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# Influence of Fruit Spacing on Fruit Quality and Mineral Partitioning of 'Redchief Delicious' Apple Under Full Crop Conditions

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## Abstract

Yield, fruit quality, and mineral partitioning in fruit and leaf tissues of 'Redchief Delicious' apple (*Malus domestica* Borkh.) on M.9/MM.106 and M.9/MM.111 with five levels of fruit spacing (thinning) at harvest and after six months of storage were studied under full crop conditions. Fruit weight in the trees thinned at 18 cm spacing was higher, but yield was lower than those of both 5 and 10 cm spacings. Trees thinned at 36 cm spacing had a higher return bloom and yield in the following year. Fruit spacing greater than10 cm increased fruit color and soluble solids concentration (SSC) both at harvest and after storage. Fruit firmness at harvest was not affected by fruit spacing, but fruit from 18 and 25 cm spacings had significantly lower firmness than all other spacings after storage. Fruit spacing greater than 10 cm decreased N but increased K expressed at mg K/100g fresh weight in both leaf and fruit tissues. Trees thinned at 5 and 10 cm spacings had similar levels of fruit Ca, and both had significantly higher fruit Ca than those thinned at 18, 25 and 36 cm spacings. All quality and mineral composition factors considered, thinning fruit to a 10 to 18 cm spacing is beneficial, depending an the market demands and objectives of production. Thinning at distances greater than 18 cm between fruit is not advisable, as yield was drastically reduced without gaining additional fruit color or firmness. 'Redchief Delicious' trees on M.9/MM.106 had a higher yield, but lighter fruit color and lower SSC than those on M.9/MM.111, although fruit on both interstock/rootstock combinations had similar weights. Fruit from trees on M.9/MM.106 had higher Cu, Mn and Mg than those on M.9/MM.111.

## Introduction

Apple fruit are chemically thinned to assure marketable fruit size and return bloom for the following year (15, 21, 25, 36). 1-naphthyl N-methyl carbamate (Sevin), naphthaleneacetic acid (NAA) or a combination of these two chemicals are the most commonly used thinners for 'Red Delicious.' However, benzyladenine (BA), gibberellins (GA) or a combination of BA and GA have been studied for apple thinning (14, 15, 16, 33). Chemical thinning sometimes results in underthinning, overthinning or pygmy fruit (12, 15, 16, 32).

Reported effects of fruit thinning on yield have been contradictory. In some reports, effects of fruit thinning on yield are negligible (2, 17, 24), while others found that thinning reduced yield substantially (1, 11, 18, 23, 27). Forshey and Elfving (13) reported that fruit thinning increased the percentage of larger fruits in 'McIntosh' apple, but reductions in yield were such that the actual number of large fruits was either unchanged or reduced. Fletcher (11) reported that hand thinning significantly increased fruit size and color, but reduced yield in apple.

In the Pacific Northwest, chemical thinning of fruit is usually followed by a hand thinning. Removal of small and weak fruit (size thinning) rather than predetermined space thinning is practiced for some apple cultivars (34). However, size thinning may not be suitable for some spur type 'Delicious' apples where fruit have a more or less uniform size throughout the branches. Fruit thinning increases leaf/fruit ratio (22) and influences crop load and crop load, in turn, correlates negatively with fruit size, color and SSC (9). Crop load can also influence the mineral status of both leaves and fruit (6, 7, 8).

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The influence of rootstock on various aspects of apple cultivars including yield, quality (3, 5, 8, 10, 20, 26, 29, 31) and mineral composition (6, 7, 9, 29, 35) have been studied. However, the genetic composition of every scion/rootstock combination and its physiological and biochemical interactions with the environment are unique. This unique feature mandates that every scion/rootstock combination be studied for its yield, quality and other pomological characteristics in every climatic condition.

Although 'Redchief Delicious' is a major commercial cultivar in the Pacific Northwest, there is no information on optimum fruit spacing, fruit quality and mineral partitioning for this cultivar under heavy crop conditions. Our objective was to study the influence of fruit spacing on yield, fruit quality and also mineral partitioning in the leaf and fruit in 'Redchief Delicious' apples with M.9 interstock on two rootstocks under full crop conditions.

## Materials and Methods

'Redchief Delicious' apple trees with an M.9 interstem on MM.106 or MM.111 rootstocks were planted at the University of Idaho Parma Research and Extension Center in early spring of 1984. The M.9 interstem was used to control tree vigor. Tree spacing was 2.3 x 6.0 m and trees were trained as a central leader. 'Winter Banana' apple (*Malus domestica* Borkh.) was used as the pollinizer.

Nitrogen as urea was broadcast in late fall or early spring of each year at the rate of 0.045 to 0.23 kg actual N per tree, depending on the age of trees. In 1990, no nitrogen fertilizer was applied. Zinc-50 (a Zn containing compound) was sprayed at late dormant season (late March) every year. Trees were irrigated every eight days during the growing season with an under tree sprinkler system. In general, all cultural practices in this experimental orchard were similar to those used in commercial orchards.

The experimental design was a randomized complete block split plot. Rootstock was the main plot and fruit spacing (including control) was the sub-plot. There were six replications per treatment. Trees were in full bloom on April 12, 1990. Trees were sprayed once with carbaryl (Sevin 50WP) at the rate of 2.24 kg/ha, when fruitlet size was about 10-12 mm on May 4, 1990. After chemical thinning, a light hand thinning was done on June 20, 1990 to remove the fruit of side blooms and reduce the number of fruit to only one fruit (king bloom fruit) per spur with approximately 5 cm spacing between fruits in all branches of the tree. Bloom density and fruit set in 1990 was so heavy that every spur had one fruit after this initial light hand thinning, making a perfect full crop condition to pursue the objective of this study. Trees with this level of thinning (5 cm apart) were considered control trees. In other treatments, fruit on each branch was further reduced to create a 10 (approximately one fruit per every other spur), 18 (one fruit per every three spurs), 25 (one fruit per every four spurs) or 36 cm (one fruit per every five spurs) spacing between fruit on all branches of the tree. Thirty leaves per tree were sampled randomly on August 28, 1990 from the middle of the current-season shoots. Leaves were washed in a mild Liqui-nox detergent solution, rinsed with distilled water and dried in a forced air oven at 65° C to a constant weight.

Twenty-four fruit from each tree were sampled randomly at commercial harvest (September 18, 1990). After sampling for quality evaluations, fruit of the whole tree were harvested, counted and yield was recorded in 1990.

In 1991, four branches of 1-1.5 m in length per tree were tagged in early spring and the number of vegetative and mixed buds (buds containing flower and leaf buds) were counted just before full bloom. Percent bloom density (return bloom) was calculated as number of mixed buds x 100/ (number of mixed buds + number of vegetative buds). The arcsin transformation was made on percent bloom density. Yield of each tree was also recorded in 1991 to study the potential effects of 1990 season hand thinning on the return crop.

In 1990, sampled fruit were divided in two groups, weighed and placed on perforated polyethylene bags. Fruit from one of these bags were tested for various fruit quality factors at harvest. The second bag of fruit was stored in a regular atmosphere storage at -1° C with about 90% relative humidity for six months and was tested after storage.

Fruit weight before and after storage was recorded and percentage of fruit water loss during storage was calculated. Fruit color was visually rated on a scale of 1 (20% red) progressively to 5 (100% red), both at harvest and after storage. Fruit length and diameter were measured at harvest with a digital caliper (Starret No. 722, Sears) and length/diameter (L/D) ratio was computed.

Fruit firmness was measured at harvest and after storage on three peeled sides of each fruit by a U.C. Davis penetrometer (McCormick Fruit Tech., Yakima, Washington). These fruit were then washed in the same procedure as described for leaves, and were cut tangentially. One wedge from the stem-end half of every fruit was juiced and the soluble solids concentration (SSC) was measured by placing three to four drops of juice on a hand held temperature compensated refractometer (Atago N1, Tokyo, Japan), both at harvest and after storage. The remaining stem-end half of the fruit at harvest was dipped in iodine solution and the starch degradation pattern (SDP) for each fruit was recorded by comparison of developed patterns with the standard SDP developed by Cascade Analytical, Inc. (Wenatchee, Washington). In this procedure, starch degradation which is indicated by a lack of blue color development, starts from the fruit core and moves outward (toward the skin). Fruit with the highest SDP exhibit a large flesh colored area and very small or no blue pattern (SDP = 6.0), suggesting more advanced maturity in the fruit. The opposite situation (the largest blue pattern) shows that fruit are immature (SDP = 1.2).

The calyx-end half of each fruit was cut in half again. The mesocarp and exocarp tissues were discarded and the flesh (with skin) was cut in small pieces, weighed and dried in the same manner as described for leaf tissue.

Leaf and fruit tissues were re-weighed after drying and the percentage dry weight was calculated. Tissues were then ground to pass a 40-mesh screen. These tissues were analyzed for N by a Kjeldahl method (30), and for K, Ca, Mg, Fe, Zn, Mn, and Cu by dry ashing at 500° C, digestion and atomic absorption spectrophotometry (Perkin-Elmer 1100 B, Norwalk, Connecticut) as described by Jones (20). Mineral elements are expressed on a dry weight basis. Fruit K and Ca content per 100 g fresh weight were also computed.

Analyses of variance were computed using SAS (28) and means in spacing treatments were separated by a Duncan's multiple range test at $P < 0.05$ when a significant F was detected. Color ratings were converted to percentage of red color ((color rating x 5)/100)) and then were transformed to arcsin values. The analysis of variance and mean separation of the original color ratings were identical to those of transformed values because the original color rating had a normal distribution. Therefore, the original fruit color rating, rather than transformed values are reported. Analysis of variance of transformed data on percent bloom density in 1991 was computed.

## Results and Discussion

**Fruit Spacing Effects:** A strong linear regression existed between fruit spacing and the yield (Fig. 1). Yield and total fruit number decreased, but fruit weight increased as fruit spacing increased (Table 1). However, the yield and fruit weight differences between trees with 5 and 10 cm fruit spacings, and also fruit weight differences between trees with 25 and 36 cm fruit spacings were not statistically significant (Table 1). Forshey and Elfving (13) also observed that fruit from trees thinned to one fruit per spur had a similar fruit weight as those thinned to 10-15 cm spacing in 'McIntosh' apple. In the winter of 1990-1991, an extreme cold front prevailed in the Pacific Northwest which killed floral structure of mixed buds in apples which decreased bloom density. Trees in which fruit were thinned at 36 cm fruit spacing in 1990, had significantly higher return bloom density and yield in 1991 compared to those with other fruit spacings. (Table 1). A higher leaf/fruit ratio in these trees may have resulted in a higher photosynthate accumulation and perhaps resulted in the production of stronger flower buds which were hardier during the winter of 1990-91. Fruit of 5 and 10 cm spacings had a significantly lighter red color than those of other fruit spacing treatments both at harvest and after storage (Table 1). Fruit color from other fruit spacings was similar (Table 1). Fruit from trees with 36 cm fruit spacing had a significantly higher SSC than those from other fruit spacings both at harvst and after storage (Table 1). Fruit of trees with 5 and 10 cm spacings had similar SSC both at harvest and after storage (Table 1). Likewise, SSC of fruit with 18 cm spacing was similar to that of 25 cm (Table 1). Fruit spacing did not affect L/D ratio (Table 1). Fruit firmness at harvest was not affected by fruit spacing, while firmness of 18 and 25 cm spacings was less than other spacings after storage (Table 1). Fruit water loss after storage was similar for all fruit spacing treatments (data not shown).

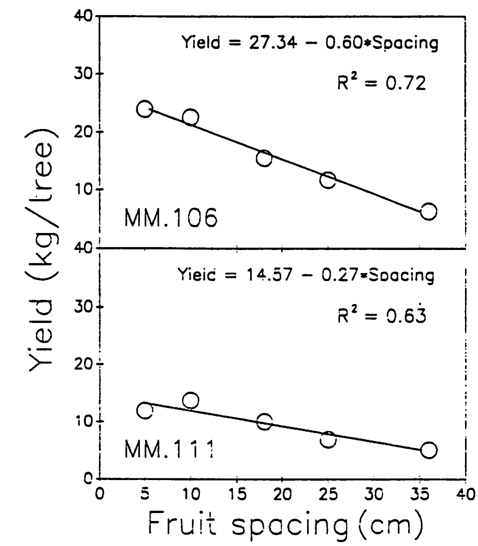


**Figure 1. Linear regression between yield and fruit spacing in 'Redchief Delicious' apple on M.9/MM.106 and M.9/MM.111.**

Fruit from trees with 36 cm spacing had a significantly higher dry weight than those in all other treatments (Table 2). Fruit dry weights in the trees with 18 and 25 cm spacing were greater than those with 5 and 10 cm spacings (Table 2). The increase in fruit dry matter with spacing is due to a higher leaf/fruit ratio that exists in the more heavily thinned trees. 'Redchief Delicious' leaf N in trees with 10 cm spacing was similar to that of 5 cm spacing trees while fruit N was significantly greater in trees with 10 cm spacing than in all other spacings. (Table 2). Trees with 18 cm fruit spacing had significantly higher leaf N than those with 25 cm and 36 cm fruit spacings (Table 2). This decrease in the leaf and fruit N is the cause for darker color and higher SSC in the fruit from trees with greater fruit thinning (Table 1). Significant negative correlation coefficients existed between fruit color and fruit N (r = 0.53) and also between fruit color and leaf

**Table 1. Effects of fruit spacing on yield and fruit quality of 'Redchief Delicious' apple.[z]**

| Fruit spacing | Total[y] fruit no. per tree | Yield 1990 (Kg/tree) | Bloom Density 1991 (%) | Yield 1991 (Kg/tree) | Fruit wt. (g) | L/D ratio | Fruit color[x] at harvest | Fruit color[x] after storage | Soluble solids(%) at harvest | Soluble solids(%) after storage | Firmness (N) at harvest | Firmness (N) after storage |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 Cm | 169 | 18.0a | 2.4b | 2.1b | 142.6c | 0.989a | 3.0b | 2.7b | 11.7c | 12.2c | 93.2a | 72.7a |
| 10 Cm | 154 | 18.2a | 5.1b | 2.1b | 150.4c | 0.994a | 3.1b | 2.5b | 11.5c | 12.3c | 93.5a | 71.5a |
| 18 Cm | 81 | 12.7b | 7.3b | 3.0b | 179.6b | 0.988a | 3.8a | 3.3a | 12.6bc | 13.2b | 93.2a | 66.2b |
| 25 Cm | 50 | 9.3c | 9.7b | 4.9b | 199.0a | 0.992a | 3.9a | 3.4a | 13.3b | 13.8b | 91.6a | 67.7b |
| 36 Cm | 29 | 5.7d | 18.2a | 8.8a | 200.4a | 0.986a | 3.9a | 3.1a | 14.5a | 14.8a | 93.7a | 70.9a |

[z]Mean separation within columns by Duncan's multiple range test at $P < 0.05$.
[y]No statistical analysis was performed on fruit number. Each number is the mean of 12 trees.
[x]Color rating: 1 = 20% red progressively to 5 = 100% red.

N (r = 0.51). A similar relationship existed between leaf N and SSC (r = 0.63) and fruit N and SSC (r = 0.40).

Leaf K expressed as percent dry weight and fruit K mg/100g fresh weight increased as fruit spacing increased, thus trees with 36 cm fruit spacing had significantly higher leaf and fruit K than those with other fruit spacing treatments (Table 2). It is noteworthy that no differences among various fruit spacings could be detected where fruit K was expressed as percent dry weight. This suggests that for any study involving K partitioning, mg/100g fresh wt of fruit is a more accurate approach than the percent dry weight basis.

Fruit from 5 and 10 cm fruit spacings had similar fruit Ca contents. However, fruit Ca (expressed as either percent dry weight or mg/100g fresh wt) was significantly reduced between every consecutive fruit spacing treatment, so that trees with 36 cm fruit spacing had the lowest fruit Ca while those with 5 and 10 cm spacings had the highest fruit Ca (Table 2). Leaf Mg and Fe were not affected by fruit spacing, while fruit Mg and Fe were greatest at the 10 cm spacing (Table 2).

Fruit spacing showed a major impact on the interpretation of mineral element status based on the leaf analysis. Fruit spacing at 18 cm showed a leaf N value of 1.98% dry weight and leaf K value of 1.07% dry weight (Table 2). These values are on the low end of sufficiency ranges for apples (34). Thinning fruit further apart than 10 cm decreased leaf N and increased leaf K causing below normal leaf N values and moving leaf K further toward a sufficiency range. Factors such as crop load and degree of fruit thinning, therefore, should be taken into account when interpreting the results of leaf analysis.

**Table 2. Influence of fruit spacing on leaf and fruit mineral partitioning in 'Redchief Delicious' apple.[z]**

| Fruit | Dry weight (%) | | N (% dwt) | | K (5 dwt) | | K (mg/100g fwt) | | Ca (% dwt) | | Ca (mg/100g wt) | Mg (% dwt) | | Fe (μg/g dwt) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spacing | Leaf | Fruit | Leaf | Fruit | Leaf | Fruit | Leaf | Fruit | Leaf | Fruit | Fruit | Leaf | Fruit | Leaf | Fruit |
| 5 Cm | 41.8a | 14.4c | 2.02ab | 0.187b | 0.93d | 0.84a | 390c | 121d | 2.13a | 0.044a | 6.26a | 0.313a | 0.045b | 72a | 6.72ab |
| 10 Cm | 40.2b | 14.1c | 2.08a | 0.214a | 0.97cd | 0.84a | 389c | 118d | 2.07ab | 0.046a | 6.50a | 0.325a | 0.049a | 76a | 7.46a |
| 18 Cm | 41.7ab | 15.7b | 1.98b | 0.173b | 1.07bc | 0.82a | 444b | 129c | 2.21a | 0.035b | 5.50b | 0.339a | 0.044b | 70a | 6.52b |
| 25 Cm | 40.3b | 16.3b | 1.89c | 0.166b | 1.16b | 0.83a | 470b | 135b | 1.99ab | 0.029c | 4.79c | 0.338a | 0.043bc | 75a | 6.30b |
| 36 Cm | 40.7ab | 17.5a | 1.87c | 0.183b | 1.35a | 0.86a | 549a | 150a | 1.84b | 0.024d | 4.18d | 0.316a | 0.040c | 69a | 5.98b |

[z]Mean separation within columns by Duncan's multiple range test at $P < 0.05$.

**Table 3. Yield, fruit quality and mineral nutrient concentrations of 'Redchief Delicious' with M.9 interstock on 2 rootstock.[z]**

| Interstock/ rootstock | Yield (kg/tree) | Fruit wt. (g) | Fruit color[y] at harvest | Fruit color[y] after storage | Soluble solids (%) at harvest | Soluble solids (%) after storage | Firmness (N) at harvest | Firmness (N) after storage | Mg (% dwt) Leaf | Mg (% dwt) Fruit | Cu (μg/g) Leaf | Cu (μg/g) Fruit | Mn (μg/g) Leaf | Mn (μg/g) Fruit |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M.9/MM.106 | 16.0* | 177NS | 3.1 | 2.9 | 12.2 | 13.1 | 94.8* | 69.7 | 0.321 | 0.0457* | 46.7NS | 4.75* | 69.4NS | 3.05* |
| M.9/MM.111 | 9.5 | 172 | 4.0* | 3.1NS | 13.2* | 13.3NS | 91.3 | 70.0NS | 0.332NS | 0.0425 | 34.6 | 3.92 | 58.8 | 2.52 |

[z]NS, *, ** Nonsignificant or significant within columns at P = 0.05 or 0.01, respectively.
[y]Color rating: 1 = 20% red progressively to 5 = 100% red.

**Comparison Between Rootstocks:** Trees on M.9/MM.106 had a significantly higher yield than those on M.9/MM.111 (Table 3). Ferree (10), however, reported that 'Golden Delicious' apple on these two interstem/rootstock combinations had similar 10-year cumulative yields. 'Redchief Delicious' trees on M.9/MM.106 and M.9/MM.111 had a similar fruit weight (Table 3) and L/D ratio (data not shown). This result is consistent with a previous report with 'Redspur Delicious' and Goldspur' on MM.106 and MM.111 (29). Fruit from trees on M.9/MM.111 had a darker red color and higher SSC at harvest than did those on M.9/MM.106 (Table 3). 'Redchief Delicious' fruit on M.9/MM.111 were softer than those on M.9.MM.106 at harvest, while this firmness difference disappeared after storage (Table 3). The darker fruit color and higher SSC but lower harvest fruit firmness in the trees on M.9/MM.111 suggest that 'Redchief Delicious' apple fruit on M.9/MM.111 were more advanced in maturity than were those on M.9/MM.106, perhaps due to the lighter crop in trees on M.9/MM.111. 'Redchief Delicious' on M.9/MM.106 had significantly higher fruit Cu, Mn and Mg than did M.9/MM.111 (Table 3).

No significant interaction was found between rootstock and fruit spacing for yield, fruit quality or mineral nutrient measurements in this experiment.

**General Comments:** All factors considered, the threshold for fruit thinning was between 10 and 18 cm. Trees thinned to 18 cm spacing produced large fruit with more red color and high SSC with a moderate N level in the leaf and fruit. However, thinning to a distance of 10 cm apart resulted in a higher fruit Ca, but smaller fruit size. Obviously, factors such as production objectives, demand and economic situation of the market should be taken into account for determination of proper fruit spacing. Cook (4) reported that hand thinning of 'Starking Delicious' was not economically profitable in Michigan. However, this economic impact should also be analyzed for other places. Thinning fruit further apart than 18 cm is not advisable, as it lead to a drastic yield and fruit Ca reduction without a significant gain in fruit weight.

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