141^y	0	0	3	0	0	132	0	0	9	0	3	126	0	0	9	3	6
High N	135	0	0	6	0	3	132	0	0	3	6	3	114	6	0	12	3	9

[z] Low N = 0g N/4 trees, high N = 68g actual N as urea/4 trees (applied in the soil).

Table 5.2 continued

	Oct. 28 ethylene ranges					
Rootstock	R_1	R_2	R_3	R_4	R_5	R_6
Seedling	18	2	2	6	5	15
M1	14	2	2	11	4	15
MM106	23	1	0	3	5	16
M7	14	3	1	3	4	23
OAR-1	24	3	3	11	4	3
M26	3	2	1	8	6	28
Levels^z of N						
Low N	51	6	5	15	17	50
High N	41	6	5	27	9	56

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CHAPTER 6

INFLUENCES OF ROOTSTOCK, K, AND N FERTILIZERS IN A HIGH DENSITY ORCHARD ON 'STARKSPUR GOLDEN DELICIOUS' APPLE FRUIT QUALITY AT THREE HARVEST MATURITIES AND AFTER STORAGE

Esmaeil Fallahi[2] and Daryl G. Richardson

Department of Horticulture, Oregon State University, Corvallis
Oregon 97331

Additional index words: *Malus domestica*, Seedling, M1, MM106, M7, OAR-1, M26.

Abstract: Fruit quality of 'Starkspur Golden Delicious' apples (*Malus domestica* Borkh.) was studied at three harvest dates and after six months of 0°C storage in a high density orchard as influenced by six rootstocks: Malling (M)1, M7, M26, Malling Merton (MM)106 and Seedling, two levels of K and two levels of N fertilizers during 1980 to 1982. Titratable acidity declined by an average of 5.4 meq. $lit.^{-1}$ (about 6-10%) and firmness decreased by

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[2] Graduate Research Assistant, partially supported by Ferdowsi University, Mashhad, Iran.

[3] Associate Professor to whom reprint requests may be made.

an average 2.7 Newton (about 1-6%) during the range of 10-14 days as harvesting dates progressed. Skin yellow color increased about 4-10% and soluble solids increased from 0.14 to 0.48% Brix. Overall, fruits on OAR-1 rootstock had greater soluble solids and more yellow color at harvest and after storage and were firmer at harvest compared to fruits on all other rootstocks. Fruits on M7 had lower soluble solids than most of the other tested rootstocks at different harvest dates. Fruits on MM106 had about 5% lower breakdown in storage than most other fruits. Crop load influenced quality both at harvest and in storage so that scion fruits on M26 which had light crops in 1981 were larger and with yellower color and higher soluble solids, but also had the highest percentage of storage breakdown (about 20%) and bitterpit (about 12%). No significant influence of rootstock or fertilizer was found on scion fruit respiration. Little effect of K fertilizer was found on any quality indices, while higher nitrogen treatment had fruits which retained more green color both at harvest and after storage.

Introduction

Well developed ground color, high soluble solids, high firmness and a balanced acid/sugar ratio are considered as desirable quality parameters at harvest and after storage. In addition, well balanced mineral nutrient composition, particularly high Ca content, is also considered as a desirable keeping quality factor in storage. The relation of mineral nutrition to apple quality and storage breakdown has been often reported (8,12,17,22,25,30). Determination of the best harvest date with highest quality for various apple cultivars under different growing conditions in standard orchards has also been reported (10,11). However, there has only been a limited number of studies of rootstock influence on the quality of scion cultivars (6,18,19,23). Although some attention has been directed toward the quality of apples in high density orchards (29) no attempt has been made to study the influence of various rootstocks on the quality of spur type 'Golden Delicious' in high density systems. The objective of this research is to study the influence of six rootstocks: M26, M7, M1, MM106, OAR-1, and Seedling, ranging from the most dwarfing, M26 to the vigorous seedling, two levels of K and N fertilizers, and three different harvest dates on quality at harvest and after storage of 'Starkspur Golden Delicious' apple fruits from a high density orchard. Although yield is the primary goal of high density orchards, evaluations of quality could identify desirable rootstock, fertilizer, and maturational interactions to optimize both yield and pack-out of high grade fruit.

Materials and Methods

The experimental design and cultural practices of the orchard were as described earlier (Chapter 3). Fruits were harvested at three different maturities, 10-14 days on each side of the projected harvest (commercial maturity) as determined by phenology predictions (i.e., degree days and days from full bloom). On April 27 in both 1980 and 1981, trees were in full bloom. The first, second, and third harvest dates were October 2, 15, and 30 for 1980; and September 30, October 10 and 20 for 1981.

At each harvest, a 32-fruit composite sample (eight fruits from each of four trees) was taken from each plot replicate with six replications per treatment. Fruits were dipped in a solution of 70ppm thiobendazole fungicide and placed in wooden boxes with perforated plastic liners. Samples were tested for various maturity and quality indices at each harvest date and after six months of 0°storage. Storage disorders such as incidences of bitterpit, breakdown and rotting were determined after six months of storage.

At each testing, color was visually rated by comparison with a standard color chart (Cornell Extension Bulletin 750) on which five ground colors were shown ranging from darkest green rated five, to bright yellow color rated one. Firmness was measured on randomly selected fruit using a U.C. Davis penetrometer with a 11mm plunger, on two peeled surfaces of each six fruits from each treatment replicate. Wedges of each of these six fruits were composited and juiced (ACME JUICERATOR Model 5000) to measure soluble solids by a hand-held temperature compensated Atago Model NC-1 refractometer. Composited juice samples were frozen in test tubes until later when 8ml of each sample was used to measure titratable acidity with 0.1 N NaoH to a pH 8.2 neutralization point.

In order to measure post harvest respiration rate, six replicates of the field design were reduced to a two combined replicates per treatment, each containing three field replicates. Each combined replicate had a total of nine fruits coming equally from three field replications. Fruits of each combined replicate were put in four liter glass respirometer jars at 20°C and respiration rate was measured at three harvest dates of both years and after six months of 0°C storage for the second harvest. Respiration was measured at 200 ml/min flow rate by the Claypool-Keefer method (3) except that CO_2 was measured by a Beckman Model 865 infrared gas analyzer.

Results and Discussion

Color. Fruits from all rootstocks became yellower as the dates of harvest progressed (obtained a lower color rate from the scale of 1 to 5; Table 6.1). Lower leaf and fruit nitrogen concentrations as reported previously (Chapters 3 and 4) were related to the reduced chlorophyll content causing yellower color similar to the report by Knee (10). For a given rootstock and harvest date, fruit color was yellower after storage compared to the color at harvest time indicating a slow breakdown of chlorophyll in storage. Fruits from 1981 were generally yellower than those of 1980, both at harvest and after storage. This corresponds to the lower concentration of N in the 1981 fruits compared to 1980 as discussed earlier (Chapter 4). Westwood et al. (29) observed poorly colored 'Golden Delicious' fruits related to excessively high leaf nitrogen in one year of their long term studies which confirms this report.

Rootstock OAR-1 induced yellower fruits than all other rootstocks (Table 6.1) at all harvest dates and after storage in both years. The influence of this rootstock on the color of fruits was so predominant that even the substantially higher yield of 1981 (Chapter 3, Table 3.1) did not affect the color. The lower nitrogen content of these fruits (Chapter 4) was closely related to the yellowish color ($r > 0.75$). Fruits on M26 in 1980 had greener color than fruits on most other rootstocks, but these fruits were yellower in 1981 which was apparently due to the higher yield in 1980 and lower yield in 1981 (Chapter 3), thus larger fruit with less N (Chapter 4) in 1981 (correlation coefficient between fruit N and color on M26 at harvest was $r = 0.68$). Color of fruits on M1, MM106, M7, and seedling rootstocks were not consistently different from each other (Table 6.1).

Potassium application had no influence on fruit color at harvest or after storage (Table 6.1). Applications of high nitrogen fertilizer, however, induced significantly greener fruit compared to the fruits receiving low N fertilizer. Darker green color of fruits in this experiment corresponded with the higher leaf N (mostly $r < 0.30$) and fruit N concentrations (mostly $r > 0.65$) as described in Chapters 3, 4, and 7 and agrees with the results of other researchers (1,14,28). The higher N could have been contributing to darker green color due to more shading foliage and/or slower degradation of chlorophyll.

Firmness. Fruit firmness from most of the rootstocks decreased at later harvest dates (Table 6.2) similarly to the results of Knee (10) on Cox's orange apple which reportedly (21) relates to an increase in polygalacturonase activity which leads to softening of the cell walls. Firmness of fruit in 1980 was greater than in 1981 at comparable sampling dates of the three harvests which can be associated with the lower fruit Ca concentrations in 1981 (Chapter 4).

Except for the third harvest of 1981, OAR-1 induced firmest fruits among all rootstocks at the three harvest dates of 1980 and 1981 (Table 6.2). Rootstock M26, however, induced relatively softer fruit at most harvest times both years. Since Ca concentrations of fruits (Chapter 4 and yield of trees on OAR-1 (Chapter 3 Table 3.1) were relatively low in 1980 and high in 1981 and the reverse situation existed in fruits on M26, perhaps the small size of fruits on OAR-1 and large size of fruits on M26 (Chapter 4) would be more related to the firmness or softness of these fruits (almost r = -0.50), than their Ca concentration or yield. Since the size of fruits on these rootstocks are considered as an influence of rootstock and only partially as a result of croppoing effect (as reported previously in Chapter 4), relatively high and low firmness of fruits on OAR-1 and M26 at harvest might be more appropriately attritubed to the influence of rootstock. Other than the case at the first harvest of first year storage, there were no significant differences in fruit firmness among various rootstocks at any harvest date after six months of storage in either years. This would suggest that at harvest, firmness evaluations cannot necessarily predict the firmness of fruits on any rootstocks after six months of storage probably due to different rates of activities by the softening enzymes such as polygalacturonase and pectin methylesterase in storage.

Higher levels of K induced slightly (but not significantly) softer fruits compared to those with lower K application at each harvest date in 1980 (Table 6.2). Although fruits with higher nitrogen application had higher flesh N concentration (Chapter 4), they were not noticeably softer at harvest than fruits receiving lower levels of nitrogen fertilizer (Table 6.2). Therefore, these results disagree with those found by Boynton and Oberly (2). This could mean that the high N application used in these experiments was near standard optimal levels and was not an excessive amount for the young trees.

Soluble Solids. At harvest, soluble solids of fruits from most of the rootstocks increased by about 0.14 to 0.48% Brix during each 10-15 day intervals between different harvesting dates (Table 6.3). Fruits of early harvest in 1980 showed a higher percentage of retained soluble solids after six months storage. Late harvested fruits had lower soluble solids after storage compared to those at harvest in both years (Table 6.3). This would mean that fruits of early harvest in 1980 had more starch and less soluble solids, but during storage more starch was converted to sugar in these fruits. But fruits of later harvests had less starch and more soluble solids at harvest as they were in a more advanced stage of maturity. During storage these soluble solids were consumed in respiration. Respiration trends in 1980-81 agree with this (Appendix Table D.1).

Fruits on OAR-1 had higher percentage of soluble solids in both years (Table 6.3). Higher yield of trees on OAR-1 rootstock in 1981 (84.1 MT/ha) only slightly decreased the soluble solids compared to those in 1980 (with 45.1 MT/ha yield) indicating that high soluble solids of 'Starkspur Golden Delicious' apples on OAR-1 is definitely due to the rootstock influence. An interesting observation indicates that this could be due to the high B concentrations of fruits on OAR-1 (Chapter 4) since B has been reported to act as a sugar translocator (5,15).

Averaging the values of both years, fruits on M26 and seedling rootstocks had intermediate levels of soluble solids (Table 6.3). However, relatively higher soluble solids of fruits on M26 in 1981 must have been due to the light crop (Chapter 3 Table 3.1) and as a result of higher leaf/fruit ratio, higher dry matter (photosynthate) and larger fruits (Chapter 4) observed on this rootstock in 1981. Fruits on seedling rootstock had a moderate level of soluble solids as compared to those on other rootstocks and this moderate level was not dramatically affected by the higher cropload of these trees in 1981 compared to 1980. Fruits on M7 had generally low soluble solids at all three harvest dates in 1980 and 1981; and a lower 1981 yield by 13.2 MT/ha on M7 had little effect on soluble solids suggesting that low soluble solids of fruits on M7 at harvest is more of a rootstock influence than is yield. However, soluble solids concentrations of first and second harvest fruits of 1980 increased after six months of storage (Table 6.3) indicating that these fruits may have been in the early stages of maturity or pre-climacteric minimum at the first and second harvests of 1980 and later reached the stage of active ripening in storage as described by Hansen (7).

Higher potassium applications slightly tended to increase the soluble solids of fruits compared to lower K treatments at all three harvest dates and after storage, although these differences were not statistically significant (Table 6.3). It would be of interest to investigate if even higher application of soil K fertilizer than that used in this research could significantly increase soluble solids of apples in high density systems. Nitrogen treatments did not have any significant influences on soluble solids at any time (Table 6.3).

Titratable Acidity. Titratable acidity of fruits with all treatments declined 6-10% as maturation progressed (Table 6.4) which agrees with the results of Knee (10) on 'Cox's Orange' apples. Also there was a great decrease (up to 60-65%) in the acidity of fruits after six months of storage in both years. Overall, titratable acidty of fruits at harvest in 1981 was about 19% lower than that of 1980 perhaps due to more advanced maturity of fruits in 1981.

Fruits from trees on OAR-1 had high titratable acidty in 1980 harvests but low at 1981 harvests (Table 6.4). Fruits on M26 had relatively lower titratable acidity in 1980 but higher in 1981 (Table 6.4). Since the yield of trees on these rootstocks (Chapter 3; Table 3.1) was inversely proportional to their fruit titratable acidity during these two years, it seems that crop loads have predominant effects in the acidity of these fruits (usually $r = 0.40$). It could be rationalized that each fruit could receive higher amounts of organic acids from the leaves of a light crop tree in the light crop year due to the higher leaf/fruit ratio, whereas the reverse situation would be expected in heavy crop years. Apparently a large part of the organic acids are synthesized in the leaves and translocated into the fruits as proposed by Ulrich (27). Fruits on light cropping trees may also have higher sugar which are translocated along with, or can be converted into organic acids. High positive correlations were found between soluble solids and titratable acidity of fruits on OAR-1 ($r=0.60$) at harvest 1980; and M26 ($r=0.74$) at harvest 1981, which agrees with the report of Tomkins (26) indicating conversion of sugar to organic acids in apples and confirms the importance of cropping effect on the levels of fruit titratable acidity.

In spite of the relatively large differences between titratable acidity in 1980 and 1981 at harvest, no such differences were observed after six months of storage between these years (Table 4).

Applications of K or N did not significantly influence fruit titratable acidity (Table 6.4). Perring (20) found that high concentrations of K in apple leaf increased fruit acidity. In our research, low positive correlations were found between leaf K and fruit acidity (almost $r=0.20$) and between fruit K and fruit acidity (almost $r=0.20$) in most treatments. However, fruit K/Ca ratio correlated strongly with titratable acidity (usually $r > 0.55$). Fruit Ca alone showed negative correlations with fruit acidity (usually $r < -0.50$).

<u>Breakdown and Rotting</u>. Breakdown observed after six months of storage was of the senescent breakdown type together with *Gloeosporium* rot (*Gloeosporium perennans*) (Table 6.5). Since both senescent breakdown and *Gloeosporium* rot incidence always were associated, data for both of these incidences are reported

together under the term of breakdown. Infection of apples only by *Gloeosporium perennans* in this research suggests that either thiabendazole was not too effective on this fungal species or that the concentration used in this experiment (70 ppm) was not enough to control *Gloeosporium* rot. Generally, breakdown in the 1980 crop was higher than in 1981, possibly due to later harvesting dates of 1980 than 1981. There was significant positive correlation between fruit size and breakdown (usually $r > 0.58$) and negative correlation between fruit flesh Ca concentrations and breakdown (usually $r < -0.40$) storage. In both years, the latest harvested fruit showed the maximum percentages of breakdown (Table 6.5).

It seems that not only high fruit Ca is essential in prevention of different kinds of breakdown as found in this research and as reported by many others (12,13,19); but also it seems to be important in prevention of *Gloeosporium* rot in storage. Fruits on OAR-1 in 1980 and those on M26 in 1981 with lowest concentrations of Ca (Chapter 4) showed the highest incidence of breakdown after storage for those years respectively (Table 6.5). Fruits on MM106 averaged lower incidence of breakdown than all of the other tested rootstocks in both years. Since *Gloeosporium perennans* invades through the lenticels of apples (9), it is a question whether lower susceptibility of scion cultivars on some rootstocks (i.e., MM106) is due to a size reduction of lenticels or whether it is due to other factors.

Neither K nor N treatments had any significant effects on fruit breakdown in storage (Table 6.5). This agrees with the reports of Perring (20) but disagrees with others (16); although, different amounts of fertilizer were used in this experiment.

Bitterpit. Other than the case for fruits on M26 rootstock in the storage of 1981, no significant differences were observed among the rootstocks with respect to fruit bitterpit incidence in either year (Table 6.5). This result agrees with other researchers who used different groups of apple scion and rootstock combinations (13,18). High negative correlations (up to r = -0.88) were found between fruit size and fruit Ca concentration and also between Ca concentrations and incidence of bitterpit (up to r = 0.83) in the storage which agrees with previous reports (22,25).

The incidence of bitterpit in the fruits on M7 and MM106 in this research was much lower than that of 'Golden Delicious' apples on the same rootstocks in the commercial orchards as reported by Terblanche et al. (25). The overall low incidence of bitterpit in this experiment could be due to higher accumulation of Ca in the 'Starkspur Golden Delicious' apple fruit in a high density orchard (about 6.2 mg Ca/100 g fresh wt.) compared to that of Golden Delicious apples (3 - 3.2 mg/100 g) based on Terblanche et al. (25). Summer pruning as done in our experimental orchard might also have contributed to reduced incidence of bitterpit as proposed by Terblanche et al. (24).

Potassium or nitrogen treatments in this test did not have a significant effect on bitterpit (Table 6.5). However, high correlations were found between incidence of bitterpit and each of the fruit ratios of N/Ca (r=0.82), K/Ca (r=0.78) and Mg/Ca (r=0.67) in M26 rootstock in 1981.

Respiration. There were no significant effects of rootstocks, K or N fertilizers on respiration rate at harvest or after six months storage (Appendix Table D.1).

It appears that the second harvest sample occurred near the pre-climacteric respiratory minimum in both 1980 and 1981, (Appendix Table D.1). This is partially confirmed by the fact that the rise in ethylene also occurred near the second harvest date in both years (Chapter 5).

Freezing Injury. During storage of the 1980 crops, the temperature of one of the cold storages containing apples from these studies accidentally dropped to -3.5°C for about 60 hours. The temperature was then adjusted to 0°C again for the rest of the storage period. In order to assess whether or not subsequent data would be affected by that event, percentage of frozen fruits in various treatments were determined by visual inspection (Table 6.5). No major injury was found in fruits of the second or third harvests, but fruits of early harvest had some injury (Table 6.5). The percentage of freezing injury on fruits of most rootstocks was proportional to their soluble solids levels, so that, fruits on OAR-1 had the least injury, while those on M7 had the most.

General Discussion

Westwood et al. (29) who studied similar cultural conditions reported that a decrease of spacing from 1.83 m to 1.22 m significantly reduced the soluble solids of 'Golden Delicious' apples on M9 rootstock from 12.3% to 11.7%. In our experiments, fruit of all treatments (except rootstock OAR-1) had an overall average of less than 10% soluble solids which could either be due to the even closer spacing used (0.6m) than in Westwood et al.'s experiment (29); or, because of different strains, years or other factors such as yield. Fruits of this experiment had a desirable overall taste at harvest but poorer mealy taste after six months storage. The lower acid to sugar ratio after storage could have contributed to the poorer quality including mushy texture of the fruits.

Better color, higher soluble solids and higher firmness in the fruits on rootstock OAR-1 presents a better quality and possibly a solution to the problem of lower soluble solids of fruit in high density orchards. However, low endogenous ethylene of these fruits (Chapter 5) suggests that ethylene measurement may not be a useful approach to determine maturity and quality of fruits on OAR-1. The relatively smaller size of these fruits on OAR-1 would not be very desirable for fresh market purposes although the small size of these fruits might be essential for their higher firmness at harvest. Averaging all quality factors in both years of evaluations, M26 rootstock appeared to slightly advance the maturity of 'Starkspur Golden Delicious' apples. Fruits on M7 had lower overall quality than others. Fruits on other rootstocks were intermediate in quality.

Although fruits of early October harvest can be suitable for six months of storage, they are not desirable for fresh market. It seems that October 10-15 is the best harvest date for both fresh market and probably short regular storage (shorter than six months). Fruits harvested at late October are suitable only for fresh market and very short term storage, thus support Dilley's (4) recommendations. Orchard factors such as pruning, irrigation, and fertilizer practices all influence the mineral composition of fruits and thus their quality. The role of Ca is particularly important in several storage factors. Fruit N and K/Ca ratio are very important in fruit color and acidity respectively. Therefore, the effects on storage quality of fruit must be taken into consideration when deciding on fertilizer applications or other orchard cultural practices.

Weak or no significant influence of K or N treatments on several quality factors is because of the cross feeding and perhaps root grafting between trees from low fertilizer applied plots with those of high fertilizer applications. Had we inserted aluminum barrier between plots or had we used higher concentrations of K or N as our high levels of fertilizer, we would have found significant differences in fertilizer treatments. These would be of interest for further studies in the future.

Table 6.1 Color of 'Starkspur Golden Delicious' apple fruit at three maturities at harvest and after 6 months of 0°C storage in 1980-1981 and 1981-1982 as influenced by rootstock and soil K and N applications. Mean values reported are based on color rankings ranging from 5 = dark green progressively to 1 = yellow.

	At Harvest 1980			At Harvest 1981		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	3.87b^{z}	3.70a	3.18c	3.70ab	3.54ab	3.40a
M1	3.89b	3.75a	3.33bc	3.90a	3.75a	3.53a
MM106	4.06ab	3.93a	3.72a	3.75ab	3.47abc	3.28ab
M7	4.00bc	3.89a	3.64ab	3.52b	3.35bc	3.25ab
OAR-1	3.33c	3.06b	2.31d	3.08c	2.82d	2.55c
M26	4.29a	3.95a	3.77a	3.55b	3.14cd	2.92bc
Levels of K^{x}						
Low K	3.85^{y}	3.72	3.33	-	-	-
High K	3.96	3.70	3.32	-	-	-
Levels of N^{x}						
Low N	3.88	3.69	3.26	3.44	3.20	3.00
High N	3.93	3.74**	3.39**	3.73**	3.49**	3.31**

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are significantly different from high levels within columns if shown by *(5%) or by **(1%).

[x] In 1980, low K = 0g K/4 trees, high K = 68g actual K as K_2SO_4 /4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees, In 1981, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees.

Table 6.1 continued

	After Storage 1980–1981			After Storage 1981–1982		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	3.41b^z	3.00b	2.75b	2.85a	2.69a	2.42a
M1	3.52b	2.97b	2.85b	2.87a	2.70a	2.43a
MM106	3.72ab	3.50a	3.31a	2.88a	2.62a	2.23a
M7	3.77ab	3.34ab	3.33a	2.78a	2.63a	2.20a
OAR-1	2.58c	2.27c	1.87c	2.20b	1.83b	1.47c
M26	3.91a	3.68a	3.35a	2.42ab	2.24ab	1.88b
Levels of K^x						
Low K	3.47^y	3.13	2.85	-	-	-
High K	3.50	3.11	2.97	-	-	-
Levels of N^x						
Low N	3.41	3.04	2.83	2.59	2.35	1.99
High N	3.56*	3.20**	2.99*	2.73**	2.55**	2.20*

Table 6.2 Flesh penetration force Newton (N) of 'Starkspur Golden Delicious' apple fruit at three harvest maturities and after six months of 0°C storage as influenced by rootstocks and soil K and N applications in 1980-1981 and 1981-1982.

	At Harvest 1980			At Harvest 1981		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	71.19b^z	64.47b	65.21b	65.41a	63.64ab	63.05a
M1	71.19b	69.43b	64.33bc	65.4a	64.03ab	63.45a
MM106	70.90b	69.23b	63.05c	64.03a	62.47b	62.27a
M7	70.12b	68.45b	62.76c	65.11a	64.33ab	63.64a
OAR-1	74.92a	76.00a	69.92a	65.90a	65.80a	63.25a
M26	69.23b	68.15b	63.74bc	63.25a	62.07b	63.54a
Levels^x of K						
Low K	71.68^y	69.82	64.92	-	-	-
High K	70.80	69.72	64.72	-	-	-
Levels^x of N						
Low N	71.68	69.72	65.11	64.43	63.35	62.76
High N	70.80	69.82	64.62	65.31	64.13	63.64

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low level N is significantly different from high levels within columns if shown by *(5%). Low level of K is not significantly different than high level within columns at 5% level.

[x] In 1980, low K = 0g K/4 trees, high K = 68g actual K as K2SO4/4 trees, low N = 34g actual N as urea/4 trees, high N = 68 g actual N as urea/4 trees. In 1981, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees.

Table 6.2 continued

	After Storage 1980-1981			After Storage 1981-1982		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 20	Sept. 30	Oct. 10	Oct. 20
Seedling	55.50a[z]	42.56a	43.34a	50.60a	46.28a	46.28a
M1	54.72a	43.83a	45.11a	49.62a	46.68a	47.46a
MM106	53.64a	44.81a	43.83a	47.95a	45.89a	45.99a
M7	59.62a	44.71a	43.54a	51.38a	47.46a	48.25a
OAR-1	44.52b	44.13a	45.79a	51.19a	47.76a	48.64a
M26	55.70a	45.11a	42.07a	47.76a	45.70a	47.56a
Levels[x] of K						
Low K	53.74[y]	44.52	44.81	-	-	-
High K	54.13	43.93	43.05	-	-	-
Levels[x] of N						
Low N	53.93	43.73	43.73	49.03	46.58	47.17
High N	54.03	44.71	44.13	50.5*	46.68	47.66

Table 6.3 Percent soluble solids of 'Starkspur Golden Delicious' apple fruits at three harvest maturities and after 6 months of 0°C storage as influenced by rootstocks and soil K and N applications in 1980-1981 and 1981-1982.

	At Harvest 1980			At Harvest 1981		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	9.22bc[z]	9.32b	9.92b	8.87b	9.24b	8.93b
M1	9.52b	9.44b	9.98b	8.90b	8.98b	9.05b
MM106	9.04bc	9.12bc	9.67bc	9.16b	9.67ab	9.58ab
M7	8.75c	8.70c	9.28c	8.90b	9.22b	9.24b
OAR-1	10.87a	11.30a	11.63a	10.01ab	10.55a	10.82a
M26	8.80c	9.12bc	9.43bc	10.76a	10.83a	10.83a
Levels of K[x]						
Low K	9.33[y]	9.45	9.94	-	-	-
High K	9.40	9.55	10.03	-	-	-
Levels of N[x]						
Low N	9.32	9.58	9.97	9.40	9.79	9.71
High N	9.41	9.42	10.0	9.46	9.70	9.77

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are not significantly different from high levels of K or N within columns at 5% level.

[x] In 1980, low K = 0g K/4 trees, high K = 68g actual K as K_2SO_4/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees; In 1981, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees.

Table 6.3 continued

	After Storage 1980-1981			After Storage 1981-1982		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct.10	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	10.03c^z	9.05bc	9.35bc	8.43c	9.34b	8.88b
M1	9.90c	9.47b	9.63b	8.77bc	9.08b	8.98b
MM106	9.51d	8.76bc	8.85c	9.44bc	9.09b	9.12b
M7	10.27b	8.97bc	8.92bc	8.89bc	9.15b	8.94b
OAR-1	11.66a	11.38a	11.15a	10.01ab	10.9a	10.8a
M26	9.62d	8.52c	8.89bc	10.89a	11.17a	10.94a
Levels of K^x						
Low K	10.07^y	9.33	9.42	-	-	-
High K	10.26	9.39	9.51	-	-	-
Levels of N^x						
Low N	10.20	9.42	9.54	9.38	9.70	9.53
High N	10.13	9.30	9.39	9.42	9.88	9.67

Table 6.4 Titratable acidity (meq. liter^{-1}) of 'Starkspur Golden Delicious' apple fruits at three harvest maturities and after 6 months of 0°C storage as influenced by rootstocks and soil applied K or N in 1980-1981 and 1981-1982.

	At Harvest 1980			At Harvest 1981		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	64.5ab[z]	57.9abc	52.5ab	46.7b	43.4a	41.5b
M1	69.7a	62.5a	51.8abc	48.1b	44.7a	40.0b
MM106	57.6c	53.9cd	47.4bc	48.7b	45.1a	43.7ab
M7	62.2bc	56.0bcd	49.2abc	46.9b	48.5a	43.4ab
OAR-1	70.0a	60.4ab	53.1a	45.2b	43.8a	40.0b
M26	60.4bc	52.6d	47.1c	59.0a	52.7a	49.8a
Levels of K[x]						
Low K	64.3[y]	56.9	48.6	-	-	-
High K	63.8	57.5	51.7	-	-	-
Levels of N[x]						
Low N	64.6	58.8	51.1	48.8	46.0	41.6
High N	63.5	55.7	49.2	49.4	46.7	44.5

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are not significantly different from high levels within columns at *(5%) level.

[x] In 1980, low K = 0g K/4 trees, high K = 68g actual K as K2SO4/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees; In 1981, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees.

Table 6.4 continued

	After Storage 1980-1981			After Storage 1981-1982		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Sept. 30	Oct. 10	Oct. 20
Seedling	29.3ab^z	21.9a	17.0b	19.8c	19.8c	17.2b
M1	30.5a	22.4a	17.9b	26.0ab	22.3bc	17.4b
MM106	24.6b	18.8bc	14.3c	26.1ab	23.3abc	19.4b
M7	27.9ab	21.3ab	16.9b	29.4a	26.1ab	21.1ab
OAR-1	28.3ab	24.2a	20.0a	20.8bc	19.0c	17.2b
M26	24.4b	17.3c	13.2c	30.0a	28.0a	25.2a
Levels of K^x						
Low K	27.1^y	20.7	17.3	-	-	-
High K	27.9	21.3	15.7	-	-	-
Levels of N^x						
Low N	28.3	21.9	17.0	25.4	22.1	19.0
High N	26.6	20.0	16.0	25.3	24.0	20.1

Table 6.5 Incidence of storage breakdown, bitter pit, and freezing susceptibility of 'Starkspur Golden Delicious' apple fruit relative to harvest maturity, rootstocks, and soil K and N application. Samples evaluated after 6 months of 0°C storage 1980-1981 and 1981-1982. Freezing susceptibility evaluated after 60 hours at -3.5°C.

	1980-1981 Frozen %	1980-1981 Storage Breakdown (%)			1981-1982 Storage Breakdown (%)		
		Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 2	Oct. 15	Oct. 30	Oct. 2	Oct. 15	Oct. 30
Seedling	29ab[z]	9.0a	26b	61a	3a	4c	12b
M1	25ab	4.0a	23b	55ab	1a	6bc	11b
MM106	15bc	6.0a	20b	42c	2a	6bc	9b
M7	41a	3.0a	22b	46bc	2a	11b	12b
OAR-1	6c	10.0a	38a	63a	2a	6bc	8b
M26	27ab	7.0a	27b	48bc	8a	18a	29a
Levels of K[x]							
Low K	20[y]	7.0	25	51	-	-	-
High K	28**	5.0	27	53	-	-	-
Levels of N[x]							
Low N	23	6.0	25	53	2	8	12
High N	25	7.0	27	52	3	8	15

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K is significantly different from high levels within columns if shown by **(1%). Low levels of N is not different from high level within columns at 5% level.

[x] In 1980, low K = 0g K/4 trees, high K = 68g actual K as K2S04/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees. In 1981, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees.

Table 6.5 continued

	1980-1981 Storage bitter pit (%)			1981-1982 Storage bitter pit (%)		
	Harvest date			Harvest date		
Rootstock	Oct. 2	Oct. 15	Oct. 30	Oct. 2	Oct. 15	Oct. 30
Seedling	1.2a[z]	3.4a	2.1a	3.2a	0.8b	0.7b
M1	0.6a	4.3a	0.5a	1.0a	0.3b	1.6b
MM106	1.1a	1.9a	1.5a	1.6a	0.8b	2.1b
M7	0.1a	1.7a	3.1a	3.1a	1.8b	3.0b
OAR-1	0.3a	1.4a	1.0a	1.7a	0.1b	1.4b
M26	2.2a	2.7a	2.2a	7.8a	5.8a	12.0a
Levels of K[x]						
Low K	0.8[y]	2.7	2.0	-	-	-
High K	1.0	2.4	1.6	-	-	-
Levels of N[x]						
Low N	0.7	2.5	2.2	2.9	1.3	2.3
High N	1.1	2.7	1.3	3.2	1.9	4.7

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CHAPTER 7

CORRELATIONS AMONG PRE-HARVEST MINERAL NUTRITION, MATURITY AND POSTHARVEST QUALITY FACTORS IN 'STARKSPUR GOLDEN DELICIOUS' APPLES ON SIX ROOTSTOCKS[1]

Esmaeil Fallahi[2] and Daryl G. Richardson[3]

Department of Horticulture, Oregon State University, Corvallis, Oregon 97331

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Abstract. All possible linear correlation coefficients were computed among several mineral elements of August harvested leaves, October harvested fruits, maturity and postharvest quality factors of 'Starkspur Golden Delicious' apple trees grown on six rootstocks: Seedling, Malling (M)1, Malling Merton (MM)106, M7, OAR-1, and M26 in a high density orchard during 1980 to 1982. Positive correlations were found between fruit N, K, P, and leaf N, K, and P respectively in most rootstocks. Leaf Ca did not correlate with fruit Ca,

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[2] Graduate Research Assistant, partially supported by Ferdowsi University, Mashhad, Iran.

[3] Associate Professor to whom reprint requests may be made.

thus leaf analysis cannot be recommended for estimates of fruit Ca. Both leaf and fruit nitrogen was positively correlated green fruit color and negatively with fruit soluble solids in all rootstocks. Fruit Ca and fruit P were both negatively correlated with fruit soluble solids at harvest and after six months of 0°C storage for all rootstocks (usually $r < -0.50$). Fruit Ca showed negative correlations with bitterpit, storage rot and field endogenous ethylene, but positive correlation with firmness. The ratio of fruit N/Ca was positively correlated with endogenous ethylene ($r > 0.19$), while higher fruit K/Ca ratio correlated with greater titratable acidity ($r > 0.26$ pooled rootstocks) at harvest. Fruit green color was negatively correlated with soluble solids and titratable acidity. Fruit dry weight was highly negatively correlated with soluble solids, ethylene and titratable acidity on most rootstocks. Higher yield had positive correlations with fruit and leaf N, Ca, and Cu; but slightly negative correlations with B of those tissues. Higher yield was associated with lower leaf K concentrations ($r < -0.11$).

Introduction

Although there have been numerous reports relating orchard factors with storage quality (1,2,3,4,5,6), there have been only a few reports where actual correlations have been studied (1,5). However, scant attention has been given to leaf and fruit mineral nutrition in relation to postharvest quality of apples (5,8), and virtually no studies have appeared documenting the influence of apple rootstocks on these correlations. This paper reports all possible correlations among analyzed leaf and fruit mineral elements, endogenous ethylene, and postharvest quality factors of 'Starkspur Golden Delicious' apple on various rootstocks in a high density orchard. The significance of each correlation and the usefulness or limitations of leaf and/or fruit analysis is discussed.

Materials and Methods

The experimental design and cultural practices of the orchard were explained in the first part of this series of studies (Chapter 3).

Leaves were sampled on August 27 in 1980 and 1981 and were analyzed by emission spectroscopy for mineral composition as described previously (Chapter 3). Fruits were sampled at commercial maturity on October 10, 1980 and October 15, 1982. Fruit internal ethylene measurement by gas chromatography was described as in Chapter 5 and fruit mineral analysis was previously described in Chapter 4. Fruit quality, such as color, soluble solids, titratable acidity and frimness were evaluated at harvest and after cold storage as described in Chapter 6.

Linear correlation coefficients among various nutritional, maturational and quality factors were computed for each rootstock and also for overall rootstocks (pooled "r" values). There were 24 observations for each rootstocks in 1980-81 and 12 in 1981-82. When rootstocks were combined for pooled "r" values, n=144 in 1980-81, and n=72 in 1981-82. Thus to be statistically significant at 95%, r values for rootstocks must be greater than ± 0.40 in 1980-81 and greater than ± 0.57 in 1981-82. Pooled "r" values must be greater than ± 0.16 in 1980-81 and ± 0.23 in 1981-82 to be significant at 95% (7).

Results and Discussion

Leaf and Fruit Mineral Analysis: Simple linear correlation between leaf and fruit mineral analysis is shown in Table 7.1 for elements exhibiting statistically 95% significant r-values and in some cases for less significant r-values for comparison with cited literature values. Composited r-values for all rootstocks for 1980 and 1981 are expressed in the pooled r-values. Individual rootstock r-values in 1981 comprise the remainder of the Tables. High positive correlations were found between fruit N, P, and K and foliar N, P, and K respectively for all rootstocks. Fruit Mg and leaf Mg were also positively correlated in most rootstocks although some of these correlations were weak (Table 7.1). In contrast to the implication of a report by Terblanche et al. (8), there was only a very weak correlation between individual rootstock fruit Ca and leaf Ca. Although the pooled leaf Ca and fruit Ca correlation was 0.38 in 1980, it was only 0.08 in 1981. Fruit Fe and leaf Fe and fruit B and leaf B correlations were also weak in various rootstocks (Table 7.1). This would imply that both fruits and leaves accumulate nitrogen when a nitrogen fertilizer is applied and leaf analysis may be a good estimator of fruit nitrogen level. The same is true to a lesser degree for K, P, and Mg. However, Ca level of fruit cannot be dependably predicted by leaf analysis and fruit tissue analysis is therefore essential for determination of fruit Ca status and prevention of calcium related storage disorders. This is most clearly shown in the fruits grown on M26 rootstock which had the highest incidence of storage rot and bitterpit in 1981. The correlation between August leaf Ca and October fruit Ca on this rootstock was very low (Table 7.1). Similarly, the correlations between leaf Ca and bitterpit or rot were also low (Table 7.2). In contrast, fruit Ca on M26 rootstock was highly negatively correlated with both bitterpit and storage rot disorders (Table 7.4).

Higher yield was associated with increased N and Ca concentrations in both leaves and fruits, but was associated with decreased leaf K (Table 7.5). It is possible that in trees with heavier crops, more uptake of K takes place due to weaker leaf-fruit competition. The mechanism by which N and Ca are related to increased yield is not yet clarified.

Leaf and Fruit Minerals and Quality Factors: Since fruit N and leaf N are closely correlated in the same direction (Table 7.1), any fluctuation in the leaf nitrogen concentration is usually correlated with some quality factors in the same manner as that of fruit N. For example, both leaf and fruit nitrogen showed positive correlations with green fruit color and negative correlations with soluble solids in both years (Tables 7.2, 7.3, 7.4). Thus, fruit color and soluble solids at harvest and after storage might be predicted by leaf nitrogen analysis in August.

The K/Ca ratio, particularly in fruit tissue had strong positive correlations with titratable acidity at harvest (Table 7.3), and after storage (Table 7.4). These strong correlations resulted from the fact that fruit Ca had occasionally negative correlations with titratable acidity while fruit K had positive correlations with titratable acidity (Tables 7.3, 7.4). Positive correlation was found between leaf K and titratable acidity in this research which agrees with the report of Perring (2). Perhaps K somehow increases the synthesis of organic acids in the leaves and fruits, while Ca has an opposite role in this process particularly in the fruit. No other statistically significant correlations were found between leaf minerals and quality factors.

Fruit N, P, Ca, Mg, and Cu all had negative correlations with soluble solids of fruits (Table 7.3). The percentage of dry matter was always strongly negatively correlated with most of the mineral elements, since greater dry matter would result in lower concentrations of minerals due to the dilution effect (Table 7.3). On the other hand, fruit dry matter had a significantly positive correlation with soluble solids on all rootstocks (Table 7.6). Therefore, the negative correlation between dry matter and fruit minerals may help to rationalize the negative correlations between soluble solids and fruit minerals. However, some other physiological connections could have existed between certain fruit minerals and between sugar translocation and accumulation.

Strong negative correlations were found between fruit Ca and fruit size (average weight) (Table 7.3). This correlation was much weaker when comparing other fruit minerals, perhaps one interpretation is that other elements are accumulated in the fruit tissue by the means of both phloem and xylem, while Ca is transported only or at least predominantly through the xylem tissue. Thus, in the larger fruits, the dilution effects of higher dry matter on other minerals is less apparent than that of small fruits.

Fruit Ca showed negative correlations with bitterpit, storage rot, but positive correlations with firmness and yield (Tables 7.4 and 7.5). Most of these correlations are interrelated, so that, lower yield results in larger fruits with higher dry matter, and therefore, lower Ca. Lower Ca then is closely associated with storage disorders as was the case in the light crop trees on M26 in 1981. On the other hand, higher yield is related to increased fruit Ca (Table 7.5), and this could be the reason for the negative correlations between yield and titratable acidity as higher Ca decreases titratable acidity (Table 7.3 and 7.4). Negative correlations between fruit Ca and titratable acidity might have been related to the negative correlation between fruit Ca and soluble solids since a direct positive correlation was seen between fruit soluble solids and titratable acidity (Table 7.6). However, it is more likely that Ca binds strongly to carboxylic acids, not allowing them to be titrated as easily as if H^+ was on them.

Fruits with higher Cu were greener on all rootstocks and had lower soluble solids (Table 7.3). From these correlations, it is suggested that fruits with higher Cu have lower overall quality and this should perhaps be taken into account when spraying Cu solutions.

Negative correlations were found between fruit Ca and internal ethylene in the field and also between Ca and evolved ethylene in storage. Positive correlations existed between fruit N/Ca ratio and fruit ethylene (Table 7.3). The relationship of fruit N and Ca to fruit ethylene and other maturational and storage quality factors implicates the usefulness of fruit N and Ca measurements to assist in marketing and storage strategies and decisions. Clearly more studies are suggested by this data which identifies the potential for practical application of this information.

Quality Factors: Negative correlations existed between green color and storage soluble solids and also between green color and storage titratable acidity (Table 7.6). As expected, positive correlations were found between green color and firmness (Table 7.6). Storage titratable acidity generally increased as fruit size increased, whereas firmness decreased as size increased for most rootstocks in both years (Table 7.6). After storage, firmness occasionally correlated negatively with soluble solids and this correlation was very strong on M7 and MM106 as compared to other rootstocks. These correlations among the quality factors confirm most of the traditional concepts for determination or predictions of fruit maturity and quality in apples.

General Conclusions: By comparing all possible one-on-one linear correlations, it is concluded that any factor which affects fruit size can influence a series of factors related to quality at harvest and after storage. Therefore, crop load and rootstock both can influence fruit size, and size-related quality factors such as soluble solids, titratable acids, firmness, fruit Ca, and storage disorders. The genotype of a rootstock may sometimes influence the correlations between two nutrition or quality parameters of the scion cultivars in a different manner than do other rootstocks. Cases such as this were occasionally observed in OAR-1 rootstock. For example, strong negative correlations were found between fruit Cu and leaf Cu and positive correlations between fruit soluble solids and firmness on OAR-1 rootstock, while these correlations were opposite in sign for most of the other rootstocks.

Strong correlations between percentage of dry matter and various mineral elements and quality factors would suggest that it could be of interest to develop an extensive model to predict the approximate effects of fruit mineral concentration or quality factors by determination of fruit percentage dry matter.

Perhaps the importance of leaf Ca and fruit Ca has been overlooked as important components in yield (as suggested in Table 7.5). Although the positive relations of N with yield are not too surprising, the weak, but negative influence of K on yield is important indicating that high cropping trees probably need more K for fruit consumption.

Table 7.1. Linear correlation coefficients between mineral concentrations of August sampled leaves and October harvested 'Starkspur Golden Delicious' apple fruits on several rootstocks.

Pairs of Comparison			1981 "r" values for each rootstock^z					Pooled "r" value^z	
Fruit (% or ppm dry wt.)	Leaf (% or ppm dry wt.)	Seedling	M1	MM 106	M7	OAR-1	M26	1980	1981
N	N	0.68	0.57	0.72	0.54	0.40	0.43	0.23	0.54
N	Ca	0.33	0.23	0.10	-0.09	0.02	0.11	0.23	0.28
K	N	0.43	0.26	0.27	-0.31	0.12	-0.28	0.14	-0.04
K	K	0.45	-0.25	0.25	0.74	0.05	0.20	0.08	0.38
K	Ca	0.57	0.003	0.18	-0.19	0.05	0.63	0.009	0.19
K	Mg	-0.29	-0.11	-0.38	-0.32	0.04	-0.17	0.02	-0.10
P	P	0.67	0.27	0.12	0.14	-0.17	0.17	0.03	0.23
Ca	N	-0.32	-0.20	0.15	0.68	-0.18	0.64	0.17	0.27
Ca	Ca	-0.09	-0.17	0.26	0.16	-0.19	0.12	0.38	-0.10
Mg	K	-0.44	-0.05	0.63	-0.60	-0.06	0.10	-0.01	-0.16
Mg	Mg	0.06	0.02	-0.12	0.23	0.21	-0.004	0.05	0.07
Fe	Fe	0.24	-0.14	-0.43	0.34	-0.34	-0.22	-0.04	-0.05
Cu	Cu	0.26	0.10	0.01	0.37	-0.62	0.12	0.19	0.45
B	B	-0.27	0.10	-0.25	0.46	0.41	-0.28	0.12	0.41
K/Ca	Cu	0.60	0.45	0.67	0.65	0.26	0.15	-0.16	-0.07
N/Ca	N	0.56	0.61	0.38	0.31	0.56	-0.61	-0.04	-0.17

[z] For each variable of each rootstock in 1981 n = 12(r > 0.57 or r < -0.57 significant at 5%). For the pooled r values, n = 144 in 1980 (r > 0.16 or r < -0.16 significant at 5%) and n = 72 in 1981 (r > 0.23 or r < -0.23 significant at 5%).

Table 7.2. Linear correlation coefficients between August sampled leaf mineral concentrations and October harvested 'Starkspur Golden Delicious' apple fruit quality factors measured after 6 months of $0^{\circ}C$ storage. Values in table are separated by rootstock and by 1980-81 season and 1981-82 season, with a pooled r-value for all rootstocks combined.

Pairs of Comparison			"r" values for each rootstock[z]						
Leaf Mineral (% dry wt.)	Quality Factors After Storage	Year	Seedling	M1	MM 106	M7	OAR-1	M26	Pooled r[z] value
N	Color[y]	80-81	0.20	0.13	0.22	0.11	0.42	0.19	0.30
		81-82	0.86	0.77	0.61	0.76	0.51	0.64	0.47
N	Soluble Solids (%)	80-81	-0.39	-0.15	-0.03	-0.30	-0.22	-0.06	-0.23
		81-82	-0.35	-0.44	-0.33	-0.71	-0.13	-0.61	-0.40
N	Titratable Acidity	80-81	0.06	-0.42	-0.16	0.31	-0.36	-0.13	-0.25
		81-82	0.57	0.49	-0.35	-0.44	-0.20	-0.55	-0.25
K	Titratable Acidity	80-81	0.18	0.57	0.08	0.14	0.25	0.15	0.28
		81-82	0.16	0.07	0.28	0.40	0.34	0.25	0.20
Ca	Soluble Solids (%)	80-81	0.12	-0.22	0.19	0.01	0.20	-0.16	-0.39
		81-82	0.17	0.12	-0.31	-0.07	-0.16	-0.35	-0.45
K/Ca	Titratable Acidity	80-81	0.21	0.35	0.22	0.31	0.09	0.26	0.37
		81-82	0.11	0.79	0.37	0.10	0.41	0.48	-0.03
Ca	Titratable Acidity	80-81	-0.01	0.16	-0.18	-0.56	0.19	-0.26	-0.23
		81-82	0.08	0.63	-0.39	0.26	-0.06	-0.50	0.15
Ca	Bitter Pit	80-81	0.18	0.10	0.01	-0.19	-0.06	0.01	-0.07
		81-82	-0.03	-0.09	0.34	-0.33	0.01	-0.22	-0.07
Ca	Rotting	80-81	0.10	0.08	-0.30	0.10	-0.18	-0.04	-0.29
		81-82	-0.11	0.14	0.41	-0.03	-0.58	0.19	-0.06

[z] For each variable of each rootstock, n = 24 in 1980-81 ($r > 0.40$ or $r < -0.40$ significant at 5%) and n = 12 in 1981-82 ($r > 0.57$ or $r < -0.57$ significant at 5%). For the pooled r values, n = 144 in 1980-81 ($r > 0.16$ or $r < -0.16$ significant at 5%) and n = 72 in 1981-82 ($r > 0.23$ or $r < -0.23$ significant at 5%).

[y] Highest color = dark green; lowest color = yellow.

Table 7.3. Linear correlation coefficient between 'Starkspur Golden Delicious' apple fruit mineral concentration and various quality factors on several rootstocks at harvest.

Pairs of Comparison Fruit Mineral (% or ppm dry wt.)	Quality Factor at Harvest	1981-1982 "r" values for each rootstock[z]						Pooled "r" value[z]	
		Seedling	M1	MM 106	M7	OAR-1	M26	1980	1981
N	Color[y]	0.66	0.46	0.53	0.80	0.88	0.68	0.54	0.68
N	Soluble Solids (%)	-0.46	-0.44	-0.58	-0.77	-0.79	-0.38	-0.56	-0.59
K	Titratable Acidity	0.34	0.39	0.11	0.26	0.22	0.14	0.06	0.27
P	Soluble Solids (%)	-0.30	-0.24	-0.76	-0.53	-0.79	-0.10	-0.26	-0.53
Ca	Soluble Solids (%)	-0.49	-0.73	-0.71	-0.84	-0.50	-0.91	-0.41	-0.62
Ca	Color	-0.32	-0.23	0.38	0.79	0.21	0.75	0.38	0.24
Ca	Field Internal C_2H_4	-0.27	-0.49	-0.20	-0.57	-0.10	-0.82	-0.21	-0.34
N/Ca	Field Internal C_2H_4	-0.10	-0.13	0.85	0.74	0.17	0.76	0.19	0.47
K/Ca	Titratable Acidity	0.57	0.42	0.69	0.26	0.31	0.78	0.25	0.64
K/Ca	Soluble Solids (%)	0.12	0.62	0.49	0.75	0.05	0.81	0.18	0.57
N	Dry Weight (%)	-0.49	-0.47	-0.71	-0.76	-0.80	-0.42	-	-0.57
K	Dry Weight (%)	-0.41	-0.30	-0.42	0.47	-0.57	0.31	-	-0.06
P	Dry Weight (%)	-0.44	-0.36	-0.70	-0.39	-0.80	-0.12	-	-0.52
Ca	Dry Weight (%)	-0.49	-0.61	-0.68	-0.80	-0.52	-0.94	-	-0.67
Mg	Dry Weight (%)	-0.37	-0.21	-0.21	-0.32	-0.48	-0.61	-	-0.30
Fe	Dry Weight (%)	0.06	-0.46	-0.25	-0.02	-0.68	-0.34	-	-0.32
Cu	Dry Weight (%)	-0.07	-0.15	-0.45	0.13	-0.65	-0.22	-	-0.38
B	Dry Weight (%)	0.05	-0.32	0.45	-0.29	-0.59	0.28	-	-0.10
Ca	Titratable Acidity	-0.38	-0.23	-0.66	-0.18	0.39	-0.84	-0.36	-0.51
Ca	Average Weight	-0.42	0.16	-0.57	-0.88	-0.36	-0.65	-0.29	-0.64

[z] For each rootstock in 1981 n = 12 ($r > 0.57$ or $r < -0.57$ significant at 5%). For the pooled "r" values, n = 144 in 1980 ($r > 0.16$ or $r < -0.16$ significant at 5%) and n = 72 in 1981 ($r > 0.23$ or $r < -0.23$ significant at 5%).

Table 7.4. Linear correlation coefficient between 'Starkspur Golden Delicious' apple fruit mineral concentration and various quality factors on several rootstocks after 6 months of 0^oC storage.

Pairs of Comparison		1981-82 "r" values for each rootstock[z]						Pooled "r" value[z]	
Fruit Mineral (% or ppm dry wt.)	Quality Factor After Storage	Seedling	M1	MM 106	M7	OAR-1	M26	1980-81	1981-82
N	Color[y]	0.73	0.32	0.69	0.65	0.75	0.31	0.54	0.58
N	Soluble Solids (%)	-0.43	-0.44	-0.61	-0.62	-0.36	-0.16	-0.46	-0.46
N	Firmness	0.02	0.24	0.89	0.59	-0.52	-0.34	0.22	0.15
P	Soluble Solids (%)	-0.11	-0.47	-0.67	-0.69	-0.61	-0.15	-0.23	-0.55
P	Firmness	-0.01	0.58	0.37	0.67	-0.34	-0.04	0.12	0.21
Ca	Soluble Solids	-0.52	-0.56	-0.30	-0.67	-0.17	-0.86	-0.35	-0.44
Ca	Bitter Pit	-0.43	-0.52	-0.16	-0.35	-0.25	-0.83	-0.09	-0.62
Ca	Rotting	-0.16	-0.37	-0.18	-0.22	-0.36	-0.58	-0.04	-0.51
Ca	Firmness	0.43	0.28	0.07	0.51	0.13	0.82	0.29	0.15
Ca	Titratable Acidity	-0.04	-0.65	-0.66	-0.59	-0.02	-0.70	-0.36	-0.64
N/Ca	Titratable Acidity	0.30	0.62	0.28	0.46	-0.68	0.66	0.31	0.41
Mg	Soluble Solids (%)	-0.37	-0.05	-0.41	-0.24	-0.56	-0.64	-0.33	-0.28
Mg	Titratable Acidity	0.50	-0.51	-0.40	-0.60	-0.70	-0.30	-0.23	-0.23
Cu	Color	0.55	0.37	0.61	0.38	0.36	0.70	0.41	0.51
Cu	Soluble Solids (%)	-0.12	-0.09	-0.51	-0.10	-0.61	-0.16	-0.37	-0.47
K	Titratable Acidity	0.30	0.17	-0.63	0.60	0.02	-0.12	0.08	0.32
K/Ca	Titratable Acidity	0.17	0.79	0.38	0.60	0.05	0.64	0.39	0.60

[z] For each variable of each rootstock in 1981-82, n = 12 ($r > 0.57$ or $r < -0.57$ significant at 5%). For the pooled "r" values, n = 144 in 1980-81 ($r > 0.16$ or $r < -0.16$ significant at 5%) and n = 72 in 1981-82 ($r > 0.23$ or $r < -0.23$ significant at 5%).

[y] Highest color = dark green; lowest color = yellow.

Table 7.5. Linear correlation coefficent between yield and mineral concentration in 'Starkspur Golden Delicious' apple August sampled leaves and October harvested fruits and fruit quality at harvest and after 6 months of 0°C storage.

Pairs of Comparison		"r" values for each year[z]	
Leaf Mineral (% or ppm dry wt.)		1980-81	1981-82
N	yield	0.39	0.25
K	yield	-0.25	-0.11
P	yield	-0.07	0.11
Ca	yield	0.47	0.24
Mg	yield	0.05	-0.20
Cu	yield	0.33	0.13
B	yield	-0.07	-0.04
Fruit Mineral (% or ppm dry wt.)			
N	yield	0.34	0.13
K	yield	0.12	-0.14
P	yield	0.13	0.13
Ca	yield	0.35	0.51
Mg	yield	0.21	0.15
Cu	yield	0.38	0.14
B	yield	-0.24	-0.03
At Harvest			
Field Internal C_2H_4	yield	-0.19	-0.23
Soluble Solids(%)	yield	-0.49	-0.49
Titratable Acidity	yield	-0.28	-0.37
Firmness	yield	-0.28	0.11
Color[y]	yield	0.52	0.06
Average Weight	yield	-0.16	-0.19
After Storage			
Color	yield	0.54	0.34
Soluble Solids(%)	yield	-0.44	-0.41
Titratable Acidity	yield	-0.39	-0.36
Firmness	yield	0.18	0.01

[z] In 1980-81, n = 144 ($r > 0.16$ or $r < -0.16$ significant at 5%); in 1981-82, n = 72 ($r > 0.23$ or $r < -0.23$ significant at 5%).

[y] Highest color = dark green; lowest color = yellow.

Table 7.6. Linear correlation coefficients among various maturity and quality factors of October harvested 'Starkspur Golden Delicious' apple fruits on several rootstocks at harvest and after 6 months of 0°C storage.

Pairs of Comparison				"r" values for each rootstock^z						Pooled^z
At Harvest	vs.	At Harvest	Year	Seedling	M1	MM 106	M7	OAR-1	M26	"r" value
Color^y		Dry Weight (%)	81	-0.21	-0.36	-0.73	-0.96	-0.69	-0.78	-0.70
Soluble Solids (%)		Dry Weight (%)	81	0.86	0.93	0.95	0.94	0.98	0.98	0.96
Field Internal C_2H_4		Dry Weight (%)	81	0.25	-0.57	0.14	0.35	-0.68	0.81	0.32
Field Internal C_2H_4		Firmness	81	-0.65	0.11	-0.63	-0.76	0.07	-0.45	-0.26
At Harvest	vs.	Storage								
Field Internal C_2H_4		Rotting	81-82	0.12	0.20	0.10	0.08	0.14	0.74	0.33
Field Internal C_2H_4		Storage C_2H_4	81-82	-	-	-	-	-	-	0.88
Dry Weight (%)		Color	81-82	-0.32	-0.15	-0.36	-0.66	-0.74	-0.41	-0.58
Dry Weight (%)		Soluble Solids (%)	81-82	0.84	0.64	0.77	0.68	0.80	0.90	0.82
Dry Weight (%)		Titratable Acidity	81-82	0.28	0.42	0.73	0.47	0.61	0.61	0.45
Dry Weight (%)		Firmness	81-82	-0.46	-0.61	-0.66	-0.65	0.67	0.86	-0.09
Storage	vs.	Storage								
Color		Soluble Solids (%)	80-81	-0.67	-0.69	-0.50	-0.63	-0.39	-0.24	-0.75
			81-82	-0.51	-0.33	-0.34	-0.64	-0.48	-0.33	-0.62
Color		Titratable Acidity	80-81	-0.16	-0.45	-0.35	0.02	-0.30	-0.48	-0.45
			81-82	0.75	0.69	-0.08	-0.37	-0.74	-0.59	-0.12
Color		Firmness	80-81	0.52	0.48	0.56	0.50	-0.20	0.39	0.37
			81-82	0.04	0.03	0.63	0.65	-0.63	0.31	-0.08
Soluble Solids (%)		Titratable Acidity	80-81	0.34	0.25	0.01	0.42	0.38	0.13	0.41
			81-82	0.33	0.21	0.71	0.50	0.58	0.69	0.32
Soluble Solids (%)		Firmness	80-81	-0.66	-0.28	-0.60	-0.83	0.28	-0.64	-0.34
			81-82	-0.51	-0.23	-0.59	-0.88	0.63	0.75	-0.14
Soluble Solids (%)		Average Weight	80-81	0.59	0.51	0.66	0.81	0.08	0.74	0.42
			81-82	0.26	0.53	0.24	0.65	-0.11	0.52	0.40
Titratable Acidity		Firmness	80-81	-0.13	-0.01	-0.23	-0.33	0.32	0.10	-0.09
			81-82	0.01	-0.29	-0.24	-0.44	0.81	0.44	-0.05
Titratable Acidity		Average Weight	80-81	0.24	0.37	0.29	0.24	0.17	0.19	0.28
			81-82	0.27	-0.01	0.43	0.45	0.07	0.46	0.20
Firmness		Average Weight	80-81	-0.68	-0.25	-0.76	-0.74	-0.40	-0.57	-0.53
			81-82	-0.39	-0.30	-0.49	-0.50	-0.27	-0.33	-0.40

[z] For each variable of each rootstock, n = 24 in 1980-81 ($r > 0.40$ or $r < -0.40$ significant at 5%) and n = 12 in 1981-82 ($r > 0.57$ or $r < -0.57$ significant at 5%). For the pooled r values, n = 144 in 1980-81 ($r > 0.16$ or $r < -0.16$ significant at 5%) and n = 72 in 1981-82 ($r > 0.23$ or $r < -0.23$ significant at 5%).

[y] Highest color = dark green; lowest color = yellow.

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CHAPTER 8

SUMMARY AND CONCLUSIONS

Leaf and fruit seasonal mineral elements, fruit endogenous ethylene, maturity and quality of 'Starkspur Golden Delicious' apple (*Malus domestica* Borkh.) on six rootstocks: seedling, Malling (M) 1, M7, M26, Malling Merton (MM) 106, OAR-1 in a high density orchard with two levels of each of the soil applied potassium (K_2SO_4) and nitrogen (urea) fertilizers were studied in 1980 to 1982. General conclusions were drawn as follows:

1) Generally, as the growing season progressed concentrations of all fruit mineral elements and leaf N, P, and K decreased, while leaf Ca and Mg increased in all treatments.

2) Fruit cropping influenced leaf and fruit mineral status. Lighter cropping leads to an increase in leaf K and P but a decrease in fruit Ca, and an increase in fruit size.

3) Trees on OAR-1 had lower leaf Ca and produced smaller fruits with lower concentrations of N, P, K, Mg, Fe and Cu, than those on other rootstocks. However, both scion leaf B and fruit B on this rootstock were higher than all other tested rootstocks. The length on diameter ratio of fruits from OAR-1 rootstock was less than that on other stocks.

4) Scion leaves on M26 had lower Mg and those on MM106 had higher leaf Ca than those on other rootstocks.

5) Trees on M7 rootstock showed about 10% higher fruit

concentrations of N, K, Fe and Cu and also higher leaf Cu than trees on most other rootstocks.

6) Fruit endogenous ethylene started to rise logarithmically between October 9 and October 15 in most treatments.

7) Fruit endogenous ethylene on OAR-1 rootstock increased 9 days later than those on other rootstocks in 1981, and generally had lower ethylene in the field and after storage indicating later maturity of these fruits.

8) Fruits on M26 rootstock showed higher internal ethylene in both 1980 and 1981 which is partially due to the influence of rootstock. However, lighter cropping in 1981 greatly contributed to the enhanced maturity of fruits on M26.

9) Higher nitrogen fertilizer significantly increased the evolved ethylene of fruits in the storage.

10) Trees on OAR-1 showed light color fruits with higher soluble solids and greater firmness, while those on M7 showed green fruits with lower soluble solids at harvest. This indicates that lower internal ethylene of fruits on OAR-1 should not be taken as an indication of lower quality.

11) Fruit Ca significantly contributed to storage disorders. Thus, fruits from trees on OAR-1 had low Ca and a high percentage of breakdown in 1980, and the same pattern was seen on M26 in 1981.

12) Any rootstock, fertilizer or cropping effects which influence mineral status, particularly fruit N, K and Ca, can

significantly affect post-harvest quality. Fruits with higher N fertilizer have greener color and fruits with higher K/Ca ratio have higher titratable acidity.

13) Light cropping would result in well developed larger fruits with high dry matter and soluble solids and generally desirable quality at harvest. Fruits from light cropping trees, however, have lower concentrations of minerals, particularly Ca, due to a dilution effect from the higher carbohydrates or dry matter. Thus, fruits from light cropping trees have a greater tendency to develop storage rot and bitterpit and also might be more prone to earlier ripening and senescence with the increased ethylene in storage.

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APPENDICES

Appendix Table A.1 'Starkspur Golden Delicious' apple leaf mineral concentrations as influenced by rootstock and soil applied K and N. Samples taken in August 1980, all values expressed as % dry weight or as ppm dry weight basis.

	N (%)	K (%)	P (%)	Ca (%)	Mg (%)	Fe (ppm)	Cu (ppm)	B (ppm)
Seedling	1.98b[z]	1.21a	.217ab	1.65b	.374b	154a	4.66cd	39.3a
M1	2.03b	1.26a	.205ab	1.82ab	.321b	165a	5.54bc	39.6a
MM106	2.11ab	1.13ab	.221a	2.00a	.337b	164a	5.83ab	39.1a
M7	2.05ab	1.20a	.222a	1.75b	.342b	164a	6.75a	37.8a
OAR-1	2.01b	1.20a	.236a	1.30c	.353b	172a	4.41d	44.6a
M26	2.18a	1.06b	.183b	1.69b	.455a	176a	4.87bcd	38.6a
Levels[x] of K								
Low K	2.04[y]	1.16	.215	1.74*	.377*	168	5.27	40.5
High K	2.08	1.20	.213	1.66	.351	163	5.41	39.2
Levels[x] of N								
Low N	2.03	1.23**	.229**	1.73	.344	166	5.47	40.7
High N	2.09**	1.13	.200	1.68	.383**	165	5.22	39.0

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are significantly different from high levels within columns if shown by *(5%) or by **(1%).

[x] Low K = zero K/4 trees, high K = 68g actual K as K_2S04/4 trees, Low N = 34g actual N as urea/4 trees, High N = 68g actual N as urea/4 trees.

Appendix Table A.2 1981 seasonal mineral concentrations of 'Starkspur Golden Delicious' apple leaves as influenced by rootstock and soil applied nitrogen, all values expressed as % dry weight or ppm dry weight basis.

		N (%)			K (%)			P (%)	
Rootstock	July	Aug.	Sept.	July	Aug.	Sept.	July	Aug.	Sept.
Seedling	2.14a[z]	2.15a	2.02a	1.38a	1.06a	0.815b	0.260ab	0.233a	0.242ab
M1	2.12a	2.09a	2.07a	1.44a	1.17a	0.95ab	0.243bc	0.234a	0.237ab
MM106	2.04a	2.07a	2.01a	1.33a	1.08a	0.96ab	0.244bc	0.221a	0.244ab
M7	2.01a	2.03a	2.05a	1.44a	1.19a	1.03a	0.251abc	0.221a	0.239ab
OAR-1	2.13a	2.06a	1.97a	1.45a	1.11a	0.99a	0.294a	0.251a	0.270a
M26	2.02a	1.98a	1.96a	1.32a	1.11a	1.10a	0.209c	0.193b	0.215b
Levels[y] of N									
Low N	2.00[y]	2.04	1.98	1.48**	1.18**	0.989	0.244	0.246**	0.257**
High N	2.15**	2.09*	2.05*	1.31	1.06	0.966	0.243	0.205	0.225

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low level of N (zero N/4 trees) is significantly different from high levels (68g actual N as urea/4 trees) within columns if shown by *(5%) or by **(1%).

Appendix Table A.2 continued

Rootstock	Ca (%) July	Ca (%) Aug.	Ca (%) Sept.	Mg (%) July	Mg (%) Aug.	Mg (%) Sept.	Fe (ppm) July	Fe (ppm) Aug.	Fe (ppm) Sept.
Seedling	1.32bc^{z}	1.65bc	2.22ab	0.281b	0.352a	0.348ab	140a	206a	171a
M1	1.51b	1.77b	2.35a	0.265b	0.271c	0.278c	137a	174a	167a
MM106	1.75a	2.07a	2.47a	0.287b	0.314bc	0.325bc	126a	159a	145a
M7	1.51b	1.80b	2.35a	0.299b	0.320bc	0.337ab	140a	168a	165a
OAR-1	1.15c	1.21d	1.65c	0.263b	0.280c	0.322bc	146a	191a	172a
M26	1.39b	1.49c	1.95bc	0.409a	0.396a	0.390a	135a	172a	161a
Levels^{y} of N									
Low N	1.49^{*y}	1.69	2.20	0.287	0.302	0.318	137	178	164
High N	1.39	1.64	2.13	0.314*	0.342**	0.348*	138	178	163

Appendix Table A.2 continued

Rootstock	Cu (ppm)			B (ppm)		
	July	Aug.	Sept.	July	Aug.	Sept.
Seedling	6.16bc[z]	5.33ab	5.66a	36.0bc	39.3b	38.4b
M1	6.58bc	5.41ab	6.16a	37.3bc	38.2b	38.0b
MM106	6.91ab	5.75a	6.25a	37.0bc	38.0b	41.9b
M7	7.66a	6.16a	6.66a	38.5b	37.8b	39.1b
OAR-1	6.25bc	4.58b	5.50a	44.7a	48.3a	49.4a
M26	5.91c	4.50b	5.58a	33.0c	33.5b	39.0b
Levels[y] of N						
Low N	6.52[y]	5.25	5.83	38.9	40.3^{**}	42.2^{*}
High N	6.63	5.33	6.11	36.6	38.1	39.7

Appendix Table B.1 1980 Seasonal Fruit Mineral Concentration of 'Starkspur Golden Delicious' apple fruits as influenced by rootstock and soil applied and K and N. Values expressed as % dry weight or ppm dry weight basis.

	N (%)						K (%)					
Rootstock	May	June	July	Aug.	Sept.	Oct.	May	June	July	Aug.	Sept.	Oct.
Seedling	2.30a[z]	0.959a	0.507ab	0.454a	0.380a	0.337a	2.05a	1.10b	0.806a	0.753a	0.592a	0.752a
M1	2.28a	0.828bc	0.543ab	0.441a	0.380a	0.350a	2.09a	1.21ab	0.793a	0.748a	0.620a	0.769a
MM106	2.28a	0.956ab	0.618a	0.486a	0.404a	0.348a	2.02a	1.29a	0.808a	0.776a	0.573a	0.740a
M7	2.24a	0.984a	0.588a	0.475a	0.416a	0.385a	2.04a	1.31a	0.852a	0.738a	0.644a	0.738a
OAR-1	2.10b	0.740c	0.418b	0.363b	0.317b	0.280b	2.10a	1.17ab	0.730a	0.580b	0.467b	0.653a
M26	2.26a	1.01a	0.605a	0.475a	0.397a	0.353a	2.04a	1.30a	0.872a	0.800a	0.622a	0.740a
Levels[x] of K												
Low K	2.24[y]	0.892	0.542	0.448	0.379	0.346	2.04	1.21	0.789	0.710	0.579	0.733
High K	2.25	0.934	0.551	0.459	0.386	0.338	2.08	1.25	0.831	0.755	0.593	0.731
Levels[x] of N												
Low N	2.24	0.898	0.547	0.443	0.376	0.338	2.09	1.27**	0.833	0.746	0.605*	0.731
High N	2.24	0.928	0.546	0.455	0.388	0.346	2.03	1.19	0.787	0.719	0.568	0.734

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are significantly different from high levels within columns if shown by *(5%) or by **(1%).

[x] Low K = zero g K/4 trees, high K = 68g actual K as K2SO4/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees.

Appendix Table B.1 Continued

	P (%)						Ca (%)					
Rootstock	May	June	July	Aug.	Sept.	Oct.	May	June	July	Aug.	Sept.	Oct.
Seedling	0.397a[z]	0.187b	0.106a	0.101a	0.075a	0.106a	0.490a	0.154a	0.075a	0.073b	0.067cd	0.094c
M1	0.357a	0.186b	0.095a	0.096a	0.072a	0.104a	0.450a	0.145a	0.067a	0.080b	0.072bc	0.098bc
MM106	0.342a	0.207ab	0.110a	0.105a	0.068a	0.113a	0.470a	0.149a	0.077a	0.10a	0.080ab	0.110ab
M7	0.366a	0.212a	0.118a	0.100a	0.080a	0.104a	0.471a	0.152a	0.082a	0.098a	0.080ab	0.110ab
OAR-1	0.378a	0.189ab	0.093a	0.069b	0.052b	0.0895a	0.453a	0.145a	0.078a	0.071b	0.057d	0.088c
M26	0.360a	0.212a	0.107a	0.108a	0.072a	0.102a	0.455a	0.150a	0.090a	0.105a	0.085a	0.117a
Levels[x] of K												
Low K	0.368[y]	0.199	0.106	0.097	0.071	0.107	0.468	0.150	0.081**	0.090	0.074	0.105
High K	0.366	0.199	0.103	0.096	0.069	0.099	0.462	0.149	0.075	0.086	0.073	0.100
Levels[x] of N												
Low N	0.380*	0.208**	0.110*	0.102*	0.075***	0.105	0.461	0.150	0.076	0.084	0.073	0.101
High N	0.353	0.189	0.100	0.091	0.065	0.101	0.461	0.148	0.080	0.091**	0.074	0.104

Appendix Table B.1 Continued

	Mg (%)						Fe (ppm)					
Rootstock	May	June	July	Aug.	Sept.	Oct.	May	June	July	Aug.	Sept.	Oct.
Seedling	0.314abc^{z}	0.070bc	0.034b	0.125a	0.036a	0.034abc	99.0a	21.3a	12.1a	12.2a	13.0a	20.6a
M1	0.280c	0.065c	0.043ab	0.222a	0.034ab	0.033abc	102.5a	25.3a	20.6a	16.3a	14.1a	21.7a
MM106	0.305abc	0.076ab	0.043ab	0.232a	0.037a	0.032bc	101.5a	28.1a	14.3a	17.1a	13.1a	20.4a
M7	0.325ab	0.076ab	0.037ab	0.203a	0.037a	0.037ab	108.1a	29.6a	14.2a	19.5a	15.1a	21.7a
OAR-1	0.296bc	0.071abc	0.029b	0.120a	0.028b	0.028c	84.6a	26.7a	7.9a	13.1a	9.8b	16.7a
M26	0.338a	0.079a	0.052a	0.266a	0.039a	0.041a	102.5a	28.1a	19.8a	15.8a	13.7a	27.2a
Levels^{x} of K												
Low K	0.309^{y}	0.072	0.039	0.199	0.035	0.034	102.1	26.7	14.7	15.0	13.3	23.3
High K	0.310	0.073	0.040	0.190	0.035	0.035	97.3	26.4	14.9	16.3	13.0	19.4
Levels^{x} of N												
Low N	0.305	0.071	0.038	0.198	0.035	0.035*	97.3	26.9	15.2	15.9	13.5	21.2
High N	0.315	0.075	0.041	0.191	0.035	0.033	102.1*	26.2	14.5	15.5	12.8	21.5

Appendix Table B.1 Continued

	Cu (ppm)						B (ppm)					
Rootstock	May	June	July	Aug.	Sept.	Oct.	May	June	July	Aug.	Sept.	Oct.
Seedling	12.18bc[z]	3.00d	1.50bc	1.56b	0.54c	1.45c	44.6a	30.0c	23.8b	25.4a	18.6ab	27.3b
M1	14.06ab	5.12abc	2.37abc	9.12a	1.00b	2.37ab	47.6a	40.4abc	24.5b	28.5a	20.5a	27.4b
MM106	14.06ab	5.87ab	2.87ab	10.12a	1.04b	2.62a	46.9a	44.0ab	24.5b	27.6a	17.3ab	26.9b
M7	16.31a	6.87a	4.18a	12.50a	1.50a	3.00a	49.5a	45.3ab	26.5ab	22.5a	17.0b	21.0c
OAR-1	9.56c	4.50bcd	0.68c	2.25b	0.04d	1.00c	52.1a	48.7a	32.8a	29.5a	19.4ab	32.7a
M26	8.93c	3.56cd	2.12bc	7.93ab	0.79bc	1.70bc	50.1a	35.9bc	22.1b	27.4a	16.4b	23.0bc
Levels[x] of K												
Low K	12.68[y]	4.85	2.39	6.91	0.87	2.13	48.9	41.5	26.4	27.5	19.2*	27.5*
High K	12.35	4.79	2.18	7.58	0.76	1.91	48.1	40.2	25.0	26.1	17.2	25.2
Levels[x] of N												
Low N	12.83	5.08	2.33	7.50	0.87	1.94	46.5	40.3	24.8	27.3	18.7	25.4
High N	12.20	4.56	2.25	7.00	0.76	2.11	50.5*	41.1	26.6	26.3	17.7	27.4*

Appendix Table B.2 1981 seasonal fruit mineral concentrations of 'Starkspur Golden Delicious' apples as influenced by rootstock, and soil applied N. Values expressed as % or ppm dry weight.

	N (%)				K (%)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	0.339a[z]	0.203a	0.181ab	0.213a	0.781ab	0.624ab	0.647ab	0.595b
M1	0.330a	0.189a	0.189a	0.217a	0.833a	0.670a	0.729a	0.672a
MM106	0.341a	0.205a	0.194a	0.215a	0.803a	0.690a	0.698a	0.625ab
M7	0.364a	0.224a	0.187a	0.204a	0.835a	0.692a	0.702a	0.690a
OAR-1	0.289a	0.159a	0.136b	0.181a	0.713b	0.595b	0.585b	0.596b
M26	0.310a	0.185a	0.155ab	0.196a	0.793ab	0.641ab	0.687a	0.669ab
Levels[y] of N								
Low N	0.310[y]	0.182	0.165	0.191	0.801	0.661	0.688	0.650
High N	0.348**	0.206**	0.182*	0.217**	0.785	0.643	0.661	0.632

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low level of N (zero N/4 trees) is significantly different from high level (68 g actual N as urea/4 trees) within columns if shown by *(5%) or by **(1%).

Appendix Table B.2 continued

Rootstock	P (%) July	P (%) Aug.	P (%) Sept.	P (%) Oct.	Ca (%) July	Ca (%) Aug.	Ca (%) Sept.	Ca (%) Oct.
Seedling	0.110a[z]	0.100a	0.107a	0.095a	0.078ab	0.070a	0.060a	0.059ab
M1	0.110a	0.094a	0.108a	0.100a	0.093a	0.078a	0.063a	0.060ab
MM106	0.109ab	0.103a	0.105ab	0.096a	0.080ab	0.066a	0.051a	0.048bc
M7	0.110a	0.100a	0.104ab	0.097a	0.073bc	0.061a	0.047ab	0.050a
OAR-1	0.099bc	0.090a	0.091b	0.090a	0.091a	0.077a	0.061a	0.065a
M26	0.097c	0.086a	0.091b	0.086a	0.059c	0.039b	0.031b	0.034c
Levels[y] of N								
Low N	0.106[y]	0.098*	0.104*	0.095	0.080	0.066	0.055*	0.053
High N	0.105	0.093	0.098	0.094	0.078	0.064	0.049	0.052

Appendix Table B.2 continued

Rootstock	Mg (%)				Fe (ppm)			
	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	0.042a[z]	0.026a	0.021a	0.024a	19.4a	7.9ab	7.5ab	7.9ab
M1	0.044a	0.030a	0.026a	0.021a	23.5a	7.4ab	9.2a	7.5b
MM106	0.048a	0.023a	0.023a	0.017a	13.2a	7.1ab	7.7ab	6.5bc
M7	0.046a	0.028a	0.023a	0.020a	19.1a	9.3a	9.4a	9.8a
OAR-1	0.047a	0.024a	0.025a	0.017a	21.1a	4.5c	5.2c	5.1c
M26	0.043a	0.026a	0.020a	0.019a	20.4a	5.6bc	6.5bc	7.7b
Levels[y] of N								
Low N	0.046[y]	0.025	0.022	0.021	19.1[y]	6.5	7.6	6.9
High N	0.044	0.027	0.024	0.018	19.8	7.4	7.5	7.9*

Appendix Table. B.2 continued

	Cu (ppm)				B (ppm)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	2.33cd [z]	2.00c	2.58c	1.5b	21.0c	19.4b	21.3c	20.2b
M1	2.83bc	2.75b	3.16bc	1.58b	23.2bc	20.6b	23.8bc	22.7b
MM106	3.25b	3.08b	3.58b	2.00b	24.5b	24.2a	25.2b	23.4b
M7	4.83a	4.25a	4.66a	3.33a	21.5bc	20.6b	21.6bc	22.1b
OAR-1	1.75d	1.41c	1.66d	0.66c	29.3a	27.0a	29.0a	27.5a
M26	1.66d	1.75c	1.75d	0.75c	20.5c	17.8b	21.2c	20.0b
Levels [y] of N								
Low N	2.83 [y]	2.52	2.97	1.63	23.7	22.1	24.1	21.9
High N	2.72	2.55	2.83	1.63	23.0	21.1	23.3	23.4

Appendix Table B.3 Seasonal fresh weight changes (grams/fruit) during development of 'Starkspur Golden Delicious' apple fruits as influenced by rootstocks and soil K and N applications, 1980 and 1981.

				1980			
Rootstock	May 27	June 27	July 27	Aug. 27	Oct. 2	Oct. 15	Oct. 30
Seedling	0.92b^{z}	15.5ab	48.3ab	96.0abc	150.0a	151.4ab	161.2ab
M1	1.08a	16.1a	53.7a	98.2ab	143.5ab	151.7a	170.4a
MM106	1.10a	16.1a	52.5a	91.5bc	139.3ab	145.9ab	159.5ab
M7	1.03ab	16.3a	53.7a	100.4a	141.2ab	146.4ab	165.4ab
OAR-1	0.94b	13.4b	43.8b	90.9c	133.5b	139.4b	152.6b
M26	1.10a	16.8a	50.6a	97.6abc	145.0ab	149.9ab	160.2 ab
Levels^{x} of K							
Low K	1.02^{y}	15.5	49.5	94.9	142.6	144.8	164.4
High K	1.03	15.9	51.4	96.6	141.6	150.1	158.6
Levels^{x} of N							
Low N	1.01	15.6	51.4	97.3*	141.7	151.7**	164.4*
High N	1.04	15.7	49.5	94.1	142.5	143.2	158.6

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are significantly different from high levels within columns if shown by *(5%) or by **(1%).

[x] In 1980, low K = 0 g K/4 trees, high K = 68g actual K as K$_2$S04/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees; in 1981, low N = 0 g/4 trees, high N = 68g actual N as urea/4 trees.

Appendix Table B.3 continued

Rootstock	July 27	Aug. 27	1981 Sept. 30	Oct. 10	Oct. 20
Seedling	61.5ab[z]	96.5b	130.8b	151.7b	150.6b
M1	61.5ab	100.4ab	135.1b	152.7b	151.2b
MM106	61.7ab	94.6bc	135.9b	143.2b	149.7b
M7	60.3b	100.1ab	139.4b	151.6b	154.5ab
OAR-1	53.4c	83.8c	110.0c	124.6c	130.8c
M26	66.9a	109.1a	155.5a	173.3a	169.8a
Levels[x] of K					
Low K	--	--	--	--	--
High K	--	--	--	--	--
Levels[x] of N					
Low N	59.8[y]	96.6	134.0	149.7	148.2
High N	61.8	98.1	134.8	149.3	154.0

Appendix Table B.4 1981 seasonal changes in dry matter content (grams/fruit) and dry matter concentration (as % of fresh weight) of 'Starkspur Golden Delicious' apple fruits as influenced by rootstocks and soil applied N.

	Dry Matter Concentration (% of fresh weight)				Dry Matter Content (grams/fruit)			
Rootstock	July 27	Aug. 27	Sept. 30	Oct. 10	July 27	Aug. 27	Sept. 30	Oct. 10
Seedling	16.37a[z]	11.81b	11.76bc	11.55b	10.09a	11.44b	15.62b	17.58b
M1	16.99a	11.89b	11.70c	11.41b	10.50a	11.96b	15.29b	17.39b
MM106	16.79a	12.05b	12.10bc	12.05b	10.43a	11.39b	14.47b	17.30b
M7	17.05a	11.81b	11.99bc	11.55b	10.40a	11.95b	15.69b	17.80b
OAR-1	16.45a	12.85ab	13.29ab	12.78ab	8.82a	10.75b	14.25b	15.96b
M26	19.01a	13.84a	13.90a	13.66a	12.82a	15.24a	20.86a	23.93a
Levels[y] of N								
Low N	16.89[y]	12.26	12.34	12.19	10.18	11.87	15.60	18.35
High N	17.33	12.48	12.57	12.15	10.83	12.38	16.46	18.30

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low level of N (zero N/4 trees) is not significantly different from high level (68g actual N as urea/4 trees) within columns at 5% level.

Appendix Table B.5 1981 seasonal mineral content (mg or µg per fruit) of 'Starkspur Golden Delicious' apple fruits as influenced by rootstock and soil applied N.

	N (mg/fruit)				K (mg/fruit)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	35.0a[z]	23.3b	27.7a	37.2b	78.6ab	71.0bc	101.2bc	104.2b
M1	35.6a	22.5b	28.4a	37.7b	87.0a	80.2abc	110.6b	116.7b
MM106	35.7a	23.4b	27.8a	36.8b	83.3ab	78.5bc	100.7bc	108.2b
M7	37.1a	25.0ab	28.2a	34.6bc	87.8a	83.6ab	109.6b	125.0b
OAR-1	25.6a	16.8c	18.7b	28.1c	61.8b	63.4c	82.6c	94.1b
M26	40.5a	27.9a	31.5a	46.5a	100.5a	96.5a	142.8a	161.3a
Levels[y] of N								
Low N	31.8[y]	21.4	25.3	34.7	81.2	78.4	107.3	117.4
High N	38.0**	24.9**	28.8*	38.9**	85.1	79.3	108.5	119.1

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low level of N (zero N/4 trees) is significantly different from high level (68 g actual N as urea/4 trees) within columns if shown by *(5%) or by **(1%).

Appendix Table B.5 continued

	P (mg/fruit)				Ca (mg/fruit)				Mg (mg/fruit)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	11.1a[z]	11.3a	16.8a	16.7b	7.7a	7.9ab	9.5a	10.3a	4.3a	3.0a	3.2a	4.2a
M1	11.7a	11.2a	16.4ab	17.3ab	9.8a	9.2a	9.4a	10.3a	4.6a	3.5a	4.0a	3.7a
MM106	11.3a	11.7a	15.2ab	16.6b	8.2a	7.5b	7.3bc	8.2b	5.0a	2.5a	3.3a	2.9a
M7	11.5a	11.9a	16.0ab	17.2ab	7.3a	6.9b	6.8bc	8.4ab	4.7a	3.2a	3.6a	3.6a
OAR-1	8.6a	9.6a	12.9b	14.2b	8.0a	8.2ab	8.5ab	10.1a	4.3a	2.5a	3.4a	2.7a
M26	12.4a	13.0a	18.9a	20.7a	7.2a	5.3b	5.4c	7.3b	5.4a	3.9a	4.0a	4.4a
Levels[y] of N												
Low N	11.4[y]	11.5	16.2	17.3	7.9	7.6	8.3	9.3	4.7	3.0	3.3	3.9
High N	10.8	11.4	15.9	16.9	8.1	7.4	7.4	8.9	4.7	3.3	3.9	3.2

Appendix Table B.5 continued

	Fe (μg/fruit)				Cu (μg/fruit)				B (μg/fruit)			
Rootstock	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.	July	Aug.	Sept.	Oct.
Seedling	195a^{z}	89a	119ab	139ab	24bcd	22cd	40bc	26bcd	208a	220a	337a	356a
M1	232a	88a	139ab	130b	28bc	33bc	48bc	26bc	243a	246a	362a	395a
MM106	143a	80ab	110bc	111b	33b	34b	51b	33b	255a	277a	365a	407a
M7	207a	108a	152a	176a	50a	50a	73a	60a	223a	248a	338a	391a
OAR-1	175a	74b	71c	79c	14d	14d	23d	10d	251a	288a	409a	434a
M26	271a	86a	132ab	182a	20cd	26cd	35cd	17cd	262a	271a	448a	481a
Levels^{y} of N												
Low N	195^{y}	77	120	129	28	29	46	30	236	259	373	398
High N	213	90*	120	143	28	30	44	28	245	258	381	423

Appendix Table B.6 1980 'Starkspur Golden Delicious' apple fruit shape changes during seasonal development as influenced by rootstock and soil K and N applications.

	Length (cm)					Diameter (cm)				
Rootstock	May	June	July	Aug.	Sept.	May	June	July	Aug.	Sept.
Seedling	1.59b[z]	3.46a	4.78a	5.95a	6.64a	1.00a	3.02a	4.47b	5.72a	6.37a
M1	1.69a	3.46a	4.93a	5.86a	6.65a	1.06a	3.09a	4.70a	5.78a	6.50a
MM106	1.68ab	3.48a	4.90a	5.81ab	6.50a	1.05a	3.09a	4.68a	5.67a	6.32a
M7	1.64ab	3.52a	4.93a	5.97a	6.60a	1.03a	3.12a	4.62ab	5.79a	6.34a
OAR-1	1.59b	3.22b	4.50b	5.66b	6.57a	1.00a	2.92a	4.42b	5.69a	6.43a
M26	1.73a	3.50a	4.82a	5.96a	6.62a	1.06a	3.13a	4.61ab	5.78a	6.42a
Levels[x] of K										
Low K	1.65[y]	3.41	4.80	5.84	6.60	1.03	3.02	4.55	5.71	6.42
High K	1.66	3.46*	4.82	5.89	6.60	1.04	3.10**	4.62*	5.76	6.37
Levels[x] of N										
Low N	1.66	3.44	4.82	5.91*	6.66	1.04	3.06	4.62	5.77	6.44
High N	1.64	3.42	4.79	5.82	6.52	1.03	3.06	4.55	5.70	6.35

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are significantly different from high levels within columns if shown by *(5%) or by **(1%).

[x] Low K = 0g K/4 trees, high K = 68g actual K as K_2S04/4 trees, Low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees.

Appendix Table B.6 continued

Rootstock	May	Length/Diameter ratio June	July	Aug.	Sept.
Seedling	1.59a^z	1.14a	1.07a	1.04a	1.04a
M1	1.61a	1.11b	1.04ab	1.01bc	1.02a
MM106	1.61a	1.12ab	1.04ab	1.02ab	1.02a
M7	1.61a	1.12ab	1.07a	1.03ab	1.04a
OAR-1	1.60a	1.10b	1.01b	0.99c	1.02a
M26	1.65a	1.11b	1.04ab	1.03ab	1.03a
Levels^x of K					
Low K	1.61^y	1.12	1.05	1.02	1.03
High K	1.61	1.11	1.04	1.02	1.03
Levels^x of N					
Low N	1.61	1.12	1.04	1.02	1.03
High N	1.61	1.12	1.05	1.02	1.02

Appendix Table C.1 Endogenous ethylene (ppb) during maturation of 'Starkspur Golden Delicious' apple fruit as influenced by rootstock and soil K and N applications (1980).

Rootstock	Sept. 15	Sept. 19	Sept. 24	Sept. 30	Oct. 9	Oct. 14	Oct. 22	Oct. 28	Nov. 4
Seedling	2a[z]	10a	7a	7a	151ab	114a	533a	1524b	21348c
M1	3a	7a	5a	5a	164ab	109a	665a	2327ab	20965c
MM106	3a	3a	3a	3a	100b	91a	183a	2156ab	27083ab
M7	3a	9a	3a	5a	157ab	152a	932a	3949a	32477ab
OAR-1	4a	5a	4a	4a	227a	172a	201a	1334b	7206d
M26	3a	5a	4a	4a	110b	94a	382a	3117ab	39163a
Levels[x] of K									
Low K	3[y]	8	5	5	142	116	383	2105	21579
High K	3	5	4	5	161	127	582	2698	27835**
Levels[x] of N									
Low N	3	8	5	6	174	132	501	2729	26076
High N	3	5	4	3	128	111	463	2073	23337

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K is significantly different from high levels within columns if shown by **(1%). Low N is not significantly different than high N within columns at 5% level.

[x] Low K = 0g K/4 trees, high K = 68g actual K as K_2S04/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees.

Appendix Table C.2 Endogenous ethylene (ppb) during maturation of 'Starkspur Golden Delicious' apple fruit as influenced by rootstock and soil N applications (1981).

Rootstock	Oct. 5	Oct. 12	Oct. 16	Oct. 21	Oct. 28
Seedling	8a[z]	929ab	1174ab	4532a	13359abc
M1	5a	153ab	233b	1976b	9410bc
MM 106	4a	103ab	55b	1347bc	14460ab
M7	3a	59ab	516b	2517b	17499ab
OAR-1	2a	3b	3b	23c	2698c
M26	9a	1299a	1953a	5912a	22192a
Levels[y] of N					
Low N	6[y]	262	678	2125	10284
High N	7	586	633	3310	16256*

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[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of N (zero N/4 trees) is significantly different from high levels (68g actual N as urea/4 trees) within columns if shown by *(5%).

Appendix Table C.3 Evolved ethylene during 20°C ripening of 'Starkspur Golden Delicious' apple fruit harvested October 10, 1981 and stored at 0°C until late December 1981 as influenced by rootstock and soil N applications. Values are expressed as ul C_2H_4/kg fruit/hr.

Rootstock	Dec. 21	Dec. 23	Dec. 25	Dec. 27	Dec. 29	Jan. 1	Jan. 5
Seedling	91.5ab[z]	92.3bc	106.0ab	142.0ab	142.7ab	114.0ab	101.0a
M1	84.8ab	88.8bc	107.8ab	137.3ab	139.0ab	110.7ab	98.2a
MM106	90.8ab	99.3ab	103.3ab	150.5ab	148.2ab	121.0a	94.0a
M7	82.0ab	86.5bc	105.5ab	132.3ab	134.7ab	112.7ab	101.7a
OAR-1	64.5b	69.5c	76.5b	105.5b	102.7b	86.2b	78.0a
M26	110.8a	119.0a	129.0a	171.8a	163.2a	117.2a	98.0a
Levels[y] of N							
Low N	79.6[y]	82.3	92.6	123.8	123.5	103.2	89.0
High N	95.1**	102.8**	116.8**	155.9**	153.3**	117.4**	101.2**

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of N (zero N/4 trees) is significantly different from high level N (68g actual N as urea/4 trees) within columns at 1%.

Appendix Table D.1 Rootstock soil applied fertilizer and harvest maturity influence on the respiration rate of 'Starkspur Golden Delicious' apple fruits in 1980 and 1981.

	At Harvest 1980			At Harvest 1981			Storage 1980-81
Rootstock	Harvest 1	Harvest 2	Harvest 3	Harvest 1	Harvest 2	Harvest 3	Harvest 2
Seedling	43.9a[z]	31.6a	32.7a	33.9a	30.4a	29.7a	40.8a
M1	42.8a	30.2a	31.1a	35.5a	30.4a	31.0a	40.7a
MM106	45.1a	32.8a	35.0a	37.9a	32.3a	34.7a	42.4a
M7	40.3a	30.6a	32.6a	38.6a	32.2a	31.3a	39.1a
OAR-1	45.5a	34.0a	35.4a	39.8a	32.8a	32.8a	43.0a
M26	41.2a	31.7a	30.4a	38.9a	34.1a	33.1a	42.8a
Levels[x] of K							
Low K	43.9[y]	31.3	32.0	-	-	-	41.0
High K	42.4	32.3	33.6	-	-	-	41.9
Levels[y] of N							
Low N	42.7	31.8	33.0	38.0	31.3	31.9	41.0
High N	43.6	31.9	32.7	36.8	32.7	32.2	41.9

[z] Rootstock mean separation within columns by Duncan's multiple range test, 5% level.

[y] Low levels of K or N are not significantly different from high levels within columns at 5%.

[x] In 1980, low K = 0g K/4 trees, high K = 68g actual K as K_2SO4/4 trees, low N = 34g actual N as urea/4 trees, high N = 68g actual N as urea/4 trees; In 1981, low N = 0g/4 trees, high N = 68g actual N as urea/4 trees.