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Title: THE EFFECT OF ROOTSTOCK AND SCION ON CHERRY TREE MINERAL NUTRITION

Abstract approved: ______________________
M. N. Westwood

The experiments in this thesis are reported as two journal articles. The first article, The effect of rootstock and scion on above- and below-graft leaf mineral nutrient content of sweet cherry, is a field sampling experiment dealing with the effect of Stockton-Morello and F 12-1 mazzard rootstocks on 'Royal Ann' and 'Corum' scion leaves and the effect of the scions on the rootstocks. The rootstocks affected the level of Ca in the 'Corum' scion. 'Royal Ann' affected the level of Fe, Cu, and Zn in the rootstock leaves. 'Corum' affected the level of K, P, Mg, Fe, Cu, and B in the rootstock leaves. The rootstock interacted with the scion for K, P, Mg, Fe, Cu, B, and Zn. The second experiment, The effect of rootstock and scion on the distribution of mineral nutrients in first-season grafted and ungrafted sweet cherry trees, is a sand culture experiment using Stockton-Morello, mahaleb seedling, mazzard seedling, and F 12-1 mazzard

rootstocks and 'Royal Ann', 'Corum', and homografts as scions. The plants were divided into rootlets, main roots, below graft trunk, below graft twigs, below graft leaves for August and September, graft union, above graft trunk, above graft twigs, and above graft leaves for August and September. Statistical comparisons were made among the plants for the same part and between parts of the same plant. Rootstock, scion, and graft union were found to affect either singly or in combination both among plant and within plant comparisons for N, K, P, Ca, Mg, Mn, Fe, B, and Zn. Ninety day old August and 38 day old September leaves were found to differ in K, Ca, Mg, B, P, and Mn content. Mahaleb leaves were found to contain only 33 ppm of B, about .33 of the next lowest leaves. A strong positive relationship between leaf content and root efficiency was noted for the root efficiency data contained in the appendix.

The Effect of Rootstock and Scion on Cherry Tree Mineral Nutrition

by

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This thesis is dedicated to the memory of Elizabeth Jane Davis, the Auntie who got me started in horticulture.

I would also like to express my appreciation to Dr. M. N. Westwood, my major professor, and the other professors on my committee for their help over the past three years.

A special word of thanks goes to Fred Dixon who labored with me in the lab. His help with the chemical analysis of the samples was invaluable.

Last but not least a "Thank You" to my parents. Their foresight in providing for my education truly made this thesis possible. Their help with this thesis as in all things is gratefully acknowledged.

Note to the Reader

For convenience this thesis was divided into four parts, introduction, two journal articles, and appendix. The introduction is a review of literature and justification of rootstock-scion research. The first paper, to be submitted to HortScience, deals with the effect of two rootstocks and two scions on each other. The second paper, to be submitted to the Journal of the American Society for Horticultural Science, reports the effect of four rootstocks and two scions on the distribution of nutrients throughout the plant, the effect of leaf age on the mineral nutrient content of morphologically similar above and below graft plant parts. The appendix contains additional data not presented fully in the two papers.

TABLE OF CONTENTS

LIST OF TABLES

THE EFFECT OF ROOTSTOCK AND SCION ON ABOVE- AND BELOW-GRAFT MINERAL NUTRIENT CONTENT OF SWEET CHERRY

THE EFFECT OF ROOTSTOCK AND SCION ON THE DISTRIBUTION OF MINERAL NUTRIENTS IN FIRST SEASON GRAFTED AND UNGRAFTED SWEET CHERRY TREES

LIST OF TABLES (Cont.)

LIST OF APPENDIX TABLES

LIST OF APPENDIX TABLES (Cont.)

LIST OF FIGURES

THE EFFECT OF ROOTSTOCK AND SCION ON ABOVE- AND BELOW-GRAFT MINERAL NUTRIENT CONTENT OF SWEET CHERRY

THE EFFECT OF ROOTSTOCK AND SCION ON THE DISTRIBUTION OF MINERAL NUTRIENTS IN FIRST-SEASON GRAFTED AND UNGRAFTED SWEET CHERRY TREES

LIST OF APPENDIX FIGURES

LIST OF APPENDIX FIGURES (Cont.)

THE EFFECT OF ROOTSTOCK AND SCION ON CHERRY TREE MINERAL NUTRITION

INTRODUCTION

Research into the rootstock-scion effect on mineral nutrition has had three interrelated objectives. The first is more intensive land use, the second is to increase the economic efficiency of woody perennial cropping, the third is to increase the basic understanding of these plants and to facilitate research in the field of grafted woody plants. Rootstock research aimed at more intensive land use has as its objective either finding rootstocks to exclude toxic concentrations of elements like B and Cl or to find stocks not badly affected by chlorosis on soils of high pH. In this case economic efficiency research is finding rootstocks that respond better or require less fertilizer to produce a crop. The third of these objectives is typified by research on such varied problems as, the cause of rootstock related dwarfness, why scions on some rootstocks are more fruitful, and the need to know the rootstock when doing nutrition research. These objectives are so closely entwined that all three objectives may be contained in the same paper.

Land Use

Most of the mineral nutrition research for rootstocks to expand the area of production has been in finding rootstocks to exclude toxic concentrations of elements so that crops not adapted to soils and irrigation water of high salt content can be adapted to soils and irrigation waters of high salt content. Most of the research deals with the exclusion of elements such as B, Cl, Na, and Li. The second paper in this thesis suggests the possibility that *Prunus mahaleb* may be able to reduce the B content of sweet cherry grafted on it. The discovery of rootstocks resistant to lime induced chlorosis falls in the category of adapting plants normally found on soils of slightly acid pH to soils of higher pH.

Avocado (28, 18), rose (9), stone-fruit (4, 34, 35), citrus (14, 21, 70, 71), and grape (5) have been researched in relation to Cl toxicity as affected by rootstock. The use of Salt Creek grape rootstock can reduce the level of Cl to .075 the level of self rooted plants.

Research has had some success in finding rootstocks capable of reducing B toxicity. Swingle *et al.* (58) first suggested that the rootstock could reduce B accumulation and thus injury to the scion. Eaton and Blair (16) took the suggestion, and in 1935 tried reciprocal grafts of Jerusalem artichoke to sunflower and Chinese box orange to lemon. Their experiment supported the hypothesis of Swingle *et al.* (58). The box orange and sunflower stocks reduced the B content of the lemon and artichoke scions from .35 to .50. Unfortunately there is not much point in grafting Jerusalem artichoke on sunflower. Also, Wuntscher *et al.* (70) found Chinese box orange, *Severinia buxifolia* (Poir), insufficiently compatible to citrus to be used as a rootstock. *Citrus macrophylla* (Wester) has proved to be a useful rootstock for lemons in areas of high B irrigation water (17, 32). Almond is a possible rootstock for almond and peach in high B areas (31). Rootstocks for plums (30), prunes (30), and roses (9) reduced B injury or content of the scion.

Rootstocks that reduce the percentage of Na in the leaves have been found for citrus (39, 52) and grape (5). Sharples and Hilgeman (52) found that the Li content of citrus grown on sour orange was lower than when grown on rough lemon.

Lime-induced chlorosis is another problem of site adaptability that may be overcome by rootstock. Wann (63) took the report of Perold (47) that *Vitis vinifera* on *V. labrusca* is susceptible to Fe chlorosis when grown on high lime soils while own rooted *V. vinifera* is not, and postulated that *V. labrusca* could be grown on calcareous soils if *V. vinifera* was the rootstock. The idea was correct. Higdon (36, 37) reported that pears grown on *Pyrus calleryana*, *P. ussuriensis*, and *Cydonia* were more susceptible to Fe chlorosis than those on *P. communis*. In some cases pear orchards in the Medford area of Oregon have been removed because of the severity of the condition (36). Wallihan and Garber (62) confirmed that sweet orange was more adversely affected by lime in the soil than sour orange. Bryant (8), studying rootstocks for sour cherry in eastern Colorado, found that trees on mazzard were more frequently chlorotic than those on mahaleb. In the case of grape, pear, sour cherry, and citrus the selection of the proper rootstock can make it possible to grow these crops on soils to which they are otherwise poorly adapted because of the high lime content.

Economic Efficiency

Eaton and Blair (16), as well as suggesting that the range of adaptation for woody perennials could be increased by the selection of the proper rootstock, suggested that it might be possible to reduce the cost of production by selecting rootstocks more efficient in nutrient uptake. There are two ways this improved efficiency can be effective, greater uptake efficiency and better response to fertilizer applications. One of the objectives of the first experiment in this thesis was to find out if there was a difference in uptake efficiency between Stockton-Morello and F 12-1 rootstocks as measured by leaf nutrient content. Increased concern about pollution from fertilizer applications, as well as any increase in the cost of fertilizer in relation to the price received for the crop, has increased the interest in rootstocks of high uptake efficiency.

Many researchers have studied the effect of rootstock on nutrient uptake and fertilizer efficiency for apple. Whitfield (68) noted that fertilizer requirements may vary by rootstock. Roach (50) noted that rootstocks could affect the quantity and quality of Fe and B nutrition of the scion. Awad and Kenworthy (2) confirmed the report that M 5 and 2 are low K suppliers and that M 1 is a low Mg supplier. Sistrunk and Campbell (55) found that apples grown on Nibernal rootstocks were more responsive to both foliar and soil applications of Ca than trees grown on French crab.

Haas (24, 25) pointed out that as long as such factors as soil, fertilizer, scion, and temperature remain constant the rootstock may affect the quality of scion nutrition in citrus. It therefore stands to reason that some rootstocks are more technically efficient at removing nutrients from the soil and hence would result in reduced fertilizer costs. Citrus rootstocks have been studied for their efficiency of uptake for at least five nutrients: B (51), P (25), Mn (41), S (48), and Fe (62). In addition to apple and citrus, cherry (1, 40), tung (45), peach (59), and prune (10, 67) have been studied from this standpoint.

Preliminary Research

The third interrelated objective of research into the interrelation of rootstock-scion and mineral nutrition is to facilitate further research into the area with the ultimate objective of improved cultural practices and economic efficiency. This was the main objective of the two experiments in this thesis. This research can be divided into two approaches, effect of physiology and genetics on mineral nutrition and effect of mineral nutrition on physiology.

The nutrition of dwarf apple rootstocks has been extensively studied (49, 50, 38, 46, 6, 15). Jones (38) found that the sap above dwarfing interstems or rootstocks had a lower concentration of N, P, and K than above nondwarfing rootstocks and interstems. There was as much as 100-fold reduction of N in the sap after it had passed through a dwarfing interstem. He suggested this reduced nutrient concentration of the xylem sap may be one of the reasons for the dwarfing influence of M 9 rootstock or interstem.

Fruitfulness has also been attributed to mineral nutrition. Cook and Lider (13) related fruitfulness in grape to rootstocks that supplied adequate but not excessive amounts of N to the scion. Neff et al. (45) felt there was a relation between N/K ratio induced by the rootstock and fruitfulness of tung.

Studies of apple (60, 2, 68), citrus (48, 70, 24, 25, 26, 56, 52), olives (33), pears (69, 66), avocados (27, 18), prunes (10, 67), and cherries (11, 40) have been made to determine the effect of rootstock on fertilizer requirements and nutrition experiments. Awad and Kenworthy (2) felt that diagnosis of the nutritional status of apples grown on different Malling rootstocks could be done without knowing which rootstock was used. Tukey et al. (60) felt, however, that it might be necessary to know not only which rootstock was used but also interstock and scion variety before a correct diagnosis of the nutritional status could be made. Whitfield (68) felt that rootstock could influence the fertilizer recommendations for an orchard. Working with six olive rootstocks representing five species of olive and one close olive relative, Hartmann and Whisler (33) concluded that rootstock had no significant bearing on nutrition. Haas (26) felt that the rootstock should be known when nutrition studies were conducted. For sweet cherry Christensen (11) found that mahaleb and mazzard rootstocks gave results that were nearly identical. Kirkpatrick (40), working with sour cherry, found that trees on mahaleb had more trouble with leaf scorch and low K than trees on mazzard.

The nutrients in a plant may be divided into water-soluble and water-insoluble fractions for any given element (23, 24, 29). In the case of citrus, Haas (23) found that the amount of water-insoluble B remained nearly constant for the leaves of a scion grafted on several different rootstocks, but that the amount of water-soluble B varied by rootstock. Time of year affected the observance of a rootstock effect on water-insoluble B.

Some attention has been given to the effect of hereditary variation of the rootstock on nutrient content of scion leaves. Shear and Smith (53) tested populations of seedlings grown from seven different apple cultivars and found that differences among populations were greater than within populations for the uptake of nutrients as measured by leaf content on a dry weight basis. This fits well with theories of heredity. Weiss (65) found several soybean seedlings that were inefficient in Fe utilization and developed symptoms of Fe chlorosis. Iron efficiency proved to be governed by a single gene. Brown _et al._ (7) showed that the gene operated by affecting the plant's ability to absorb Fe from a calcareous soil. Epstein (19) made a list of points at which nutrient uptake can be affected. Those points are: initial absorption by the roots, translocation into and through the xylem, degree of retention next to the conducting elements, mobility in the phloem, efficiency of metabolism. Also, the physical shape of the root system may affect the uptake ability of the rootstock (20, 62, 61).

The scion has an effect on the nutrient content of the rootstock. Haas and Halma (29) found that the scion affected the water-soluble Mg content of the rootstock bark. Wallace _et al._ (61) found that the scion influenced the level of K in citrus rootlets. The results of Colby (12) show that the scion affected the content of P and N in the young roots and root trunk of apples.

The scion effect can be very orderly with no interaction and follow the pattern of nutrient content of the rootstock as it generally does in citrus (24, 48, 61). However, compound genetic systems can be so complex, composed of roots, stems, and leaves of different clones, that Tukey _et al._ (60) suggested calling the interaction a stionic effect. Naumann (44) studied the nutrient content of both rootstock and scion pear leaves, and found an interaction. A rootstock high in P produced a low P reading in the scion, and a low K rootstock resulted in a high K reading in the scion. Neither the significance nor cause of the rootstock-scion interaction has been explained.

THE EFFECT OF ROOTSTOCK AND SCION ON ABOVE- AND BELOW-GRAFT LEAF MINERAL NUTRIENT CONTENT OF SWEET CHERRY[1]

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Abstract. The nutrient content of rootstock and scion leaves from 'Royal Ann' and 'Corum' trees growing on Stockton-Morello and F 12-1 mazzard rootstocks was analyzed. The concentration of Ca was greater in 'Corum' on F 12-1 than on Stockton-Morello. 'Royal Ann' raised the level of Fe and Cu and lowered Zn in the Stockton-Morello leaves in relation to F 12-1. 'Corum' raised the level of K, P, Fe, Cu, and B and reduced Mg in the F 12-1 leaves in relation to the Stockton-Morello leaves. The rootstocks interacted with the scions for K, P, Mg, Fe, Cu, B, and Zn.

In citrus it has been found that the rootstock tends to influence the nutrient content of the scion more than does the scion (23, 61). In apple (60, 2) and pear (44) it has been found that the nutrient content of the scion is affected as much by the scion as by the rootstock. Christensen (11) found few and small differences in scion nutrition caused by mazzard and mahaleb rootstocks in sweet cherry nutrition.

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[1] To be submitted to HortScience.

This study was conducted to see what effect rootstocks F 12-1 mazzard (Prunus avium L.) and Stockton-Morello (Prunus cerasus L.) had on the leaf compositional values of 'Royal Ann' and 'Corum' scions. Also studied was the effect of scion on the nutrient content of rootstock leaves. A main objective of this experiment was to find out if there was a difference in nutrient uptake efficiency as measured by leaf nutrient content. Rootstocks more efficient in nutrient uptake may be of value in establishing orchards that produce fruit at a lower cost.

Field sampling was done on trees growing in a research plot at the Lewis-Brown Horticultural Research Farm, Corvallis, Oregon. The selected trees were five or six years old, growing in a uniform Chehalis silt loam soil, and receiving uniform irrigation and fertilization. The trees all had rootstock leaves either as root sprouts or ungrafted branches. Visual inspection of the data indicated no difference in nutrient content between root sprouts and ungrafted branches. Leaf samples were collected on August 19, the normal period for leaf sampling for mineral nutrient analysis.

After sampling, the leaves were dried in a tunnel dryer at 80^{o}C for 48 hours and ground in a Wiley mill to pass a 40 mesh screen. They were then analyzed for N, K, P, Ca, Mg, Mn, Fe, Cu, B, and Zn content. Nitrogen analysis was done on a Technicon Auto Analyzer using Kjeldahl continuous flow analysis (64). The other nine nutrients were analyzed using a Jarrel-Ash 750 Atomcounter direct-reading emission spectograph.

The data were then analyzed as a completely randomized design. The LSDs were calculated using a method described in Steel and Torrie (57) for use between means of unequal numbers of observations.

There are ten questions that can be answered about the rootstock-scion effect from these data. In Table 1 are the questions and answers for all of the nutrients. Table 2 contains the data to verify the answers to the questions. Also presented are graphs of N, K, Ca, and Fe to help illustrate the points further. An interaction is present when two or more factors of one class have a different effect on two or more factors of a second class as measured by a single variable. In this experiment there are two classes, rootstocks and scions. Each class has two factors. The variable is nutrient content on a dry weight basis expressed as either parts per million (ppm) or percent (%).

These results are in general agreement with Christensen (11) who found new and small differences in scion nutrition caused by rootstock. On a different soil, however, there might be a pronounced rootstock effect. As Chaplin _et al._ (10) found with K levels in 'Italian' prune growing on myroblan 29-C and myroblan 2-7 rootstocks in different soils, soil can affect the expression of rootstock effects.

The scion has been shown to affect the stock mineral concentrations of bark (29) and roots (12, 61). In this paper, it is shown that the scion also affects the nutrient content of rootstock leaves.

Table 1. Answers to ten questions about the effect and interaction of 'Royal Ann' and 'Corum' scions and F 12-1 and Stockton-Morello rootstocks on rootstock and scion leaf mineral nutrient content.

Question*	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn
1	no	no	no	no	no	no	yes	yes	no	yes
2	no	no	no	no	no	no	no	no	no	no
3	no	yes	yes	no	yes	no	yes	yes	yes	no
4	no	no	no	yes	no	no	no	no	no	no
5	no	no	no	no	yes	no	no	no	yes	yes
6	no	yes	no	no	yes	no	no	yes	yes	no
7	yes	yes	yes	yes	yes	no	no	yes	yes	yes
8	yes	no	yes	yes	yes	no	yes	yes	no	yes
9	no	yes	yes	no	yes	no	yes	yes	yes	yes
10	no	no	no	no	no	no	no	no	no	no

*With respect to leaf nutrients:

1. Do the rootstocks differ under 'Royal Ann'?
2. Does 'Royal Ann' change with the different rootstocks?
3. Do the rootstocks differ under 'Corum'?
4. Does 'Corum' change with the different rootstocks?
5. Do 'Royal Ann' and 'Corum' differ on F 12-1 stock?
6. Do 'Royal Ann' and 'Corum' differ on Stockton-Morello stock?
7. Does F 12-1 differ under 'Royal Ann' and 'Corum' scions?
8. Does Stockton-Morello differ under 'Royal Ann' and 'Corum' scions?
9. Does the rootstock interact with the scion?
10. Does the scion interact with the rootstock?

Table 2. Leaf compositional values for 'Royal Ann' and 'Corum' scions and F 12-1 and Stockton-Morello rootstocks and statistical analysis.

			Percent					ppm				
Tree	Leaf	n	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn
FR	R	7	2.90	1.61	.35	2.07	.67	52	232	16	40	19
	F	7	1.92	2.12	.45	2.12	.74	51	370	13	46	38
FC	C	11	2.84	2.01	.43	2.39	.53	54	235	14	49	14
	F	11	2.60	3.36	.69	1.64	.37	60	407	17	64	20
SR	R	12	2.57	1.63	.32	2.00	.63	46	220	16	43	18
	S	12	2.07	2.07	.41	2.17	.71	55	543	17	46	29
SC	C	7	2.86	2.20	.44	1.95	.49	54	213	13	53	15
	S	7	2.95	2.07	.54	1.77	.48	62	245	14	49	18

LSD values for leaf compositional values

n of means	Percent					ppm				
being compared	N	K	P	Ca	Mg	Mn*	Fe	Cu	B	Zn
7-7	.41	.48	.14	.42	.12		100	3	8	5
11-11	.32	.32	.11	.34	.10		82	2	6	4
12-12	.31	.31	.11	.32	.09		76	2	6	4
7-11	.37	.44	.13	.38	.11		90	3	7	5
7-12	.36	.43	.13	.37	.11		89	3	7	5

*F value was not significant.

FR = 'Royal Ann' on F 12-1; FC = 'Corum' on F 12-1; SR = 'Royal Ann' on Stockton-Morello; SC = 'Corum' on Stockton-Morello; R = 'Royal Ann', F = F 12-1, C = 'Corum', S = Stockton-Morello.

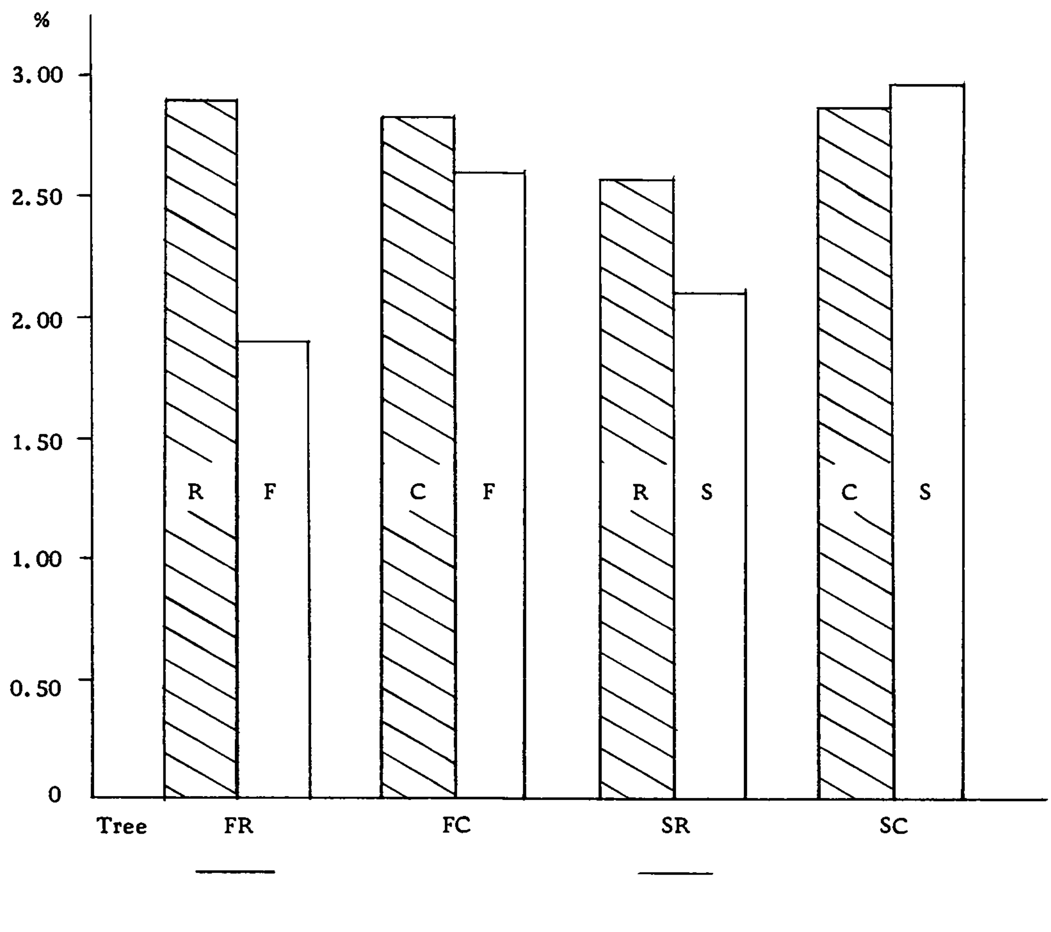

Fig. 1. Nitrogen content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level. FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello

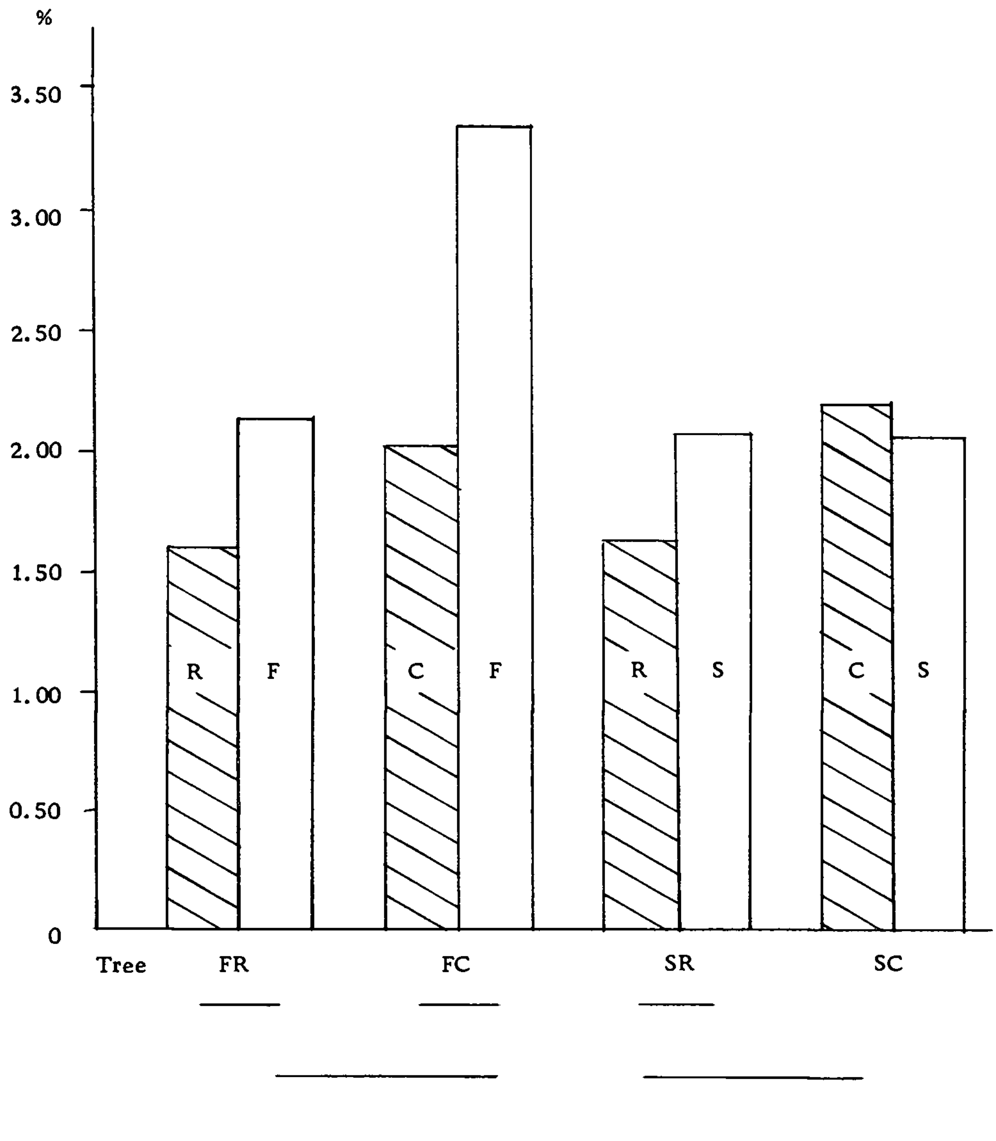

Fig. 2. Potassium content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello

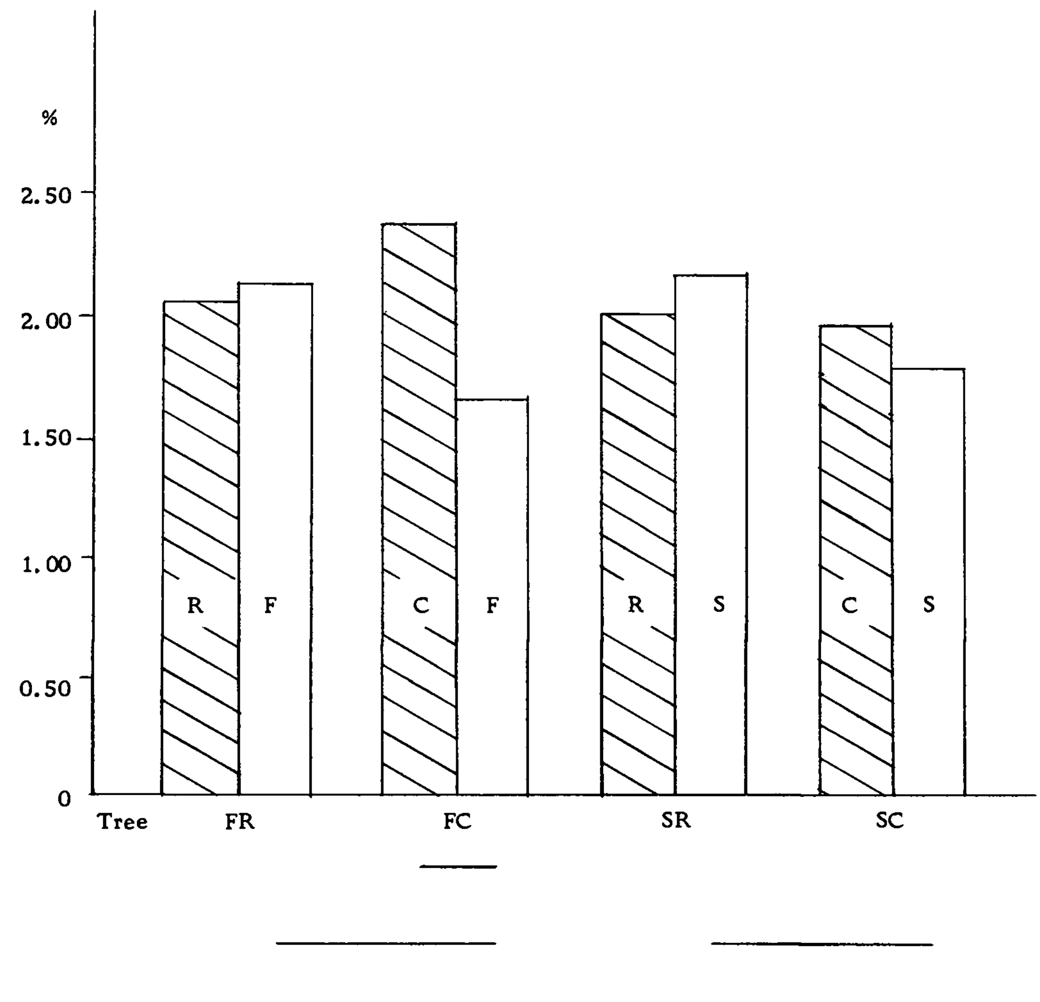

Fig. 3. Calcium content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello

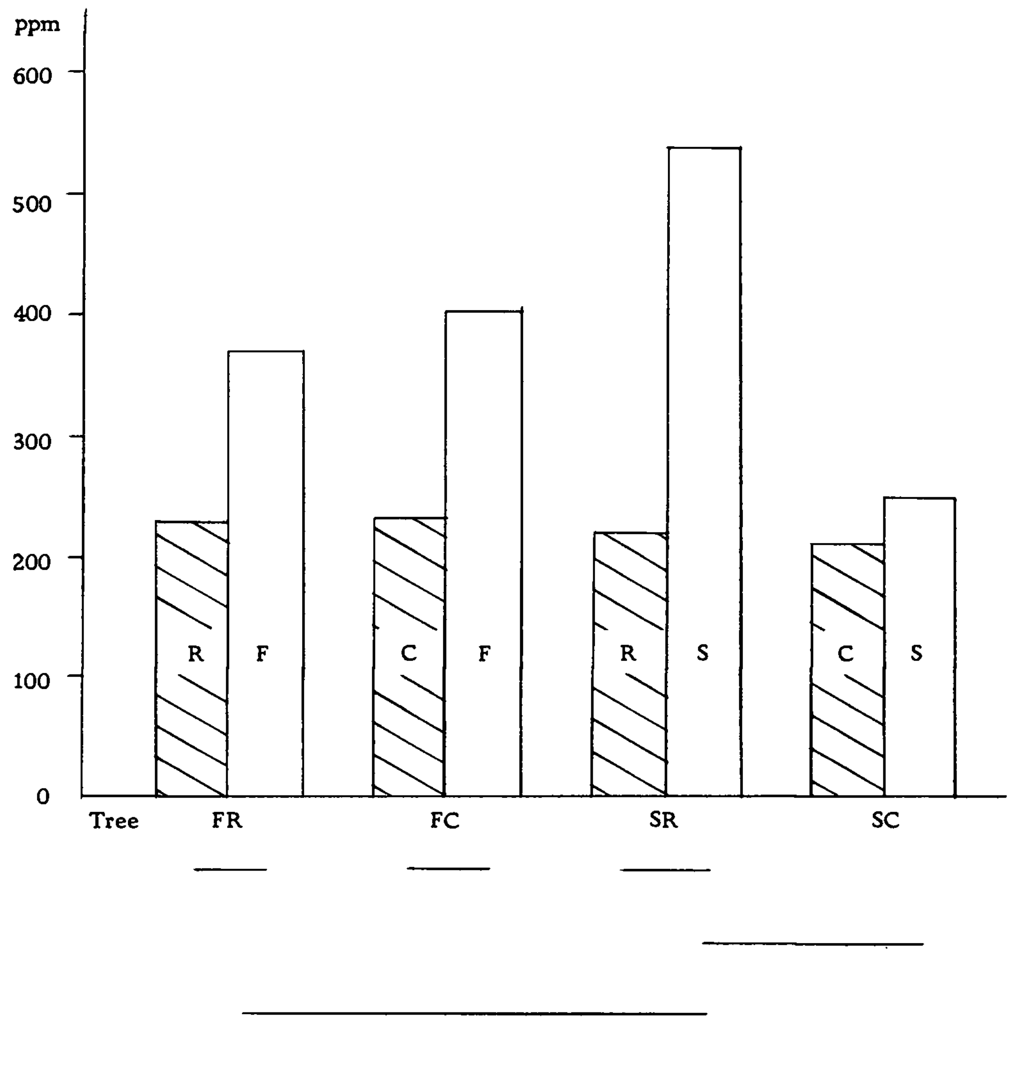

Fig. 4. Iron content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level. FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello

THE EFFECT OF ROOTSTOCK AND SCION ON THE DISTRIBUTION OF MINERAL NUTRIENTS IN FIRST-SEASON GRAFTED AND UNGRAFTED SWEET CHERRY TREES[1]

M. A. Axford

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Abstract. The rootstocks Stockton-Morello, mahaleb seedling, mazzard seedling, and F 12-1 mazzard and the scions 'Royal Ann', 'Corum', and homografts were used to study the effect of rootstock and scion on nutrient content among and within cherry trees. Rootstock, scion, and graft union were found to affect either singly or in combination both among plant and within plant content of N, K, P, Ca, Mg, Mn, Fe, B, and Zn. Ninety-day-old August and 38-day-old September leaves were found to differ in K, Ca, Mg, B, P, and Mn. Mahaleb leaves were found to contain only 33 ppm B, about .33 of the next lowest leaves.

The influence of rootstock on scion nutrition has been studied for many crops. Among these crops are avocado (18), apple (12, 2), pear (44), citrus (61, 24, 26, 56), prune (10), rose (9), grape (4), tung (45), and cherry (40, 11, 1).

In addition to the studies of the effect of rootstock on scion there have been studies mentioning the effect of scion on rootstock. Haas

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[1]To be submitted to the Journal of the American Society for Horticultural Science.

and Halma (29) found that the scion affected the level of soluble Mg in the bark of sour orange rootstock. Wallace (61) observed that the scion affected the amount of K in the rootlets of various citrus rootstocks. Colby (12) observed an effect of scion on young root and root trunk N and P of apple.

This experiment was done to learn more about the effects of rootstock and scion on cherry tree mineral nutrition. The ultimate objective is to develop through better plant nutrition a tree of maximum economic efficiency as measured by farm net income. Effects of rootstock and scion on nutrient content of all parts of the tree were studied, both on grafted and ungrafted trees.

Materials and Methods

Sand culture was used to grow the trees. The pots were located outside at the Lewis-Brown Horticultural Research Farm, Corvallis, Oregon. After the trees were planted, the pots were set in holes with gravel drains to provide root temperatures similar to an orchard. Mahaleb seedling, mazzard seedling, F 12-1 mazzard, and Stockton-Morello rootstocks were used. All rootstocks were grafted with three different scions: 'Royal Ann', 'Corum', and own. Only the *Prunus avium*, 'Royal Ann', 'Corum' and own scions survived. A number of the grafts failed, apparently from *Pseudomonas* infection, resulting in a fourth class, ungrafted. There were eight rootstock-scion combinations, own grafted F 12-1 (FO), ungrafted F 12-1 (F), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), own grafted mazzard (ZO), ungrafted mazzard (Z), ungrafted Stockton-Morello (S), and ungrafted mahaleb (B).

After planting, the trees were sprinkled to prevent drying during the hot weather following planting and at other periods of heat stress. The trees were watered every other day from June to September with a nutrient solution modified from Simons (54).

All shoots were allowed to develop from above and below the graft union. The first sampling of leaves was made August 19. The trees were defoliated by the sampling. The second sampling of leaves was harvested on September 27 after the first frost. The new leaves were still green at that time. The trees were harvested October 6 and 7.

After harvesting, the trees were divided into morphologically distinct parts, rootlets (r), main roots (R), below graft trunk (BT), below graft twigs (BW), below graft leaves for August (BA) and September (BS), graft union (G), above graft trunk (AT), above graft twigs (AW), and above graft leaves for August (AA) and September (AS). The samples were then dried in a tunnel dryer at 80°C for 48 hours before being ground in a Wiley mill to pass a 40 mesh screen. The plant parts were then analyzed for mineral nutrient content. Nitrogen analysis was done on a Technicon Auto Analyzer using

Kjeldahl nitrogen continuous sampling analysis (64). The other nutrients were analyzed with a Jarrel-Ash 750 Atomcounter direct-reading emission spectograph.

Differences between rootstocks were analyzed by an analysis of variance for a completely randomized design. Using own grafted F 12-1 as a standard, differences among rootstocks were tested by using a LSD calculated for unequal numbers of observations as described in Steel and Torrie (57). Differences between plant parts were analyzed during the same technique except the $\log_{10}$ of the data was used in the computations in order to meet the assumption of homogeneity of variance for the analysis of variance.

Results and Discussion

In Tables 1-9 are the mean values for all of the nutrients by plant part. Table 10 shows what factor, rootstock (RS), scion (SN), or graft union (G), was the apparent cause of the differences among the same plant part for the different rootstock-scion combinations. It is not always possible to predict what the relative nutrient content on a dry weight basis for one part is by looking at the relative nutrient content of another part. For example, sometimes own grafted mazzard is higher, sometimes lower, and sometimes the same as own grafted F 12-1 in K content. On the other hand, mahaleb seedling is always higher in Mg than any other plant in this experiment.

Table 1. Mean nitrogen content in percent dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	.94a	.57a	.47a	.33a	.35a	.52a	.61a	---	2.43a	2.49a	2.42a
F	.87a	.46a	.43a	---	---	.59a	---	2.33	---	2.30a	---
FR	1.07a	.72a	.50a	.40a	.52b	---	---	---	---	---	2.47a
FC	.86a	.48a	.41a	---	---	.59a	---	---	---	2.54a	---
ZO	1.67b	1.27b	.70b	.47b	.44b	.52a	.58a	---	2.82b	---	2.65a
Z	1.71b	1.28b	.80b	---	---	.81b	---	2.78	---	---	---
S	1.07a	.69a	.46a	---	---	.78b	---	2.47	---	2.45a	---
B	.98a	.54a	.49a	---	---	.68a	---	---	---	2.29a	---

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.
The F value for the BA comparison is significant.
*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own scioned mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 2. Mean potassium content in percent dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	r	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	.47a	.39a	.26a	.16a	.19a	.35a	.40a	--	.71a	1.97a	1.98a
F	.57a	.40a	.30a	--	--	.44a	--	.86	--	1.96a	--
FR	.56a	.37a	.31a	.29b	.39b	--	--	--	--	--	2.24a
FC	.59a	.38a	.28a	.17a	.24a	.42a	--	--	.35a	1.86a	--
ZO	.79b	.28b	.24a	.22a	.27a	.50b	.59b	--	.55a	--	1.93a
Z	.75b	.25b	.24a	--	--	.55b	--	.42	--	--	--
S	.32c	.18b	.17b	--	--	.43a	--	.87	--	1.87a	--
B	.73b	.30b	.21b	--	--	.42a	--	--	--	1.40b	--

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.

The F value for the BA comparison is significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own scioned mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 3. Mean phosphorus content in percent dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	.51a	.15b	.06b	.03a	.04b	.08a	.08a	--	.29b	.36a	.37a
F	.46a	.13c	.07a	--	--	.08a	--	.26	--	.30a	--
FR	.49a	.17a	.09a	.06b	.10a	--	--	--	--	--	.37a
FC	.50a	.13c	.07a	.03a	.07a	.07a	--	--	.24a	.33a	--
ZO	.58a	.19a	.11a	.06b	.07a	.14b	.14b	--	.30b	--	.36a
Z	.61a	.19a	.13a	--	--	.17b	--	.29	--	--	--
S	.31b	.09c	.04c	--	--	.12b	--	.37	--	.40a	--
B	.50a	.11a	.06b	--	--	.11a	--	--	--	.31a	--

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.

The F values for the BA comparison is significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 4. Mean calcium content in percent dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	.93b	.38b	.44a	.25a	.27a	.56a	.56b	--	1.72a	1.07a	1.05a
F	.83c	.36b	.44a	--	--	.56a	--	1.89	--	1.12a	--
FR	.90b	.41b	.50a	.36a	.69b	--	--	--	--	--	1.03a
FC	.82c	.33b	.44a	.52a	.89b	.57a	--	--	1.95a	1.14a	--
ZO	1.00b	.34b	.53a	.41a	.38a	.81b	.71a	--	1.83a	--	1.33a
Z	1.14a	.36b	.52a	--	--	.84b	--	1.76	--	--	--
S	.87b	.39b	.49a	--	--	.99b	--	1.83	--	1.04a	--
B	.98b	.57a	.56a	--	--	.83b	--	--	--	1.35b	--

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.

The F value for the BA comparison is not significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 5. Mean magnesium content in percent dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	.23b	.07a	.02a	.01a	.01a	.10a	.08a	--	1.11a	.49a	.47a
F	.26b	.08b	.05b	--	--	.10a	--	1.18	--	.49a	--
FR	.23b	.08b	.05b	.03b	.09b	--	--	--	--	--	.49a
FC	.24b	.08b	.05b	.03b	.09b	.10a	--	--	1.10a	.51a	--
ZO	.23b	.05c	.05b	.02b	.04b	.17b	.15b	--	1.30a	--	.54a
Z	.23b	.04c	.05b	--	--	.20b	--	1.41	--	--	--
S	.29a	.05c	.05b	--	--	.19b	--	1.25	--	.46a	--
B	.34a	.11b	.10b	--	--	.23b	--	--	--	.68a	--

The same letter following a mean as that following the FO mean indicated that there is no significant difference at the .05 level.

The F value for the BA comparison is significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 6. Mean manganese content in parts per million dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	840a	75a	37a	31a	34a	103b	90a	--	160a	213a	177a
F	731a	53b	33a	--	--	75b	--	163	--	208a	--
FR	834a	72a	39a	27a	43a	--	--	--	--	--	174a
FC	799a	63a	41a	35a	33a	92b	--	--	162a	297a	--
ZO	1047a	36b	52b	27a	41a	119b	99a	--	129a	--	155a
Z	949a	35b	50b	--	--	131b	--	134	--	--	--
S	558b	28b	45a	--	--	163a	--	117	--	251b	--
B	691a	30b	35a	--	--	68c	--	--	--	170b	--

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.

The F value for the BA comparison is not significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r=rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 7. Mean iron content in parts per million dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	703a	757a	158b	52a	255b	54b	48a	--	125a	119a	120a
F	683a	694a	167b	--	--	36b	--	79	--	95a	--
FR	788a	956a	126b	41a	197b	--	--	--	--	--	55b
FC	671a	838a	169b	60a	431a	53b	--	--	51a	145a	--
ZO	668a	496b	283a	63a	308b	79a	59a	--	149a	--	112a
Z	826a	635a	375a	--	--	92a	--	203	--	--	--
S	693a	449b	167b	--	--	66b	--	85	--	75a	--
B	354b	286b	161b	--	--	91a	--	--	--	124a	--

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.

The F value for the BA comparison is significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S= ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 8. Mean boron content in parts per million dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	43b	18a	23a	14a	17a	37b	50a	--	86a	119a	129a
F	35b	17a	23a	--	--	44b	--	78	--	109a	--
FR	46b	25a	23a	14a	28a	--	--	--	--	--	150b
FC	34b	19a	21a	13a	24a	42b	--	--	64b	102a	--
ZO	51a	20a	19a	15a	20a	32b	51a	--	66b	--	107c
Z	51a	19a	19a	--	--	42b	--	57	--	--	--
S	42b	19a	19a	--	--	53a	--	71	--	98a	--
B	37b	15a	12b	--	--	30b	--	--	--	33b	--

The same letter following a mean as that following the FO mean indicates that there is no significant difference at the .05 level.

The F value for the BA comparison is significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 9. Mean zinc content in parts per million dry weight of sweet cherry trees grown in sand culture compared by plant part.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	189a	20b	66a	107b	13a	21a	21a	--	16a	14a	12a
F	119b	17b	37a	--	--	20a	--	15	--	15a	--
FR	157a	23b	74a	101b	51b	--	--	--	--	--	14a
FC	137a	17b	43a	247a	58b	25a	--	--	13a	20b	--
ZO	184a	15b	74a	116b	20a	52c	43b	--	22b	--	16a
Z	187a	12c	54a	--	--	60c	--	32	--	--	--
S	152a	26a	69a	--	--	60c	--	14	--	20b	--
B	112b	24b	49a	--	--	41c	--	--	--	9c	--

The same letter following a mean as that following the FO mean indicated that there is no significant difference at the .05 level.

The F value for the BA comparison is significant at the .05 level.

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twigs, AW = above graft twigs, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 10. Probable cause of variation among sand culture sweet cherry trees for N, K, P, Ca, Mg, Mn, Fe, B, and Zn analyzed by plant part.

Nutrient	r	R	BT	G	AT	BW	AW	AA	BS	AS
Nitrogen	RS	RS	RS	RS	RS	RS	--	RS	--	--
	--	--	--	--	SN	--	--	--	--	--
	--	--	--	--	--	G	--	--	--	--
Potassium	RS	RS	RS	--	--	RS	RS	--	RS	--
	--	--	--	SN	SN	--	--	--	--	--
Phosphorus	RS	RS	RS	RS	RS	RS	RS	--	RS	--
	--	G	G	--	--	--	--	--	--	--
	--	SN	SN	SN	SN	--	--	--	--	--
Caocium	RS	RS	--	--	--	RS	RS	--	RS	--
	SN	--	--	--	SN	--	--	--	--	--
	G	--	--	--	--	--	--	--	--	--
Magnesium	RS	RS	RS	RS	RS	RS	RS	--	--	--
	--	SN	SN	SN	SN	--	--	--	--	--
	--	G	G	--	--	--	--	--	--	--
Manganese	RS	RS	RS	--	--	RS	--	--	--	--
	--	--	--	--	--	--	--	--	SM	--
	--	G	--	--	--	--	--	--	--	--
Iron	RS	RS	RS	--	--	RS	--	--	--	--
	--	--	--	--	SN	--	--	--	--	--
Boron	RS	--	RS	--	--	RS	--	RS	RS	RS
	--	--	--	--	--	--	--	SN	--	SN
Zinc	RS	RS	--	--	--	RS	RS	RS	RS	--
	--	--	--	SN	SN	--	--	--	SN	--
	G	--	--	--	--	--	--	--	--	--

RS = rootstock, SN = scion, G = graft union, r = rootlet, R = main root, BT = below graft trunk, AT = above graft trunk, BW = below graft twig, AW = above graft twig, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.

Table 11 indicates whether scion, rootstock or both affected the pattern of nutrient distribution in the various plants. The pattern for a plant was established by comparing the adjacent parts for statistically significant differences. Scion in this case refers to 'Royal Ann' and 'Corum'. The rootstock comparisons were made between own grafted F 12-1 and own grafted mazzard. The stock of the 'Royal Ann' on F 12-1 tree had the highest N level of any F 12-1 rootstock. The scion effect on rootstock has previously been shown (29, 12, 61). The overall distribution of nutrients within the plant follow the same general pattern as that found for apple (43, 12) and citrus (24), i.e., the rootlets and leaves generally contain the highest concentrations of nutrients. This is probably related to the leaves and roots being the areas of the most complex physiological activity.

For the ungrafted and below graft portions of grafted trees it was also found that both scion and rootstock affected the pattern of nutrient distribution. The presence or absence of a graft union may affect the pattern of nutrient distribution. Bernstein et al. (4) found that grafted grape plants had 10% more Cl in their leaves than own rooted plants. Wallace et al. (61) found that the newly made graft union had an effect like ringing on the scion. Table 12 shows the interpretation of the results.

The graft union had an effect on the content and distribution of N, P, Ca, Mg, Mn, Fe, and Zn in the plant. The distribution of Fe

Table 11. Causes of variation in, above and below graft pattern in mineral distribution among grafted and culture sweet cherry trees.

Nutrient	Cause of variation	
Nitrogen	rootstock	scion
Potassium	rootstock	scion
Phosphorus	--	scion
Calcium	rootstock	scion
Magnesium	--	scion
Manganese	rootstock	--
Iron	rootstock	--
Boron	rootstock?	scion
Zinc	rootstock?	scion

Table 12. Cause of different patterns of nutrient distribution among ungrafted and below graft portions of grafted sand culture sweet cherry trees.

Nutrient	Causes		
Nitrogen	rootstock	scion?	graft union
Potassium	rootstock	scion	graft union
Phosphorus	rootstock	scion?	graft union?
Calcium	rootstock	scion	graft union
Magnesium	--	scion?	graft union
Manganese	rootstock	scion	--
Iron	rootstock	--	graft union
Boron	rootstock?	scion	graft union
Zinc	rootstock	scion	--

and Zn (Figures 1-2) was the most markedly affected. The accumulation of Zn below and in the graft is what would be expected on the basis of the finding of Gur and Samish (22), which was that Zn injected below the graft of pear trees growing on semi-compatible quince rootstocks did not affect the level of Zn in the leaves as much as injections of Zn above the graft.

For the grafted plants a comparison of the nutrient content of comparable morphological parts from above and below the graft union was made. The parts were, AT and BT, AW and BW, and AS and BS. The 'Royal Ann' scion had an effect on the relationship between the AT and BT N. For Ca, the scions were insignificantly higher above the graft for 'Royal Ann' and 'Corum' plants whereas the own grafted plants were significantly lower above the graft union than below. For Fe, there was a rootstock and scion effect on the above and below graft trunk content. There was a scion effect on the above and below graft tissue for Zn. There was a rootstock effect on above and below graft twig B and K content.

Leaf age affected the level of K, Ca, Mg, and B for the August and September leaves of the own grafted F 12-1; ungrafted F 12-1, own grafted mazzard, and ungrafted Stockton-Morello plants. Leaf age only affected the level of P in the own grafted F 12-1 and ungrafted F 12-1 trees. The Stockton-Morello plants were the only ones for which there was a leaf age effect for Mn. Because of

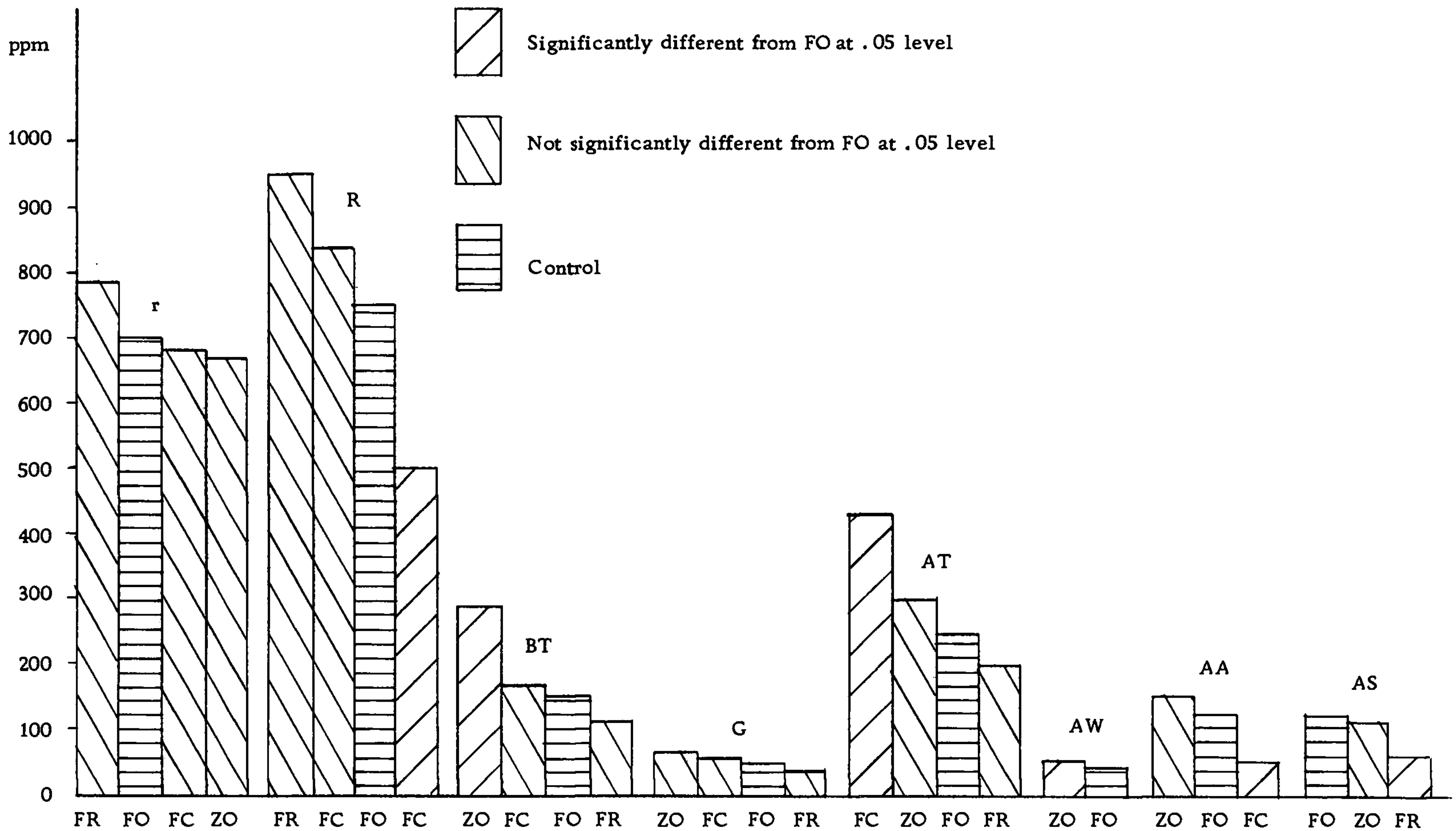

Fig. 1. Iron content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) cherry trees grown in sand culture. the plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.

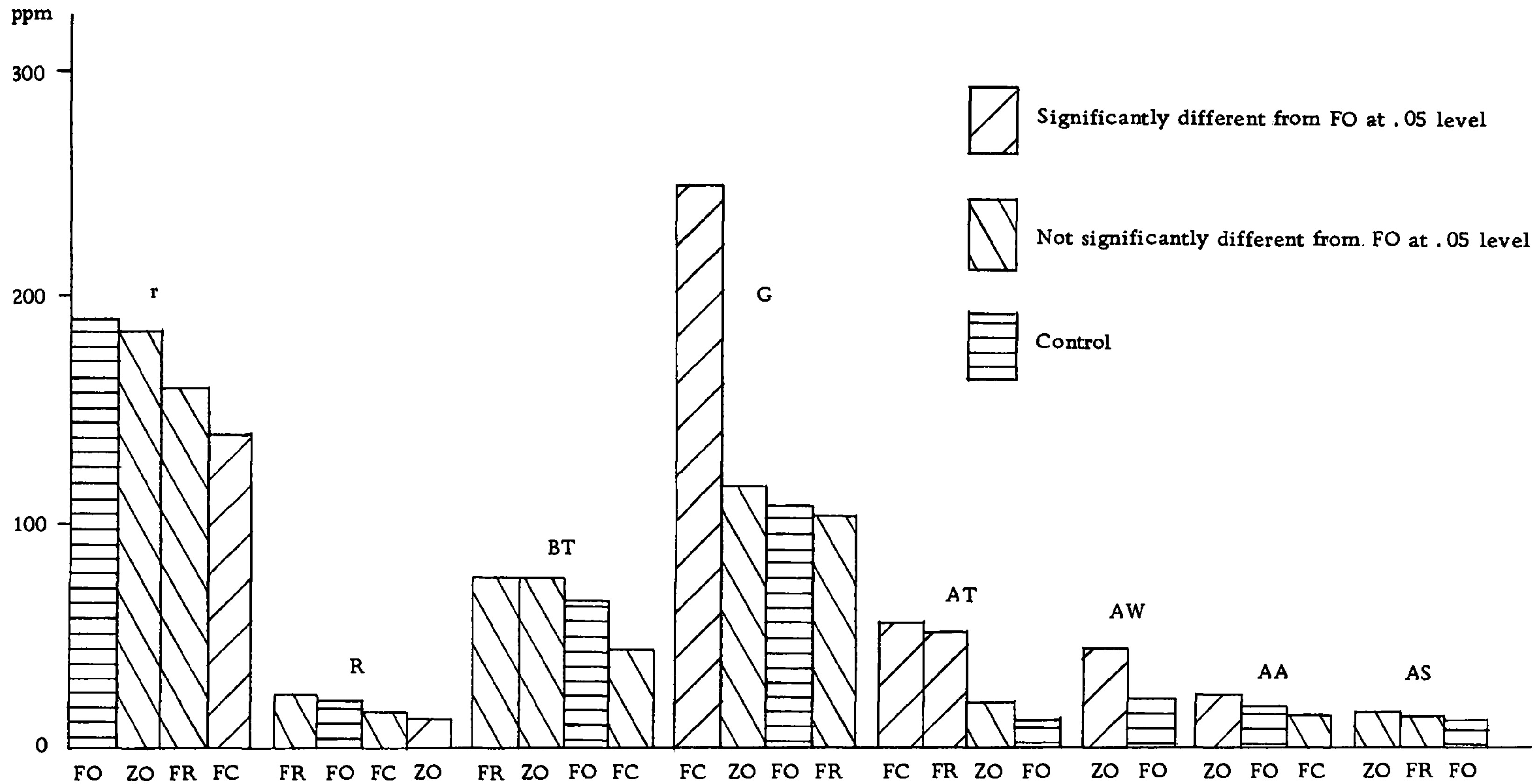

Fig. 2. Zinc content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) cherry trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.

defoliation by August sampling these results show a pattern of change different from the seasonal one of peach (3). The K, Ca, P, and Mg patterns are reversed. The September leaves were only 38 days old instead of 90 days like the August leaves. The difference between the observed pattern for cherry leaf values and the normal peach pattern probably represents the difference in leaf content between 90 and 38-day-old leaves. Mason (42), working with apple leaves, found that leaves sampled in September from plants that had lost all of their leaves in August and had subsequently regrown them, showed a pattern of nutrient content similar to leaves of the same age sampled earlier in the season.

The low level of B in the leaf tissue of the mahaleb plants suggests their use in areas of B toxicity problems and disuse in areas of B deficiency unless there are other advantages that outweigh this possible disadvantage. Only 33 ppm of B were found in the leaves of the mahaleb plants versus 109 ppm in the ungrafted F 12-1 plants. Parts per million per gram dry weight of tissue is a measure of nutrient retention, and does not necessarily indicate efficiency of uptake or transport. When root uptake efficiency is calculated as milligrams of B in the leaf tissue per gram of root tissue, mahaleb is about half as efficient as ungrafted F 12-1. The difference between transport and retention was illustrated by M 9 rootstock. The results of Mason and Whitfield (43) indicate that M 9 retains more N, P, K, Mg, and Ca than M 16. Jones (38) showed that the sap of an apple tree is far more dilute in its N, P, and K content after it has passed through an M 9 interstem. Scion leaf values do not necessarily follow those of the rootstock. Naumann (44) found that for pear the rootstock leaf values for K and P were no indication of what the scion values for these two nutrients would be.

This work has shown that the plant must be studied as a whole for rootstock selection. For the fullest understanding the plant must be subdivided into at least six parts: leaves, twigs, above graft trunk, below graft trunk, main roots, and rootlets.

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APPENDIX

This appendix contains additional data relating to the preceding experiment but not included because it represented too few observations or in the case of copper was deemed unreliable. Presented here are the data regarding root efficiency. Root efficiency is a concept used by Wallihan and Garber (67) to measure the ability of a plant's root system to extract nutrients from a root medium.

General Material and Methods

Sixteen liter plastic pots filled with a 3:1 mixture of 20 and 30 mesh Delmonte white sand were used for the sand culture experiment. Four rootstocks, F 12-1, mazzard seedling, mahaleb seedling, and Stockton-Morello, were selected for use because of their widespread use by the cherry industry. 'Royal Ann' and 'Corum' scions were used because they are the ones of greatest current commercial use in Oregon. The F 12-1, mazzard, and mahaleb rootstocks came from Daybreak Nursery of Forest Grove, Oregon. The F 12-1 and mahaleb stocks were about the same size, 7 mm caliper, mahaleb being the smaller. The mazzard was about 10 mm caliper. The Stockton-Morello plants came from a similar experiment conducted the previous year and averaged 13 mm caliper. After grafting, the plants were callused for two weeks at 16^{o}C in a dark room, then planted.

The nutrient solution modified from Simons (54) contained 225 ppm N, 70 ppm P, 90 ppm K, 180 ppm Ca, 60 ppm Mg, 5 ppm Mn, 2 ppm Fe, .3 ppm B, 2 ppm Zn, and 2 ppm Cu. These nutrients were supplied by H_2PO_3, KCl, $CaCl_2$ and $Ca(NO_3)_2$, $Mg(NO_3)_2$, H_2BO_3, $MnSO_4$, $CuSO_4$, $ZnSO_4$, and $FeSO_4$. The nutrient solution was mixed in a concentrated form and then diluted 100:1 using a mixer proportioner. There was a problem of $CaSO_4$ precipitation.

To obtain the root efficiency data, the leaves and rootlets were weighed after grinding. It was assumed that an equal percentage of leaf and rootlet tissue was lost in grinding. To determine the root efficiency expressed as milligrams of nutrient in leaf tissue per gram of rootlet tissue, the weight of the leaf tissue, both above and below graft leaves for compound plants, was multiplied by the mean concentration of the leaves which was calculated by multiplying the weight of a sample times its mean concentration adding all of the leaf samples for one rootstock together and dividing by the number of samples and then dividing by the weight of the rootlet tissue for the rootstock.

The values of the means not presented in the second paper and the means for the copper data were calculated and analyzed in the same way as the values presented in the second paper. Statistical analysis was done on the copper data but not on the other data.

The $\log_{10}$ of the data was used for between part comparisons after a plot of the data on linear graph paper indicated that the variance was proportional to the mean and not independent of the mean.

The graph of the data on semi-log paper showed that a $\log_{10}$ transformation would correct the difficulty. The Cu data were not transformed for the within plant comparisons because of too many zero observations.

General Results and Discussion

The weights of all of the samples are in Appendix Table 1. Appendix Table 2 contains the root efficiencies that were calculated. It appears that root efficiency is influenced by the same factors, rootstock, scion, and graft union, as nutrient distribution and content. When looking at the data for Stockton-Morello one should remember that it was one year old when planted in the pot and consequently the rootlet weight includes the weight of dead rootlets from the previous year. This means that the root efficiency assigned to it may be too low. The root efficiency assigned to the ungrafted mazzard may be too high. The ungrafted mazzard like the other ungrafted rootstocks was made up of plants on which the grafts had failed. As an apparent result of the Pseudomonas infection the ungrafted mazzard trees developed very light weight root systems which were able to supply nutrients for normal top growth because of the sand culture conditions.

The data representing less than five observations appeared to follow the same pattern as the other data. They also tended to indicate that 'Royal Ann' and 'Corum' scions grafted on F 12-1 and mazzard

Appendix Table 1. Average sample weight in grams of sand culture sweet cherry trees.

Plant*	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	11.9	10.4	6.8	2.1	2.9	4.3	4.7	2.2	2.3	6.5	7.0
F	10.3	7.7	4.3	-	-	8.1	-	2.8	-	11.5	-
FR	10.9	7.3	4.7	2.3	1.9	12.1	3.8	-	3.7	-	9.9
FC	16.5	12.6	5.9	1.1	1.2	12.1	-	2.9	0.8	13.8	-
ZO	9.8	19.7	7.6	2.1	2.6	2.3	2.9	3.0	2.4	4.9	4.9
Z	3.8	11.3	5.7	-	-	2.9	-	3.5	-	6.2	-
ZR	7.2	17.8	7.8	2.0	1.7	5.5	1.5	5.1	3.5	-	1.5
ZC	8.1	15.5	5.4	1.9	1.7	1.4	1.8	-	4.5	2.8	1.8
SO	13.5	17.9	11.0	0.9	1.1	3.9	1.0	4.7	1.5	4.4	-
S	9.6	15.0	33.6	-	-	3.4	-	4.7	-	5.2	-
B	9.9	7.1	3.4	-	-	8.2	-	1.6	-	5.7	-

*r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September. FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum'on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 2. Root efficiency expressed as milligrams of nutrient in leaf tissue per gram of rootlet tissue for sand culture sweet cherry trees.

Plant*	N	K	P	Ca	Mg	Mn	Fe	Cu	B	Zn
FO	26.4	15.3	3.6	14.7	8.2	0.19	0.13	0.005	0.12	0.02
F	25.6	13.8	3.1	17.2	10.0	0.20	0.10	0.006	0.10	0.02
FR	28.9	20.0	3.7	14.6	7.8	0.21	0.08	0.005	0.14	0.02
FC	24.6	9.9	2.9	16.1	8.8	0.21	0.09	0.005	0.08	0.02
ZO	27.4	11.1	3.3	16.3	9.9	0.16	0.16	0.008	0.06	0.02
Z	39.0	12.4	4.1	22.6	15.9	0.25	0.27	0.041	0.10	0.04
ZR	22.3	9.5	3.2	11.9	8.2	0.10	0.11	0.007	0.10	0.02
ZC	20.9	10.5	3.1	12.0	7.6	0.13	0.09	0.005	0.09	0.02
SO	20.0	9.4	3.4	11.4	7.1	0.11	0.04	0.004	0.06	0.02
S	18.2	8.9	2.8	11.6	7.3	0.12	0.06	0.004	0.06	0.02
B	14.5	7.9	1.9	8.1	4.2	0.10	0.07	0.003	0.02	0.01

*FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1; ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

seedling roots are influenced by rootstock for N and Mg. The Cu values were affected by the same factors as the other nine nutrients.

Appendix Table 3. Mean nitrogen content in percent dry weight by plant part for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	0.94	0.57	0.47	0.33	0.35	0.52	0.61	2.43x	2.43	2.49	2.42
F	-	0.87	0.46	0.43	-	-	0.59	-	2.33	-	2.30	-
FR	-	1.07	0.72	0.50	0.40	0.52	0.58x	0.87x	-	2.56x	-	2.47
FC	-	0.86	0.48	0.41	0.40x	0.57x	0.59	-	2.37x	2.73x	2.54	-
ZO	-	1.67	1.27	0.70	0.47	0.44	0.52	0.58	2.67x	2.82	2.80x	2.65
Z	-	1.71	1.28	0.80	-	-	0.81	-	2.78	-	2.50x	-
ZR	-	1.61x	1.47x	0.77x	0.53x	0.46x	1.12x	1.11x	2.60x	2.50x	-	2.70x
ZC	-	1.58x	1.12x	0.53x	0.47x	0.48x	0.91x	1.14x	-	3.15x	2.95x	2.83x
SO	-	1.15x	0.51x	0.40x	0.34x	0.57x	0.80x	-	2.50x	2.41x	2.72x	-
S	-	1.07	0.69	0.46	-	-	0.78	-	2.47	-	2.45	-
B	-	0.98	0.54	0.49	-	-	0.68	-	3.96x	-	2.29	-

[x] Less than five observations

*r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA= above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 4. Mean potassium content in percent dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	0. 47	0. 39	0. 26	0. 16	0. 19	0. 35	0. 40	0. 53x	0. 71	1. 97	1. 98
F	-	0. 57	0. 40	0. 30	-	-	0. 44	-	0. 86	-	1. 96	-
FR	-	0. 56	0. 37	0. 31	0. 29	0. 39	0. 51x	0. 71x	-	1. 05x	-	2. 24
FC	-	0. 59	0. 38	0. 28	0. 17	0. 24	0. 42	-	0. 75x	0. 35	1. 86	-
ZO	1. 48	0. 79	0. 28	0. 24	0. 22	0. 27	0. 50	0. 59	0. 54x	0. 55	1. 92x	1. 93
Z	-	0. 75	0. 25	0. 24	-	-	0. 55	-	0. 42	-	1. 57x	-
ZR	-	0. 81x	0. 25x	0. 22x	0. 33x	0. 31x	0. 53x	0. 84x	0. 52x	0. 75x	-	2. 40x
ZC	-	0. 56x	0. 19x	0. 18x	0. 35x	0. 50x	0. 30x	0. 78x	-	0. 61x	1. 60x	1. 76x
SO	-	0. 27x	0. 16x	0. 18x	0. 11x	0. 20x	0. 38x	0. 36x	0. 97x	0. 90x	1. 75x	-
S	-	0. 32	0. 18	0. 17	-	-	0. 43	-	0. 87	-	1. 87	-
B	-	0. 73	0. 30	0. 21	-	-	0. 42	-	1. 04x	-	1. 40	-

[x] Less than five observations

*r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 5. Mean phosphorus content in percent dry weight by plant part for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	0.51	0.15	0.06	0.03	0.04	0.08	0.08	0.25x	0.29	0.36	0.37
F	-	0.46	0.13	0.07	-	-	0.08	-	0.26	-	0.30	-
FR	-	0.49	0.17	0.09	0.06	0.10	0.08x	0.14x	-	0.29x	-	0.37
FC	-	0.50	0.13	0.07	0.03	0.07	0.07	-	0.29x	0.24	0.33	-
ZO	0.27	0.58	0.19	0.11	0.06	0.07	0.14	0.14	0.33x	0.30	0.34x	0.36
Z	-	0.61	0.19	0.13	-	-	0.17	-	0.29	-	0.27x	-
ZR	-	0.66x	0.18x	0.11x	0.11x	0.09x	0.20x	0.21x	0.30x	0.31x	-	0.48x
ZC	-	0.51x	0.18x	0.10x	0.09x	0.13x	0.11x	0.25x	-	0.36x	0.30x	0.44x
SO	-	0.32x	0.09x	0.04x	0.02x	0.02x	0.09x	0.11x	0.46x	0.47x	0.39x	-
S	-	0.31	0.09	0.04	-	-	0.12	-	0.37	-	0.40	-
B	-	0.50	0.11	0.06	-	-	0.11	-	0.36x	-	0.31	-

x Less than five observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 6. Mean calcium content in percent dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	0.93	0.38	0.44	0.25	0.27	0.56	0.56	1.81x	1.72	1.07	1.05
F	-	0.83	0.36	0.44	-	-	0.56	-	1.89	-	1.12	-
FR	-	0.90	0.41	0.50	0.36	0.69	0.59x	0.96x	-	1.73x	-	1.03
FC	-	0.82	0.33	0.44	0.52	0.89	0.57	-	1.85x	1.95	1.14	-
ZO	0.19	1.00	0.34	0.53	0.41	0.38	0.81	0.71	1.99x	1.83	1.25x	1.33
Z	-	1.14	0.36	0.52	-	-	0.84	-	1.76	-	1.17x	-
ZR	-	1.13x	0.39x	0.58x	0.66x	0.67x	0.99x	1.04x	1.88x	1.64x	-	0.70x
ZC	-	0.99x	0.39x	0.56x	0.58x	0.92x	0.63x	1.07x	-	1.80x	1.22x	1.07x
SO	-	0.85x	0.37x	0.53x	0.50x	0.60x	0.72x	0.81x	1.78x	1.70x	0.91x	-
S	-	0.87	0.39	0.49	-	-	0.99	-	1.83	-	1.04	-
B	-	0.98	0.57	0.56	-	-	0.83	-	1.69x	-	1.35	-

x Less than five observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 7. Mean magnesium content in percent dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	0.23	0.07	0.02	0.01	0.01	0.10	0.08	1.20x	1.11	0.49	0.47
F	-	0.26	0.08	0.05	-	-	0.10	-	1.18	-	0.49	
FR	-	0.23	0.08	0.05	0.03	0.09	0.10x	0.23x	-	1.05x	-	0.49
FC	-	0.24	0.08	0.05	0.03	0.09	0.10	-	1.11x	1.10	0.51	-
ZO	0.12	0.23	0.05	0.05	0.02	0.04	0.17	0.15	1.44x	1.30	0.51x	0.54
Z	-	0.23	0.04	0.05	-	-	0.20	-	1.41	-	0.52x	-
ZR	-	0.24x	0.04x	0.03x	0.07x	0.10x	0.20x	0.32x	1.30x	1.19x	-	0.40x
ZC	-	0.22x	0.05x	0.05x	0.05x	0.11x	0.11x	0.36x	-	1.25x	0.52x	0.61x
SO	-	0.30x	0.06x	0.05x	0.03x	0.02x	0.16x	0.14x	1.18x	1.13x	0.43x	-
S	-	0.29	0.05	0.05	-	-	0.19	-	1.25	-	0.46	-
B	-	0.34	0.11	0.10	-	-	0.23	-	1.11x	-	0.68	-

[x]Less than five observations

*r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 8. Mean manganese content in parts per million dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	840	75	37	31	34	103	90	159x	160	213	177
F	-	731	53	33	-	-	75	-	163	-	208	-
FR	-	834	72	39	27	43	65x	102x	-	184x	-	174
FC	-	799	63	41	35	33	92	-	164x	162	297	-
ZO	17	1047	36	52	27	41	119	99	177x	124	218x	155
Z	-	949	35	50	-	-	131	-	134	-	229x	-
ZR	-	809x	36x	47x	36x	25x	146x	75x	158x	114x	-	101x
ZC	-	749x	39x	50x	27x	40x	140x	96x	-	169x	184x	129x
SO	-	619x	27x	40x	51x	58x	132x	90x	113x	84x	229x	-
S	-	558	28	45	-	-	163	-	117	-	251	-
B	-	691	30	35	-	-	68	-	118x	-	170	-

[x] Less than 5 observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 9. Mean iron content in parts per million dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	703	757	158	52	255	54	48	147x	125	119	120
F	-	683	694	167	-	-	46	-	79	-	95	-
FR	-	788	956	126	41	197	37x	45x	-	73x	-	55
FC	-	671	838	169	60	431	53	-	71x	51	145	-
ZO	149	668	496	283	63	308	79	59	269x	149	133x	112
Z	-	826	635	375	-	-	92	-	203	-	156x	-
ZR	-	931x	661x	358x	103x	373x	130x	70x	250x	139x	-	50x
ZC	-	1019x	795x	201x	77x	375x	49x	67x	-	125x	58x	102x
SO	-	631x	633x	143x	12x	59x	47x	39x	66x	36x	38x	-
S	-	693	449	167	-	-	66	-	85	-	75	-
B	-	354	286	161	-	-	91	-	76x	-	124	-

x Less than five observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 10. Mean copper content in parts per million dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	42	5	6	1	1	2	3	7x	6	4	3
F	-	38	6	10	-	-	2	-	7	-	3	-
FR	-	48	10	9	1	3	0x	5x	-	6x	-	3
FC	-	36	3	8	3	4	2	-	4x	5	5	-
ZO	9	41	5	9	2	3	5	4	13x	8	7x	4
Z	-	40	5	8	-	-	11	-	21	-	39x	-
ZR	-	42x	5x	6x	3x	3x	15x	5x	14x	9x	-	3x
ZC	-	46x	44x	9x	4x	4x	7x	6x	-	10x	1x	3x
SO	-	43x	9x	12x	1x	0x	5x	1x	6x	5x	4x	-
S	-	41	5	15	-	-	5	-	7	-	4	-
B	-	24	6	6	-	-	4	-	10x	-	4	-

x Less than five observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 11. Mean boron content in parts per million dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	43	18	23	14	17	37	50	77x	86	119	129
F	-	35	17	23	-	-	44	-	78	-	109	-
FR	-	46	25	23	14	28	49x	80x	-	94x	-	150
FC	-	34	19	21	13	24	42	-	64x	64	102	-
ZO	212	51	20	19	15	20	32	51	70x	66	88x	107
Z	-	51	19	19	-	-	42	-	57	-	88x	-
ZR	-	51x	21x	17x	20x	18x	45x	72x	64x	81x	-	197x
ZC	-	46x	17x	16x	20x	30x	16x	96x	-	71x	64x	173x
SO	-	33x	14x	20x	18x	27x	45x	63x	68x	67x	76x	-
S	-	42	19	19	-	-	53	-	71	-	98	-
B	-	37	15	12	-	-	30	-	21x	-	33	-

x Less than five observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 12. Mean zinc content in parts per million dry weight by plant parts for all sand culture sweet cherry trees.

Plant*	Gall	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	-	189	20	66	107	13	21	21	15x	16	14	12
F	-	119	17	37	-	-	20	-	15	-	15	-
FR	-	157	23	74	101	51	20x	80x	-	16x	-	14
FC	-	137	17	43	247	58	25	-	14x	13	20	-
ZO	9	184	15	74	116	20	52	43	23x	22	19x	16
Z	-	187	12	54	-	-	60	-	32	-	18x	-
ZR	-	182x	14x	65x	144x	36x	75x	56x	30x	21x	-	27x
ZC	-	185x	13x	100x	146x	71x	35x	70x	-	19x	22x	32x
SO	-	190x	33x	76x	263x	48x	61x	78x	24x	21x	26x	-
S	-	152	26	69	-	-	60	-	14	-	20	-
B	-	112	24	49	-	-	41	-	18x	-	9	-

x Less than five observations

* r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, ZR = 'Royal Ann' on mazzard, ZC = 'Corum' on mazzard, SO = own grafted Stockton-Morello, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 13. Number of observations per mean for statistically analyzed N, K, P, Ca, Mg, Mn, Fe, Cu, B, and Zn data of the sand culture experiment.

Plant	r	R	BT	G	AT	BW	AW	BA	AA	BS	AS
FO	12	12	12	12	12	9v	12	-	11	7	11
F	10	10	10	-	-	10	-	5	-	10	-
FR	5	5	5	5	5	-	-	-	-	-	5
FC	5	5	5	5w	5w	5	-	-	5w	5	-
ZO	12	12x	12	12	12	11y	10z	-	9	-	6
Z	9	9	9	-	-	9v	-	7	-	-	-
S	11	11	11	-	-	11	-	12	-	6	-
B	15	15	15	-	-	15	-	-	-	15	-

[v] Eight observations for nitrogen
[w] Less than five observations for nitrogen
[x] Eleven observations for nitrogen
[y] Seven observations for nitrogen
[z] Six observations for nitrogen

*r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, BW = below graft twig, AW = above graft twig, BA = below graft leaves August, AA = above graft leaves August, BS = below graft leaves September, AS = above graft leaves September.
FO = own grafted F 12-1, F = ungrafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb.

Appendix Table 14. Evaluation of the comparisons between adjacent plant parts by plant for the grafted trees of the sand culture experiment for N, K, P, Ca, Mg, Mn, Fe, Cu, B, and Zn.

Nutrient	Plant*	r-R	R-BT	BT-G	G-AT	AT-AW	AW-AA	AW-AS
Nitrogen	FO	X	X	X	NS	X	X	X
	FR	X	NS	NS	NS			
	FC	X	NS					
	ZO	NS	X	X	NS	X	X	X
Potassium	FO	NS	X	X	NS	X	X	X
	FR	NS	NS	NS	NS			
	FC	X	NS	X	NS			
	ZO	X	NS	NS	NS	NS	X	X
Phosphorus	FO	X	X	X	NS	X	X	X
	FR	X	X	NS	NS			
	FC	X	X	NS	NS			
	ZO	X	X	X	NS	X	X	X
Calcium	FO	X	NS	X	NS	X	X	X
	FR	X	NS	NS	X			
	FC	X	NS	X	X			
	ZO	X	X	X	NS	X	X	X
Magnesium	FO	X	NS	NS	NS	X	X	X
	FR	X	NS	NS	X			
	FC	X	NS	X	NS			
	ZO	X	NS	NS	NS	X	X	X

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Appendix Table 14. (Continued)

Nutrient	Plant*	r-R	R-BT	BT-G	G-AT	AT-AW	AW-AA	AW-AS
Manganese	FO	X	X	NS	NS	X	X	X
	FR	X	NS	NS	NS			
	FC	X	NS	NS	NS			
	ZO	X	NS	X	X	X	NS	NS
Iron	FO	NS	X	X	X	X	X	X
	FR	NS	X	X	X			
	FC	NS	X	X	X			
	ZO	X	X	X	X	X	X	X
Copper	FO	X	NS	NS	NS	NS	NS	X
	FR	X	NS	NS	NS			
	FC	X	NS	NS	NS			
	ZO	X	NS	X	NS	NS	NS	NS
Boron	FO	X	NS	X	NS	X	X	X
	FR	X	NS	NS	X			
	FC	NS	NS	X	X			
	ZO	X	NS	X	NS	X	NS	X
Zinc	FO	X	X	X	X	X	NS	X
	FR	X	X	NS	X			
	FC	X	NS	X	X			
	ZO	X	X	X	X	X	X	X

X = significantly different at the .05 level; NS = not significantly different at the .05 level

*FO = own grafted F 12-1, FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, ZO = own grafted mazzard, r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.

Appendix Table 15. Evaluation of the comparisons between adjacent plant parts by plant for the ungrafted and below graft portions of the grafted trees of the sand culture experiment (macro-nutrients).

Nutrient	Plant*	r-R	R-BT	BT-BW	BW-BA	BW-BS
Nitrogen	FC	X	NS	X		
	FO	X	X	X		X
	F	X	NS	X	X	X
	ZO	NS	X	NS		
	Z	X	X	NS	X	
	S	X	X	X	NS	X
	B	X	X	X		X
Potassium	FC	X	NS	X		X
	FO	NS	X	X		X
	F	X	X	X	X	X
	ZO	X	NS	X		
	Z	X	NS	X	X	
	S	X	NS	X	X	X
	B	X	X	X		X
Phosphorus	FC	X	X	NS		X
	FO	X	X	NS		X
	F	X	X	X	X	X
	ZO	X	X	NS		
	Z	X	X	NS	X	
	S	X	X	X	X	X
	B	X	X	X		X
Calcium	FC	X	NS	NS		X
	FO	X	NS	X		X
	F	X	X	X	X	X
	ZO	X	X	X		
	Z	X	X	X	X	
	S	X	X	X	X	NS
	B	X	NS	X		X

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Appendix Table 15. (Continued)

Nutrient	Plant*	r-R	R-BT	BT-BW	BW-BA	BW-BS
Magnesium	FC	X	NS	NS		X
	FO	X	NS	X		X
	F	X	NS	NS	X	X
	ZO	X	NS	X		
	Z	X	NS	X	X	
	S	X	NS	X	X	X
	B	X	NS	X		X

X - significantly different at the .05 level; NS - not significantly different at the .05 level

*FC = 'Corum' on F 12-1, FO = own grafted F 12-1, F = ungrafted F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, BW = below graft twig, BA = below graft leaves August, BS = below graft leaves September.

Appendix Table 16. Evaluation of the comparisons between adjacent plant parts by plant for the ungrafted and below graft portions of the grafted trees of the sand culture experiment (micro-nutrients).

Nutrient	Plant*	r-R	R-BT	BT-BW	BW-BA	BW-BS
Manganese	FC	X	NS	X		X
	FO	X	X	X		X
	F	X	X	X	X	X
	ZO	X	NS	X		
	Z	X	NS	X	NS	
	S	X	X	X	X	X
	B	X	X	X		X
Iron	FC	NS	X	X		X
	FO	NS	X	X		X
	F	NS	X	X	X	X
	ZO	X	X	X		
	Z	NS	X	X	X	
	S	X	X	NS	NS	NS
	B	X	X	X		NS
Copper	FC	X	NS	X		X
	FO	X	NS	NS		NS
	F	X	X	NS	NS	NS
	ZO	X	NS	NS		
	Z	X	NS	NS	X	
	S	X	X	NS	NS	NS
	B	X	NS	NS		NS
Boron	FC	NS	NS	X		X
	FO	X	NS	X		X
	F	X	X	X	X	X
	ZO	X	NS	X		
	Z	X	NS	X	X	
	S	X	NS	X	X	X
	B	X	NS	X		NS

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Appendix Table 16. (Continued)

Nutrient	Plant*	r-R	R-BT	BT-BW	BW-BA	BW-BS
Zinc	FC	X	NS	X		NS
	FO	X	X	X		NS
	F	X	X	X	NS	NS
	ZO	X	X	NS		
	Z	X	X	NS	X	
	S	X	X	NS	X	X
	B	X	X	NS		X

X - significantly different at the .05 level; NS - not significantly different at the .05 level

*FC = 'Corum' on F 12-1, FO = own grafted F 12-1, F = ungrafted F 12-1, ZO = own grafted mazzard, Z = ungrafted mazzard, S = ungrafted Stockton-Morello, B = ungrafted mahaleb, r = rootlet, R = main root, BT = below graft trunk, BW = below graft twig, BA = below graft leaves August, BS = below graft leaves September.

Appendix Table 17. Evaluation of comparisons between morphologically similar above and below graft plant parts of the sand culture experiment for N, K, P, Ca, Mg, Mn, Fe, B, and Zn.

Nutrient	Plant*	BT-AT	BW-AW	AS-BS	Nutrient	Plant*	BT-AT	BW-AW	AS-BS
Nitrogen	FR	NS			Manganese	FR	NS		
	FO	X	NS	NS		FC	NS		
	ZO	X	NS			FO	NS	NS	NS
						ZO	NS	NS	
Potassium	FR	NS							
	FC	NS			Iron	FR	NS		
	FO	NS	NS	NS		FC	X		
	ZO	NS	X			FO	X	NS	NS
						ZO	NS	NS	
Phosphorus	FR	NS							
	FC	NS			Boron	FR	NS		
	FO	NS	NS	NS		FC	NS		
	ZO	X	NS			FO	NS	NS	NS
						ZO	NS	X	
Calcium	FR	X							
	FC	X			Zinc	FR	NS		
	FO	X	NS	NS		FC	NS		
	ZO	X	NS			FO	X	NS	NS
						ZO	X	NS	
Magnesium	FR	NS							
	FC	NS							
	FO	NS	NS	NS					
	ZO	NS	NS						

X - significantly different at the .05 level; NS - not significantly different at the .05 level

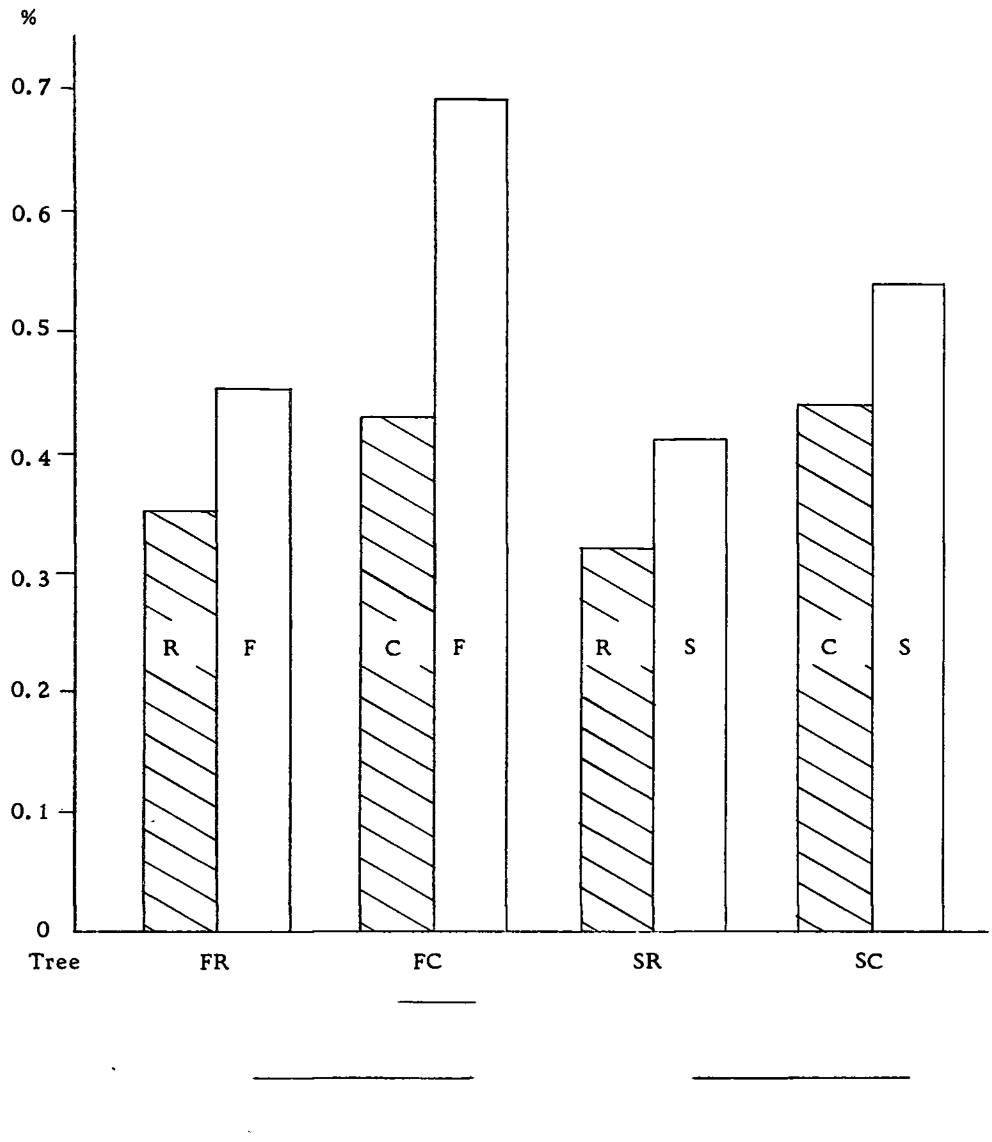
*FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, FO = own grafted F 12-1, ZO = own grafted mazzard, BT = below graft trunk, AT = above graft trunk, BW = below graft twig, AW = above graft twig, AS = above graft leaves September, BS = below graft leaves September.

Appendix Table 18. Effect of sampling date on nutrient content of leaves from trees grown in sand culture (August 19-September 23).

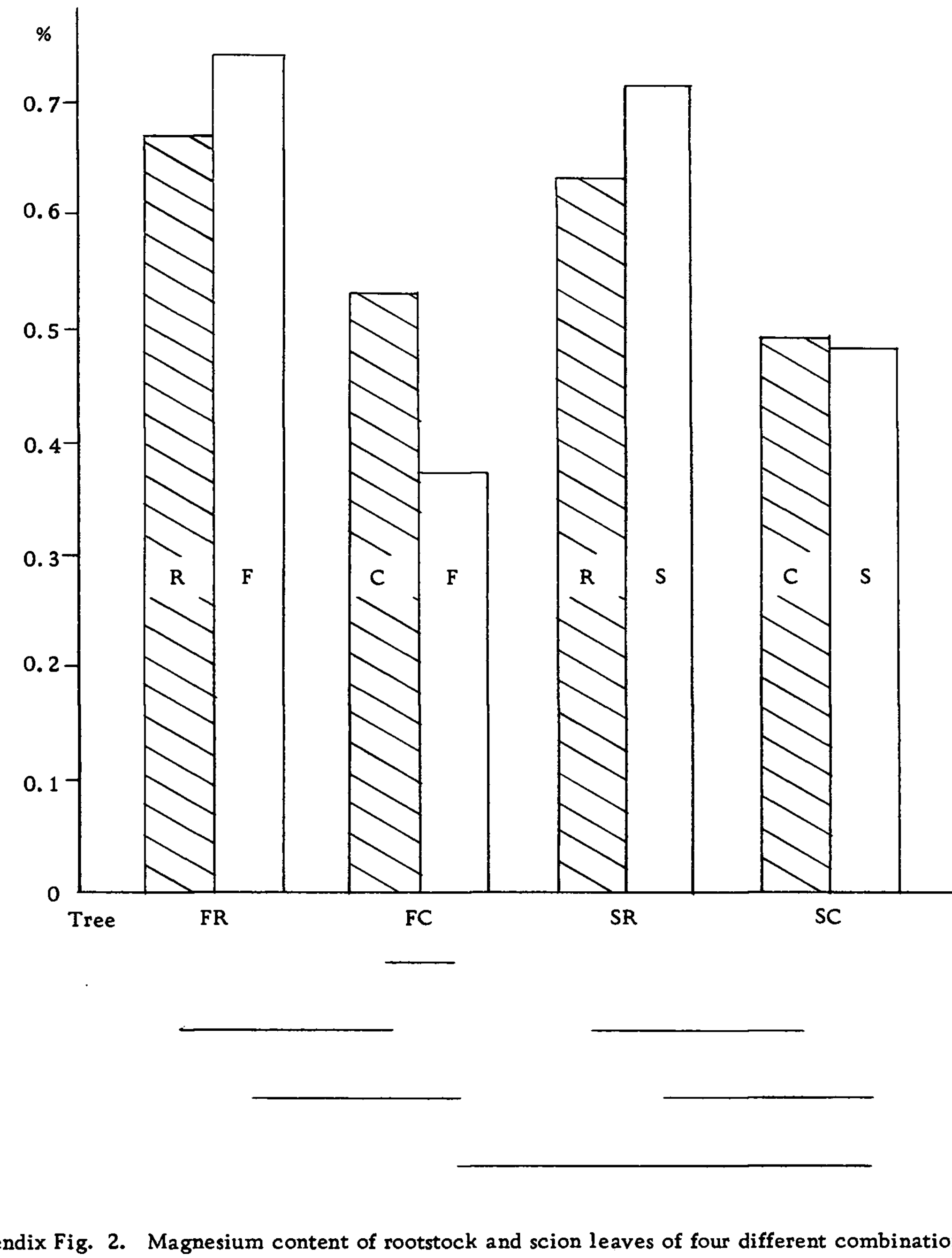
Nutrient	Plant*	Aug. -Sept.	Nutrient	Plant*	Aug. -Sept.
Nitrogen	FO	NS	Manganese	FO	NS
	F	NS		F	NS
	ZO	NS		ZO	NS
	S	NS		S	X
Potassium	FO	X	Iron	FO	NS
	F	X		F	NS
	ZO	X		ZO	NS
	S	X		S	NS
Phosphorus	FO	X	Boron	FO	X
	F	X		F	X
	ZO	NS		ZO	X
	S	NS		S	X
Calcium	FO	X	Zinc	FO	NS
	F	X		F	NS
	ZO	X		ZO	NS
	S	X		S	NS
Magnesium	FO	X			
	F	X			
	ZO	X			
	S	X			

X - significantly different at the .05 level; NS - not significantly different at the .05 level

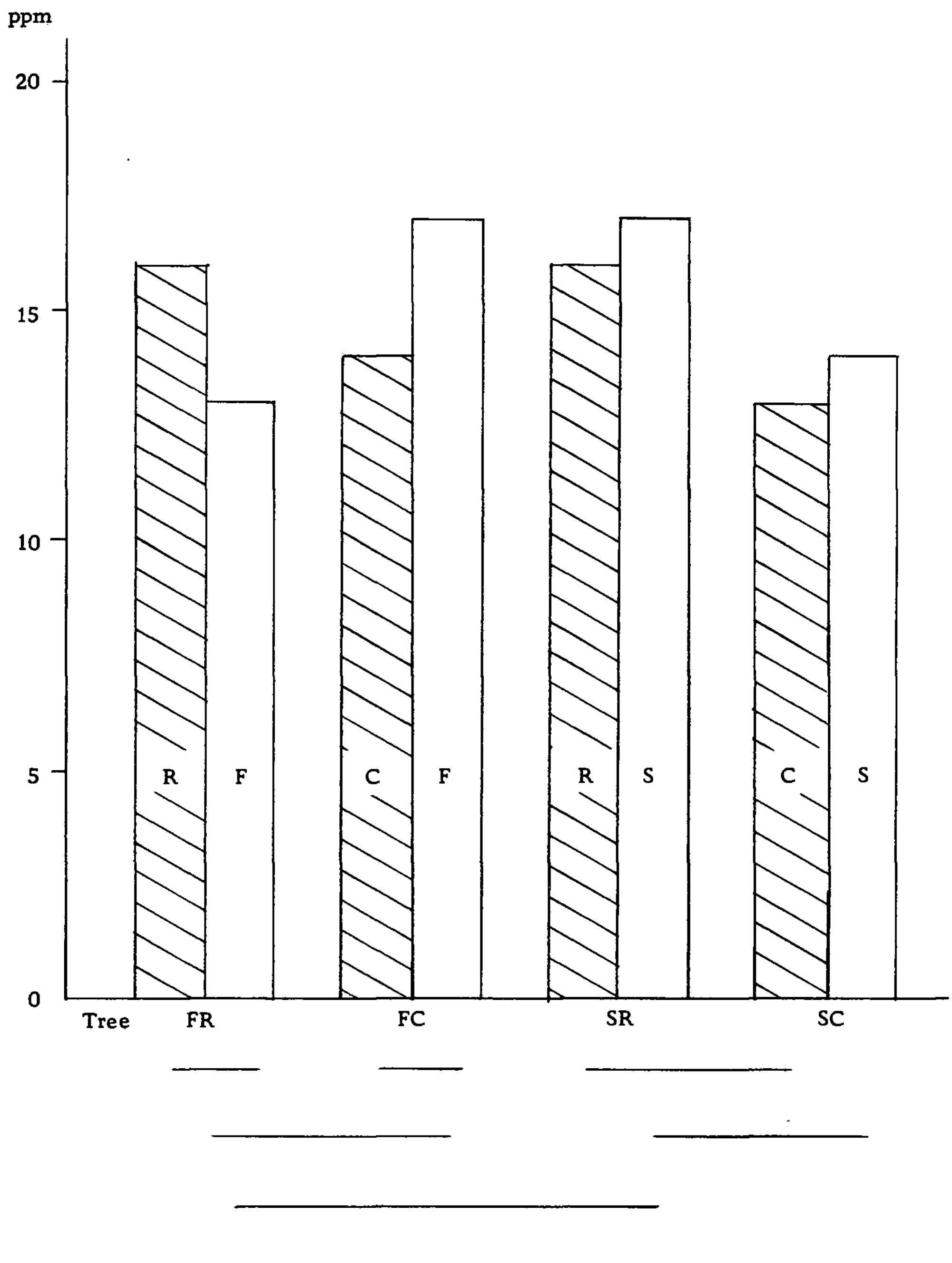
*FO = own grafted F 12-1, F = ungrafted F 12-1, ZO = own grafted mazzard, S = ungrafted Stockton-Morello.



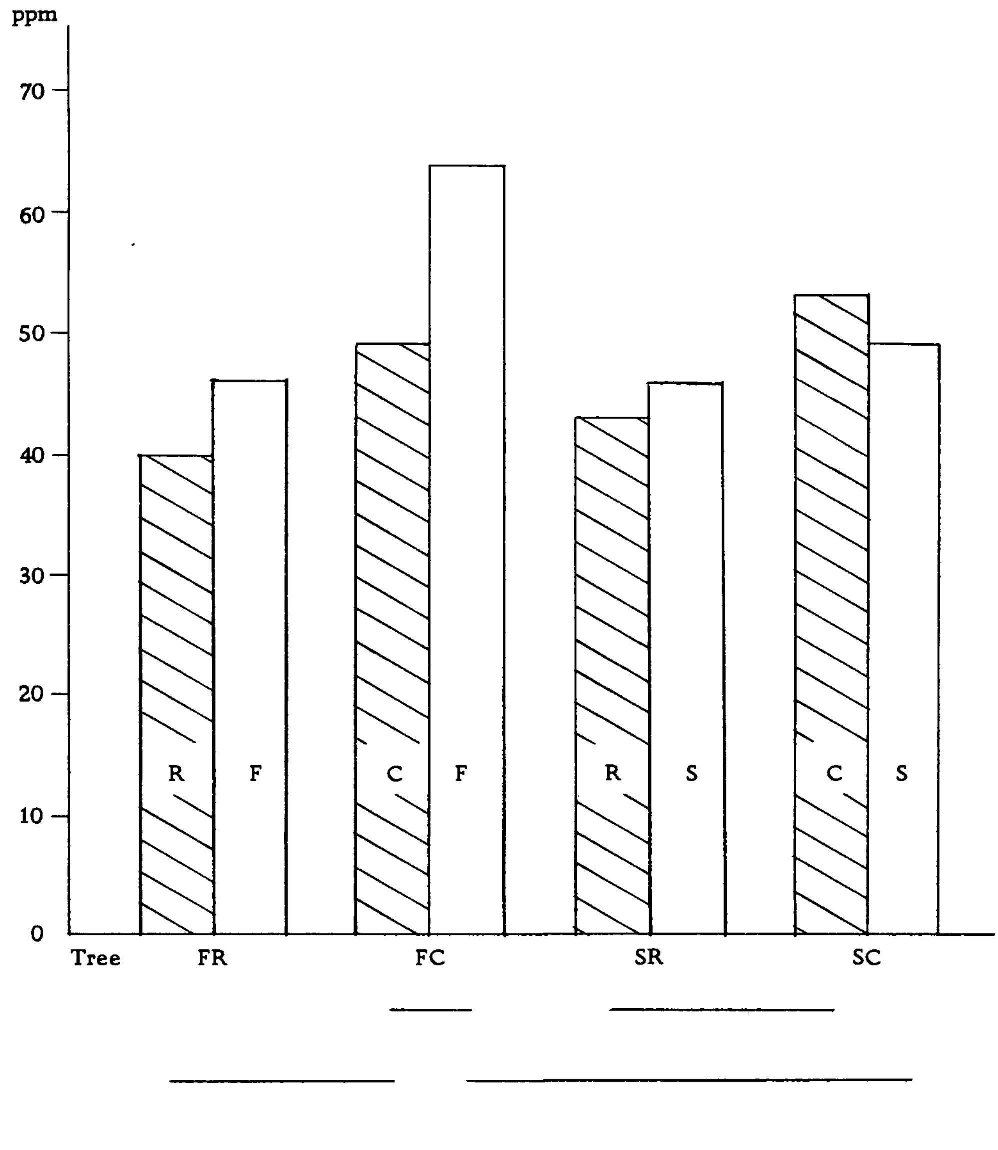
Appendix Fig. 1. Phosphorus content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR= 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello



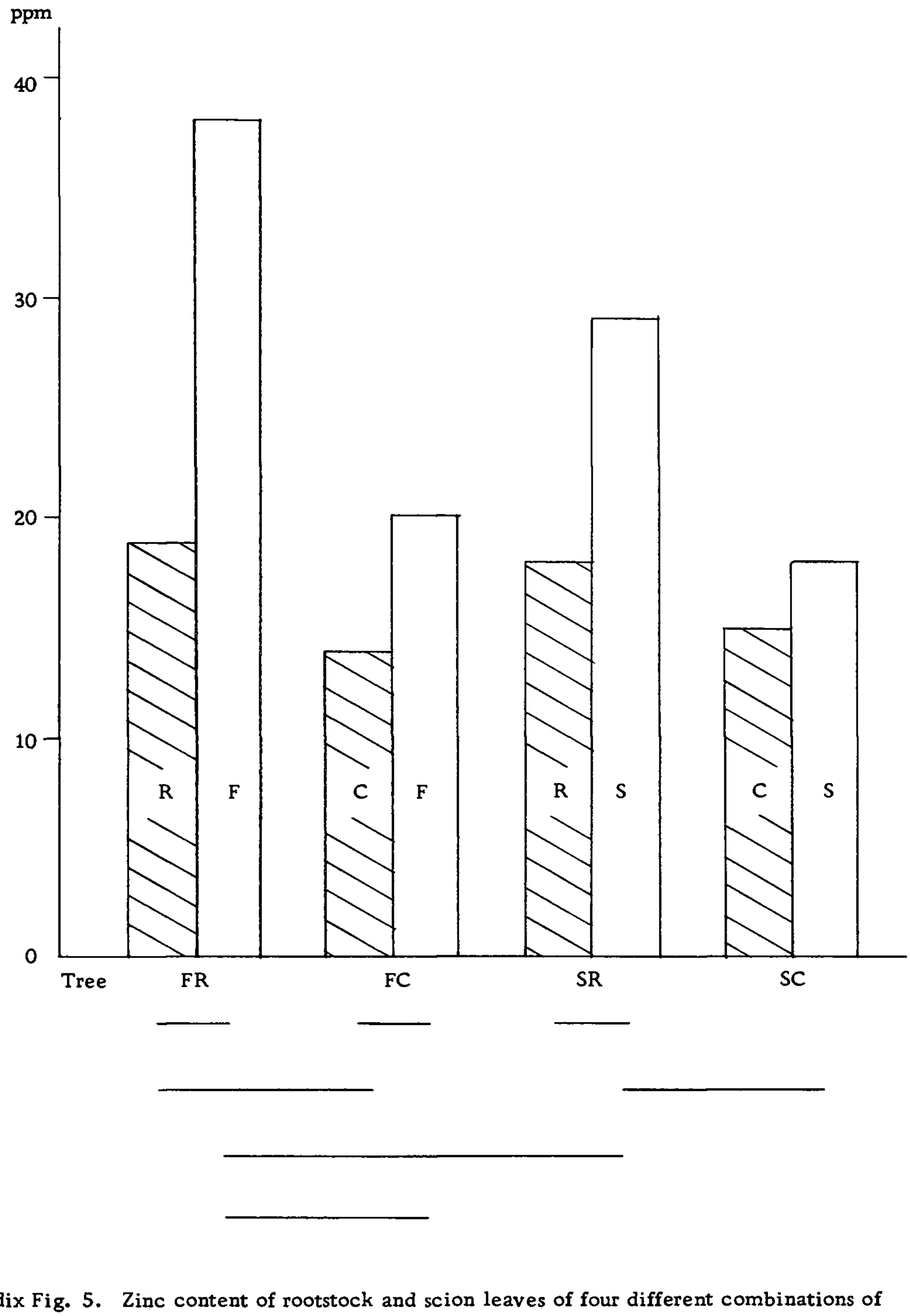
Appendix Fig. 2. Magnesium content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello



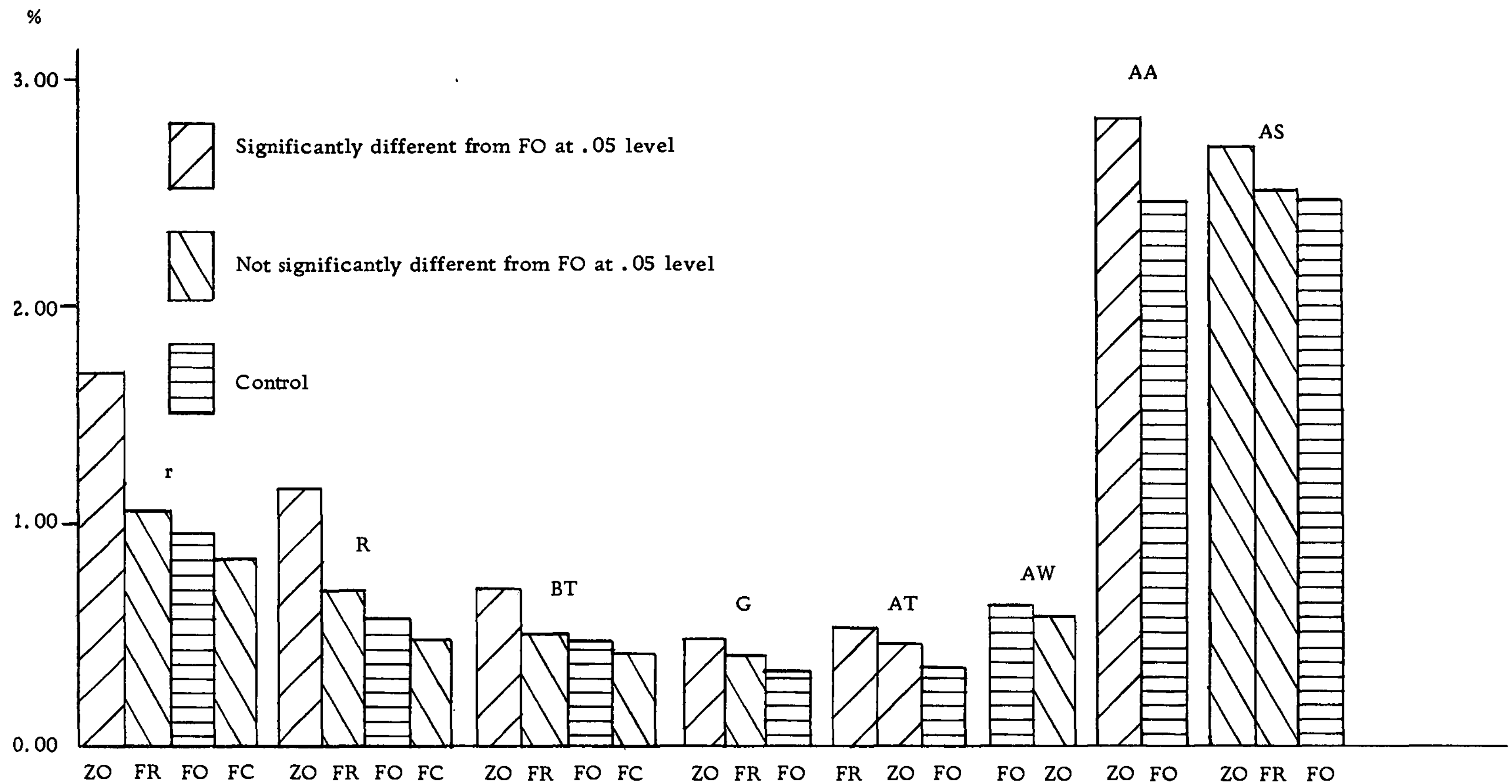
Appendix Fig. 3. Copper content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graft indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello



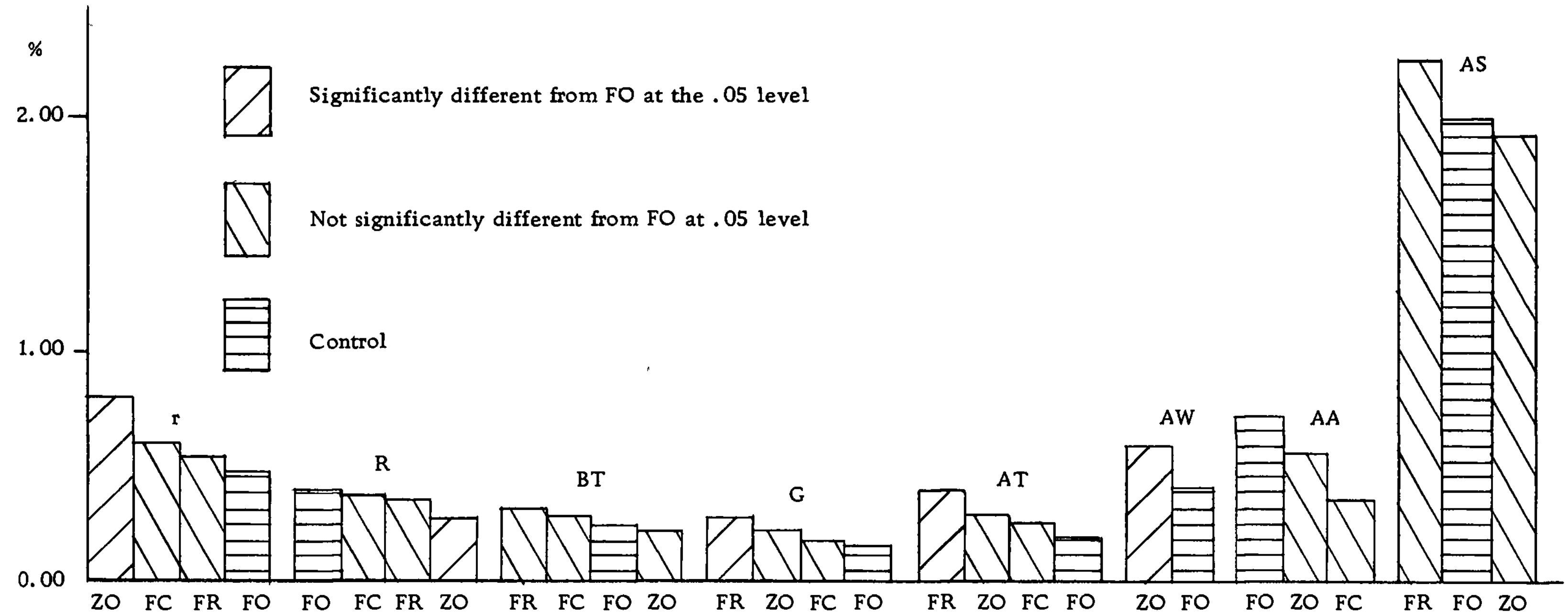
Appendix Fig. 4. Boron content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello



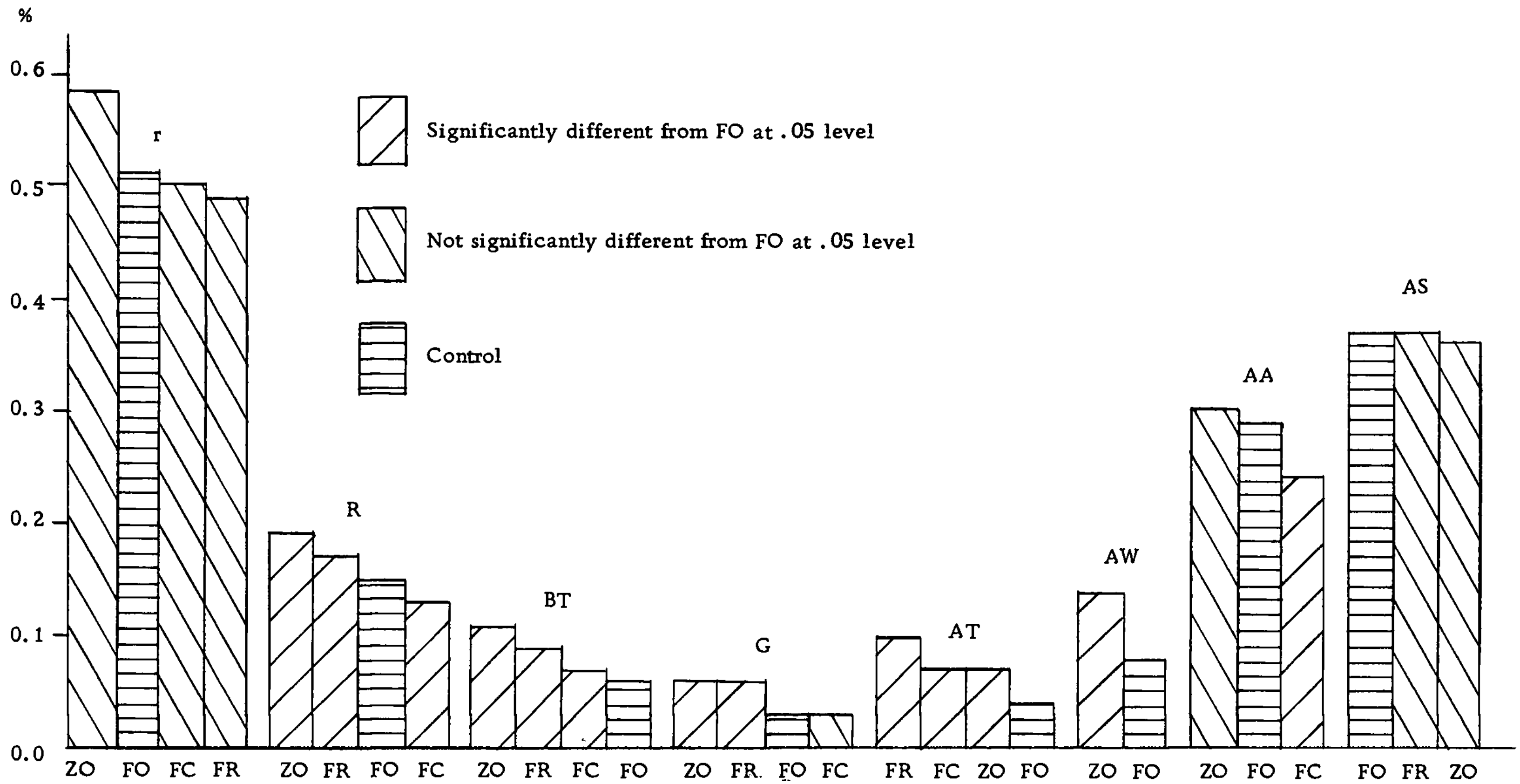
Appendix Fig. 5. Zinc content of rootstock and scion leaves of four different combinations of 'Royal Ann' (R) and 'Corum' (C) scions and F 12-1 (F) and Stockton-Morello (S) rootstocks. Lines beneath the graph indicate that the differences between the bars are significant at the .05 level.
FR = 'Royal Ann' on F 12-1, FC = 'Corum' on F 12-1, SR = 'Royal Ann' on Stockton-Morello, SC = 'Corum' on Stockton-Morello



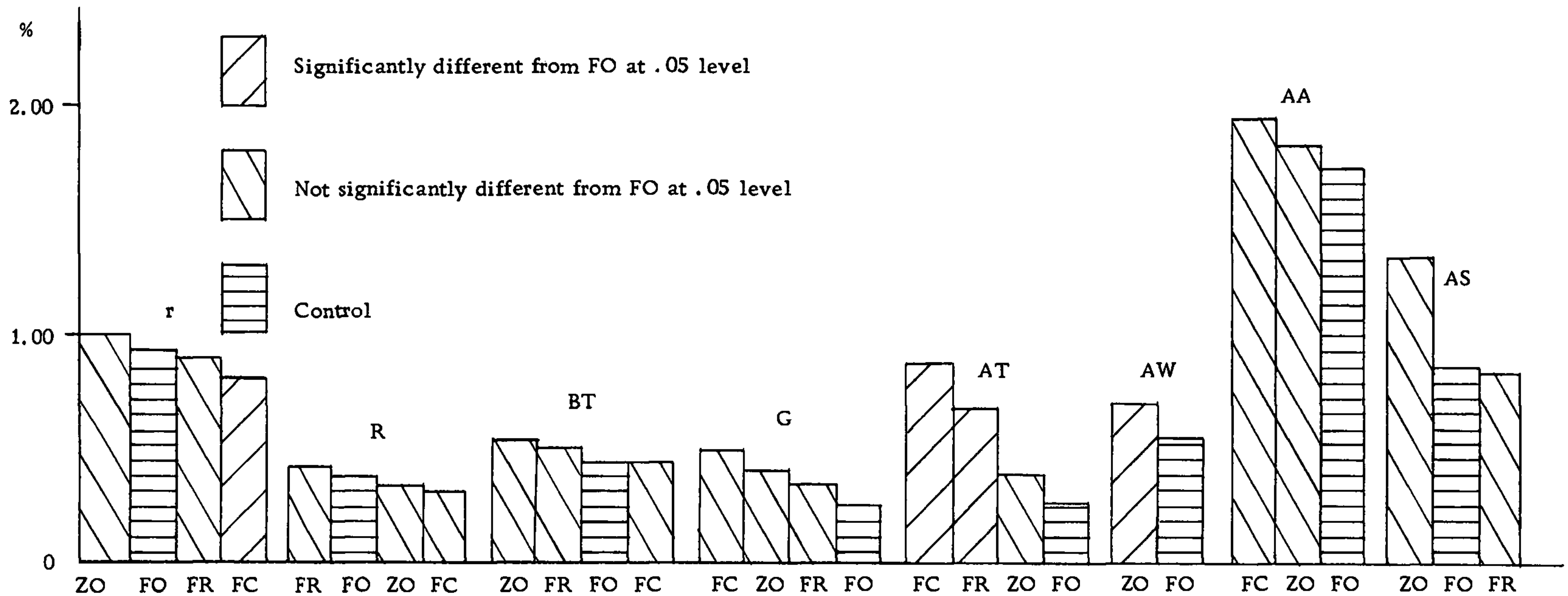
Appendix Fig. 6. Nitrogen content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = agove graft twig, AA = above graft leaves August, AS = above graft leaves September.



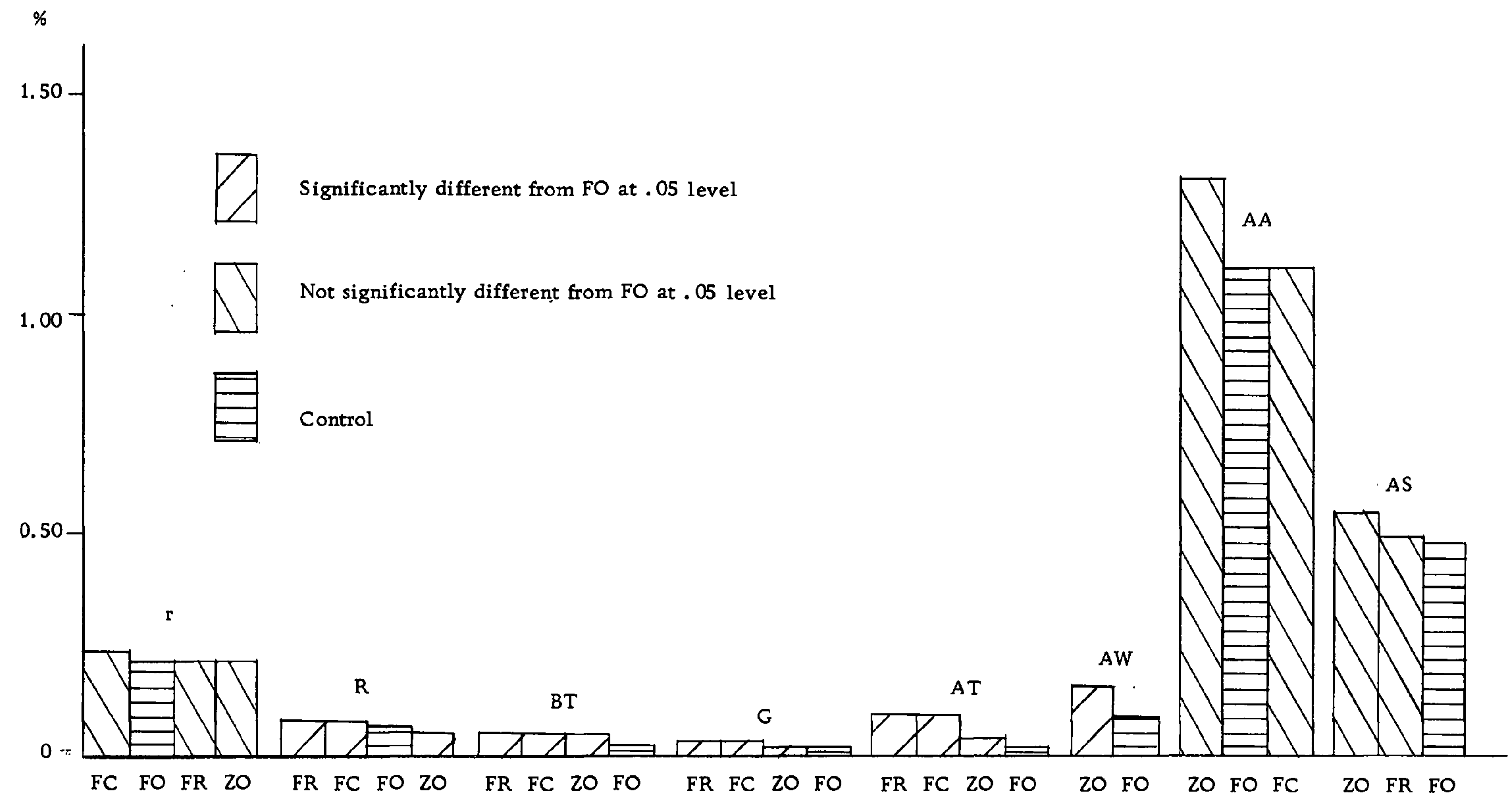
Appendix Fig. 7. Potassium content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.



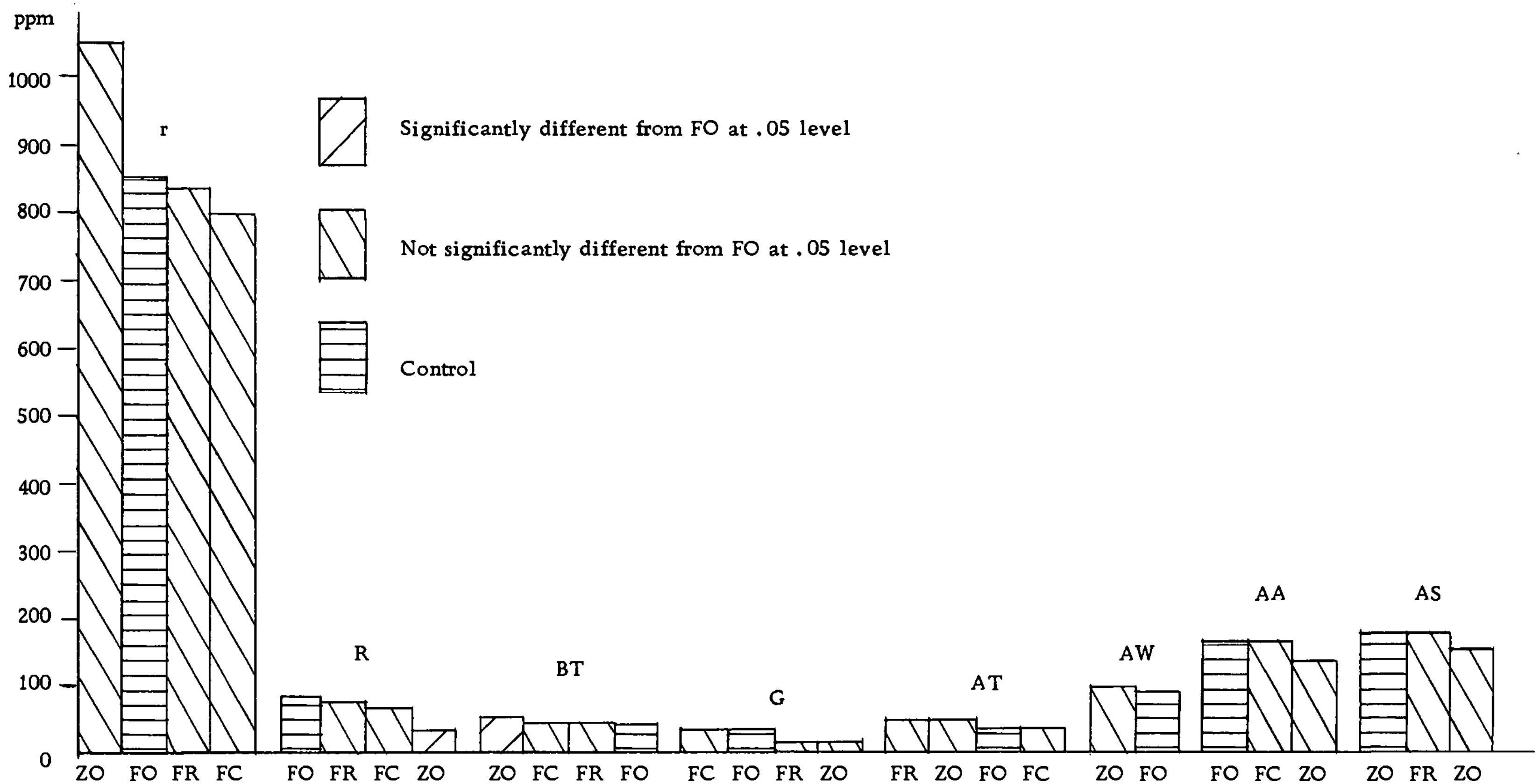
Appendix Fig. 8. Phosphorus content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.



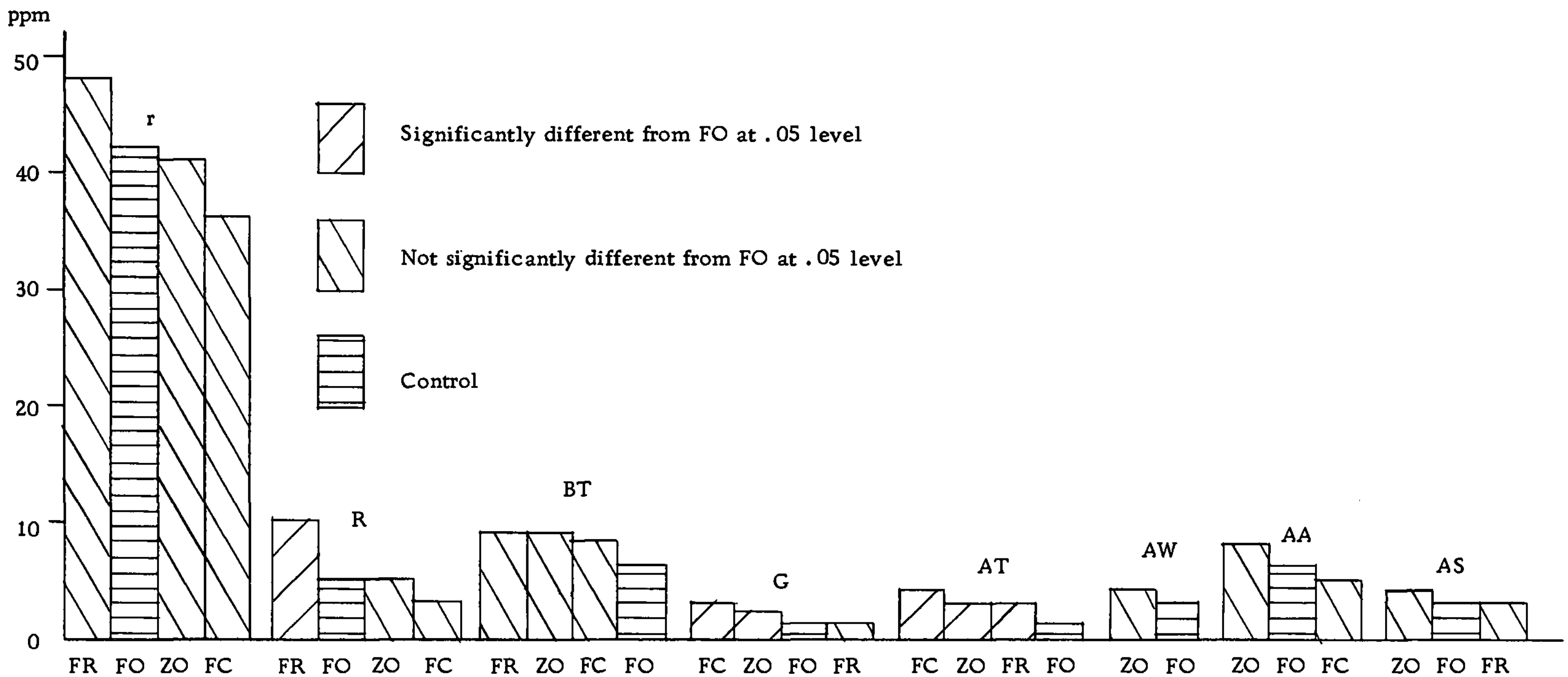
Appendix Fig. 9. Calcium content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.



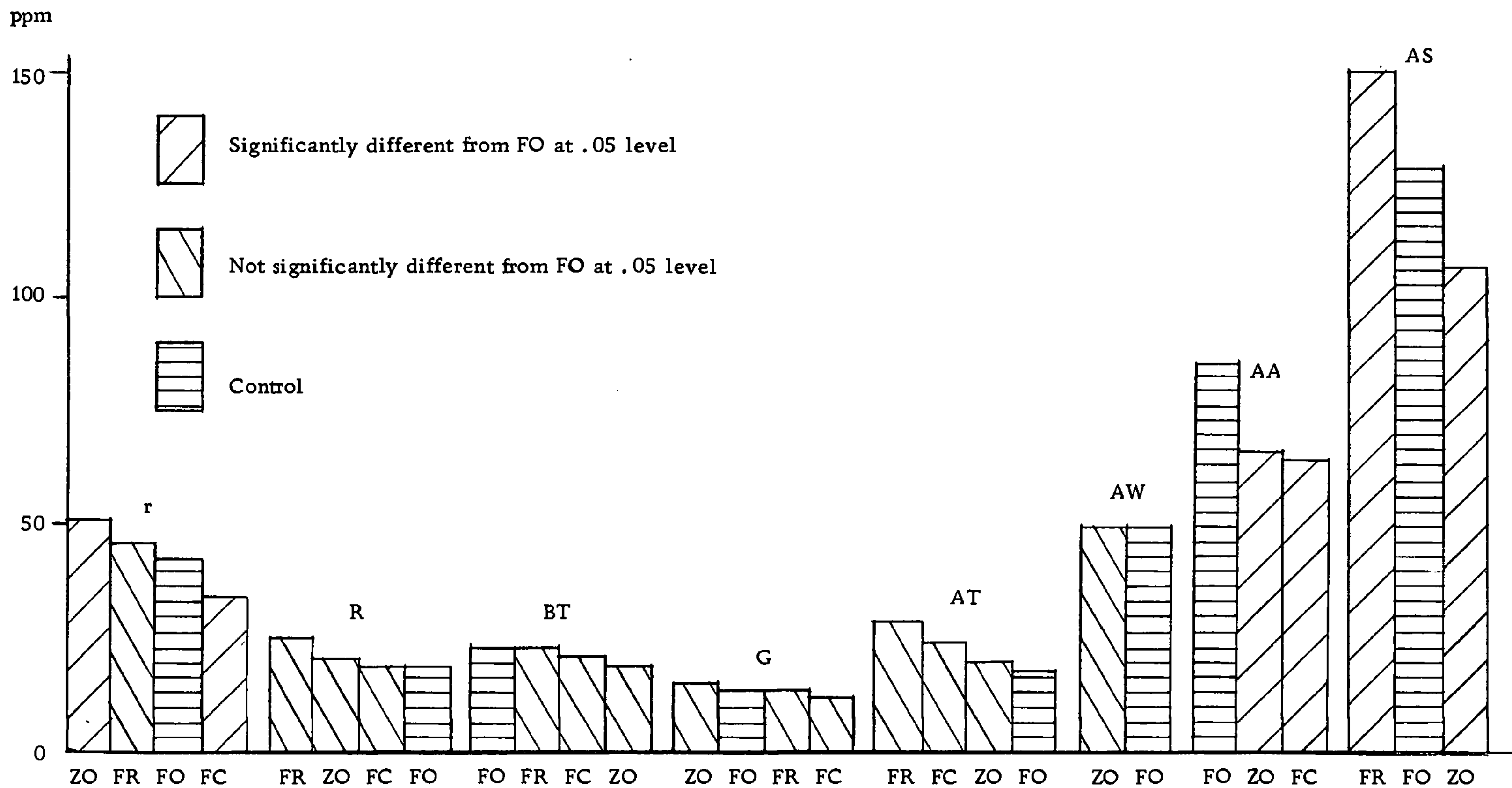
Appendix Fig. 10. Magnesium content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) on cherry trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.



Appendix Fig. 11. Manganese content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) cherry trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.



Appendix Fig. 12. Copper content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO) cherry trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.



Appendix Fig. 13. Boron content of own grafted F 12-1 (FO), 'Royal Ann' on F 12-1 (FR), 'Corum' on F 12-1 (FC), and own grafted mazzard (ZO), cherry trees grown in sand culture. The plant parts are: r = rootlet, R = main root, BT = below graft trunk, G = graft, AT = above graft trunk, AW = above graft twig, AA = above graft leaves August, AS = above graft leaves September.