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EFFECTS OF ROOTSTOCK AND ENVIRONMENT ON THE COMPOSITION OF ORANGES AND GRAPEFRUIT[1, 2]

WALTON B. SINCLAIR[3] AND E. T. BARTHOLOMEW[4]

INTRODUCTION

THE INFLUENCE of different rootstocks on important citrus varieties is being studied in a long-term experiment at this station. The present paper deals with rootstock effects on fruit composition. The effects on growth and yield of the trees in the same plots are being investigated by other workers coöperating in this project.

On the basis of results with soil and fertilizer studies, rootstock differences may be expected to have less effect on the fruit than on the foliage. But even small differences in composition may appreciably affect fruit quality, which is of immediate practical importance to the grower.

Unfortunately, edible quality is a subjective judgment not closely correlated with any one quantitative test. Flavor varies not only with concentration of total soluble solids and with relative amounts of sugar and acids, but also with other, independent variables. Differences in amounts of aromatic substances, for example, may cause noticeable differences in palatability in oranges with the same concentration of total soluble solids. But though chemical composition is difficult to relate directly to fruit quality, especially in citrus, it does measure quantitatively certain pertinent characteristics. It is of further interest scientifically for the light it throws on the physiological activities in budded citrus trees.

The effect of rootstock on the composition of citrus fruits has been studied in various parts of the world, notably in Australia (*31*),[5] South Africa (*29*), South America (*33*), and the United States (*20, 23*). Reports on some of these investigations are brief and limited in experimental data, while others are more extended. The chief criticism of much of the work is that some conclu-

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[5] Italic numbers in parentheses refer to "Literature Cited" at the end of this paper.

sions have been drawn on scant data. Certain facts have, however, been fairly well established.

Hume (*24*) reported on a Florida experiment in which fruit samples from Rough-lemon stock had a higher acid percentage and a lower sugar percentage than those of the same variety on sour-orange stock. Since these results were published, later investigations (*20*) in Florida have shown the reverse to be true. In Australia, Quinn (*31*) has observed that fruit samples from the Washington Navel and the Thompson Navel varieties on sweet-orange rootstock had higher concentrations of sugars and acids than similar fruit produced on Rough-lemon stock. Under California conditions, Hodgson and Eggers (*23*) have reported that fruit samples from Valencia orange, Marsh grapefruit, Bearss lime, and Eureka and Lisbon lemons yielded higher soluble solids and acids when on Trifoliate-orange rootstock than when on sour-orange, sweet-orange, grapefruit, or Rough-lemon rootstock. Fruits from the Rough-lemon stock had, in every instance, the lowest soluble solids and acids. Similarly, Harding *et al.* (*20*), in Florida, found that the concentrations of soluble solids and acids were higher in Valencias grown on sour-orange rootstock than in those grown on Rough lemon.

In a report on rootstock experiments in Argentina, Schultz (*33*) has recorded the total soluble solids, total sugars, and total acids in the juice of several citrus varieties on various rootstocks. The portion of his data that is of particular interest in the present paper is that concerning the comparative amounts of soluble constituents in the juice of several citrus varieties on sour-orange and on Trifoliate-orange stocks. The mean total soluble solids of 10 determinations from seven varieties of citrus on sour-orange stock was 13.38 per cent; the mean total soluble solids for similar determinations from Trifoliate stock was 13.24 per cent. In 8 of the 10 determinations, samples from the Trifoliate stock had lower total soluble solids, in 9 less acid, and in 5 slightly higher amounts of total sugars than those from the sour-orange stock.

All these investigations, therefore, have served to establish the fact that the rootstock does, in some cases, affect the composition of the fruit. Rough-lemon rootstock appears to be an extreme example: most commercial varieties of citrus on Rough lemon yield fruit of low acid content, with, usually, a low sugar concentration and, consequently, a low concentration of total soluble solids in the juice. The characteristic low acid content of fruits from Rough-lemon stock would result in higher ratios of total soluble solids to acids earlier in the season than in fruits from the other stocks.

The present experiments were designed to test these findings for oranges and grapefruit on a large number of rootstocks growing on different soil types and under different climatic conditions in California. The originators of the Station experiment attempted to eliminate as many as possible of the other variable factors inherent in such a problem.

On the samples gathered from these plots, determinations were made not only of total soluble solids, total sugars, and total acids, as in previous investigations, but also of reducing sugars, pH values, and several inorganic constituents.

The work was conducted at Riverside, Tustin, and Brawley, and data were collected from 1936 to 1942.

MATERIALS AND METHODS

Rootstocks and Rootstock Plots.—The trees from which fruits were taken for these studies were Valencia and Washington Navel oranges (*Citrus sinensis* [L.] Osbeck) and Marsh grapefruit (*C. paradisi* Macf.), on various rootstocks and in plots at three locations, as follows: Valencia orange, on 14 different rootstocks at Riverside and at Tustin; Washington Navel orange, on 14 different rootstocks at Riverside; and Marsh grapefruit, on 13 different rootstocks at Riverside and on 11 at Brawley.

The following rootstocks were used in the experiments:

Koethen sweet orange, *Citrus sinensis* (L.) Osbeck
Oroville sweet orange, *C. sinensis* (L.) Osbeck
C.E.S. 362 sweet orange, *C. sinensis* (L.) Osbeck
Rubidoux sour orange, *C. Aurantium* L.
African sour orange, *C. Aurantium* L.
Brazilian sour orange, *C. Aurantium* L.
Duncan grapefruit, *C. paradisi* Macf.
C.E.S. 343 grapefruit, *C. paradisi* Macf.
Tresca grapefruit,[6] *C. grandis* (L.) Osbeck
Siamese shaddock, *C. grandis* (L.) Osbeck
Lemon shaddock, *C. Limon* (L.) Burm. × *C. paradisi* Macf.[7]
Savage citrange, *Poncirus trifoliata* (L.) Raf. ♀ × *C. sinensis* (L.) Osbeck ♂
Morton citrange, *P. trifoliata* (L.) Raf. ♀ × *C. sinensis* (L.) Osbeck ♂
Cleopatra mandarin, *C. reticulata* Blanco
Sampson tangelo, *C. reticulata* Blanco ♂ × *C. paradisi* Macf. ♀
Palestine sweet lime, *C. aurantifolia* (Christm.) Swingle
Rough lemon, *C. Limon* (L.) Burm.
Trifoliate orange, *P. trifoliata* (L.) Raf.

Rootstock plots consisting of 5 trees each were duplicated (giving a total of 10 trees) for each of the rootstocks used for the different citrus varieties in the various localities.

The general plan of the experiment has been described by Batchelor and Webber (*6*):

> Certain precautions have been taken in this experiment to enable us to place reasonable reliance upon the results; these include the use of an adequate number of trees in each rootstock, duplication of plots within each experimental orchard, and duplication of the entire experiment to include two different soil types as well as climatic zones. In consideration of the inherent variability of all soils and plant materials, this simple precaution becomes fundamental to any experiment which is worth while to conduct or worthy of being reported upon.

All the scion buds for any one variety came from a single tree, and the seedlings used as rootstocks were carefully selected, first from the seedbed, and again when the young budded trees were dug from the nursery for orchard planting. The origin of the scions and the manner of selecting the rootstocks have been described in detail by Webber (*39*).

It should be stated here that these were not fertilizer experiments, and no

[6] According to H. J. Webber, the Tresca grapefruit exhibits more of the characteristics of the pummelo than of the grapefruit, and should probably be classed as a pummelo (*Citrus grandis* [L.] Osbeck).

[7] According to H. J. Webber, it is not definitely known whether this parentage is correct for this hybrid.

attempt was made to evaluate the differential fertilizer treatments of the plots. The plots in any one orchard were fertilized alike, but the fertilizer practice in the various experimental orchards differed. As determined by general observation, however, the trees in these plots showed no deficiency symptoms.

Selection of Fruit Samples.—Before fruit samples were picked from the trees, preliminary experiments had to be performed to determine the sampling method. Since the object was to determine the variation in composition of fruit, not from individual trees, but from different rootstocks, the problem was to obtain a representative number of fruits from each of 10 trees on the same kind of rootstock.

The size of the fruit is an important factor in securing representative samples from the trees. Quinn (*31*), among others, drew attention to the fact that

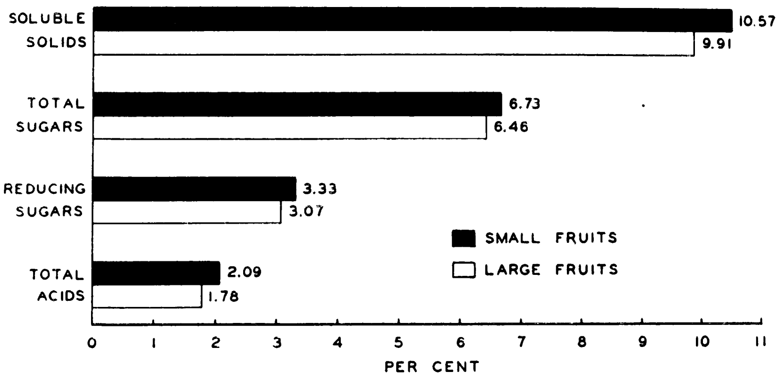

Fig. 1.—Relative concentrations of various soluble constituents in the juice of small and large Valencia-orange fruits.

the concentration of sugar in Navel oranges increased with the decrease in size of the fruit. In an extensive study of the distribution of the soluble solids in citrus juice, Bartholomew and Sinclair (*4*) found that the total soluble solids, total sugars, and reducing sugars, in both Navels and Valencias, increased with a decrease in fruit size. Recently, Harding and Lewis (*21*) have reported on the relation of fruit size to soluble constituents and juice volume in Florida oranges. A brief summary of a portion of the present work with small and large fruits is shown graphically in figure 1, which gives the relative concentrations of total soluble solids, total sugars, reducing sugars, and acids in the juice of small and large Valencia fruits from the same trees. The average diameters of the small and the large fruits tested were $2\frac{1}{16}$ and $2\frac{10}{16}$ inches, respectively. Each sample was composed of 100 fruits—that is, 10 fruits from each of 10 trees. The samples of small fruits contained the greater amounts of soluble constituents. With such a condition existing in the fruits on the tree, representative sampling of the fruit obviously involves a certain amount of difficulty. This is the reason for the special experiments on sampling reported in the present paper.

Six average-sized fruits were accordingly picked, 3 from the north side and 3 from the south side, from each of 10 trees. The sampling was immediately repeated twice in the same way on the same trees, except that first 12 and then 18 fruits were picked per tree. The analyses were made on the day the fruit was picked. The three samples, totaling respectively 60, 120, and 180 fruits, had corresponding total-soluble-solids contents of 13.12, 13.12, and 13.07 per cent, and concentrations of total acidity of 1.31, 1.35, and 1.32 per cent, respectively.

Another experiment was performed to compare the results of a selected sample with those of a random sample on a group of 10 trees. As before, 6 average-sized fruits, 3 from the north side and 3 from the south side of each tree, were picked and subsequently analyzed in the laboratory. A second sampling was made from the same trees by picking 40 fruits per tree, at random. The 400 fruits of this second sampling were mixed as thoroughly as possible, and a blindfolded person picked 100 fruits at random for analysis. The selected sample of 6 fruits per tree gave 12.97 per cent total soluble solids and 1.15 per cent total acidity, the random sample 12.84 per cent soluble solids and 1.14 per cent total acidity.

These results show that the determinations for the selected samples of average-sized fruits agreed satisfactorily with those for the samples picked at random (all sizes). It was therefore decided that 6 average-sized fruits, 3 from the north side and 3 from the south side of each tree, would be sufficient for sampling. For the 10 trees of the duplicate rootstock plots, the sample accordingly consisted of 60 fruits.

Preparation of the Samples for Analyses.—The 60 fruits of each sample were halved, and the juice was extracted from both halves by means of a hand reamer. After the juice had been thoroughly mixed, strained, and centrifuged, aliquot portions were taken for the various organic analyses; and 30 ml of the juice was placed in 100 ml of alcohol (95 per cent), heated to boiling, and set aside for inorganic analyses.

Samples of peel for the inorganic analyses were obtained from 10 fruits taken at random from the 60 fruits picked for each rootstock, as described above. A sector of peel, approximately an inch wide at the center and running from stem to stylar end of the fruit, was taken from each of the 10 fruits. These samples, which weighed from 100 to 150 grams, were placed in an oven at 100° C for 1 hour to inactivate the enzymes; they were then placed in a vacuum oven at 55° for further drying, the loss in weight being ascertained as moisture. The dried peel was ground in a Wiley mill to a sufficient fineness for passage through a 2-mm opening, and known portions of this material were used for the analyses.

The same fruits from which the peel was taken served as sources of the pulp samples used for the inorganic analyses. One segment was selected from each fruit, and the two end thirds were taken as representative samples for inorganic analysis. The weighed pulp samples were placed in 500-ml Erlenmeyer flasks with 250 ml of 95 per cent ethyl alcohol, and were boiled for 10 minutes. The samples were then set aside to await a convenient time for ashing and analyzing the material for the various inorganic constituents.

Chemical Methods.—Total soluble solids were determined with an Abbé refractometer. Total acidity, expressed as citric acid, was determined by titrating an aliquot portion of the juice with a standard solution of NaOH, with phenolphthalein as an indicator. The pH values were determined with a Beckman glass-electrode pH meter.

The sugar determinations were made by the Hagedorn and Jensen (*17, 18*) method as modified by Blish (*8, 9*). The strength of the reagents employed by Blish was satisfactory for determining the reducing and total sugars as glucose, when the values ranged from 3 mg to 10 mg in 10 ml of citrus juice. When necessary, the samples were diluted so that the values fell within this range. This method was used because comparative tests showed that it was more rapid than the best of the copper-reduction methods, and that it gave comparable results for the quantity of sugar in the sample. The glucose factor of the reagents was determined with a sample furnished by the National Bureau of Standards.

The juice to be ashed was evaporated to dryness and charred in an open crucible, transferred to an ignition boat with dilute HCl, and dried in an oven at 95° C. The material was then ashed and brought to constant weight, at 450°, in a combustion tube through which a slow stream of oxygen was passed. Each weighed ash sample was dissolved in water containing HCl, and was stored until the analyses could be made. The pulp was similarly dried, ashed, weighed, dissolved, and stored. The peel was dried in a vacuum oven at 55° before ashing; subsequent treatment was the same as for pulp and juice.

Each sample was filtered immediately before analysis, and any appreciable residue was reburned and dissolved in 3 to 4 drops of concentrated HCl and about 15 ml of water. The solution was then filtered, the two filtrates were combined, and the solution was made to 100 ml in a volumetric flask. Aliquot portions were then removed to be analyzed for calcium, magnesium, sodium, potassium, sulfate, and phosphate.

Calcium was determined volumetrically by treating the oxalate with dilute H_2SO_4 and subsequently titrating the liberated oxalic acid with standard potassium permanganate. The magnesium was precipitated as magnesium ammonium phosphate and weighed as the pyrophosphate. Sodium was determined gravimetrically by the method of Barber and Kolthoff (*2*), and the potassium was determined gravimetrically according to the method described by Wilcox (*41*). The sulfate ion was determined by the barium chromate method of Foster (*13*). Phosphate was determined by the method of Truog and Meyer (*36*), as improved by Dyer and Wrenshall (*11*) and Smith *et al.* (*35*). The color comparisons were made with a photoelectric colorimeter.

CHANGES IN CONCENTRATION OF SOLUBLE CONSTITUENTS OF FRUIT DURING GROWTH AND MATURATION

It has long been known that the total soluble solids, total sugars, and reducing sugars increase, and that the total acids decrease, during fruit maturation. In order to determine whether there were differences in the rate of maturation of fruits on the different rootstocks or grown in different localities, Valencia and Washington Navel oranges were sampled at intervals during the growing season, and the concentration of various soluble constituents in the juice was determined.

Experiments on Valencia Oranges.—During the season of 1939, samples of fruit were taken from the Valencia trees in the rootstock plots at Riverside, on

January 12, February 27, March 28, and May 9; and from corresponding plots at Tustin, on January 16, March 1, March 29, and May 12. These paired samples of fruit from the two localities were picked as nearly as possible on

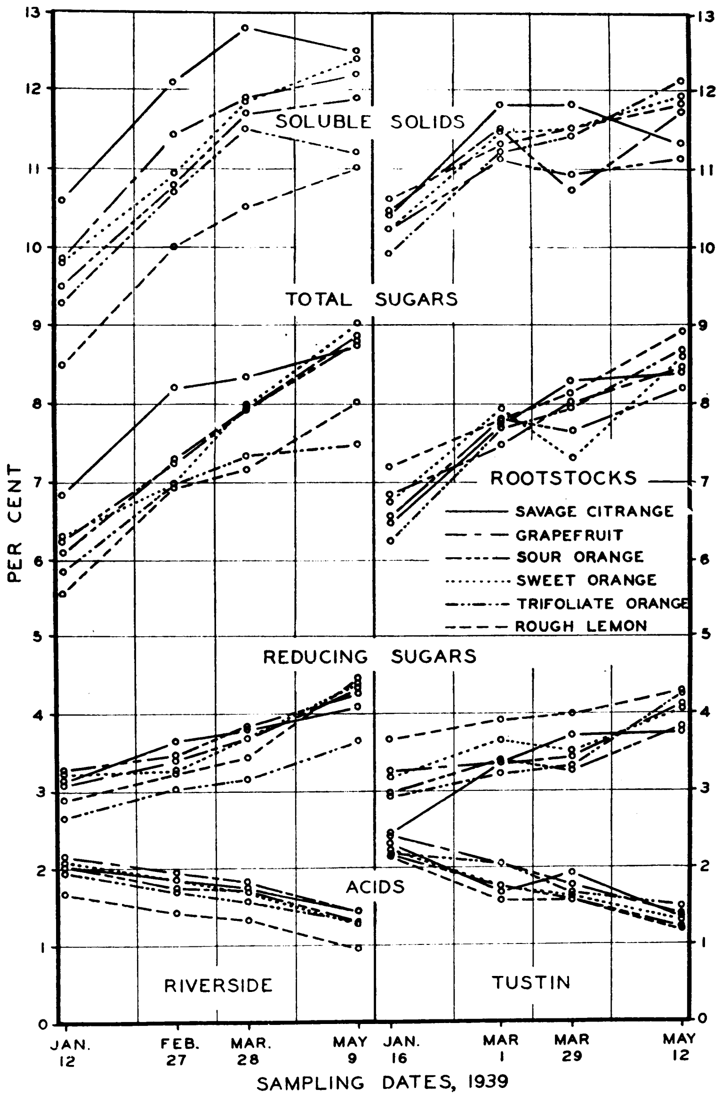

Fig. 2.—Changes in concentrations of different soluble organic constituents in juice of Valencia oranges, during maturation of the fruit. Samples were taken at intervals from Valencia trees budded on different stocks and grown in plots at Riverside and Tustin.

the same date, in order to make them comparable. Although the samples from one locality had to be analyzed before the corresponding samples from the other locality could be picked, the greatest difference between picking dates of any two paired samples was 4 days.

The results of this study are shown graphically in figure 2. The values reported are those for total soluble solids, total sugars, reducing sugars, and total acids (as citric) in the juice of Valencia samples from both Riverside and Tustin plots. The plots in these two districts consisted of Valencia orange on 14 different rootstocks. The differences between samples from some of the rootstocks were not sufficiently large, however, to permit plotting the data for all the rootstocks in the same graph. The data for Savage citrange, Trifoliate orange, and Rough lemon are plotted individually. The curves labeled "grapefruit" and "sweet orange" represent the mean values for two kinds of rootstock each; those labeled "sour orange" represent three kinds.

Although there are some striking differences in the effects of the various stocks, the close grouping of the curves demonstrates the relatively uniform rate of change in the various soluble constituents during this period. The two notable exceptions are Savage citrange and Rough lemon. In samples from the Riverside plots, Savage citrange had the highest percentages of soluble solids and total sugars in the juice prior to the last sampling; Rough lemon, on the other hand, had the lowest percentages of soluble solids and acids during the entire sampling period. In samples from the Tustin plots, Savage citrange had a tendency to have the highest percentages of soluble solids in the juice, but samples from Rough lemon did not yield the lowest percentages of soluble solids. During the period in which these samples were taken, the concentration of acid in the Rough-lemon samples was slightly lower than that of the other stocks at both Riverside and Tustin.

Heavy applications of water to the soil, by irrigation or rain, during the growing season, temporarily reduced the concentration of soluble constituents in Valencia fruits. For example, when heavy rains occurred between the January and February sampling dates, the later samples often had less soluble solids in the juice than the earlier samples. Apparently, this temporary reduction in soluble constituents does not retard the time required for the fruit to reach maturity, for with subsequent increase in daily temperatures during the remainder of the season, the rate of formation of the sugars was greatly accelerated.

It was unfortunate that sampling of these plots was not continued from May through July. The final samples of this series, collected in May, showed that, although the fruit from most of the stocks was up to, or slightly beyond, the legal maturity requirement of eight to one,[8] the fruit would undergo further change and increase in various soluble constituents during the season. The ratio of soluble solids to acids in the juice of fruit samples collected in May from the Riverside stocks ranged from 8.36 to 9.98, with the exceptions of fruit samples from Rough lemon, which had a much higher ratio (11.49), and from Sampson tangelo, which had a much lower ratio (7.38). In corresponding samples from Tustin, the ratio of soluble solids to acids ranged from 8.00 to 9.68, with the exceptions of Rough lemon, which was higher (9.89), and lemon shaddock, which was lower (7.58).

In figure 2 it is difficult to observe the relation of the fruit samples from the Riverside and Tustin areas on the final date of sampling. This relation is clearly shown in table 1 by the ratios of various soluble constituents in the

[8] The ratio of soluble solids to acids (8:1) required in the juice of oranges marketed in California.

final samples from Riverside to the corresponding values of those from Tustin. Thus in Savage citrange, grapefruit, and sour and sweet oranges, the Riverside fruit had the higher percentage of soluble solids on the final sampling, and in Trifoliate orange and Rough lemon the Tustin fruit had the higher. These ratios (table 1) reveal that when the sampling was terminated, in May, the Riverside fruit was, in general, slightly more mature than the Tustin fruit. As shown elsewhere in this paper (see fig. 4), fruit samples collected in July, 1936, 1937, and 1938, showed the fruit from Riverside to contain a higher concentration of soluble constituents than that from Tustin. No doubt the 1939 results would have shown this difference if additional samples of fruit had been taken through July.

TABLE 1

RATIOS (RIVERSIDE TO TUSTIN) OF VARIOUS SOLUBLE CONSTITUENTS IN JUICE OF VALENCIA FRUIT SAMPLES COLLECTED FROM ROOTSTOCK PLOTS AT RIVERSIDE AND AT TUSTIN MAY 9 AND 12, 1939, RESPECTIVELY

Rootstock	Ratio (Riverside to Tustin) of:			
	Total soluble solids	Total sugars	Reducing sugars	Acids (titratable acidity)
Savage citrange	1.106	1.04	0.92	1.04
Grapefruit	1.044	1.06	1.06	1.07
Sour orange	1.064	1.07	1.12	1.07
Sweet orange	1.042	1.05	1.09	0.99
Trifoliate orange	0.927	0.86	0.86	0.86
Rough lemon	0.937	0.90	1.04	0.81

Experiments on Washington Navel Oranges.—The procedure for sampling the fruit for analysis from the Navel-orange rootstock plots in Riverside was similar to that used in the Valencia experiments, except that, since the Navel variety matures during the winter, the sampling was begun early in the fall. Six samples of fruit were taken from the plots at approximately monthly intervals during the growing and maturation season of 1941–42. The sampling began on September 29, 1941, and ended on March 2, 1942. As the Navel plots were located only in Riverside, comparisons of the changes in the soluble constituents in the juice of the fruits could not be made with similar samples obtained from another district. In these plots, Morton citrange replaced lemon shaddock; otherwise, the varieties of rootstocks used were the same as in the Valencia plots. The results of this study are shown graphically in figure 3.

The important differences in fruit samples from the Navel rootstock plots are similar to those in samples from the Valencia plots. Fruit samples from Morton citrange in these experiments, like those from Savage citrange in the Valencia experiments, had the highest concentration of soluble solids and total sugars. Fruit samples from the Navel variety on Rough-lemon stock had the lowest concentration of soluble solids and total acids. Aside from these major differences, the various soluble constituents in fruit samples from the different stocks changed at about the same uniform rate during the season.

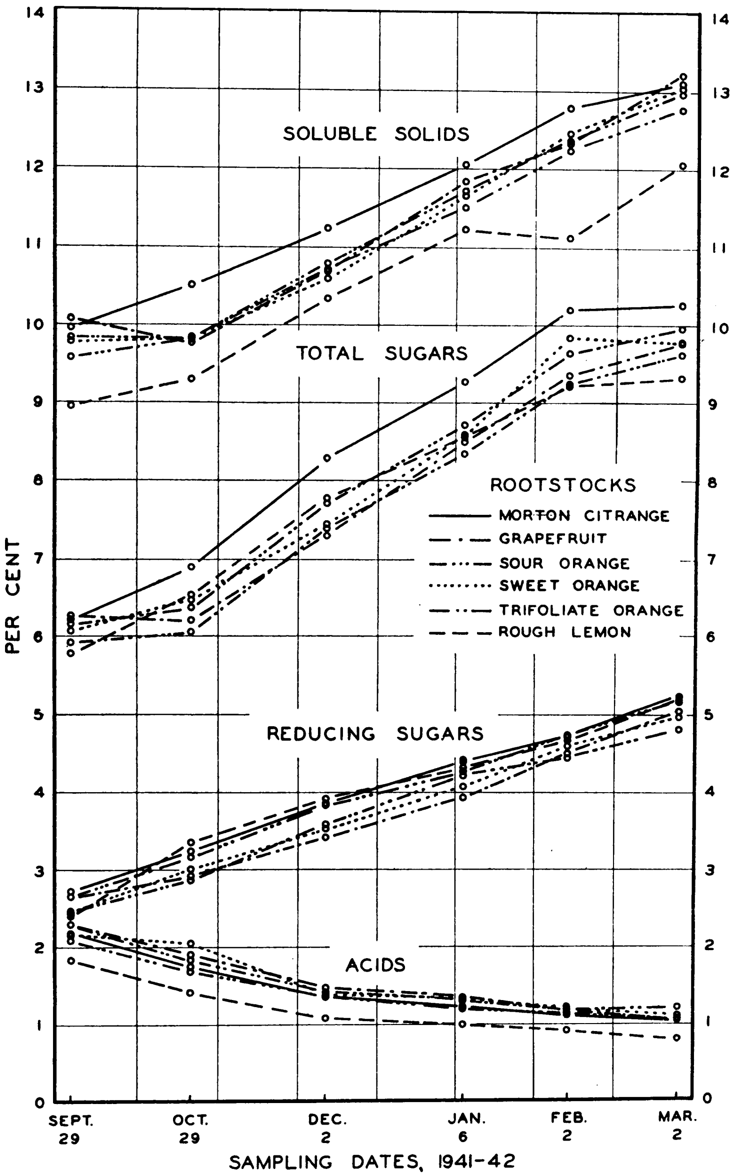

Fig. 3.—Changes in concentrations of different soluble organic constituents in juice of Washington Navel oranges, during maturation of the fruit. Samples were taken at intervals from Navel trees budded on different stocks and grown in plots at Riverside only, instead of in two localities, as with the Valencias.

The ratios of soluble solids to acids in the juice of the final samples from the various plots ranged from 11.52 to 12.93, with the exception of fruit samples from Rough lemon, which had a higher ratio (15.08), and Trifoliate orange, which had a lower (10.56).

EFFECT OF ENVIRONMENTAL FACTORS AND ROOTSTOCK ON THE SOLUBLE CONSTITUENTS IN THE JUICE

Citrus fruits have been shown to differ in composition not only with variety but also with the locality in which they are grown and with seasonal changes which affect the rate of the ripening processes. These environmental factors account for much of the difference in chemical composition within a given variety. The kind of rootstock also affects the chemical composition of the fruit within a given variety.

In these particular experiments, the Valencia fruit samples from the different rootstocks in the two localities were picked as nearly as possible on the same date. As the Navel-orange plots were in only one locality, the environmental study of Navels was limited to yearly and seasonal changes within these plots. An attempt was made to pick the grapefruit in the two localities so that they would be at approximately the same stage of maturity, but subsequent chemical analyses showed that this effort was not entirely successful.

TABLE 2

TYPES OF SOIL AND CLIMATIC CONDITIONS AT THE VARIOUS ROOTSTOCK-PLOT LOCATIONS*

Location of rootstock plots	Soil	Temperature, degrees Fahrenheit				Killing frost		Average length of growing season, days	Average annual precipitation, inches
		January average	July average	Maximum	Minimum	Spring (average of latest dates)	Fall (average of earliest dates)		
Riverside	Ramona series	52.0	75.6	118	21	Mar. 6	Nov. 26	265	11.53
Tustin	Yolo series	52.9	71.7	111	18	Feb. 7	Dec. 7	303	12.65
Brawley	Holtville series	52.7	91.1	121	19	Feb. 5	Dec. 5	303	2.43

* Climatic data based on continuous records for twenty-eight years or longer.

Soil and Climatic Factors.—The types of soil and some of the climatic factors which may have influenced the results obtained in the rootstock tests are shown in table 2. In general, the soil type in a given grove was uniform, possibly a little lighter or heavier in some parts than in others. The climatological data were taken from a publication of the United States Department of Agriculture (*26*), and they are for a continuous period of twenty-eight years, or longer, ending with the year 1938. As may be seen from table 2, there was considerably more difference in the summer temperatures of the three localities than in the winter temperatures. The comparatively small amounts of rainfall make it clear that irrigation is necessary for citrus culture in these localities.

But the mean temperatures (table 2) do not reveal the real differences in climate in the three locations. The mean temperature at Tustin, in January, is only 0.2° F higher than that at Brawley, and the average length of the growing season is the same, but the rates at which citrus fruits grow and mature in the two districts are markedly different. What appears to be a reasonable explanation for these differences is brought out by Webber (*40*) in his calculations on the available heat index for the annual growing season. The index

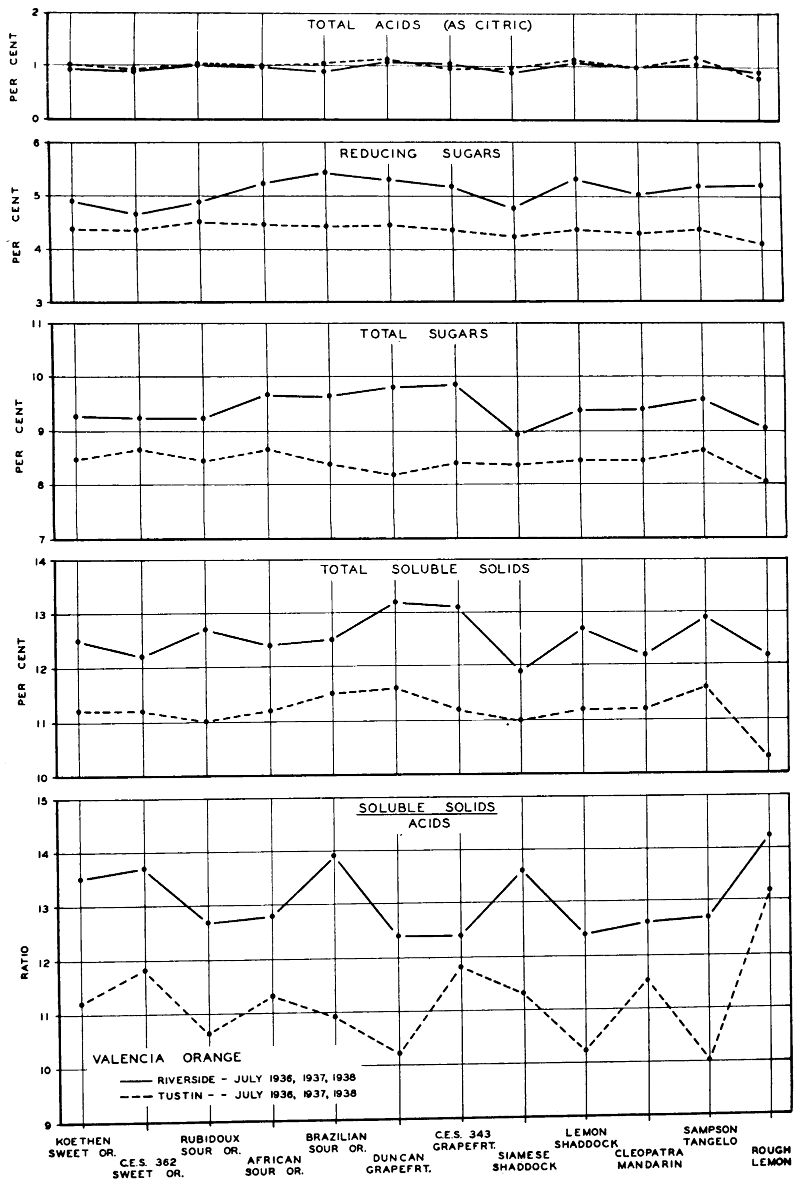

Fig. 4.—Relative concentrations of certain soluble organic constituents in the juice of mature fruits from Valencia-orange trees budded on different stocks and grown in plots at Riverside and Tustin. Fruit samples were taken from both locations in July, on three consecutive years. The value recorded for each stock is the mean value for the three years.

of total available heat for the month is calculated by subtracting 55°, which Webber calls the vital temperature for growth of citrus, from the mean daily temperature for the month, and multiplying the difference by the number of days in each month. The summation of these values for each month from

March to November, inclusive, gives the total available heat units for the growing season. These values for Riverside (Riverside County), Tustin (Orange County), and Brawley (Imperial County) are given as 3,209, 2,728, and 6,078 degree-days, respectively. Such differences in total available heat units are directly related to the rate of the biochemical reactions occurring in the fruit during growth and ripening. From this it would appear that, given the requisite amount of water, the total available heat units, along with the implied comparable amount of sunshine, are more important in determining the growth rate and time of ripening of citrus fruits than are any of the other factors, such as soil type and rootstock.

Experiments on the Juice of Valencia Fruits from Different Rootstocks.— Samples of Valencia fruits for analysis were taken from the plots at Riverside and Tustin in July of three successive years: in 1936, they were collected on July 7 and 10, respectively; in 1937, on July 14 and 27; and in 1938, on July 6 and 12—all within a range of 3 weeks. In 1942, determinations were also made on samples collected on July 27, from the Riverside plot only; and on samples collected on September 15 and 22, from the Riverside and Tustin plots, respectively. The results of analyses for 1936, 1937, and 1938 are shown in figure 4 as the means of the values for the three years. The concentration of total acids was practically the same in the juice of fruit samples from the different stocks, with the exception of Rough lemon, for which the samples from both Riverside and Tustin showed low acid content. Reducing sugars in samples from the Riverside plots were highest in the Brazilian sour orange and lowest in C.E.S. 362 sweet orange; they were almost as low in the Siamese shaddock. The corresponding values from the Tustin plots are more uniform. There the reducing sugars were lowest in the samples from Rough lemon. The total sugars for the Riverside samples were highest in C.E.S. 343 grapefruit and lowest in Siamese shaddock, with Rough lemon a close second; and for the Tustin samples, they were highest in African sour orange and lowest in Rough lemon, with Duncan grapefruit a close second. In total soluble solids, Duncan grapefruit was highest and Siamese shaddock lowest for Riverside; and Duncan grapefruit highest and Rough lemon lowest for Tustin. Unfortunately, at the time the data for figure 4 were obtained, Savage citrange and Trifoliate orange were not included.

The ratio of soluble solids to acids requires only a brief comment. Although, for commercial purposes, this ratio serves in part as an index to maturity, it has little if any physiological significance. The ratio is easily affected by very small changes in the acid concentration in the juice. For example, although samples from Rough lemon, grown at both Riverside and Tustin, had only slightly lower acid content than samples from the other rootstocks, the difference was sufficient to cause unduly high ratios.

The effect of annual environmental factors on the soluble constituents in the juice is clearly demonstrated in table 3, which gives the comparative analyses of fruit samples from the two districts for the years previously noted. The notable differences in these data are the greater concentrations of soluble solids, total sugars, and reducing sugars in the samples from the Riverside plots. The concentration of acids was, on the average, lower in these samples. In addition to seasonal differences in the fruits from a given locality, these

TABLE 3

CONCENTRATION OF SOLUBLE CONSTITUENTS IN THE JUICE OF VALENCIA ORANGES PICKED FROM RIVERSIDE AND TUSTIN PLOTS IN 1936 TO 1938 AND 1942

Rootstock	Riverside					Tustin			
	July, 1936	July, 1937	July, 1938	July, 1942	September, 1942	July, 1936	July, 1937	July, 1938	September, 1942
	Total soluble solids, per cent								
Koethen sweet orange	12.0	12.9	12.5	13.5	14.0	10.5	11.4	11.8	13.0
C.E.S. 362 sweet orange	11.5	12.6	12.4	13.2	13.8	10.3	11.6	11.6	12.9
Rubidoux sour orange	12.0	12.7	13.3	13.3	14.0	9.5	11.6	12.0	12.1
African sour orange	12.0	12.6	12.6	13.5	14.2	10.5	11.7	11.3	12.3
Brazilian sour orange	11.5	12.9	13.1	13.1	13.8	11.8	10.9	11.8	12.1
Duncan grapefruit	12.5	13.5	13.6	14.0	14.5	11.0	11.4	12.3	....
C.E.S. 343 grapefruit	12.5	13.5	13.2	13.4	14.0	10.5	11.8	11.3	11.9
Siamese shaddock	12.0	11.7	12.0	13.1	13.8	10.5	11.2	11.2	....
Lemon shaddock	12.5	13.5	12.9	13.8	15.0	10.8	11.5	11.4	....
Savage citrange	....	....	13.3	13.6	14.2	....	....	12.8	13.3
Cleopatra mandarin	12.0	12.1	12.6	13.8	14.4	10.5	11.4	11.6	12.4
Sampson tangelo	12.5	13.0	13.1	13.1	14.0	10.5	12.3	11.9	12.8
Rough lemon	12.5	11.6	12.5	12.1	12.5	10.0	10.3	10.6	10.8
Trifoliate orange	....	....	12.4	12.5	13.0	....	....	12.3	12.9
Mean	12.1	12.7	12.8	13.3	13.9	10.5	11.4	11.7	12.4
	Total sugars, per cent								
Koethen sweet orange	7.75	10.06	10.03	10.56	10.68	7.15	8.91	9.34	9.72
C.E.S. 362 sweet orange	7.72	10.00	9.98	10.49	10.19	7.21	9.36	9.34	10.05
Rubidoux sour orange	7.32	9.85	10.48	10.18	10.82	6.88	9.06	9.34	8.88
African sour orange	9.10	9.93	9.92	10.32	10.86	8.02	8.98	8.90	8.87
Brazilian sour orange	8.67	10.06	10.18	10.31	10.40	7.25	8.49	9.41	8.88
Duncan grapefruit	8.73	10.11	10.54	10.23	10.67	7.89	8.76	9.62	....
C.E.S. 343 grapefruit	8.70	10.49	10.33	10.48	10.90	7.14	9.20	8.83	8.81
Siamese shaddock	7.87	9.43	9.40	10.19	10.54	7.27	8.69	9.06	....
Lemon shaddock	7.97	10.49	9.60	10.31	10.56	7.45	8.76	9.05	....
Savage citrange	....	.....	10.21	9.57	10.70	....	....	10.05	10.03
Cleopatra mandarin	8.37	9.64	10.13	10.39	11.03	7.02	8.84	9.38	9.24
Sampson tangelo	8.34	10.06	10.26	9.74	10.45	6.89	9.56	9.33	9.86
Rough lemon	7.93	9.21	9.91	9.33	9.49	7.16	8.19	8.77	8.77
Trifoliate orange	....	.....	9.62	9.46	9.95	....	....	9.69	9.60
Mean	8.21	9.94	10.04	10.11	10.52	7.28	8.90	9.29	9.34
	Reducing sugars, per cent								
Koethen sweet orange	4.39	5.33	4.95	5.69	5.67	4.09	4.30	4.69	5.25
C.E.S. 362 sweet orange	4.17	5.00	4.79	5.47	5.77	4.15	4.30	4.61	5.40
Rubidoux sour orange	4.15	5.05	5.42	5.54	5.91	4.43	4.30	4.74	4.85
African sour orange	5.17	5.19	5.26	5.46	5.89	4.63	4.22	4.45	5.04
Brazilian sour orange	5.18	5.25	5.80	5.55	5.69	4.49	3.93	4.78	5.04
Duncan grapefruit	5.09	5.35	5.42	5.60	6.04	4.56	4.00	4.77	....
C.E.S. 343 grapefruit	4.73	5.24	5.47	5.39	5.71	4.30	4.22	4.44	4.65
Siamese shaddock	4.59	4.78	4.89	5.25	5.77	4.26	4.08	4.27	....
Lemon shaddock	5.23	5.47	5.21	5.90	6.38	4.37	4.23	4.53	....
Savage citrange	....	....	5.16	5.50	5.59	....	....	4.95	5.47
Cleopatra mandarin	4.81	4.94	5.22	5.75	6.11	4.07	4.23	4.55	4.77
Sampson tangelo	4.55	5.40	5.54	5.36	5.79	3.96	4.40	4.65	5.14
Rough lemon	5.20	4.94	5.34	4.88	5.11	3.84	3.79	4.65	4.69
Trifoliate orange	....	....	4.84	5.07	5.25	....	....	4.61	4.72
Mean	4.77	5.16	5.24	5.46	5.76	4.26	4.17	4.62	5.00

TABLE 3—(*Continued*)

Rootstock	Riverside					Tustin			
	July, 1936	July, 1937	July, 1938	July, 1942	September, 1942	July, 1936	July, 1937	July, 1938	September, 1942
	Acids (titratable acidity), per cent								
Koethen sweet orange....	0.90	0.96	0.90	0.85	0.70	1.05	0.97	1.01	1.00
C.E.S. 362 sweet orange..	0.85	0.94	0.88	0.83	0.73	0.91	0.90	1.05	1.05
Rubidoux sour orange....	0.97	1.03	1.00	0.80	0.71	1.01	1.00	1.12	0.98
African sour orange......	1.03	0.97	0.91	0.80	0.76	1.00	0.94	1.03	0.98
Brazilian sour orange.....	0.76	0.98	0.97	0.85	0.76	1.05	1.00	1.11	0.96
Duncan grapefruit.......	0.97	1.13	1.09	0.96	0.82	1.12	1.11	1.17	....
C.E.S. 343 grapefruit.....	1.04	1.08	1.04	0.87	0.76	0.92	0.96	0.97	0.98
Siamese shaddock........	0.95	0.85	0.83	0.81	0.75	1.04	0.96	0.92	....
Lemon shaddock.........	0.98	1.08	1.08	0.95	0.81	1.17	1.11	1.05	....
Savage citrange..........	....	....	1.06	0.94	0.76	....	....	1.21	1.13
Cleopatra mandarin......	0.99	0.93	0.99	0.86	0.73	1.00	0.94	0.99	0.98
Sampson tangelo.........	1.03	0.98	1.04	0.95	0.73	1.22	1.12	1.15	1.11
Rough lemon.............	0.94	0.78	0.86	0.62	0.58	0.76	0.77	0.82	0.80
Trifoliate orange.........	....	....	0.88	0.87	0.76	....	....	1.02	1.03
Mean..................	0.95	0.98	0.97	0.85	0.74	1.02	0.98	1.04	1.00

data show that the Valencia fruits from the stocks in the inland district (Riverside) accumulated more soluble constituents during the season than the corresponding fruits from the coastal district (Tustin). The relative differences persisted to the end of the season, as shown by the determinations made on fruit samples picked in September, 1942 (table 3).

Experiments on the Juice of Washington Navel Fruits from Different Rootstocks.—Mature fruit samples for analysis were taken from the Navel-orange plots in Riverside on January 10 and 24, 1939, and again on February 13, 1940. As may be seen in figure 5, the various soluble constituents changed relatively little between January 10 and January 24, 1939. The closeness of these two sets of curves also shows the reproducibility of the results when fruit samples were taken twice within this period.

An inspection of the curves for samples that were collected on February 13, 1940, shows that the fruit of this sampling was much more mature than that of the last sampling made the preceding year (January 24, 1939) : the concentration of acids was much lower, and the total soluble solids much higher, with consequent higher ratios of soluble solids to acids in samples from all the rootstocks. Furthermore, in samples from every rootstock, the total and reducing sugars were much higher in fruit samples gathered in 1940. Although the 1940 samples of fruit were gathered 3 weeks later than the last sampling made in 1939, it is probable that the differences in the analyses were due more to annual variations in climate than to delay in sampling in 1940. In fruit samples collected from the same trees on February 2, 1942, the level of concentration of the various soluble constituents in the juice fell between the values obtained on January 24, 1939, and those obtained on February 13, 1940. The results of these experiments give an opportunity to compare yearly and seasonal variations of fruits from Washington Navel orange on the different stocks.

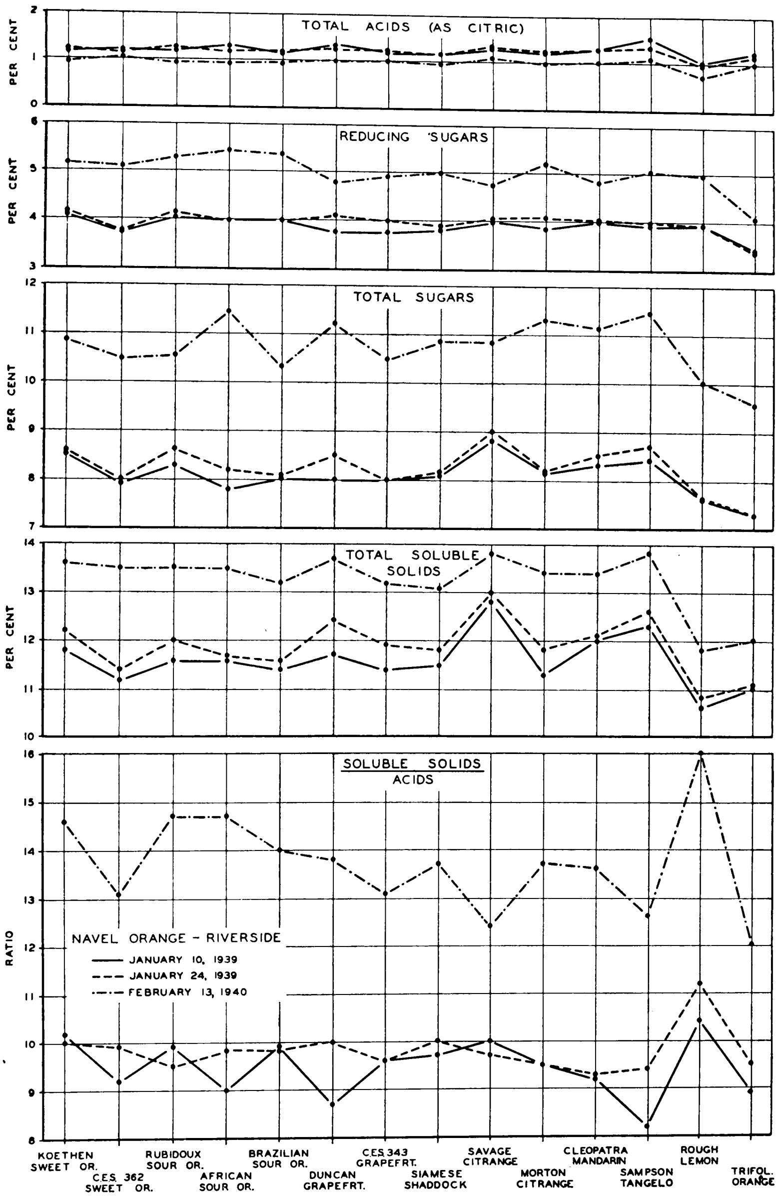

Fig. 5.—Relative concentrations of certain soluble organic constituents in the juice of mature fruits from Washington-Navel-orange trees budded on different stocks and grown in plots at Riverside. Values recorded are those of two fruit samples gathered in January, 1939, and one sample gathered in February, 1940.

Experiments on the Juice of Grapefruit from Different Rootstocks.—Samples of grapefruit for analysis were taken from the plots at Riverside on May 19, 1938, and again on May 16, 1940. Similar samples were taken from the corresponding plots at Brawley on November 8, in both 1938 and 1939. At

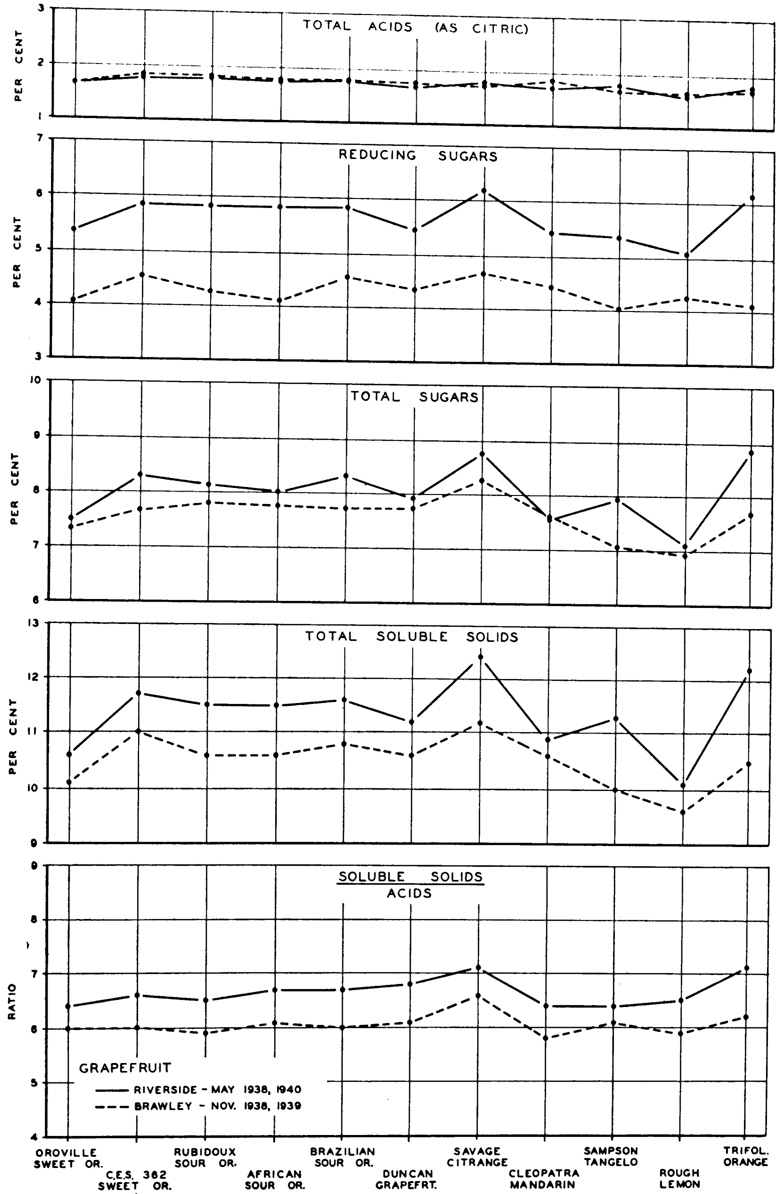

Fig. 6.—Relative concentrations of certain soluble organic constituents in the juice of mature fruits from grapefruit trees budded on different stocks and grown in plots at Riverside and Brawley. The mean value for two years' results is recorded for each stock.

Riverside the grapefruit tree sets its fruit about April 15, and at Brawley about April 1. The grapefruits from Riverside had therefore been on the trees for about 13 months, those from Brawley, only about 7 months. The Riverside fruit had higher concentrations of the various soluble constituents in the juice and was more mature than the Brawley fruit (fig. 6).

TABLE 4

PERCENTAGES OF TOTAL SOLUBLE SOLIDS, TOTAL ACIDS, TOTAL SUGARS, AND REDUCING SUGARS IN JUICE OF MARSH GRAPEFRUIT FROM ROOTSTOCK PLOTS AT RIVERSIDE AND BRAWLEY, ON VARIOUS SAMPLING DATES

Rootstock	Riverside									
	May 19, 1938					May 16, 1940				
	Total soluble solids, per cent	Total acids, per cent	Total sugars, per cent	Reducing sugars		Total soluble solids, per cent	Total acids, per cent	Total sugars, per cent	Reducing sugars	
				Per cent of fresh weight	Per cent of total sugars				Per cent of fresh weight	Per cent of total sugars
Oroville sweet orange	10.7	1.83	7.49	5.08	67.8	10.5	1.50	7.50	5.64	75.2
C.E.S. 362 sweet orange	11.3	1.89	8.15	5.40	66.3	12.0	1.67	8.43	6.32	75.0
Rubidoux sour orange	11.7	1.94	8.43	5.57	66.1	11.2	1.61	7.82	6.12	78.3
African sour orange	11.1	1.89	7.80	5.43	69.6	11.9	1.62	8.21	6.25	76.1
Brazilian sour orange	11.2	1.87	8.18	5.33	65.2	12.0	1.63	8.43	6.36	75.4
Duncan grapefruit	11.0	1.76	7.88	5.43	68.9	11.4	1.57	8.00	5.47	68.4
Tresca grapefruit	10.4	1.80	7.57	5.12	67.6	10.5	1.61	7.65	5.44	71.1
Savage citrange	12.0	1.88	8.50	5.74	67.5	12.8	1.65	9.00	6.62	73.6
Cleopatra mandarin	10.5	1.83	7.49	5.05	67.4	11.2	1.57	7.85	5.78	73.6
Sampson tangelo	11.1	1.89	7.70	5.01	65.1	11.5	1.66	8.14	5.73	70.4
Palestine sweet lime	9.2	1.54	6.54	4.56	69.7	9.2	1.37	6.24	5.02	80.4
Rough lemon	9.8	1.65	7.05	4.79	67.9	10.4	1.50	7.12	5.30	74.4
Trifoliate orange	11.9	1.87	8.73	5.87	67.2	12.5	1.63	8.92	6.38	71.5
Mean	10.9	1.82	7.81	5.26	67.4	11.3	1.58	7.95	5.88	74.1

Rootstock	Brawley									
	November 8, 1938					November 8, 1939				
	Total soluble solids, per cent	Total acids, per cent	Total sugars, per cent	Reducing sugars		Total soluble solids, per cent	Total acids, per cent	Total sugars, per cent	Reducing sugars	
				Per cent of fresh weight	Per cent of total sugars				Per cent of fresh weight	Per cent of total sugars
Oroville sweet orange	10.6	1.70	7.80	4.23	54.2	9.5	1.65	6.84	3.91	57.2
C.E.S. 362 sweet orange	11.6	1.79	8.37	4.76	56.9	10.3	1.89	6.97	4.32	62.0
Rubidoux sour orange	11.1	1.74	8.08	4.56	56.4	10.0	1.87	7.51	3.98	53.0
African sour orange	11.0	1.74	8.16	4.02	49.3	10.2	1.74	7.35	4.17	56.7
Brazilian sour orange	11.2	1.83	8.00	4.59	57.4	10.3	1.73	7.43	4.52	60.8
Duncan grapefruit	11.2	1.83	8.46	4.68	55.3	10.0	1.67	6.98	4.02	57.6
Tresca grapefruit	....	....	....	....	....	....	....	....	....	....
Savage citrange	12.0	1.76	8.88	4.82	54.3	10.3	1.67	7.65	4.47	58.4
Cleopatra mandarin	11.4	1.85	8.08	4.63	57.3	9.8	1.82	7.14	4.18	58.5
Sampson tangelo	10.5	1.68	7.57	4.13	54.6	9.4	1.62	6.54	3.92	59.9
Palestine sweet lime	....	....	....	....	....	....	....	....	....	....
Rough lemon	9.8	1.66	7.17	4.43	61.8	9.4	1.62	6.69	4.05	60.5
Trifoliate orange	11.4	1.81	8.23	4.23	51.4	9.5	1.55	7.15	3.95	55.2
Mean	11.1	1.76	8.07	4.46	55.4	9.9	1.71	7.11	4.14	58.2

The greater maturity of the Riverside fruit can be demonstrated in a different way by the data shown in table 4. This involves the application of some interesting experimental results of Hilgeman and Smith (*22*), who showed that the sucrose in Arizona grapefruit gradually hydrolizes to invert sugars during the late winter and spring. These investigators found that the fruits containing the lower ratios of invert sugars to total sugars, in the juice, remained attached to the tree longer than the other fruits without softening, and that they deteriorated less under storage conditions. As shown in table 4, in both years the invert sugars formed a higher percentage of the total sugars in the samples from Riverside (67.4 per cent in 1938 and 74.1 per cent in 1940) than in those from Brawley (55.4 per cent in 1938 and 58.2 per cent in 1939).

Of the Riverside samples, those from Palestine-sweet-lime stock had the lowest concentration of total soluble solids, total sugars, and reducing sugars; those from Rough-lemon stock next to the lowest. Samples from Oroville-

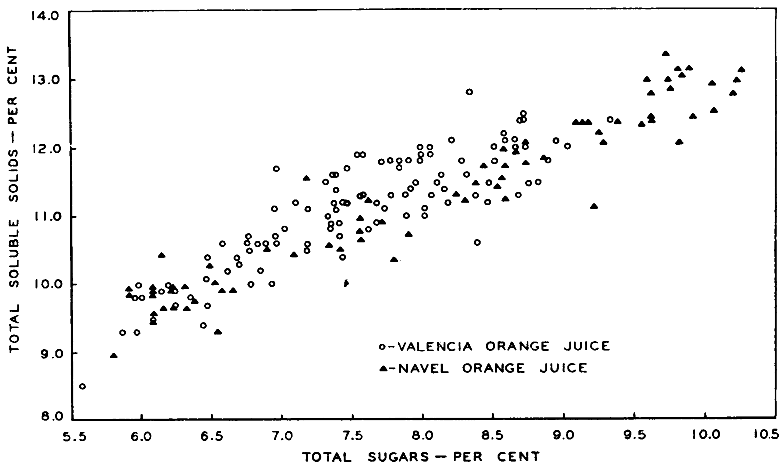

Fig. 7.—Scatter diagram showing the relation of total soluble solids to total sugars in juice of Valencia and Washington Navel oranges. Fruit maturity ranged from immature (green) to mature (Valencias picked January 14 to July 13, 1939; Navels, September 29, 1941, to March 2, 1942).

sweet-orange and Tresca-grapefruit stocks were also low in soluble constituents. Savage-citrange stock yielded fruit with the highest percentage of soluble constituents, while Trifoliate orange yielded fruit with only slightly less.

Samplings from the Brawley plots showed that Rough-lemon stock yielded the lowest percentage of total soluble solids for both years, and Savage citrange the highest. Tresca-grapefruit and Palestine-sweet-lime stocks were not planted in the Brawley plots.

RELATION OF TOTAL SOLUBLE SOLIDS TO TOTAL SUGARS IN CITRUS JUICES

The total sugars represent the major portion of the soluble solids in the juice of oranges and grapefruit. Hence changes in total soluble solids of the juice, as determined by the refractometer, should be associated with corresponding changes in the total sugars. The large number of determinations made on the juice of Valencia-orange and Washington-Navel-orange fruits from the different rootstocks furnish sufficient data to illustrate important and worth-while relations between these constituents.

In figure 7 the percentages of total soluble solids are plotted against percentages of total sugars of different samples of juice of Valencia and Washington Navel oranges. The wide variation shown in concentration of total sugars represents the differences occurring in fruits ranging from immature to fully mature. It is evident that, within this range of fruit development, the increase in total sugars parallels that of total soluble solids. The total sugars represented, on the average, from 63 to nearly 80 per cent of the total soluble

TABLE 5

RELATION BETWEEN TOTAL SOLUBLE SOLIDS AND TOTAL SUGARS IN MATURE ORANGES AND GRAPEFRUIT FROM THE VARIOUS ROOTSTOCK PLOTS

Rootstock	Soluble solids and sugars, Washington Navel oranges, Riverside, February, 1942		Ratio between total sugars and total soluble solids				
			Washington Navel oranges, Riverside, February, 1942	Valencia oranges*		Marsh grapefruit†	
	Total soluble solids, per cent	Total sugars, per cent		Riverside, July, 1938	Tustin, July, 1938	Riverside, May, 1938	Brawley, November, 1938
Koethen sweet orange	12.5	10.06	0.805	0.802	0.792	....	....
Oroville sweet orange	....	....	....	....	....	0.700	0.736
C.E.S. 362 sweet orange	12.4	9.62	.776	.805	.805	.721	.722
Rubidoux sour orange	12.4	9.39	.757	.788	.778	.721	.728
African sour orange	12.4	9.62	.776	.787	.788	.703	.742
Brazilian sour orange	12.4	9.92	.800	.777	.797	.730	.714
Duncan grapefruit	12.3	9.55	.776	.775	.782	.716	.755
C.E.S. 343 grapefruit	12.4	9.17	.740	.783	.781	....	....
Tresca grapefruit	....	....	....	....	....	.728	....
Siamese shaddock	12.4	9.14	.737	.783	.809	....	....
Lemon shaddock	....	....	....	.744	.794	....	....
Savage citrange	....	....	....	.768	.785	.708	.740
Morton citrange	12.8	10.20	.797	....	....	....	....
Cleopatra mandarin	12.4	9.09	.733	.804	.809	.713	.709
Sampson tangelo	13.0	9.60	.738	.783	.784	.694	.721
Palestine sweet lime	....	....	....	....	....	.711	....
Rough lemon	11.1	9.22	.831	.793	.827	.719	.732
Trifoliate orange	12.2	9.25	.758	.776	.788	.734	.722
Mean	12.4	9.53	0.771	0.784	0.794	0.716	0.729

* Ratios based on certain data from table 3.
† Ratios based on certain data from table 4.

solids during the period over which this study was made—further evidence that these two constituents have a tendency to increase at about the same rate. There is considerable scattering of the points (fig. 7), however; for example, juice containing 11.0 per cent total soluble solids may have a total-sugars content varying from 7 to 9 per cent; or juice containing 8.5 per cent total sugars may vary from 10.5 to 12.5 per cent in total soluble solids.

The degree of closeness with which the total soluble solids and total sugars in the juice may be related is more definitely expressed by the correlation coefficients. The highest correlation coefficient ($n = 79$, $r = +0.9700$) between the two was obtained with Washington Navel fruits from Riverside, the next highest ($n = 72$, $r = +0.9219$) with Valencia fruits from Riverside, the lowest ($n = 56$, $r = +0.8024$) with Valencia fruits from Tustin. The low correlation in the Tustin samples resulted from the fact that many of these were picked in the winter, after heavy rains followed by long periods of cloudy weather. It was found experimentally that such climatic conditions contribute to abnormal relations in the various constituents in the juice of fruits.

The relation between total soluble solids and total sugars in mature oranges and grapefruit from the various stocks, grown in different localities, is shown in table 5. The Valencia fruit samples were picked from the Riverside plots on July 6, 1938, and from the Tustin plots on July 12, 1938. Grapefruit samples were picked from the Riverside and Brawley plots on May 19, 1938, and November 8, 1938, respectively. Similar fruit samples were taken from the Washington Navel plots at Riverside on February 2, 1942. The results of these determinations show a direct relation between total soluble solids and total sugars. With Valencia oranges the ratios of total sugars to total soluble solids in the Riverside samples ranged from 0.744 to 0.805, and in the Tustin samples, from 0.778 to 0.827. The ratios for grapefruit ranged from 0.694 to 0.734 in the Riverside samples, and from 0.709 to 0.755 in the Brawley samples. The Washington Navel fruits showed a range in ratios from 0.733 to 0.831. It can be seen, therefore, that the fraction of total soluble solids existing as total sugars is not noticeably influenced by the rootstock.

In discussing figure 7, it was stated that the total sugars in the juice of the oranges upon which those data were based composed from 63 to nearly 80 per cent of the total soluble solids. The values given in table 5 are for mature fruit only, and the Navels were all picked February 2, 1942, whereas those in figure 7 are based on fruit picked from September 29, 1941, to March 2, 1942. The data in table 5 show that the total sugars may compose from 74 to 83 per cent of the total soluble solids in the juice of mature Valencia oranges, from 73 to 83 per cent in the juice of mature Navel oranges, and from 69 to 76 per cent in the juice of mature grapefruit. As a rule, the more mature the fruit, the higher the ratio of total sugars to total soluble solids in the juice.

RELATION OF pH TO TOTAL ACIDITY OF THE JUICE

The pH values were obtained on portions of the same juice samples on which the total acidities were determined. Curves showing the changes in pH of the juice during fruit development were not included in figures 2 and 3, however. As the fruit matured, the total acidity of the juice decreased, with, in general, a corresponding increase in pH.

The average pH values for Valencia juice from the 14 stocks on January 12, February 27, March 28, and May 9, 1939, were 2.99, 3.10, 3.28, and 3.42, respectively. There was an increase in pH value of only 0.43 in these four months. The values from the different stocks at a given time were not widely dispersed from the mean. For example, the mean for May 9 was pH 3.42 and the range pH 3.38 to 3.52, or only pH 0.14. The maximum occurred in the juice of fruits from Rough-lemon stock, the minimum alike in juice samples from Siamese-shaddock, African-sour, and lemon-shaddock stocks. Similar studies were made on fruit samples from the 14 rootstock plots at Tustin. The average pH changed from 2.79 to 3.34—a difference of pH 0.55—during the sampling period January 16 to May 12, 1939. The juice samples from the different stocks on any given sampling date showed a range of pH 0.14, the same as that of the Riverside samples.

In the Washington-Navel-orange juice from the 14 rootstocks at Riverside, the average pH values for the six samplings between September 29, 1941, and March 2, 1942, were 2.82, 2.94, 3.18, 3.40, 3.39, and 3.47, an increase of 0.65 during the experimental period. The samples from the different stocks on a given date showed a maximum range of only 0.20; hence the pH curve for each stock would deviate only slightly from one representing mean values. The total acids (as citric) on these same samples are reported in figure 3.

Samples of grapefruit were not collected periodically during a single season, as with Valencias and Navels. The pH values were determined, however, on the same mature grapefruit samples used for the data reported in table 4.

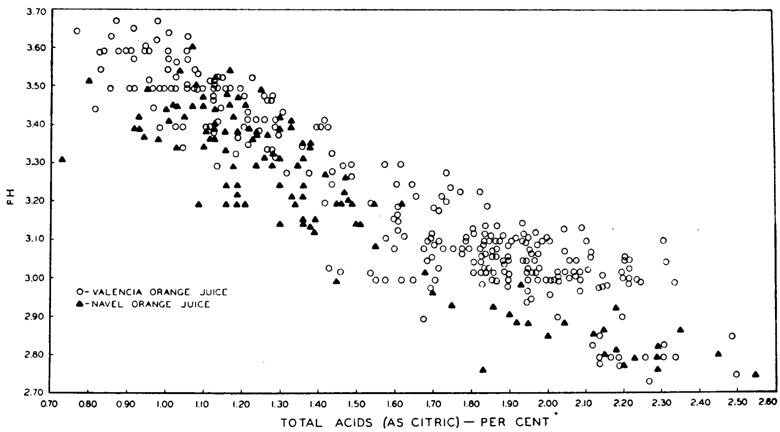

Fig. 8.—Changes in pH and total acidity (titratable acidity) in juice of Valencia and Washington Navel oranges as the season advanced. A given value in one variable may represent many values in the other. Fruit maturity ranged from immature (green) to fully mature (Valencias picked January 14 to September 5, 1939; Navels, September 29, 1941, to March 25, 1942).

The juice of grapefruit samples collected May 19, 1938, from the 13 rootstock plots at Riverside, had a mean pH of 2.95, with a range of only 0.10. A mean pH of 3.06 and a range of 0.06 were obtained on juice of similar samples picked on May 16, 1940. For comparison, pH values were determined on the juice of grapefruit samples picked from the 11 rootstock plots at Brawley in 1938 and 1939. Although the samples were collected on November 8 both years, there was a fairly large difference in the mean values. The juice of the 1938 samples had a mean pH of 3.19, with a range of 0.05, that of the 1939 samples a mean pH of 2.84, with a range of 0.11.

The small ranges in the pH values of samples of juice from a given variety of citrus picked from the different rootstocks on a given date are due to the high buffering capacity of citrus juices (*5*). The pH values of fruit and vegetable juices may remain approximately constant from a comparatively low total acidity to a high one, the condition depending upon the kinds and amounts of buffer salts present. To illustrate with an actual example, juice of Washington Navel oranges grown on Rough-lemon stock showed 0.80 per cent total acids (as citric), with a pH of 3.52, while juice of the same variety grown on Trifoliate orange showed 1.21 per cent total acids, with a pH of 3.46. Although the sample from the Rough-lemon stock was 34 per cent lower in total acids than that from the Trifoliate stock, its pH value was only 0.06 higher. These two samples of oranges were picked on the same day (March 3, 1942) from two different plots in the same grove.

In the course of this investigation, it was necessary to make a large number of determinations of pH and of total acids (titratable acidity) on juice of oranges from samples collected at various stages of maturity from the Valencia and Washington Navel rootstock plots at Riverside and Tustin. These data, as represented in figure 8, show the relation between pH value and titratable acidity. It can be observed that the pH values were determined over a wide range of total-acids concentration (2.60 to 0.70 per cent), the samples representing immature (green) to fully mature fruits.

The data show that the pH value of orange juice bears a definite relation to the titratable acidity, if compared over a wide range of acid concentration. This relation is not so definite, however, over shorter ranges of acid concentration; two samples having fairly large differences in total acidity may have the same pH value. For example (fig. 8), orange juice with a pH value of 3.20 may have a total acidity ranging from approximately 1.10 to 1.85 per cent; or, conversely, juice with a total acidity of approximately 1.43 per cent may yield pH readings ranging from 3.00 to 3.43. Under these conditions, the pH value does not indicate the amount of acid present, nor does a given acid value represent a definite pH value.

INORGANIC CONSTITUENTS AND DRY MATTER IN THE PEEL, THE PULP, AND THE JUICE

That the rootstock influences the accumulation of inorganic constituents in certain plants (scions) has been experimentally determined. In making reciprocal grafts of sunflower and Jerusalèm artichoke, Eaton and Blair (*12*) observed that the accumulation of boron in the leaves was directly related to the stock, and the amount of boron in the scion leaves was governed by the amount normally present in the stock. Conversely, Haas and Halma (*16*) observed that the soluble magnesium in the bark of various citrus stocks is markedly affected by the scion variety—that is, that the concentration of soluble magnesium in the stock is high or low in proportion to the amount in the scion. Roach (*32*) reported the presence of molybdenum in the wood of one of two apple stocks, but the element was absent from the scions of both. The results of the investigations cited are sufficient to demonstrate that there is a definite relation between the stock and scion.

The studies showing the chemical relation between the scion and stock have, however, been confined solely to the vegetative portions of the plant. Experimental data showing the influence of rootstock on the relative concentrations of inorganic constituents in the fruit are reported to a limited extent, if at all, in the literature. It was therefore decided to determine separately, by chemical analysis, the inorganic content of the peel, pulp, and juice of mature fruit from the different rootstocks.

The relative amounts of the inorganic constituents determined on different portions of the fruit are shown graphically in figures 9 to 13, as percentages of

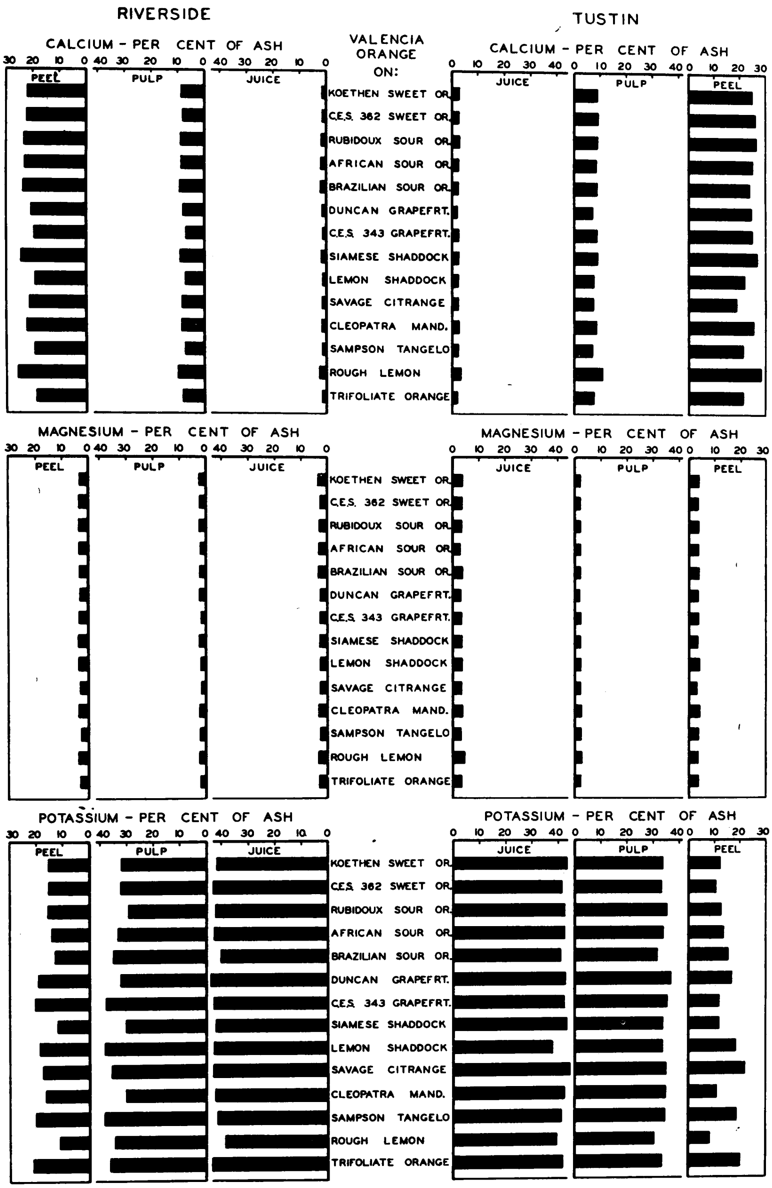

Fig. 9.—Relative percentages (ash-weight basis) of calcium, magnesium, and potassium in the peel, pulp, and juice of mature Valencia fruits from the different rootstocks in plots at Riverside and Tustin. Fruits were picked at Riverside on July 5, and at Tustin on July 11, 1938. (Continued in fig. 10.)

total ash. The percentages on a dry-weight basis are presented numerically in tables 6, 7, and 8.

In the graphs showing the percentages of the elements in the ash of the fruit samples (figs. 9 to 13), most striking are the differences in the relative amounts

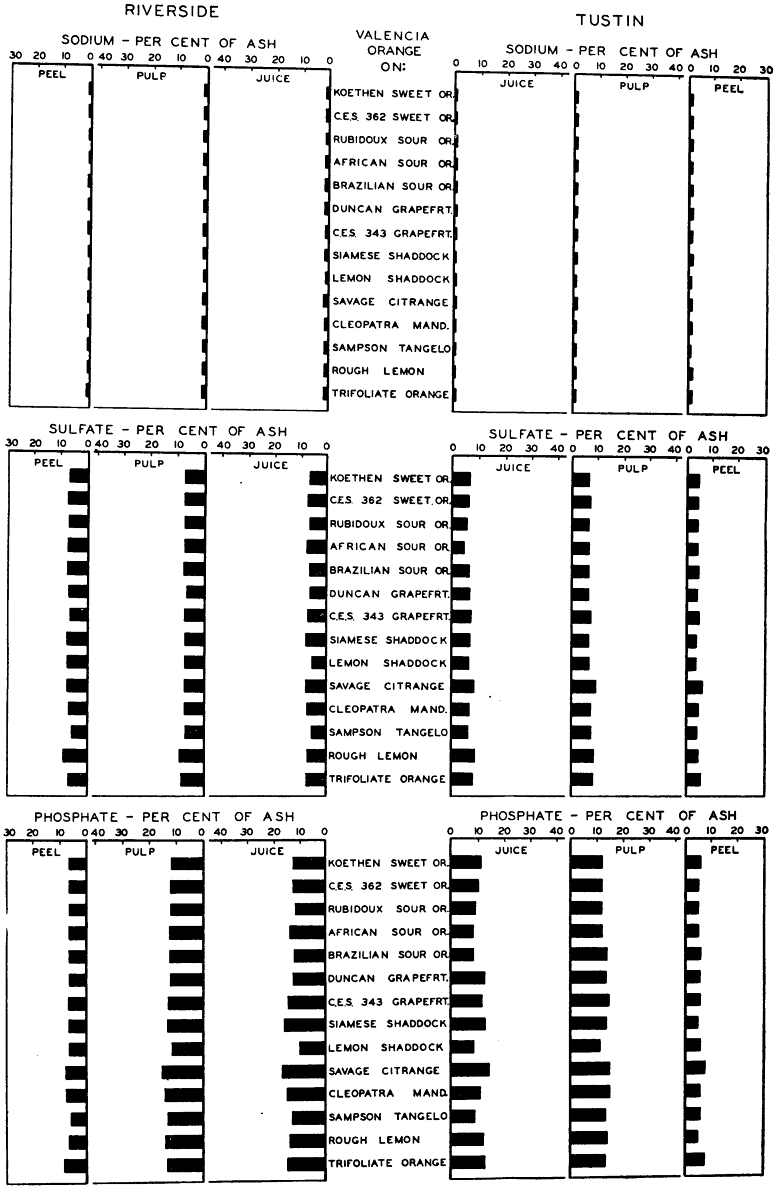

Fig. 10.—Relative percentages (ash-weight basis) of sodium, sulfate, and phosphate in the peel, pulp, and juice of mature Valencia fruits from the different rootstocks in plots at Riverside and Tustin. Fruits were picked at Riverside on July 5, and at Tustin on July 11, 1938. (Continued from fig. 9.)

of the elements found in the peel, in the pulp, and in the juice. The relation of the inorganic constituents in different portions of the fruit is clearly demonstrated by the ash analyses of Valencia fruits from the Riverside and Tustin plots (figs. 9 and 10). In fruit samples from both districts, the peel had a

TABLE 6

PERCENTAGES OF DRY MATTER, TOTAL ASH, AND INORGANIC CONSTITUENTS OF PEEL, PULP, AND JUICE OF VALENCIA ORANGES GROWN ON DIFFERENT ROOTSTOCKS AT RIVERSIDE AND AT TUSTIN

Rootstock	Dry matter, per cent of fresh weight		Total ash, per cent of dry weight		Inorganic constituents, per cent of dry weight											
					Ca		Mg		K		Na		SO_4		PO_4	
	Riverside	Tustin	Riverside	Tustin	Riverside	Tustin	Riverside	Tustin	Riverside	Tustin	Riverside	Tustin	Riverside	Tustin	Riverside	Tustin
Peel																
Koethen sweet orange	28.64	27.87	3.43	3.62	0.76	0.89	0.12	0.13	0.53	0.42	0.03	0.02	0.23	0.16	0.21	0.20
C.E.S. 362 sweet orange	28.59	28.25	3.57	3.99	.83	1.03	.13	.14	.54	.40	.03	.02	.25	.17	.22	.19
Rubidoux sour orange	29.37	27.36	3.36	3.98	.74	1.03	.12	.14	.53	.49	.02	.03	.23	.16	.21	.19
African sour orange	28.91	25.78	3.49	3.39	.81	0.83	.13	.12	.50	.44	.02	.02	.25	.13	.22	.17
Brazilian sour orange	27.84	24.55	3.45	3.47	.82	0.79	.12	.12	.45	.58	.03	.02	.23	.16	.22	.19
Duncan grapefruit	32.38	29.18	3.94	3.94	.81	0.90	.13	.13	.76	.65	.03	.03	.27	.16	.25	.21
C.E.S. 343 grapefruit	29.69	27.96	3.52	3.77	.64	0.92	.12	.13	.72	.43	.03	.02	.23	.18	.23	.20
Siamese shaddock	28.16	26.62	3.72	4.16	.91	1.09	.14	.13	.47	.46	.03	.02	.28	.15	.25	.19
Lemon shaddock	28.65	27.93	3.48	3.30	.66	0.71	.13	.13	.65	.59	.03	.02	.22	.12	.22	.18
Savage citrange	29.80	28.73	3.50	3.28	.74	0.60	.11	.10	.62	.70	.03	.03	.23	.20	.27	.24
Cleopatra mandarin	28.92	26.33	3.21	3.55	.72	0.88	.13	.13	.53	.37	.03	.02	.22	.16	.24	.19
Sampson tangelo	28.48	27.32	4.11	3.99	.78	0.82	.12	.14	.84	.73	.03	.03	.23	.16	.24	.22
Rough lemon	27.88	26.52	3.23	4.09	.80	1.12	.13	.13	.37	.32	.02	.02	.26	.19	.22	.19
Trifoliate orange	29.40	29.41	3.46	3.36	66	0.70	.11	.12	.74	.66	.03	.03	.22	.18	.28	.25
Mean	29.05	27.42	3.53	3.71	0.76	0.88	0.12	0.13	0.59	0.52	0.03	0.02	0.24	0.16	0.23	0.20
Pulp																
Koethen sweet orange	14.46	13.86	3.50	3.32	0.31	0.30	0.10	0.09	1.12	1.12	0.05	0.04	0.27	0.22	0.42	0.40
C.E.S. 362 sweet orange	14.60	14.21	3.64	3.33	.30	.32	.09	.08	1.16	1.11	.05	.04	.30	.24	.45	.39
Rubidoux sour orange	15.48	13.96	3.34	3.38	.30	.31	.09	.08	0.97	1.19	.05	.04	.26	.22	.40	.39
African sour orange	14.47	13.20	3.47	3.38	.31	.30	.07	.08	1.16	1.15	.05	.04	.23	.21	.45	.40
Brazilian sour orange	16.19	14.13	3.29	3.20	.31	.39	.08	.08	1.16	1.00	.04	.04	.24	.21	.42	.44
Duncan grapefruit	15.90	14.65	3.61	3.40	.29	.26	.09	.08	1.15	1.26	.05	.04	.25	.21	.45	.45
C.E.S. 343 grapefruit	15.15	13.91	3.54	3.25	.25	.30	.07	.08	1.34	1.14	.05	.04	.23	.23	.47	.47
Siamese shaddock	13.89	12.79	3.54	3.59	.33	.34	.09	.09	1.06	1.21	.05	.04	.27	.24	.47	.48
Lemon shaddock	15.10	14.13	3.62	3.20	.26	.25	.08	.09	1.37	1.07	.04	.04	.23	.22	.42	.36
Savage citrange	15.70	15.14	3.74	3.24	.33	.25	.07	.08	1.26	1.12	.06	.05	.26	.30	.57	.48
Cleopatra mandarin	15.07	14.92	3.26	3.10	.29	.28	.08	.08	0.98	1.07	.05	.04	.28	.22	.47	.46
Sampson tangelo	15.05	14.03	3.67	3.51	.26	.27	.08	.09	1.41	1.21	.05	.05	.25	.26	.49	.46
Rough lemon	14.86	13.22	3.19	2.99	.32	.33	.08	.09	1.09	0.91	.04	.04	.25	.26	.46	.41
Trifoliate orange	15.57	14.57	3.50	3.38	.28	.26	.07	.09	1.26	1.13	.05	.04	.28	.28	.43	.44
Mean	15.11	14.05	3.49	3.31	0.30	0.29	0.08	0.08	1.18	1.12	0.05	0.04	0.26	0.24	0.45	0.43

							Juice									
Koethen sweet orange	12.51	11.84	3.18	2.80	0.05	0.08	0.10	0.10	1.35	1.22	0.06	0.05	0.22	0.19	0.46	0.32
C.E.S. 362 sweet orange	12.44	11.64	3.37	2.81	.05	.07	.09	.10	1.47	1.16	.06	.05	.24	.17	.50	.29
Rubidoux sour orange	13.31	11.96	2.96	3.08	.05	.08	.09	.10	1.26	1.30	.05	.05	.20	.19	.35	.29
African sour orange	12.57	11.31	2.89	3.21	.06	.08	.09	.10	1.25	1.36	.06	.05	.22	.15	.40	.27
Brazilian sour orange	13.11	11.84	2.92	2.90	.06	.07	.09	.10	1.18	1.19	.05	.05	.20	.19	.35	.25
Duncan grapefruit	13.57	12.31	3.07	3.16	.05	.06	.08	.09	1.36	1.35	.06	.06	.19	.22	.37	.41
C.E.S. 343 grapefruit	13.18	11.31	3.12	3.06	.05	.07	.09	.09	1.35	1.29	.05	.05	.23	.22	.44	.37
Siamese shaddock	11.96	11.18	3.15	3.30	.06	.08	.09	.10	1.34	1.43	.06	.06	.25	.23	.49	.44
Lemon shaddock	12.91	11.44	3.28	3.00	.05	.07	.09	.09	1.41	1.13	.04	.04	.18	.19	.32	.26
Savage citrange	13.31	12.84	3.00	3.23	.06	.06	.08	.08	1.30	1.43	.06	.06	.24	.26	.50	.48
Cleopatra mandarin	12.57	11.64	2.98	3.03	.05	.07	.09	.10	1.26	1.27	.05	.05	.22	.22	.43	.34
Sampson tangelo	13.06	11.91	3.26	3.34	.05	.07	.10	.08	1.37	1.37	.04	.05	.19	.21	.40	.30
Rough lemon	12.51	10.64	2.67	2.78	.07	.09	.09	.12	1.04	1.09	.04	.05	.19	.25	.36	.35
Trifoliate orange	12.44	12.31	3.50	3.29	.06	.06	.10	.08	1.53	1.37	.06	.06	.26	.26	0.48	.42
Mean	12.82	11.73	3.10	3.07	0.06	0.07	0.09	0.10	1.32	1.28	0.05	0.05	0.22	0.21	0.42	0.34

larger percentage of its ash as calcium than had either the pulp or the juice. Much of the calcium in the peel and pulp is insoluble in water, since it is present in the form of calcium pectate. As the peel contains more pectin than the pulp, more calcium is required to combine with the pectin. Approximately 30 per cent of the total calcium in orange vesicles is insoluble in water.

As the scale in figures 9 and 10 is too small to bring out minor differences, the relative amounts of magnesium in different portions of the fruit samples can more readily be noted—but on a dry-weight basis—in table 6. The data in this table can be used to calculate percentages on a total-ash basis for each rootstock. Averages for all rootstocks on that basis are given in table 9. The amount of magnesium in the ash of samples from the Valencia plots at both Riverside and Tustin was distinctly higher in the peel than in either the juice or the pulp, and higher in the juice than in the pulp.

Potassium was higher than any of the other inorganic constituents in the ash of both juice and pulp of fruits from both districts (fig. 9 and table 6), and was exceeded only by calcium in the ash of the peel.

There is a striking contrast between the amounts of sodium (fig. 10) and potassium (fig. 9) in the ash of these samples. In all portions of the fruit, the average amount of sodium in these samples was lower than that of the other elements determined. As the scale is too small to designate such small quantities, reference should again be made to table 6 for relative amounts of sodium in the samples on a dry-weight basis. Averages for all rootstocks on an ash-weight basis are given in table 9. In samples from both Riverside and Tustin, sodium was lower in the peel than in the pulp or juice, and lower in the ash of the pulp than in that of the juice. The sodium values of the pulp of course include those of the juice. This means that other inorganic constituents which were high in the pulp and low in the juice served to reduce the percentage of sodium in the pulp. It may be inferred from this that the sodium in the edible portion of the orange exists in a salt form readily soluble in the juice and not combined with the insoluble material of the pulp.

The relative proportions of sulfate in the ash of the juice, pulp, and peel of Valencia fruits from the Riverside plots were very uniform. The juice and pulp of fruit samples from Tustin had approximately the same amount of sulfate, but the peel had considerably less—significantly less, also, than that of the Riverside samples.

The amount of phosphate was about the same in the pulp of samples from the two districts, but the peel and juice of the Riverside samples tended to have higher amounts than those of the Tustin samples. The peel of these samples contained the least phosphate.

To compare the inorganic constituents of Valencia fruits from the various rootstocks in the two districts, reference should be made to table 6. As previously stated, Valencia fruits from Rough-lemon stock were low in total soluble solids; but, as shown in table 6, these fruits did not always contain the lowest concentration of a given inorganic constituent. For instance, at Riverside the pulp of fruit from the African-sour variety had 14.47 per cent dry matter, while that from Rough lemon had 14.86 per cent; but the mean value for the three sour-orange stocks (15.38 per cent dry matter) was higher. The average percentages of dry matter in fruits from the three sour-orange stocks and the Rough-lemon stock were as follows:

	Sour-orange rootstocks	Rough-lemon rootstock
Riverside:		
Peel	28.71	27.88
Pulp	15.38	14.86
Juice	13.00	12.51
Tustin:		
Peel	25.90	26.52
Pulp	13.76	13.22
Juice	11.70	10.64

At Tustin the dry-matter percentages were, except in the peel, consistently lower in samples from Rough-lemon stock than in those from the sour-orange stocks. Similarly (table 6), total-ash values for peel, pulp, and juice of samples from the two districts were lower for Rough lemon than for the sour-orange stocks, except in the peel of samples from Tustin.

A further examination of the values in table 6 will show that fruit samples from other stocks were higher than those from the sour oranges and Rough lemon in dry-matter percentages and in total ash. In the Riverside plots, the two grapefruit stocks averaged highest in dry matter of the peel (mean of the two stocks, 31.04 per cent) ; Savage citrange was next highest, with 29.80 per cent; and Trifoliate orange was third, with 29.40 per cent. In the Tustin plots, Trifoliate orange was highest in dry matter of the peel (29.41 per cent).

The lowest amounts of potassium occurred in the peel and juice of fruits from Rough-lemon stocks of both districts, and in the pulp of fruits from Rough-lemon stock of the Tustin district; but Rough lemon did not produce the lowest potassium in similar pulp samples from the Riverside plots. In the peel, fruits from Sampson tangelo had the highest amount of potassium at both Riverside (0.84 per cent) and Tustin (0.73 per cent). In the pulp, the highest amounts of potassium were found in samples from Sampson tangelo (1.41 per cent), at Riverside, and in samples from Duncan grapefruit (1.26 per cent), at Tustin. In the juice, samples from Trifoliate orange (1.53), at Riverside, and from Siamese shaddock and Savage citrange (both 1.43 per cent), at Tustin, had the highest amounts of potassium. Similar comparisons of other inorganic constituents in various portions of Valencia fruits can be made from the data of table 6.

In Washington Navel oranges (table 7), the dry matter was lowest in peel and juice of fruits from Rough-lemon, and highest in peel, pulp, and juice of fruits from Savage-citrange stocks. The total ash also was lowest in the juice samples from Rough-lemon stock (2.91 per cent) ; but in the pulp samples, Cleopatra mandarin yielded the lowest ash (3.14 per cent), with Rough lemon slightly higher (3.28 per cent). The total ash in peel, pulp, and juice of samples from Trifoliate orange was higher than that for any other stock listed in the Navel-orange data.

The average amount of calcium in the peel of the Navels, on a dry-weight basis, was significantly lower than that found in the peel of Valencia fruits from Riverside and Tustin, but the amounts in the pulp and juice had about the same range as in fruit samples from the Valencia rootstock plots.

In the Navel-orange experiments, the fruit grown on Rough-lemon roots

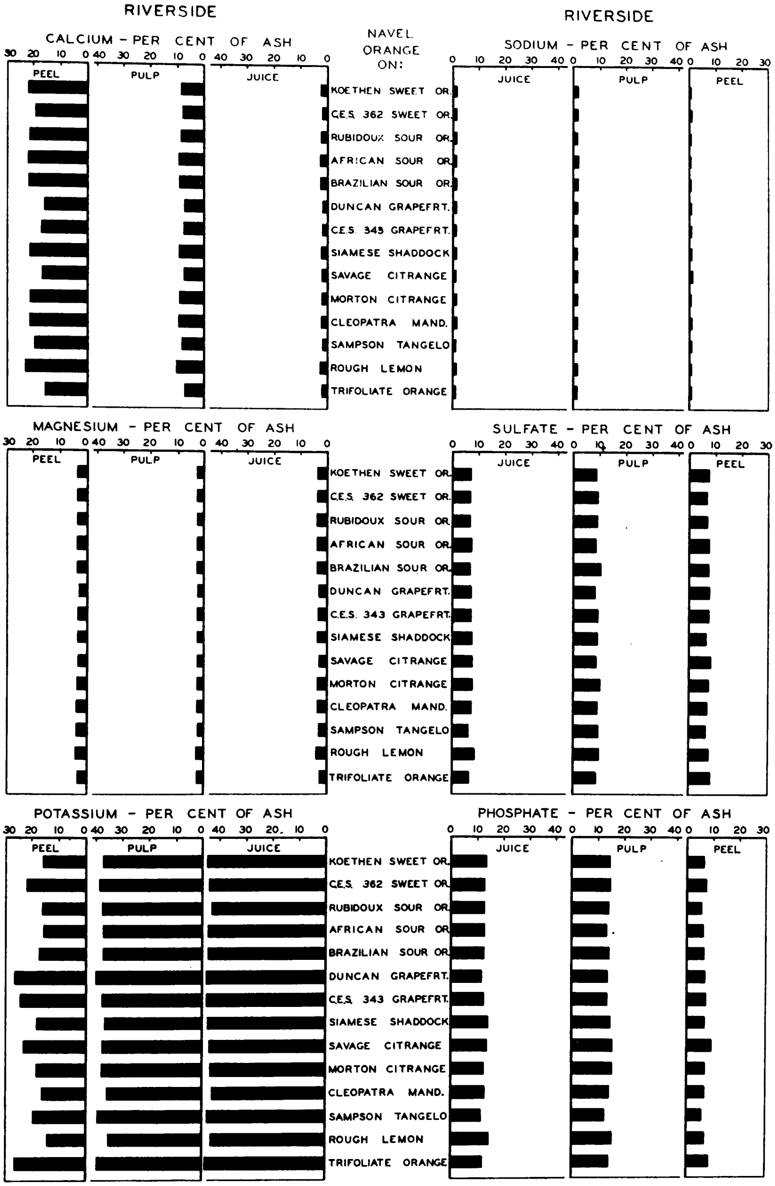

Fig. 11.—Relative percentages (ash-weight basis) of various inorganic constituents in the peel, pulp, and juice of mature Washington Navel fruits from the different rootstocks in plots at Riverside (fruits picked January 24, 1939).

had the lowest amount of potassium in the peel (0.38 per cent) and next to the lowest in the pulp and the juice (1.15 and 1.25 per cent, respectively), Cleopatra mandarin being lowest in these two portions. In all three portions of the fruit, samples from Trifoliate orange had the highest amounts of potassium. Similar relations are indicated in figure 11.

TABLE 7

PERCENTAGES OF DRY MATTER, TOTAL ASH, AND INORGANIC CONSTITUENTS OF PEEL, PULP, AND JUICE OF WASHINGTON NAVEL ORANGES GROWN ON DIFFERENT ROOTSTOCKS AT RIVERSIDE

Rootstock	Dry matter, per cent of fresh weight	Total ash, per cent of dry weight	Inorganic constituents, per cent of dry weight					
			Ca	Mg	K	Na	SO_4	PO_4
		Peel						
Koethen sweet orange	26.00	2.91	0.64	0.11	0.46	0.02	0.23	0.19
C.E.S. 362 sweet orange	25.20	2.57	.50	.09	.57	.03	.18	.19
Rubidoux sour orange	25.48	2.92	.64	.10	.48	.02	.21	.16
African sour orange	24.88	2.74	.61	.10	.43	.02	.21	.17
Brazilian sour orange	24.47	2.63	.58	.10	.46	.02	.20	.17
Duncan grapefruit	26.34	2.89	.48	.09	.77	.02	.23	.20
C.E.S. 343 grapefruit	26.41	2.85	.49	.10	.70	.02	.21	.20
Siamese shaddock	25.47	2.74	.59	.10	.51	.03	.18	.19
Savage citrange	28.92	2.76	.47	.09	.64	.04	.22	.27
Morton citrange	25.54	2.73	.58	.11	.50	.02	.21	.19
Cleopatra mandarin	27.20	2.71	.59	.11	.45	.03	.19	.19
Sampson tangelo	26.84	3.00	.59	.10	.60	.03	.19	.18
Rough lemon	24.12	2.64	.61	.11	.38	.02	.20	.18
Trifoliate orange	26.93	3.05	.49	.09	.82	.03	.25	.26
Mean	25.99	2.80	0.56	0.10	0.56	0.03	0.21	0.20
		Pulp						
Koethen sweet orange	14.50	3.43	0.35	0.09	1.27	0.05	0.30	0.50
C.E.S. 362 sweet orange	13.74	3.43	.28	.09	1.33	.05	.32	.51
Rubidoux sour orange	14.46	3.50	.31	.09	1.32	.06	.32	.49
African sour orange	13.95	3.61	.34	.09	1.34	.05	.32	.47
Brazilian sour orange	13.75	3.49	.33	.09	1.31	.05	.38	.49
Duncan grapefruit	14.65	3.59	.27	.09	1.44	.05	.29	.49
C.E.S. 343 grapefruit	14.37	3.61	.31	.09	1.36	.06	.33	.49
Siamese shaddock	13.85	3.38	.32	.09	1.25	.06	.31	.50
Savage citrange	16.12	3.41	.26	.08	1.30	.06	.30	.52
Morton citrange	14.06	3.40	.31	.09	1.29	.05	.35	.52
Cleopatra mandarin	15.22	3.14	.30	.08	1.13	.05	.28	.45
Sampson tangelo	15.18	3.58	.30	.09	1.41	.05	.34	.45
Rough lemon	12.98	3.28	.34	.10	1.15	.05	.33	.51
Trifoliate orange	12.76	3.88	.29	.10	1.54	.06	.34	.54
Mean	14.26	3.48	0.31	0.09	1.32	0.05	0.32	0.50
		Juice						
Koethen sweet orange	12.24	3.03	0.06	0.10	1.35	0.05	0.21	0.40
C.E.S. 362 sweet orange	11.43	3.17	.06	.11	1.39	.05	.22	.41
Rubidoux sour orange	12.01	3.28	.07	.12	1.41	.06	.22	.40
African sour orange	11.71	3.27	.07	.11	1.44	.05	23	.42
Brazilian sour orange	11.57	3.13	.07	.11	1.38	.05	.21	.39
Duncan grapefruit	12.43	3.33	.05	.10	1.49	.05	.23	.39
C.E.S. 343 grapefruit	11.91	3.23	.06	.10	1.43	.05	.23	.40
Siamese shaddock	11.83	3.19	.06	.10	1.42	.05	.25	.45
Savage citrange	13.01	3.37	.06	.10	1.47	.05	.26	.45
Morton citrange	11.83	3.11	.06	.11	1.34	.05	.24	.39
Cleopatra Mandarin	12.11	2.97	.06	.10	1.22	.05	.21	.37
Sampson tangelo	12.62	3.40	.06	.10	1.50	.04	.20	.37
Rough lemon	10.83	2.91	.07	.12	1.25	.05	.25	.42
Trifoliate orange	11.11	4.34	.07	.12	1.98	.06	.27	.50
Mean	11.90	3.27	0.06	0.11	1.43	0.05	0.23	0.41

TABLE 8

PERCENTAGES OF DRY MATTER, TOTAL ASH, AND INORGANIC CONSTITUENTS OF PEEL, PULP, AND JUICE OF MARSH GRAPEFRUITS GROWN ON DIFFERENT ROOTSTOCKS AT RIVERSIDE AND BRAWLEY

Rootstock	Dry matter, per cent of fresh weight		Total ash, per cent of dry weight		Inorganic constituents, per cent of dry weight											
					Ca		Mg		K		Na		SO_4		PO_4	
	Riverside	Brawley	Riverside	Brawley	Riverside	Brawley	Riverside	Brawley	Riverside	Brawley	Riverside	Brawley	Riverside	Brawley	Riverside	Brawley
Peel																
Oroville sweet orange	18.74	25.57	3.39	5.49	0.63	1.12	0.10	0.12	0.80	1.08	0.03	0.02	0.21	0.23	0.22	0.19
C.E.S. 362 sweet orange	19.70	26.02	3.45	5.53	.66	1.17	.09	.13	.74	1.08	.03	.02	.24	.28	.24	.21
Rubidoux sour orange	19.93	26.80	3.20	5.65	.66	1.22	.10	.14	.64	1.03	.02	.02	.19	.27	.20	.20
African sour orange	19.54	28.05	3.28	5.64	.64	1.19	.11	.13	.69	0.92	.03	.03	.23	.28	.22	.19
Brazilian sour orange	20.70	26.28	3.22	5.59	.62	1.27	.09	.14	.63	0.98	.03	.03	.22	.25	.22	.20
Duncan grapefruit	20.08	26.01	3.67	5.74	.67	1.08	.10	.13	.86	1.31	.03	.02	.24	.28	.21	.18
Tresca grapefruit	18.44	.....	3.36	....	.62	....	.09	....	.75	....	.03	....	.22	....	.23	....
Savage citrange	21.94	27.15	3.55	5.87	.70	1.17	.12	.14	.71	1.22	.04	.03	.22	.25	.25	.23
Cleopatra mandarin	19.12	27.05	3.19	5.62	.59	1.18	.09	.12	.58	0.96	.03	.03	.22	.30	.26	.18
Sampson tangelo	20.94	25.60	3.84	5.83	.68	1.21	.13	.14	.83	1.12	.03	.03	.23	.25	.24	.18
Palestine sweet lime	16.97	.....	3.10	....	.63	....	.08	....	.66	....	.03	....	.21	....	.21	....
Rough lemon	17.79	23.81	3.06	5.26	.61	1.14	.10	.12	.62	0.95	03	.04	.22	.19	.22	.16
Trifoliate orange	21.89	27.38	3.62	5.34	.65	0.90	.12	.15	.88	1.39	.03	.03	.25	.26	.24	.25
Mean	19.68	26.34	3.38	5.60	0.64	1.15	0.10	0.13	0.72	1.09	0.03	0.03	0.22	0.26	0.23	0.20
Pulp																
Oroville sweet orange	12.19	13.22	3.06	3.64	0.25	0.27	0.10	0.08	1.12	1.45	0.05	0.04	0.29	0.27	0.46	0.41
C.E.S. 362 sweet orange	12.61	13.87	2.96	3.70	.24	.26	.10	.09	1.08	1.53	.05	.04	.31	.26	.51	.44
Rubidoux sour orange	13.04	13.52	2.77	3.54	.26	.26	.09	.08	0.98	1.46	.05	.04	.29	.28	.44	.42
African sour orange	12.97	13.85	2.90	3.56	26	.27	.10	.08	0.99	1.47	.05	.04	.30	.28	.45	.41
Brazilian sour orange	12.99	13.85	2.91	3.51	.28	.27	.09	.08	1.01	1.15	.05	.04	.28	.29	.45	.40
Duncan grapefruit	13.02	13.87	3.20	3.76	.23	.25	.10	.08	1.13	1.59	.05	.04	.33	.26	.48	.42
Tresca grapefruit	12.30	.....	2.92	....	.23	....	.10	....	1.06	....	.05	....	.31	....	.48	....
Savage citrange	14.25	14.57	3.10	3.53	.29	.24	.10	.08	1.07	1.42	.05	.04	.30	.28	.48	.43
Cleopatra mandarin	12.16	13.31	2.83	3.71	.23	.28	.11	.08	0.97	1.45	.06	.05	.31	.26	.53	.42
Sampson tangelo	13.51	12.88	3.36	3.96	.26	.28	.10	.09	1.24	1.65	.05	.05	.31	.31	.51	.44
Palestine sweet lime	10.68	.....	2.99	....	.29	....	.10	....	1.03	....	.05	....	.32	....	.52	....
Rough lemon	11.53	11.27	2.98	3.52	.27	.27	.10	.09	0.98	1.41	.05	.05	.35	.26	.50	.43
Trifoliate orange	14.38	14.64	2.99	3.83	.24	.24	.09	.09	1.00	1.60	.05	.05	.27	.29	.48	.45
Mean	12.74	13.53	3.00	3.66	0.26	0.26	0.10	0.08	1.05	1.47	0.05	0.04	0.31	0.28	0.48	0.42

	Juice															
Oroville sweet orange	10.58	10.56	2.55	3.43	0.07	0.07	0.11	0.11	1.15	1.26	0.07	0.06	0.20	0.19	0.37	0.33
C.E.S. 362 sweet orange	11.31	11.57	2.53	3.21	.06	.07	.11	.10	1.14	1.44	.07	.05	.22	.20	.42	.34
Rubidoux sour orange	11.71	11.11	2.71	3.26	.08	.08	.11	.10	1.19	1.37	.08	.05	.20	.19	.37	.34
African sour orange	11.11	11.03	2.52	3.22	.07	.08	.11	.10	1.16	1.48	.06	.06	.22	.20	.38	.34
Brazilian sour orange	11.24	11.17	2.58	3.25	.07	.08	.11	.11	1.18	1.16	.07	.05	.20	.22	.37	.35
Duncan grapefruit	11.04	11.17	2.76	3.54	.07	.07	.11	.11	1.30	1.60	.07	.05	.20	.22	.39	.37
Tresca grapefruit	10.44	....	3.03	....	.08	....	.12	....	1.27	....	.10	....	.25	....	.44	....
Savage citrange	11.96	11.97	2.66	3.16	.08	.07	.10	.10	1.22	1.38	.07	.05	.23	.20	.45	.34
Cleopatra mandarin	10.51	11.37	2.64	3.23	.07	.08	.12	.11	1.06	1.45	.08	.05	.22	.20	.42	.34
Sampson tangelo	11.11	10.51	2.94	3.47	.07	.08	.11	.12	1.20	1.57	.07	.06	.22	.21	.42	.35
Palestine sweet lime	9.18	....	2.62	....	.08	....	.12	....	1.17	....	.07	....	.23	....	.41	....
Rough lemon	9.84	9.76	2.46	3.06	.08	.07	.12	.11	0.93	1.37	.10	.06	.25	.17	.39	.30
Trifoliate orange	11.91	11.37	2.78	3.55	.06	.07	.11	.13	1.32	1.60	.06	.06	.19	.21	.43	.35
Mean	10.92	11.05	2.68	3.31	0.07	0.07	0.11	0.11	1.18	1.43	0.07	0.05	0.22	0.20	0.40	0.34

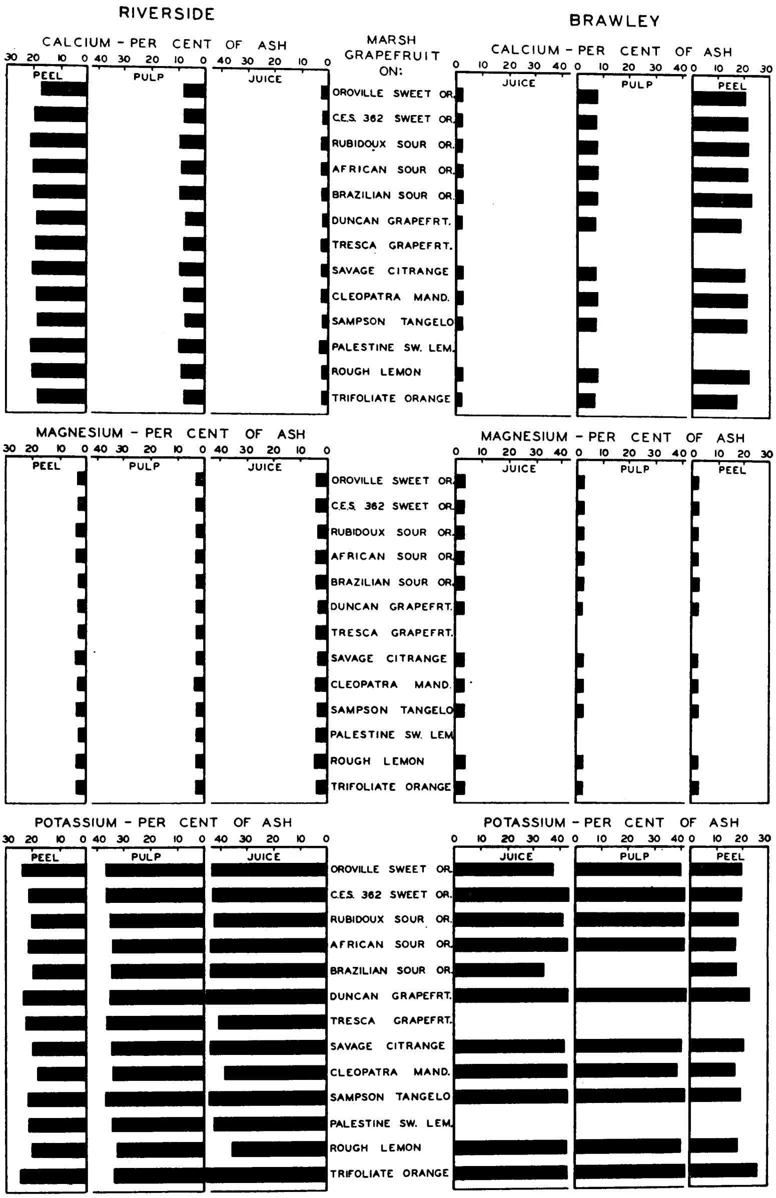

Fig. 12.—Relative percentages (ash-weight basis) of calcium, magnesium, and potassium in the peel, pulp, and juice of mature grapefruit from the different rootstocks in plots at Riverside and Brawley. Fruits were picked at Riverside on May 19, and at Brawley on November 8, 1938. (Continued in fig. 13.)

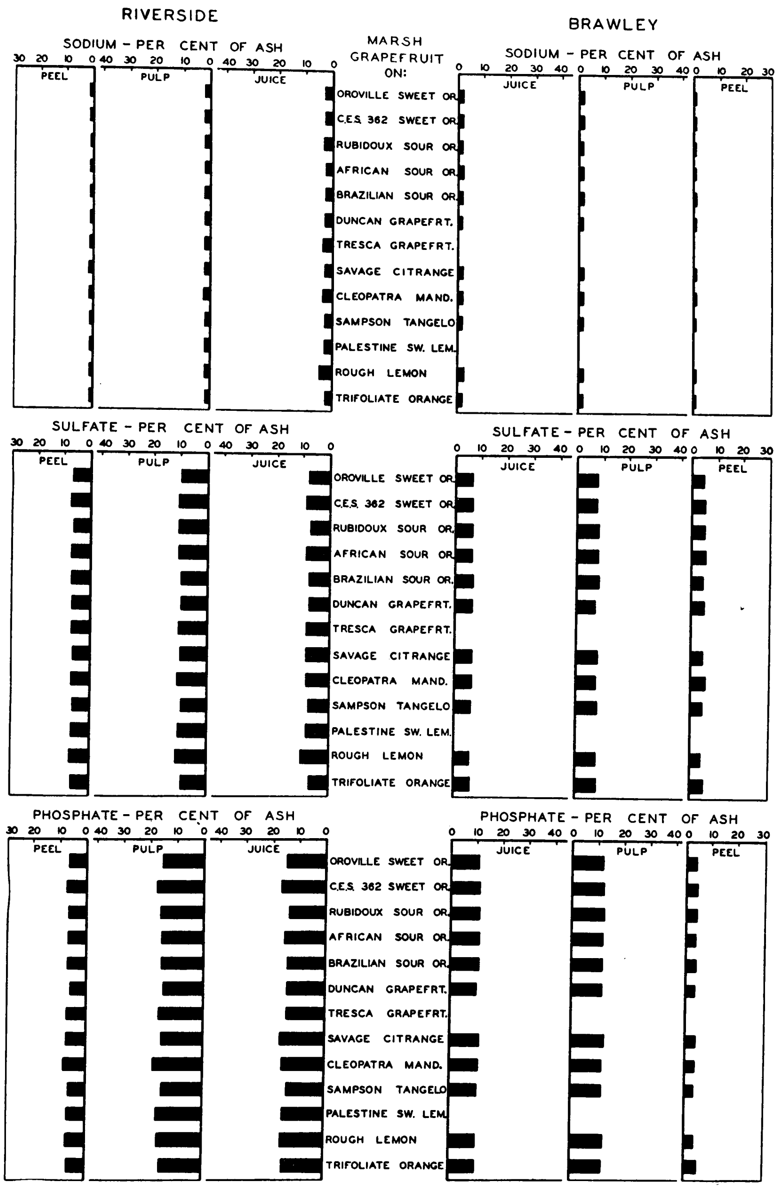

Fig. 13.—Relative percentages (ash-weight basis) of sodium, sulfate, and phosphate in the peel, pulp, and juice of grapefruit from the different rootstocks in plots at Riverside and Brawley. Fruits were picked at Riverside on May 19, and at Brawley on November 8, 1938. (Continued from fig. 12.)

Figures 12 and 13 and table 8 show the results of inorganic analyses of peel, pulp, and juice of grapefruits from the various stocks at Riverside and Brawley. The percentages of ash (dry-weight basis) were much greater in all the samples from the Brawley plots than in corresponding samples from the Riverside plots. This is especially noticeable in the peel (table 8).

TABLE 9

COMPARISON OF MEAN PERCENTAGES OF DRY MATTER, TOTAL ASH, AND INORGANIC CONSTITUENTS OF PEEL, PULP, AND JUICE OF FRUITS OF CITRUS VARIETIES GROWN ON VARIOUS ROOTSTOCKS IN DIFFERENT LOCALITIES

Location of plots and portion of fruit tested	Dry matter, per cent of fresh weight	Total ash, per cent of dry weight	Inorganic constituents, per cent of ash					
			Ca	Mg	K	Na	SO_4	PO_4
			Valencia orange*					
Riverside:								
Peel	29.05	3.53	21.53	3.40	16.71	0.85	6 80	6.52
Pulp	15.11	3.49	8.60	2.29	33.81	1.43	7.45	12.89
Juice	12.82	3.10	1.94	2.90	42.58	1.61	7.10	13.55
Tustin:								
Peel	27.42	3.71	23.72	3.50	14.02	0.54	4.31	5.39
Pulp	14.05	3.31	8.76	2.42	33.84	1.21	7.25	12.99
Juice	11.73	3.07	2.28	3.26	41.69	1.63	6.51	11.07
			Washington Navel orange*					
Riverside:								
Peel	25.99	2.80	20.00	3.57	20.00	0.71	7.50	7.14
Pulp	14.26	3.48	8.91	2.59	37.93	1.44	9.20	14.37
Juice	11.90	3.27	1.83	3.36	43.73	1.53	7.03	12.54
			Marsh grapefruit†					
Riverside:								
Peel	19.68	3.38	18.93	2.96	21.30	0.89	6.51	6.80
Pulp	12.74	3.00	8.67	3.33	35.00	1.67	10.33	16.00
Juice	10.92	2.68	2.61	4.10	44.03	2.61	8.21	14.93
Brawley:								
Peel	26.34	5.60	20.54	2.32	19.46	0.54	4.64	3.57
Pulp	13.53	3.66	7.10	2.19	40.16	1.09	7.65	11.48
Juice	11.05	3.31	2.11	3.32	43.20	1.51	6.04	10.27

* Grown on 14 different rootstocks.
† Grown on 13 different rootstocks at Riverside and on 11 different rootstocks at Brawley.

An examination of the data from individual rootstocks shows that in all three portions of the fruit, Palestine sweet lime produced the lowest dry-matter percentages at Riverside, and Rough lemon next to the lowest there and the lowest at Brawley (where Palestine sweet lime was not grown). Except in the peel of samples from African-sour orange at Brawley, the highest dry-matter percentages in all portions of the fruit occurred in samples from Savage citrange and Trifoliate orange in both districts. Results from these two stocks showed only very slight differences.

The total-ash content was lowest in the peel and juice of fruit from the Rough-lemon stocks at both Riverside and Brawley. In the pulp, the lowest amounts of ash occurred in fruit from Rubidoux-sour stock (2.77 per cent) at Riverside, and in that from Brazilian-sour (3.51 per cent) and Rough-lemon (3.52 per cent) stocks at Brawley. The highest total ash in the peel occurred in fruit from Sampson tangelo (3.84 per cent) at Riverside, and in that from Savage citrange (5.87 per cent) at Brawley. In the pulp, fruit from Sampson tangelo was highest in total ash at both Riverside (3.36 per cent) and Brawley (3.96 per cent).

An inspection of the values for the individual inorganic constituents in the three portions of grapefruit from the different stocks at Riverside and Brawley shows numerous instances of departure from the lowest and highest values usually produced by the Rough-lemon and Trifoliate stocks, respectively. The elements existing in relatively low concentrations, such as magnesium and sodium, are comparatively uniform in samples from all the stocks.

The summary data of table 9 represent the mean percentages of the inorganic constituents in fruits from all stocks in each district. Since these mean values represent an average for all stocks in a given locality, they represent also the effect of the location on the average composition of the fruit. The mean amounts of total ash (dry-weight basis) were not significantly different in Valencia-fruit samples from stocks of the two districts.

In the Valencia-orange analyses, the elements, as percentages of the ash, were fairly uniform in corresponding samples from stocks of the two districts. For example, the percentages of potassium and of sodium in the ash of peel, pulp, and juice of fruit from the stocks at Riverside were not significantly different from those of corresponding portions at Tustin.

As the Washington-Navel-orange stocks were planted only in one district, the influence of location on the inorganic constituents cannot be observed.

Despite differences due to variety, there are certain similarities between Washington Navel and Valencia analyses. The total ash in the peel was much lower in the Washington Navel than in the Valencia samples, but the percentages of total ash in the pulp and juice of these two varieties, even when the Valencias from Tustin are included, were astonishingly close. The relative proportions of the various inorganic constituents in the ash of peel, pulp, and juice of the Navel fruits were of the same order of magnitude as those found in the Valencias.

The average amounts of the various constituents occurring in fruit from the grapefruit plots at Riverside and Brawley are also noted in table 9. In all three portions of the fruit, the average dry-weight percentages were greater at Brawley than at Riverside, although in the juice the difference was small and statistically insignificant.

RELATION OF TOTAL SUGARS AND TOTAL ACIDS TO THE MINERAL COMPOSITION OF THE JUICE

In the present experiments, it was important to determine whether the amount of a given inorganic constituent was related to the amounts of sugars and acids in the juice of fruit samples from the various stocks. The results of these studies are shown by means of bar diagrams in figures 14 to 18. For each rootstock, the percentages of the maximum differences between values, for total sugars, total acids, calcium, magnesium, sodium, potassium, phosphate, and sulfate, respectively, in the juice of fruit samples from the different rootstocks, are given for comparison. Similarly constructed figures for the peel

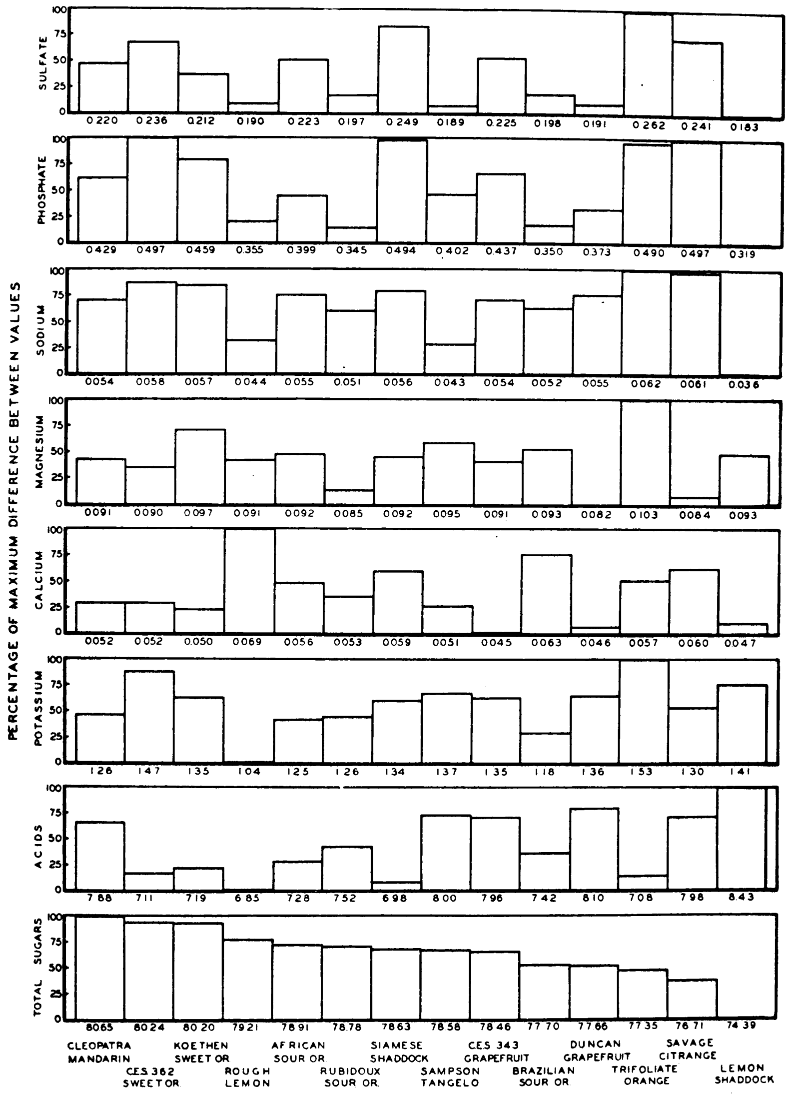

Fig. 14.—The relation between total sugars, total acids, and inorganic constituents of the juice of Valencia fruits from the rootstock plots at Riverside. The actual percentages of the various constituents, determined on samples from the different rootstocks (dry-weight basis), are placed below each column. For each constituent the "maximum difference" is the difference between the highest and lowest values shown for that constituent. Each column represents a proportional part (percentage) of the maximum difference, for a specified rootstock. Compare with similar data on juice of Valencia fruits from the rootstock plots at Tustin (fig. 15).

and the pulp would show much the same relation between the different constituents.

By "maximum difference" (see figs. 14 to 18) is meant the difference between the highest and the lowest values for a given constituent in samples

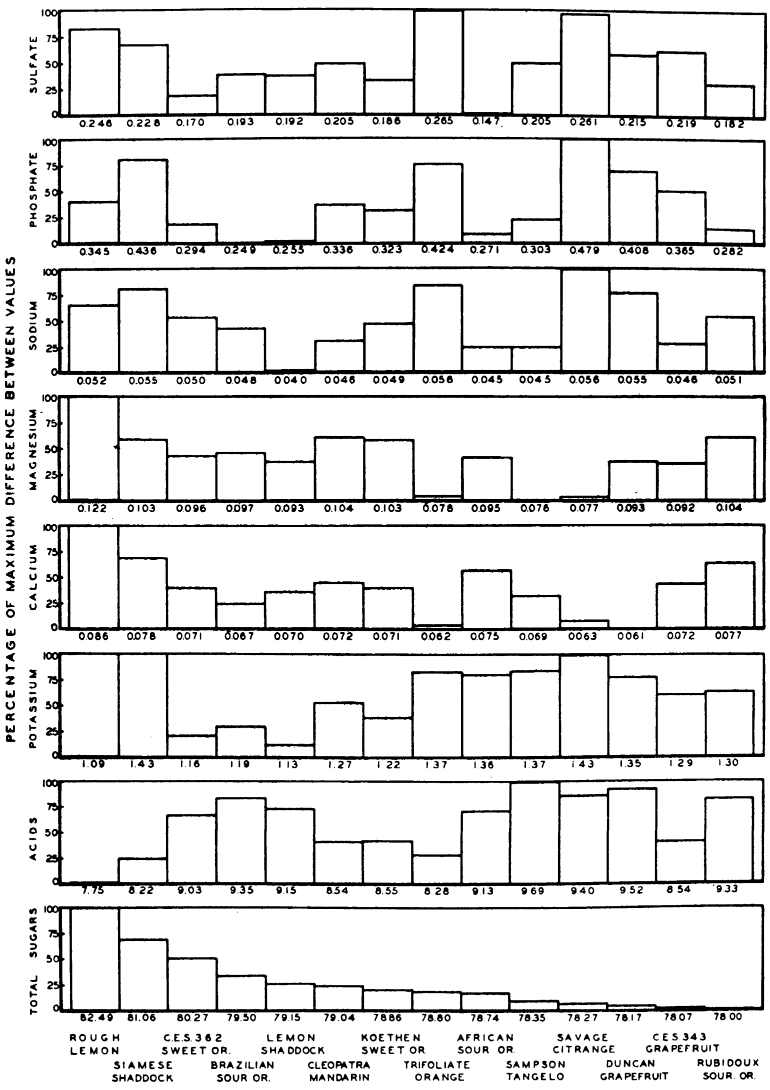

Fig. 15.—The relation between total sugars, total acids, and inorganic constituents of the juice of Valencia fruits from the rootstock plots at Tustin. The actual percentages of the various constituents, determined on samples from the different rootstocks (dry-weight basis), are placed below each column. For each constituent the "maximum difference" is the difference between the highest and lowest values shown for that constituent. Each column represents a proportional part (percentage) of the maximum difference, for a specified rootstock. Compare with similar data on juice of Valencia fruits from the rootstock plots at Riverside (fig. 14).

from the various rootstocks. To illustrate, the maximum difference for the total sugars in Valencia fruits from the Riverside plots (fig. 14) is the difference between the sugar percentage (dry-weight basis) in the juice of samples from Cleopatra-mandarin stock (80.65) and that in similar samples from lemon-shaddock stock (74.39). Cleopatra mandarin, then, represents the maximum difference, designated as 100 per cent, and lemon shaddock represents the zero difference. For the remaining stocks, the total-sugar values are proportional parts of the maximum difference, expressed in percentages, and listed in the descending order of concentration. This method of expressing the results saves space. If actual values were used, it would be difficult to express all constituents on the same scale. The percentage of constituent shown under each bar in figures 14 to 18 is the mean of duplicate determinations made from the 1938 samplings of the juice, expressed on a dry-weight basis.

It is apparent from figure 14 that no relation exists between the concentrations of sugars and acids in the juice of Valencia oranges at Riverside and the amounts of mineral constituents in the same samples. There is, however, a distinctive feature of the mineral composition of the juice of fruit from the Trifoliate stock: although the Trifoliate samples were third from lowest in sugar content, they were highest of the rootstock group in potassium, magnesium, sodium, and sulfate, and were very high in phosphate. The samples from Rough-lemon stock, lowest in acid content and fourth from highest in sugar content, had the least amount of potassium but the highest amount of calcium. It should be pointed out that the inorganic constituents tend to increase the total soluble solids in the juice and are reflected in the readings.

Similar determinations were made on Valencia juice from corresponding plots at Tustin (fig. 15). In this series, samples from Rough-lemon stock had the highest concentration of total sugars, and those from Rubidoux-sour the lowest. The Rough-lemon samples had the lowest concentration of acids but the highest calcium and magnesium contents of the rootstock group; samples from Trifoliate orange were highest of the stocks in sulfate, and they were very high in sodium, phosphate, and potassium. Savage citrange had only 78.27 per cent of its dry weight as sugar, but, in comparison with the other stocks, it had the highest amounts of sodium and phosphate, and was next to the highest in sulfate and potassium.

Figure 16 presents the corresponding data for Washington Navel oranges at Riverside. Total sugars were highest in juice of fruits from Rubidoux sour and lowest in those from Trifoliate orange; but as with the Valencias at Riverside, samples from the Trifoliate stock had the highest percentages of potassium, magnesium, sodium, and sulfate; they were also highest in phosphate and high in calcium. Samples from Rough-lemon stock were next to the highest in sugars, lowest in acids, and they, with the samples from African sour, were highest in calcium. Samples from Cleopatra mandarin and Rough lemon were the lowest in potassium.

When the grapefruit samples from the Riverside and Brawley plots were tested on a fresh-weight basis (see "Experiments on the Juice of Grapefruit from Different Rootstocks," p. 140), it was found that the percentages of total soluble solids and of total and reducing sugars were higher in samples from the Riverside plots than in those from the Brawley plots (fig. 6). In these later experiments, with percentages based on dry weight, the proportion of dry weight that was sugar was higher in samples from the Brawley plots than in those from the Riverside plots (fig. 17). This was due to the difference in total-soluble-solids content of the fruits from the two districts, the samples with the lower total soluble solids having the higher percentage of total sugars.

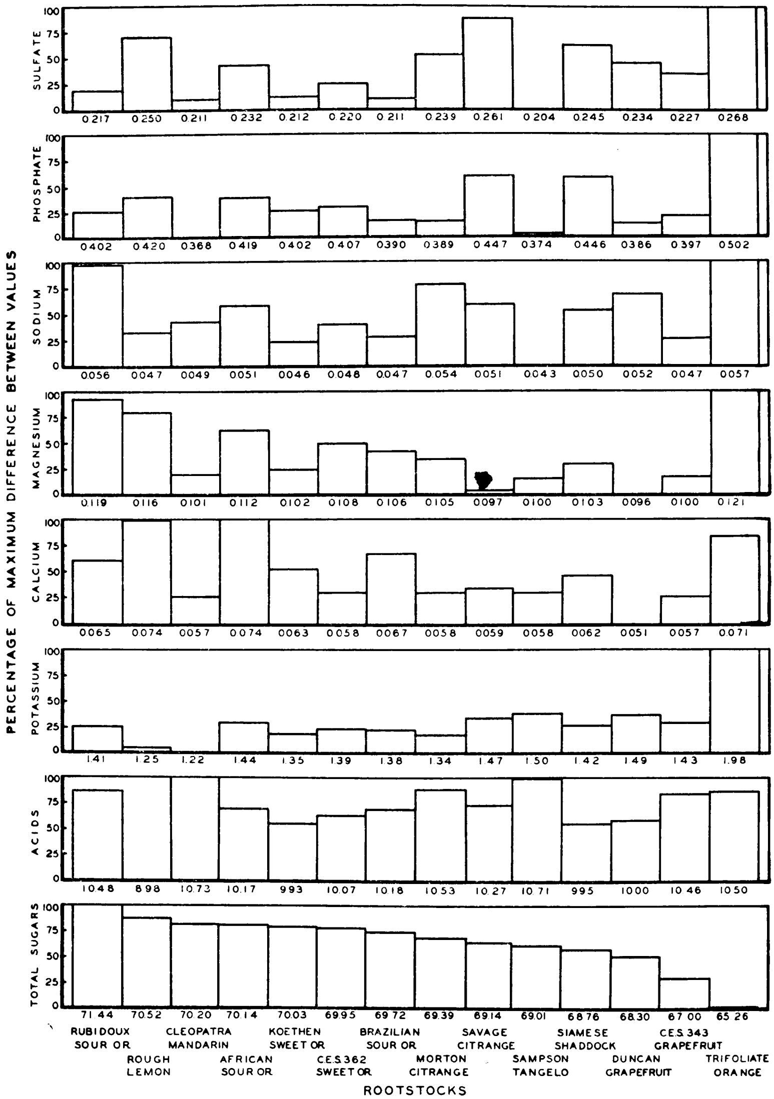

Fig. 16.—The relation between total sugars, total acids, and inorganic constituents of the juice of Washington Navel fruits from the rootstock plots at Riverside. The actual percentages of the various constituents, determined on samples from the different rootstocks (dry-weight basis), are placed below each column. For each constituent the "maximum difference" is the difference between the highest and lowest values shown for that constituent. Each column represents a proportional part (percentage) of the maximum difference, for a specified rootstock.

In samples from the Riverside plots (fig. 17), grapefruits from Trifoliate stock had the highest percentage of total sugars, and those from Sampson tangelo the lowest (dry-weight basis). The Trifoliate samples had the lowest

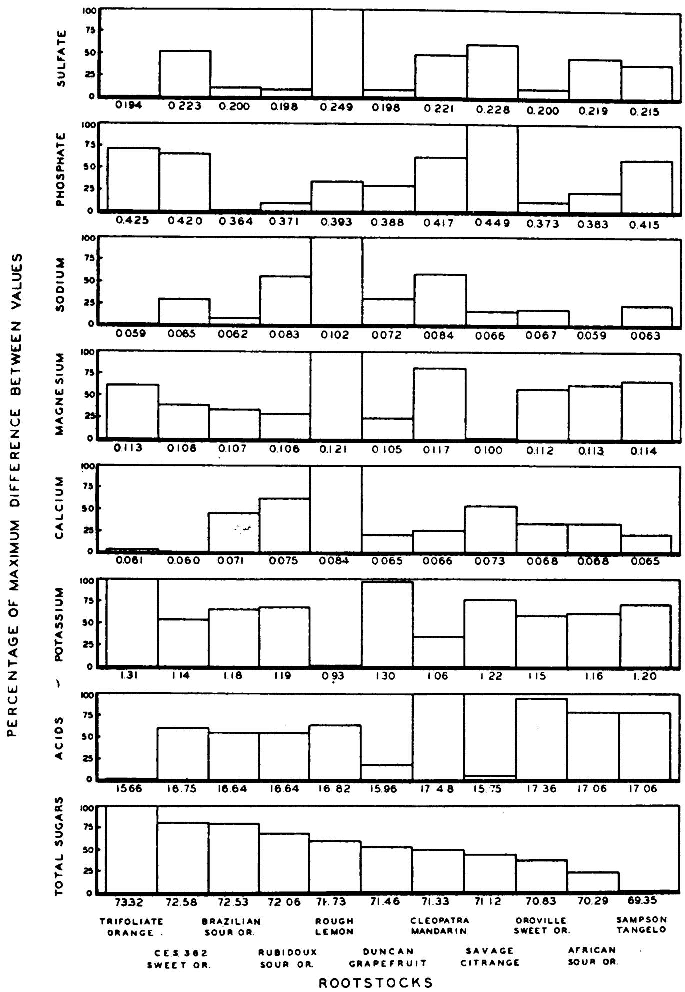

Fig.17.—The relation between total sugars, total acids, and inorganic constituents of the juice of grapefruit from the rootstock plots at Riverside. The actual percentages of the various constituents, determined on samples from the different rootstocks (dry-weight basis), are placed below each column. For each constituent the "maximum difference" is the difference between the highest and lowest values shown for that constituent. Each column represents a proportional part (percentage) of the maximum difference, for a specified rootstock. Compare with similar data on juice of grapefruit from the rootstock plots at Brawley (fig. 18).

amount of acid (dry-weight basis). Although fruits from the Rough lemon proved to be intermediate in sugar and in acid concentration, they nevertheless contained the highest concentrations of calcium, magnesium, sodium, and sulfate.

In the corresponding grapefruit plots at Brawley (fig. 18), fruit samples from Duncan-grapefruit stock had the highest concentration of total sugars, and those from Cleopatra mandarin the lowest. Samples from Savage-citrange

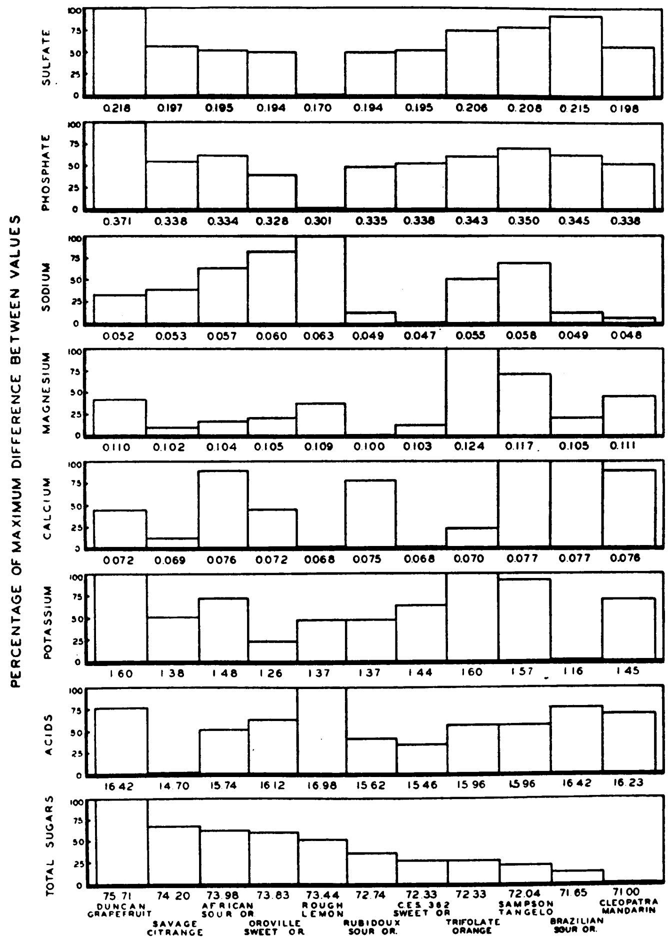

Fig. 18.—The relation between total sugars, total acids, and inorganic constituents of the juice of grapefruit from the rootstock plots at Brawley. The actual percentages of the various constituents, determined on samples from the different rootstocks (dry-weight basis), are placed below each column. For each constituent the "maximum difference" is the difference between the highest and lowest values shown for that constituent. Each column represents a proportional part (percentage) of the maximum difference, for a specified rootstock. Compare with similar data on juice of grapefruit from the rootstock plots at Riverside (fig. 17).

stock had the lowest percentage of total acids, and those from Rough lemon, oddly enough, the greatest amount. In this series, samples from Rough lemon had the highest amount of sodium, and those from Trifoliate orange the highest amounts of potassium and magnesium.

As previously stated, these were not fertilizer experiments, and no attempt was made to evaluate the differential fertilizer treatments of the plots. These data, however, are in accord with those of Parker and Batchelor (*30*), who showed that the total soluble solids and total acidity of the fruit were not influenced by changes in fertilizer practice.

DISCUSSION

The results of the present investigation substantiate earlier findings that the rootstock sometimes influences fruit composition, and that citrus varieties on Rough lemon in particular, usually have a low concentration of total soluble solids in the juice. The low concentrations of soluble constituents in samples from Rough-lemon stock were not confined solely to the juice, but also occurred in the peel and pulp. The dry-matter percentages were usually lowest in the peel and pulp of oranges and grapefruit samples from the Rough-lemon stock. The total-ash content was also lowest in the peel and juice of fruits from Rough lemon.

Considering the other extreme, the highest concentrations of total soluble solids in different portions of the fruit usually occurred in samples from the Morton- and Savage-citrange stocks, or from the Trifoliate-orange stocks. With Washington-Navel-orange samples picked at intervals during the season, the juice of those from Morton-citrange stock had the highest total soluble solids and total sugars. The dry-matter content was highest in peel, pulp, and juice of mature fruits from Savage citrange. In grapefruit from the Riverside plots, the dry-matter content in the peel, pulp, and juice in samples from Savage citrange and from Trifoliate orange were about equal, and higher than those of others of the rootstock group. Similar results were obtained on fruit samples from the Valencia plots at Riverside and Tustin. It can be seen, therefore, that with the exception of fruits from Palestine-sweet-lime stock in the Riverside plots, the concentrations of the various chemical constituents were lowest in fruits from Rough-lemon stocks and highest in fruits from Morton- and Savage-citrange stocks, with Trifoliate orange close behind.

In a previous publication (*5*), the relations between total soluble solids and various soluble constituents of orange juice were reported in detail. It was pointed out that the sugars are the chief soluble constituents in the juice, but that the remaining soluble material, composed principally of acids, salts, amino acids, and pectins, varies with the amount of total soluble solids. Attention was also drawn to the fact that concentrations of total soluble solids, total sugars, and reducing sugars increased at about the same rate, and that the acids decreased, with the advance of the season.

In the present studies, there is a high positive correlation between total sugars and total soluble solids in the juice of oranges from different rootstocks. The same relation is evidenced by the consistently high ratios of sugars to solids; also by the distribution of dots in a diagram in which the two constituents were plotted against each other, though a noticeable scattering of points occurred. There is also a direct relation between total soluble solids and reducing sugars, but considerably greater scattering of the points occurred. On the other hand, the concentration of total acids decreased during ripening, with an increase in total soluble solids; and large fluctuations in acids occurred without change in the total soluble solids, and vice versa.

The results of these investigations clearly demonstrate the dynamic nature of citrus fruits. Within the fruit many chemical reactions are proceeding at different rates as a result of metabolic activity. The compounds found in the fruit are the result of these chemical reactions. The rates of some of these reactions are comparatively slow, whereas others are fast. These reactions may proceed at different rates in different fruits. The rates depend upon many factors within the plant and fruit, as well as upon climatic factors of temperature and humidity, which vastly affect the rate at which these materials are produced in the fruit. This was made evident by the *variation* of the total soluble solids with the other constituents in the fruit. In the advanced stage of maturity, while the fruit is still on the tree, softening of the tissues occurs, with corresponding changes in the amount and distribution of water; the tissues dry, and disintegration of the fruit follows.

The relation of the pH value to the titratable acidity of orange juice is important because it is, in general, associated with fruit maturity; also because large changes in acid concentrations can occur with only very slight changes in pH (fig. 8). An inspection of figure 8 shows that, at a given pH value, the juice may have various concentrations of total acids. If a narrow range of acid concentration is chosen (for example, a range of 0.70 to 1.00 per cent, such as often occurs in fruit that is commercially mature) it is difficult to detect a direct relation between pH and total acidity. Over the total range of acid (0.70 to 2.60 per cent) shown in figure 8, however, the pH tends to decrease with an increase in concentration of acid. The relation of pH to titratable acidity thus depends upon the acid range. The stability of pH in orange juice, which is due to the buffer action, is exhibited to a greater or lesser degree by most acid fruits. A quantitative measure of this characteristic may be obtained by observing the change in pH value of the juice upon the addition of increments of standard NaOH (*5*).

Other investigators, with other fruits, have found varying degrees of correlation between pH and titratable acidity. In studies with 33 varieties of mature Minnesota apples, Barnes (*3*) obtained a high correlation coefficient ($r = 0.9265$) between titratable acidity and hydrogen-ion concentration of the juice; with 11 varieties of mature grapes, a high correlation ($r = 0.9213$) was also obtained; with 11 varieties of plums at different stages of maturation, the correlation was much lower ($r = 0.6198$). Askew (*1*), on the other hand, did not find a definite relation between pH and titratable acidity (total acids) of mature apple juice.

The inorganic content of plants is influenced by many factors that are not completely understood. The voluminous investigations (*7*) reported on this subject reveal the complexity of the problem. Without attempting to evaluate these factors, it can be said that, in general, the mineral composition of plants is influenced by their age and variety, and by climate, soil, fertilizers, and many other factors of more or less importance. With respect to citrus, some of these factors have been investigated. Kelley and Cummins (*25*) noted that the composition of orange leaves changed rapidly with age. The proportion of dry matter existing as calcium changed from 1.36 per cent in leaves 1 week of age, to 7.36 per cent in very old leaves. Changes in a similar direction were noted for the dry matter and total ash. It was shown in the present investigations that many of the soluble constituents of orange fruits, such as reducing and total sugars and ash, increased with age, while the concentration of acid decreased.

Young (*42*) has noted that the application of phosphorus and potassium fertilizers to the soil did not increase the amounts of these materials in orange fruits. But according to Parker and Batchelor (*30*), fruits from trees in plots that had received phosphorus and potassium for a period of five years, were higher in these constituents than fruits from untreated trees. These differences in fertilizer treatments, however, did not influence the total-soluble-solids and total-acids contents of the fruit.

The total mineral constituents (*7*) in vegetative portions of most plants apparently respond to climatic and soil changes more readily than do those in the fruit. Although plants obtain their mineral constituents from the soil, the climatic environment affects the metabolic rates of transpiration, respiration, and photosynthesis to the extent that differences occur in plants grown on identical soils. Fudge and Fehmerling (*15*) have drawn attention to the fact that rootstocks, soil, and fertilizers effect changes in the organic composition of citrus fruits. Their experiments were performed on two rootstock varieties only, Rough lemon and sour orange.

Probably the fruit samples from the different stocks should not be expected to vary greatly in mineral content; for Fudge (*14*) observed that excessive amounts of fertilizers had to be applied to the soil to effect a small change in the mineral composition of citrus-fruit juices; and St. John *et al.* (*34*) have shown that fertilizer treatments of the soil had little effect on the mineral and carbohydrate composition of apples.

In comparing data on fruit from any of the stocks grown in two different environments, the fruit must be in the same stage of maturity. The ripening of orange fruits involves the formation and elaboration of large quantities of chemical materials, and these substances are not all formed at the same rate. To determine what constitutes commercial maturity from a biochemical point of view is therefore an important but difficult problem. At best, it means the selection of the fruit at a time when certain reactions are at a maximum and others are at a minimum, and before still other undesirable reactions are initiated.

That maturity of citrus fruit on a given date, as measured by its chemical composition, is affected by the conditions under which it is grown is strikingly demonstrated by the data presented in figure 4. These show that the various soluble constituents in Valencia fruits picked in July of each of three years, from the Riverside plots, were greater than those in similar samples from the Tustin plots. The variations in fruit composition due to location are about as great as those due to rootstock. These relative differences in fruit samples from the two locations persisted to September 22, which was the latest date upon which samples were taken (see table 3).

Grapefruit is outstanding in the difference in time required for fruit to mature under different climatic conditions. Buds on grapefruit trees come to full bloom and set fruit at approximately the same time at Riverside and at Brawley, but about 13 months are required to mature the fruit at Riverside, and only about 7 to 8 months at Brawley. The shortening of the time required for grapefruit to reach maturity at Brawley is due chiefly to the excessive heat units, which accelerate the reactions involved in growth and in elaboration of food materials.

A similar situation exists in the deciduous-fruit-growing regions of California. The time required to mature most deciduous fruits—that is, the time from full bloom to maturity—varies greatly with the climate and region. This is demonstrated by the results of Tufts (*37*), who showed that differences in temperature in two locations, only 14 miles apart, caused a 30-day difference in the rate of ripening apricots. Davis and Tufts (*10*) also reported a difference of 2 to 2½ months in the time required to mature Bartlett pears in the earliest- and latest-ripening districts. The importance of temperature to fruit growth is strikingly illustrated by Lilleland's (*27*) experiments on apricots. By exposing attached fruits to higher temperatures, within a shelter, without altering the natural environment and growth of other portions of the tree, he was able to terminate the depressed period of growth 28 days in advance of the fruit outside and thus to shorten the time between bloom and harvest by that amount.

Investigators in other parts of the United States have not found such great differences in time intervals between full bloom and maturity of various fruits. This is probably because climate during the growing season varies less there. For example, Magness *et al.* (*28*), working with apples, have drawn attention to the consistency of the time intervals between full bloom and the best picking date in different years. Haller (*19*) has found that, within the regions studied and for a given variety of apple, the locality and seasonal variations did not greatly alter the time interval between full bloom and the earliest possible picking maturity. In an extended study of many varieties of apples, pears, peaches, and cherries in New York state, Tukey (*38*) observed that each variety had a remarkably constant time interval between full bloom and full maturity.

Within a limited climatic environment, the time interval between full bloom and maturity of citrus fruits would very probably approximate a constant over a period of several years. In California, however, citrus is grown under widely different climatic conditions, ranging from the very hot, dry climate of the desert valleys to the temperate, rather humid climate of the coastal regions. As previously noted, such differences in climatic conditions would markedly affect the rates of the biochemical reactions occurring in the fruit during development and maturation. This means that the time interval between full bloom and maturity might be greatly altered by the climate. In connection with this problem, it should be mentioned that the citrus tree is an evergreen and does not have a rest period comparable with that of deciduous trees. Citrus has a very long growing season, and some varieties, such as the lemon, may bloom and produce fruit the year round.

SUMMARY

The experimental data reported in this paper are the results of seven years' investigations on the composition of fruits of Valencia orange, Washington Navel orange, and Marsh grapefruit, grown on various rootstocks and under different environmental conditions. For each variety and location, the

fruit samples on which analytical determinations were made came from the same rootstock plots during the entire experimental period.

Seasonal changes in concentration of the soluble constituents of Valencia and Navel fruits from different rootstocks were followed by determining the total soluble solids, total sugars, reducing sugars, and acids on samples picked from the plots at intervals during a single season.

Annual and seasonal variations in fruit composition caused by environmental factors were demonstrated by determining the total soluble solids, total sugars, and total acids in the juice of Valencia fruit picked in two widely separated locations at approximately the same date in each of three years. Similar experiments were carried out on grapefruit from two different locations, for two years.

Inorganic constituents were determined on the peel, pulp, and juice of mature Valencia, Navel, and grapefruit samples from the various rootstocks and locations.

With the change in soluble constituents as an index to the rate of development of the fruit, it has been shown that Valencia fruits from the various stocks in the Riverside plots (inland district) matured, as measured by the eight-to-one standard maturity test, slightly in advance of those from the rootstock plots at Tustin (coastal district). By sampling the fruit from the different stocks at intervals, it was shown that, in the early part of the season (May 9 to 12, 1939), fruits from the Riverside plots were only slightly higher than those from the Tustin plots in concentrations of total soluble solids, total sugars, and reducing sugars; but the results of analyses on mid- and late-season samples, collected in July and September, respectively, showed that, with the advance of the season, the soluble constituents accumulated in greater amounts in the Riverside fruit than in the Tustin fruit. The additional amounts of sunshine and the higher mean temperatures in the inland district during late spring and summer produced favorable conditions for increased photosynthetic activity and resulted in increased accumulation of soluble carbohydrates in the fruit.

With all three scion varieties, the highest amount of chemical substances in peel, pulp, and juice of the fruit was found, usually, in samples from Morton- and Savage-citrange and Trifoliate-orange rootstocks; the lowest values, except for limited data reported for Palestine sweet lime, were obtained in samples from Rough-lemon stock. The results on fruits from the other rootstocks fell between these extremes, and the data were so closely grouped that no real differences could be observed.

Total sugars and acids, as percentages of the total soluble solids in the juice of fruit samples from the different rootstocks, bore no relation to the mineral constituents.

There was a high correlation between total soluble solids and total sugars in orange juice of both varieties. The fraction of total soluble solids existing as total sugars is not influenced by the rootstock.

Although the total acids decreased during the growth and ripening of the oranges, while total solids increased, large fluctuations in total acids occurred without change in the total soluble solids, and vice versa. Owing to the relatively high buffer capacity of orange juice, large fluctuations in total acidity occurred without change in pH; but over a wide range of acid concentration (0.70 to 2.60 per cent), the pH increased with a decrease in total acidity.

The dry matter, as a percentage of the fresh weight, was significantly higher in the peel, pulp, and juice of Valencia fruit samples from the Riverside plots (inland district) than in those from the Tustin plots (coastal district). The total ash, on a dry-weight basis, in the peel, pulp, and juice was about the same in samples from the two districts.

In grapefruit, the mean dry matter and total ash were significantly higher in the peel and pulp of fruit samples from Brawley than in those from Riverside. The mean dry-matter content of the juice was about the same in samples from the two districts, but the total ash was much higher in the juice samples from the Brawley plots.

With all rootstocks, the inorganic constituents comprised different proportions of the total ash of the peel, of the pulp, and of the juice of fruits. The highest percentages of calcium occurred in the ash of the peel of all three scion varieties from all the stocks. The amount of magnesium (ash-weight basis) was, on the average, slightly higher in the peel than in either the pulp or the juice of Valencias (both districts) and Navels. In grapefruit the percentage of magnesium was slightly higher in the juice. This slight difference was not evident when calculations of magnesium were made on a dry-weight basis. In oranges and grapefruit from all the rootstocks, potassium composed 15 to 20 per cent of the total ash of the peel, approximately 30 per cent of the total ash of the pulp, and more than 40 per cent of that of the juice. The amount of sodium in these portions of the fruit, from all rootstocks, was less than 3 per cent of the total ash and less than 0.1 per cent of the dry weight. Phosphates, in fruit samples from all rootstocks, were higher in the pulp and juice than in the peel.

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