A COMPARATIVE STUDY OF THE STRUCTURE AND COMPOSITION OF SEEDLING AND SCION ROOTS OF THE APPLE

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Frank N. Hewetson

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THESIS

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Introduction

In recent years there has been considerable controversy as to whether the root or the stem exerts the greater influence upon the character of the tree. Hatton and his associates (7) believe that the root system, which in his experiments consists of scion or adventitious roots arising from the stem of layered shoots, controls the growth and dominates the scion variety. Roberts (21), on the other hand, thinks that the stem or trunk has more influence on the character of the tree than the seedling roots upon which it was grafted. The conditions of the experiments were not entirely comparable because of the difference in the type of root used in the experiments. However, an understanding of the differences in the composition of the seedling and scion roots and the relationship which each bears to the composition of the stem may indicate that both viewpoints are correct and thus help to conciliate the two ideas.

Review of Literature

A study of the literature has not revealed any direct references to the problem taken up in this thesis, but a short discussion of the observations recorded by the various writers on the behavior of seedling and scion-rooted plants may prove of interest.

The idea has long been held by gardeners that seedling-rooted or grafted plants are more vigorous than those grown on their own roots. Burbidge (3) cites several observations to prove this point. Cobbett (6), Malet (13), Thirion (25), Schmidt (22), Rivers (20), "J. T." (9), Bailey and Munson (2) and Marcille (14) all believe that seedlings are healthier and produce larger plants than those which are grown on their own adventitious roots. On the other hand, many writers - Loudon (12), "Celine" (4), "J. G." (8), Bailey and Corbett (1), Pynaert (18), Schneider (23) and Molisch (16) claim that plants on their own adventitious roots come into bearing quicker and are more productive than seedlings. These divergent opinions can be explained when it is realized that those favoring seedling roots are chiefly interested in the production of large plants; on the other hand, those holding that own-rooted plants are better, judge superiority by the amount and precocity of fruiting. This precocity of fruiting with adventitious-rooted plants is probably due to the greater maturity of the stems as compared to the roots of these plants, whereas the vegetative stage in seedling development is a necessary precursor of maturity and fruit production. It is well known, and has been proved by Murneek (17), that fruiting is a dwarfing process, so that own-rooted trees which produce fruit will naturally be small plants. Recently Lagassee (10, 11) compared the growth of a number of apple varieties on seedling roots and on their own roots and found that the own-rooted trees were becoming more uniform as they grew older, without losing anything in vigor. From his data he concluded that the results were in favor of scion-rooted trees.

The above observations show the need for growing seedlings and own-rooted plants under identical conditions so that a fair comparison can be made of the relative vigor and precocity of each.

Material

The material used in this study was grown in the college orchard of Michigan State College. The seed which produced the trees was sown in the spring of 1924 in the college nursery. Four average sized trees resulting from this planting were set out, and in 1928 a branch from each tree was layered by bending it down to ground level and mounding it up with earth. In the spring of 1930 this branch was separated from the parent tree. By this time a sufficient number of roots had developed to maintain the branch as an individual tree. There was thus, for comparison, a seedling tree on its natural (seedling) roots, and one on its scion or adventitious roots. There were four such pairs of trees planted out so that in each pair the scion-rooted tree was next to its parent tree. In this study, two such pairs were used, making four trees in all.

Methods

Collection and Preparation of Material:

The four trees used in this experiment were excavated in December, 1935, sufficient roots being taken for analysis. The material was immediately brought inside in damp sacks and stored in a cool laboratory. As soon as possible, the roots were washed free from dirt and immediately graded according to diameter as follows: 0-1 mm., 1-5 mm., 5-10 mm. A root which included two or more grades was divided into the various grades which it included, the finer roots being first removed, and then the larger ones divided according to diameter. After all the roots from a tree had been washed and graded, they were cut up into 1/4 - 1/2" lengths, placed in covered beakers, and weighed as quickly as possible. Drying was done at 90 degrees Fahrenheit for one-two hours and then at 70 degrees Fahrenheit until the material had reached a constant weight. Samples were ground in an electric grinder and finished by means of a pestle and mortar until all the material could pass through a 60-mesh sieve. One-year wood was also collected, dried and ground as above, except, of course, that it was not washed. Second and third grade roots (1-5 and 5-10 mm.) and one-year old stems were used for analysis.

Analysis:

Composition of the material was determined by analysing for reducing sugars, total sugars, starch, hemicellulose, nitrogen, phosphorous and potassium. Moisture determinations were also made on the material.

Structure was studied by the use of cross sections, 20 microns in thickness, and stained with safranin and light green. (5)

The Quisumbing and Thomas method (19) was used for heating the mixture of sugar and Fehlings solution, while the volumetric thiosulphate method (15) was used for estimating the amount of precipitated copper. Starch was converted to reducing sugars by the use of 10 c.c. of saliva and subsequent hydrolysis with concentrated sulphuric acid.

Preliminary comparisons of three methods for determining the amount of precipitated copper were made in the winter of 1934-5. These methods included the Shaffer-Hartman (24), volumetric potassium permanganate (15), and the volumetric thiosulphate method. The alcoholic extract of fibrous apple roots was used for purposes of comparison. The results are recorded in Table I and show that the results obtained from the Shaffer-Hartman method were about double those of either of the other methods. The high results obtained with the Shaffer-Hartman method have also been found by other workers in this laboratory. A further comparison was carried out in the fall of 1935. This time the volumetric potassium permanganate and the volumetric thiosulphate methods were compared with the gravimetric method, using a 0.100 per cent standard glucose solution. While the gravimetric method gave the greatest recovery, as shown in Table I, the results obtained by using the volumetric thiosulphate method were nearly as high. As in the first preliminary comparison, the volumetric potassium permanganate method gave the lowest result.

Table I

METHODS OF ANALYSIS

Method	Results	
	1934-5	1935
	(Fibrous apple roots) (% Dry Weight)	(0.100% glucose solution)
Shaffer-Hartman	7.981	-
Volumetric Thiosulphate	4.030	0.09436 %
Volumetric Potassium Permanganate	3.826	0.0886 %
Gravimetric	-	0.0953 %

The preliminary comparisons of 1934-5 eliminated the Shaffer-Hartman method for this type of material because it gives results which were too high. The combined work of 1934-5 and 1935 have shown the advisability of using the volumetric thiosulphate method in preference to the potassium permanganate one, as the former gave slightly higher results than the latter in both years, and was nearer the figure for the standard solution in the second comparison.

The effect of clearing on reducing power of the alcoholic extract was determined. Different amounts of neutral lead acetate were used in clearing the solution and compared with uncleared solution. Di-sodium phosphate was used as a deleading agent. The results are recorded in Table II and show the extent to which different amounts of lead acetate clear the solution and carry down foreign materials which have the power to reduce copper. Though clearing lowers the results, this is probably due to the removal of foreign materials which are not sugars and which should not therefore be included under this heading. Three cc. of neutral lead acetate was considered sufficient to clear the solution. Nitrogen determinations were made by the Kjeldahl-Gunning-Arnold method (15). Phosphorous and potassium analyses were made by the Experiment Station chemist.

Table II

EFFECT OF CLEARING ON REDUCING POWER OF SOLUTION

Treatment	Reducing sugar
Uncleared	3.88
1 cc neutral lead acetate	3.24
3 cc neutral lead acetate	3.24

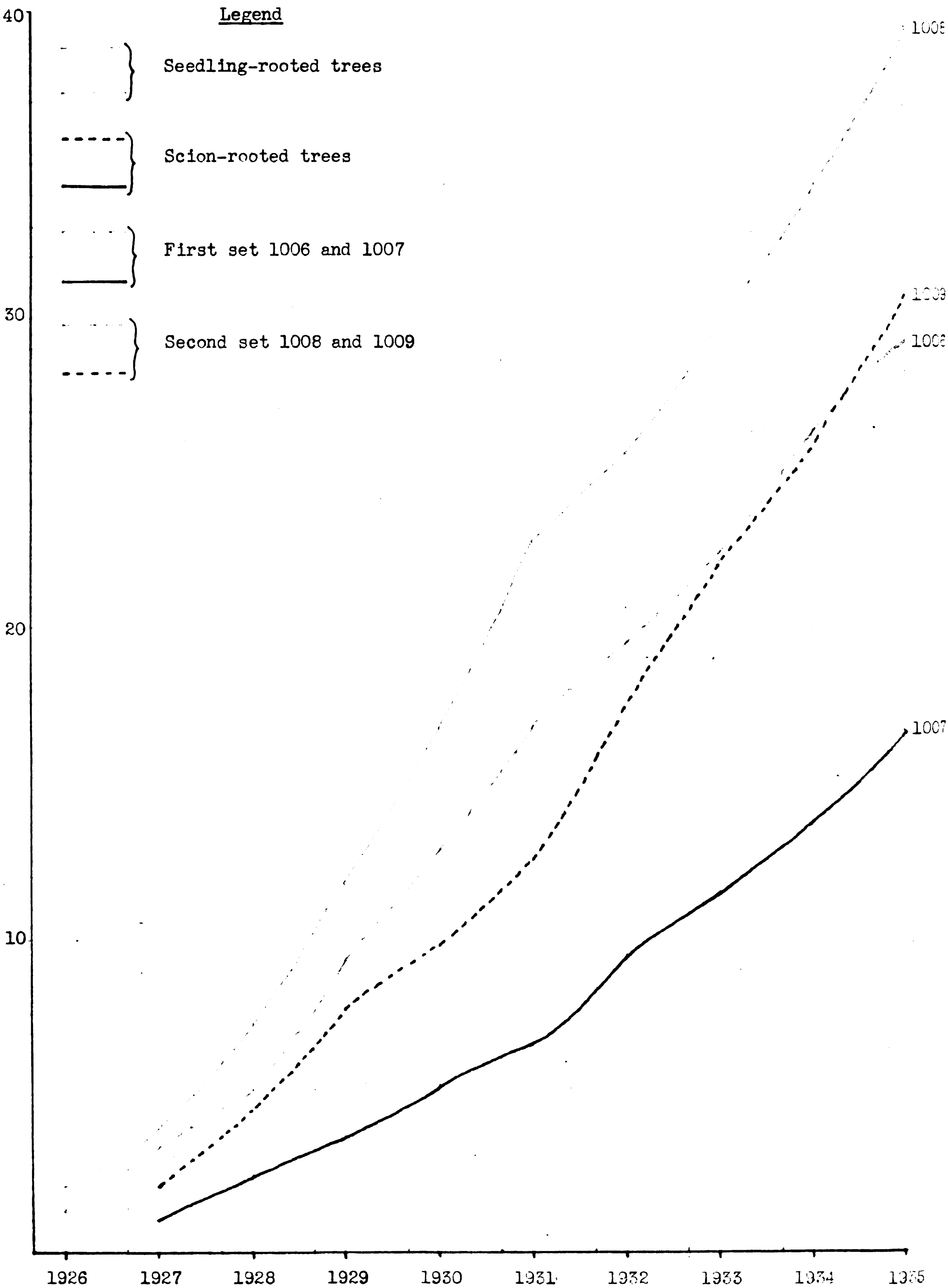

Fig. I. ANNUAL GROWTH OF SEEDLING AND SCION ROOTED APPLE TREES

Results

Tree Measurements and Characteristics:

Table III and Fig. I show the various measurements recorded for the four trees included in this experiment.

Table III

TREE MEASUREMENTS

Tree No.	Tree Type	Weight (portion above ground level) (lbs.)	Area Trunk Cross Section (sq. cm.)
1006	seedling-rooted	10.8	24.04
1007	scion-rooted	3.2	8.77
1008	seedling-rooted	24.0	38.52
1009	scion-rooted	11.7	25.78

Circumference measurements were taken at one foot above ground level and afterwards converted into area trunk cross section. The yearly growth was found by recording the annual rings on four radii at right angles to one another and averaging these figures. While there was considerable difference in weight and area of trunk cross section of seedling and scion rooted trees as between each pair, it is interesting to note that one seedling rooted tree (No. 1006) and one scion rooted tree (No. 1009) are comparable as to size and might be used for comparison. Fig. I shows how the seedling-rooted trees gained their lead in 1929 at the expense of the scion-rooted trees, but also shows how, since 1931, the scion-rooted trees maintained their relative position after having overcome their original set back. Up to 1930 the scion-rooted tree was attached to the parent seedling tree, and, being a subordinate branch, could not be expected to attain the same size as the leader. The parallel growth after 1931 indicates that after that year the scion rooted tree grew just as well as the seedling rooted tree, when the difference in age was taken into consideration, and also shows that the growth rates are somewhat similar.

There was little difference in the general form of seedling and scion-rooted trees, except that which could be ascribed to differences in age and size, such as greater abundance of branches in the seedling-rooted trees. The root system of the scion-rooted trees was characterized by a horizontal main root (the original layer) from which arose the scion roots. In contrast, the seedling-rooted trees possessed a well developed symmetrical root system. In the first pair of trees there was a greater number of small roots on the seedling-rooted tree (No. 1006) than on the scion-rooted tree (No. 1007), but in the second pair (Nos. 1008 and 1009) there was no marked difference. The difference in the first pair was probably due to the smaller size of these trees, as the second scion-rooted tree (No. 1009) had about as many small roots as the corresponding seedling-rooted tree (No. 1008).

Moisture:

Percentage moisture determinations are shown in Table IV.

Table IV

PERCENTAGE MOISTURE IN ROOTS AND STEMS OF ALL TREES

Roots (Diam.)	1006 seedling-rooted	1007 scion-rooted	1008 seedling-rooted	1009 scion-rooted
0-1 mm.	60.873	62.210	59.611	58.891
1-5 mm.	61.402	60.181	57.640	57.866
5-10 mm.	60.051	58.796	56.458	57.517
AVERAGE	60.775	60.396	57.903	58.091
Stems (Age)				
1 yr.	50.719	50.928	50.931	50.880
2 yrs.	49.766	50.106	48.988	50.046
3 yrs.	48.626	49.334	47.722	48.401
AVERAGE	49.703	50.123	49.213	49.776

These figures reveal no differences as between scion and seedling roots, though they do show a consistent difference between the roots of the two sets of trees, suggesting that seedling roots may vary in moisture content. The percentage moisture of the stems is practically the same, irrespective of which set is considered, or whether seedling or scion rooted trees are compared.

Carbohydrates:

The results of the carbohydrate analyses are shown in Table V. A comparison of the amount of reducing sugar in seedling and scion roots showed in every case a greater amount of this carbohydrate in the scion roots than in the seedling roots. The average ratio between seedling and scion roots was 1.411 for the first set (Nos. 1006 and 1007) and 1.381 for the second set (Nos. 1008 and 1009), which is about the same in each case. The reducing sugar content of the stems of seedling and scion-rooted trees was the same for all trees. A comparison of these figures also showed that, for roots of equal size, the reducing sugar contents of the stems and roots of scion-rooted trees were more nearly the same than in the case of the stems and roots of seedling-rooted trees.

The starch analysis also revealed some interesting relationships. In each pair of trees there was less starch in the scion-rooted trees than in the corresponding seedling-rooted tree.

Table V.

CARBOHYDRATE ANALYSES OF STEMS AND ROOTS

OF SEEDLING AND SCION ROOTED TREES

(All reported as glucose)

(% Dry Weight)

Carbohydrate	Tree						
	1006 seedling rooted	1007 scion rooted	Ratio	1008 seedling rooted	1009 scion rooted	Ratio	Average
Reducing sugar							
Roots 1-5	3.2406	4.4539	1.374	3.2299	4.0875	1.266	1.320
" 5-10	2.5159	3.6410	1.447	2.6154	3.9145	1.496	1.4725
" average			1.411			1.381	1.396
Stems 1 yr.	4.4756	4.4944	1.004	4.2687	4.2266	0.990	0.997
Total sugars							
Roots 1-5	4.3179	5.0988	1.181	4.7272	4.9949	1.056	1.119
" 5-10	3.3644	3.9276	1.167	3.7776	4.0227	1.065	1.116
" average			1.174			1.061	1.117
Stems	4.2945	4.8492	1.129	4.8056	4.5814	0.953	1.041
Starch							
Roots 1-5	6.7966	6.3585	0.9356	8.5465	6.2252	0.728	0.832
" 5-10	7.4113	6.3611	0.858	8.8776	6.9604	0.784	0.821
" average			0.897			0.756	0.826
Hemi-cellulose							
Roots 1-5	12.1023	12.7316	1.052	13.9808	12.6890	0.908	0.980
" 5-10	13.7685	13.5740	0.986	12.7282	13.9342	1.094	1.040
" average			1.019			1.001	1.010
Stems	14.5743	13.7611	.944				

This difference really confirms the reducing sugar analysis, in that starch is converted to glucose. The less starch there is in a certain tissue, the more glucose one would expect to find. The sum total of reducing sugar and starch are about the same in seedling and scion roots. The slightly higher figure for the combined carbohydrates in No. 1008 was due to the larger amount of starch in this tree, probably on account of its larger size.

Comparisons of total sugars and hemi-cellulose reveal no consistent differences between seedling and scion roots, apart from the slightly larger amount of total sugars in scion roots consequent upon the greater amount of reducing sugar in the scion roots.

Nitrogen:

There was no significant difference in amount of nitrogen in the seedling and scion roots, or between the two pairs of trees, as shown in Table VI. The difference in amount of nitrogen in the stems of the first and second pair cannot be explained.

Table VI.

TOTAL NITROGEN
(% Dry Weight)

TREE	STEM	ROOT	
	1 yr.	1-5 mm. diam.	5-10 mm. diam.
1006	0.955	0.625	0.662
1007	0.891	0.606	0.566
1008	0.671	0.579	0.568
1009	0.564	0.675	0.559

Mineral Contents:

Table VII. shows the analysis of roots and stems of seedling and scion-rooted trees for phosphorous and potassium. In every comparison between seedling and scion roots, there is a larger amount of both phosphorous and potassium in the scion roots than in the seedling roots. There is also a closer relationship between scion roots and stems than between seedling roots and stems on the basis of mineral composition. The composition of the stems serves as a valuable check on this relationship, for in every case the mineral composition of comparable seedling and scion-rooted trees is the same.

Structure:

A somewhat hasty observation of the cross sections prepared from the four trees did not reveal any outstanding structural differences between seedling and scion roots as regards proportion of xylem to phloem, thickness of cell walls, or root origin.

Table VII

MINERAL ANALYSES

of

STEMS AND ROOTS OF SEEDLING AND SCION ROOTED TREES

Mineral	Tree					
	1006 seedling rooted	1007 scion rooted	Ratio	1008 seedling rooted	1009 scion rooted	Ratio
	(% Dry Weight)	(% Dry Weight)		(% Dry Weight)	(% Dry Weight)	
Phosphorous						
Roots 1-5	0.118	0.148	1.254	0.076	0.114	1.500
" 5-10	0.092	0.168	1.826	0.108	0.114	1.055
" average			1.540			1.277
Stems 1 yr.	0.186	0.184	0.9891	0.102	0.104	1.0196
Potassium						
Roots 1-5	0.459	0.507	1.1046	0.285	0.458	1.6070
" 5-10	0.357	0.517	1.4481	0.351	0.389	1.1083
" average			1.2764			1.3577
Stems 1 yr.	0.509	0.479	0.9410	0.399	0.400	1.0025

Discussion

The results of this investigation have revealed a difference between seedling and scion-rooted trees used in this experiment in respect to the amount of reducing sugars and starch, phosphorus and potassium. While it was at first thought that the difference in size of the trees might explain these differences, a combined study of Tables III and V suggests that such is not the case. Trees No. 1006 and 1009 are about the same size, the first being seedling-rooted and the second being scion-rooted - No. 1006 being one year older than No. 1009. Comparison of the amount of reducing sugar of the roots of these two trees reveals the same relationship as between the original pair, which are very different in size. Again, with the starch content, the same relationship holds between Nos. 1006 and 1007 as between Nos. 1006 and 1009. The relationship between seedling and scion roots in respect to phosphorous and potassium are somewhat variable, though in each set there is a larger amount of those elements in the scion-rooted tree than in the seedling-rooted tree. A study of these results would suggest that size and age of the tree affect the mineral composition to a greater extent than they do the carbohydrate composition. The smaller sets (Nos. 1006 and 1007) have larger amounts of each mineral while the ratio between seedling and scion roots varies according to size of root and size of tree. The ratio of phosphorous in seedling to phosphorous in scion roots 1-5 mm. in diameter is higher in the larger set (Nos. 1008 and 1009). On the other hand, in the case of roots 5-10 mm. in diameter, it is higher in the smaller set of trees (Nos. 1006 and 1007). This relationship also holds for the potassium analyses.

Thompson (26) has shown that while there are certain differences in the phosphorous and potassium content of roots of various ages, these differences are not directly correlated with age after the first two to three years of growth. During these early years, however, there was a slight increase in mineral composition of the roots. One might therefore expect to find larger amounts of phosphorous and potassium in the seedling roots than in the scion roots. The results reported herein are, however, just the reverse and serve to confirm the differences revealed by the carbohydrate analyses.

A comparison of the figures for phosphorous and potassium indicate that these minerals fluctuate together in the same direction, roots having large amounts of P also having large amounts of K. This is shown rather well by comparing the ratios of comparable sets. Such results are contrary to those found by Wallace (27, 28) but conform to those of Thompson (26).

Though it is fully realized that results based on such a small number of trees cannot be given too much consideration, the constant relationship between the various trees with different grades of roots has in itself considerable significance. A study of Fig. I shows that the growth rates of the seedling and scion-rooted trees have been practically the same during the last few years, and that differences in the composition of the roots do not appear to be due merely to differences in growth rates. That no differences were found in the hemi-cellulose content of the different roots is not surprising, as this form of carbohydrate is only used for nutritional purposes when all the other reserve materials (chiefly starch) are exhausted. The fact that there is a larger amount of reducing sugar in the scion roots than in the seedling roots shows that the scion roots bear a closer relationship to the stem than do the seedling roots. This fact also suggests that scion roots have reached a greater degree of seasonal maturity than have the seedling roots. This resemblance in composition of scion roots and stems may throw some light on the hitherto contradictory results of Hatton and Roberts. If stems and scion roots have a somewhat similar composition, it is quite possible that they might exert a similar influence on the behavior of the tree grown thereon, and that in reality Hatton and Roberts are working with comparable material.

The lower amount of starch in the scion roots would be expected if the reducing sugar content is higher, as these carbohydrates are closely associated with each other.

Conclusions

The roots of seedling and scion-rooted trees from the same seedling differed in respect to reducing sugar, starch, phosphorous, and potassium. The results suggest that the relative size of the trees was not a factor influencing the amounts of these substances and indicate that there is a real difference between seedling and scion roots and a similarity between scion roots and stems. This similarity in composition may help to reconcile the differences of opinion as regards stem and scion root influence.

Summary

1. Two pairs of scion and seedling rooted trees were compared in respect to moisture, reducing sugars, total sugars, starch, hemi-cellulose, nitrogen, phosphorous and potassium.

2. No consistent differences were found in total sugars, hemi-cellulose or nitrogen.

3. Scion roots had more reducing sugar, phosphorous, and potassium and less starch than seedling roots.

4. The composition of scion roots in respect to reducing sugars, phosphorous and potassium bore a closer relationship to the composition of stems than did the seedling roots.

5. No difference was observed in the structure of seedling and scion roots.

6. The bearing that the findings here described may have on the question of stem and scion root influence on the behavior of the tree is discussed.

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