SOME ANATOMICAL RELATIONSHIPS OF ONE YEAR WOOD OF SELECTED APPLE ROOTSTOCKS

by

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INTRODUCTION

The extreme interest in apple rootstocks has been stimulated by the need for stocks possessing certain vigor traits, adaptable to particular soils and climate, compatible with the desired scion varieties and resistant to insects and diseases. The evaluation of existing stocks as well as the search for new ones opened a broad field of investigation.

Rootstocks performance was judged in most cases, by the failure or success of the scion variety to produce an thrive over a relatively long period of time. The studies were concerned in general with scion-stock relationship. In other cases the rootstocks themselves were tested and examined to determine their distinct characteristics. Such studies have been conducted at the East Malling Research Station in England as well as at several experiment stations in the United States (2) (3) (6) (17) (26).

A wide range of variability in the rate of growth within apple varieties and rootstocks has been noticed. Chandler (5) in his discussion on the rootstock and scion relationships pointed out that strong-growing scion varieties caused an increase in the rate of growth of weak-growing stocks, and that weak-growing stocks dwarfed strong-growing scion varieties. However, Roberts (26) found that vigorous scion varieties did not affect the growth characteristics of the clonal stock Malling-9 which is a dwarf. Hatton (17) after an extended period of testing and observation has divided the clonal Malling rootstocks, on the basis of the general growth responses of the scion varieties thereon, into four groups: very dwarfing, semidwarfing, vigorous and very vigorous. This is an arbitrary classification and may not be applied in some cases. For example, Roberts (26) and Gould (13) reported that a rootstock may induce some dwarfing under a particular set of growing conditions and yet the particular rootstock was not classified as a dwarfing stock.

Several attempts were made to find why some stocks dwarf scion varieties and others induce strong growth. The degree of compatibility between the stock and the scion variety was noted (26). Methods of training and pruning (13), the soil management practices and physiological factors have been examined and found to affect the rootstock growth and its influence on the scion variety. Anatomical structure of the roots and stems of some apple rootstocks and the scions thereon were examined as was the relation between the structure and the stock behavior (3). Bark-wood relationship, the size of the vessels and the area occupied by the various tissues have been related to growth behavior (2) (3) (23).

Winter hardiness and resistance to some insect injuries were explained on the basis of hardness of wood or the prevalence of other structural characteristics (1) (25).

The experiments conducted in this study were designed to examine the anatomical relationship of the one-year-old wood of selected apple rootstocks.

REVIEW OF LITERATURE

Roberts (26) has reported the influence of a piece of stem from a clonal stock upon the scion when used as an intermediate stem in double-worked trees. In his observations on the stock-scion relationship he noticed the type of roots and anatomy of the trees on seedling piece roots was affected by the scion variety; such influence was negligible when a clonal dwarf stock was used. However, Beakbane (2) reported a slight influence of the scion on the structure of clonal rootstocks. Thompson (30) studied the influence of nine varieties budded on Crab C rootstock and found that the greater the amount of the living tissue in the scion stem, the greater the amount of living tissue in the roots of the rootstock. Cobly (6) noticed a wider bark in Wealthy apple stems when they were worked on the dwarfing stock Malling IX than when it was worked on the vigorous stock M.XII.

Mosse (23) reported interesting results concerning the rootstock influence on the scion variety. Her experiments were mainly concerned with bark-wood relationship in apple stems. Five groups of rootstocks exhibiting various degrees of vigor, i.e. very vigorous, vigorous, intermediate dwarf and very dwarf, and five varieties were included in this study. One set of unworked stocks was also examined. Measurements of the bark percentage of the variety's stems were callipered at different ages until the trees were in production. The results of the study have shown a higher percentage of bark in relation to the wood portion in the dwarfing stocks, than in nondwarfing, and that such a characteristic is induced in the scion varieties grafted on them. The differences in bark percentages were striking in mature years.

Beakbane and Thompson (3) studied the root structure of some clonal apple rootstocks to which Cox's orange apple was budded. In an effort to compare the structure of roots of the vigorous and the dwarfing stocks, microscopic examinations of transverse sections were made. Their investigations indicated a close correlation between the percentage of bark in the roots and the vigor and precocity of the scion grafted on the rootstock. A relationship was also established between the size of the root and the bark percentage, the bigger the root the smaller the percentage of bark present. This relationship was more clear in the vigorous stocks.

It has been reported by Luce (22) that during the grafting process wood of the K-41 rootstock was relatively soft and easy to work with.

Kains and McQuesten (19) mentioned the results obtained by E. Leroux, a French investigator, who conducted his experiments with cider apples. Leroux's findings indicated that grafting was most successful when tender wood apples were worked on tender wood, and hard-wooded on soft-wooded. He found that success follows only rarely when a hard-wood is grafted on a tender-wooded stock. The tests by which hardness and tenderness were measured were not utilized.

Eames and McDaniels (7) in describing the wood in general, pointed out that the variations in the histological structure of the different species bring about the differences in wood properties. Variations in the presence or absence of certain tissues such as fibers, the arrangement of cells, the thickness of the cell wall, the diameter of cells and the chemical nature of the cell wall were all considered to impart certain wood properties. Specific gravity of the wood, for instance, is affected by thickness and nature of the cell wall and by the lumen space. The wood is expected to be dense and heavy when the lumen is small and vice versa. Mechanical strength is related to overlaping and amount of fibers present, and since the fibers have thick walls and a small lumen, therefore, a heavy or dense wood is expected to be strong. Wood properties are changed considerably with the amount of water content in the tissues.

There is not much published in the available literature about the properties of the wood of fruit trees.

Patrick (24) conducted specific gravity determinations on four varieties of apples in a comparative study between winter hardy and nonhardy varieties. The method used is not mentioned, however, wood specimens were not dried. Patrick stated that the differences in density were mainly dependent on the relative proportions of bark and pith to the wood, and that the density usually increased with the distance from the tip of twigs in most cases.

Beach and Allen (1) conducted several tests on apple varieties to determine the density, hardness and cutting of wood. The purpose of their investigations was to study the relationship between hardness and hardiness of apple wood against frost injury.

The material used in the study was collected from different localities ranging from warm regions in Arkansas to a cool one in Alaska. The method used for density determinations was the liquid displacement method in castor oil and the specimens were over dried. The compression test was used to measure the hardness of dry wood, because the green wood had split and could not be tested. A cutting device was made to measure the amount of pressure required to cut the stems of different varieties. These studies concluded that some correlation exists between hardness and hardiness, with some exceptions, and that the results of specific gravity tests of dry wood corresponded very closely with results of the mechanical test. It was also indicated that hardness was the same for varieties from different geographical locations with few exceptions. However, the specific gravity was affected with the part of the twig from which the specimens were taken.

Sharp (28) determined the densities of wheat grains using the liquid displacement method. Pycnometers were filled with toluene under controlled temperatures by means of a water bath. The wheat grains were dried and weighed. The air was occluded from the intercellular spaces of the grains under a reduced pressure. He found that moisture and air free specimens were essential in order to obtain representative densities of wheat. The pycnometers filled with toluene were weighed, then the grain specimens were added to the flasks and weighed again. The density was then calculated from the following equation:

$$\text{Density} = \frac{(\text{Weight of Wheat})\ \ (\text{Density of toluene})}{(\text{Weight of flask and toluene plus weight of wheat}) - \text{weight of flask containing wheat and toluene}}$$

Forest Products Laboratory (11) published a technical note in which several methods for the determination of the specific gravity of wood were listed. Immersion or water displacement, and flotation methods were recommended. The floatation method was found to be rapid but not accurate. To find the specific gravity of wood based upon volume when oven dry, the specimen is placed in an oven at about 100°C. until a constant weight is reached. The specimen is weighed and its volume is obtained either by measurement or by the displacement method. The specific gravity of a substance, which is its weight divided by the weight of an equal volume of water, is computed by using the following formula:

Specific gravity = $\frac{D}{V}$, where D equals weight in grams, and V equals volume in cubic centimeters.

MATERIALS AND METHODS

Ten apple rootstocks, where vegetative growth varied from exceedingly strong-growing to extremely weak-growing were utilized in this study. According to the size commonly ascribed to the trees worked on them and following Hatton's grouping (17), stocks used in the study were classified arbitrarily as follows:

Very dwarfing: Clark, Malling-8

Semidwarfing: K-4, K-41, MM-106

Vigorous: Muzalma, MM-104

Extremely vigorous: Hibernal, Virginia Crab, K-62

This grouping was arbitrarily applied for the sake of convenience only, because no clear cut line of demarcation could be drawn to separate these groups from each other. K-series stocks are clones derived from French Crab seedlings grown at Kansas Experiment Station which survived the extended drouth of 1930's and the Armistice Day freeze of 1940 (9). Muzalma, a clonal rootstock belongs to the species Malus sylvestris. It was introduced from Chinese Turkestan through the Division of Plant Explorations and Introduction in the U.S. Department of Agriculture in 1941.

Malling-8 is a Paradise apple developed at East Malling research station in England and was considered one of the most dwarfing of all the Malling stocks. Hibernal, a winter hardy stock was imported by the USDA from Russia in 1870. Virginia Crab was developed asexually from a chance seedling in Iowa in 1862 (16). MM-104 and MM-106 are hybrids resulting from crosses between Malling stocks and Northern Spy. These stocks were released commercially by East Malling Station and are considered resistant to woolly aphids and have a strong root chorage (29). Lantz (21) reported that Clark originated in Muscatine, Iowa, and that it dwarfed apple varieties and brought them into bearing early. One year old twigs were collected during the dormant season after they were fully matured. The twigs were of different diameters and lengths. They were tied in bundles, labeled, placed in moistened peat moss and stored at 40°F.

Characteristics of the various rootstocks studied included the bark-wood relationship, toughness, hardness, density and structural relationship of the wood. An attempt was made to determine if any relation existed between the anatomy of the wood and the rootstock behavior. It was also intended to determine if correlations existed between the results of various tests.

Toughness as used in this study refers to the resistance of the twig to cutting expressed in pounds of pressure required to make the cut. Hardness was determined as the resistance of the tissues of transverse sections of wood to compression applied by Impressor testor. The numbers obtained on the Impressor were used for relative comparison.

In the following pages, a complete description of each of the tests is given separately.

Bark-Wood Relationship

One-year-old stems of the 10 rootstocks were collected during the dormant season. All the materials were obtained at the Kansas Experiment Station, except for MM-104 and MM-106 which came from Interstate nurseries as Hamburg, Iowa. The wood was stored at 40°F. and a relative humidity of 90 per cent. Before any measurements were taken, the stems were placed in water so the bark would separate readily from the wood near the cambium region. Ten twigs were picked at random to represent each rootstock variety, one-inch was trimmed from the base to facilitate water absorption. Each bunch of twigs was placed in water in a separate container at room temperature for three days.

The diameter was obtained with callipers at a point midway between the two buds nearest the middle of each twig. At the site of this measurement a ring of the bark, containing the phloem and cortex was removed and the diameter was callipered once more to the nearest tenth of a millimeter. (Plate I) The difference between the two readings represents the bark portion which was computed on percentage basis as compared to the total cross sectional area.

Toughness - Cutting Test

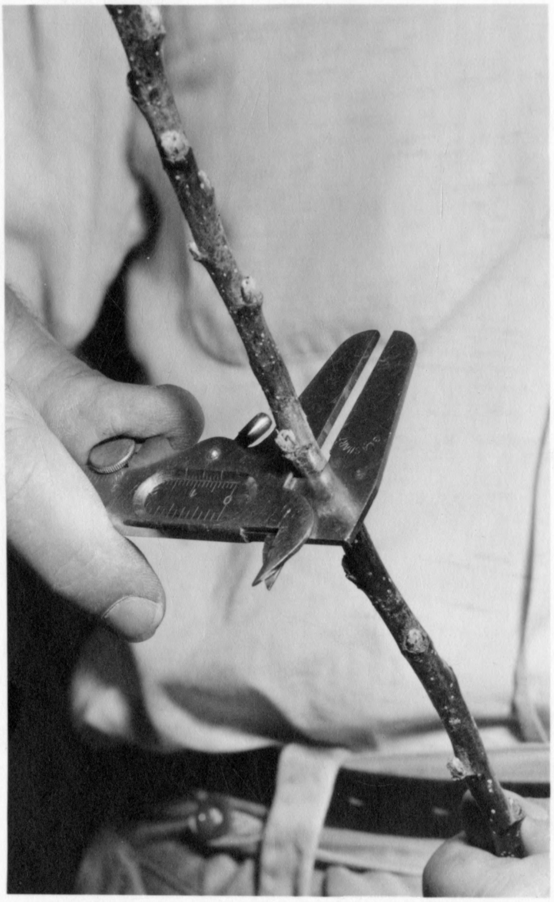
Twigs of each of the 10 apple rootstocks were collected and stored as previously described.

The device used for this test (Plate II) was designed to record the amount of pressure expressed in pounds needed to cut through each twig. The amount of pressure applied was indicated on a spring scale dial attached to one of the two knives. The second knife was attached to a handle by which force was applied. When the knives were matched, the pointer of the scale stood at zero and a space was left between the edges of the knives. This space was large enough to accommodate any twig up to 20 millimeters in diameter. The diameter was measured at a point midway of the internode nearest to the median point of each twig. After each twig was inserted in the hole between the edges of the two knives, the handle was pulled away from the scale until the twig was cut at the designated point. The scale was equipped with an additional pointer which indicated that maximum pressure created and remained in position until the reading was recorded. After

EXPLANATION OF PLATE I

Fig. (Left) Calliperation of diameter of twig at internode before removing ring of bark.

(Right) The twig on left calliperated again at same location after a ring of bark is removed.



EXPLANATION OF PLATE II

Fig. (Upper) A device designed for testing toughness of apple twigs.

A. Spring scale.

B. Knife attached to scale.

C. Knife attached to lever.

D. Hard slant splitted metal tube holding two knives together.

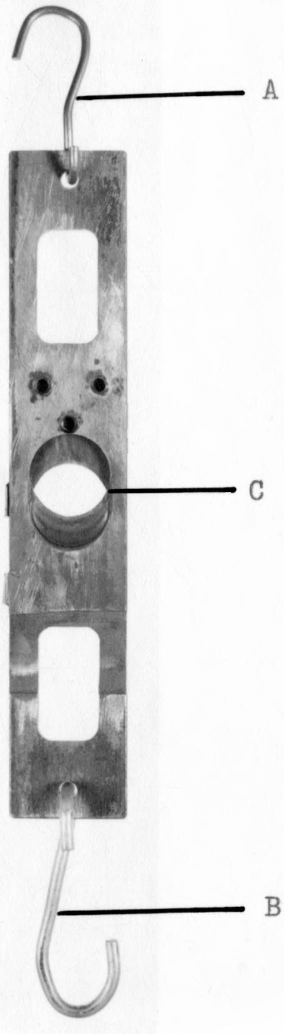
E. Twig in position.

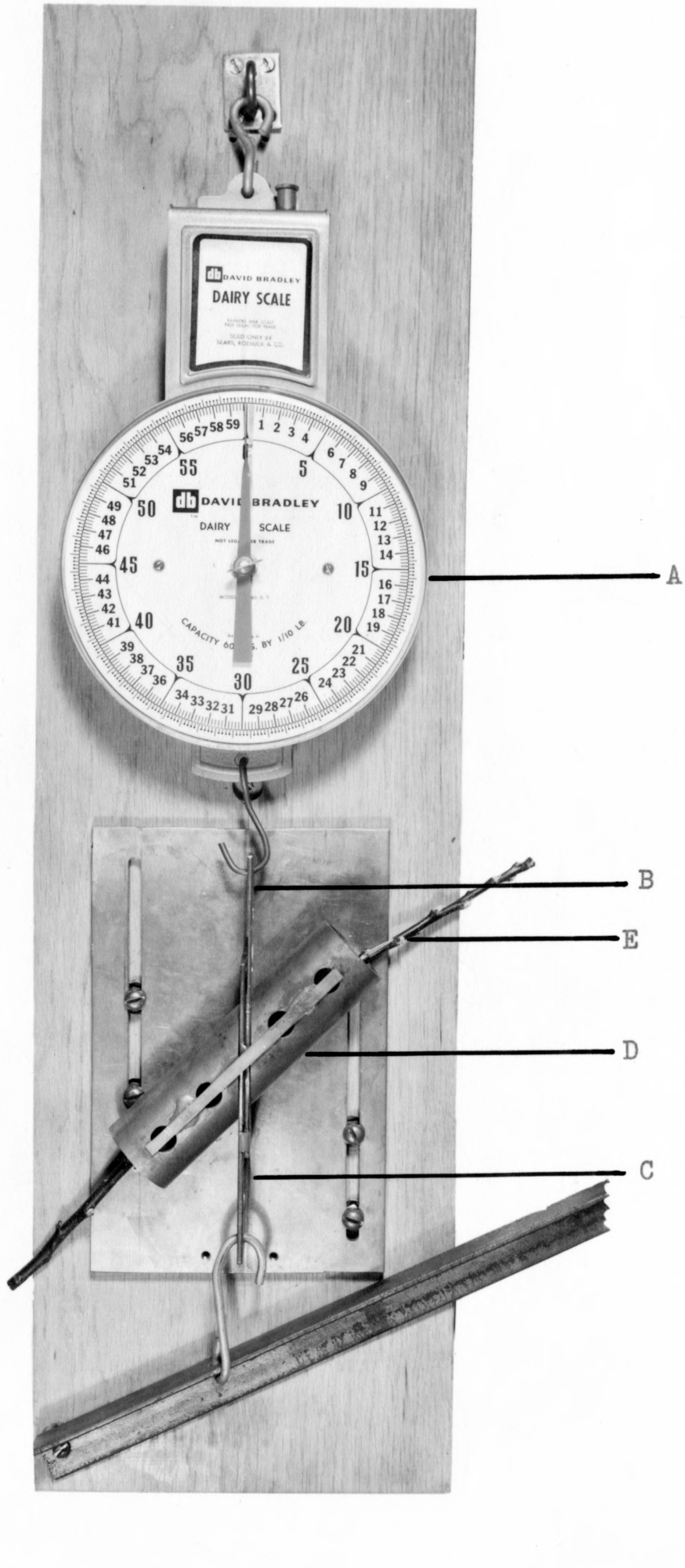
(Lower) Knives are matched.

A. Hook separated from scales attached to one knife.

B. Hook separated from lever attached to second knife.

C. Edges of knives set apart to accommodate the twig to be tested.


A
C
B


DAVID BRADLEY
DAIRY SCALE
DAVID BRADLEY
DAIRY SCALE
CAPACITY 60 LBS. BY 1/10 LB.
A
B
E
D
C

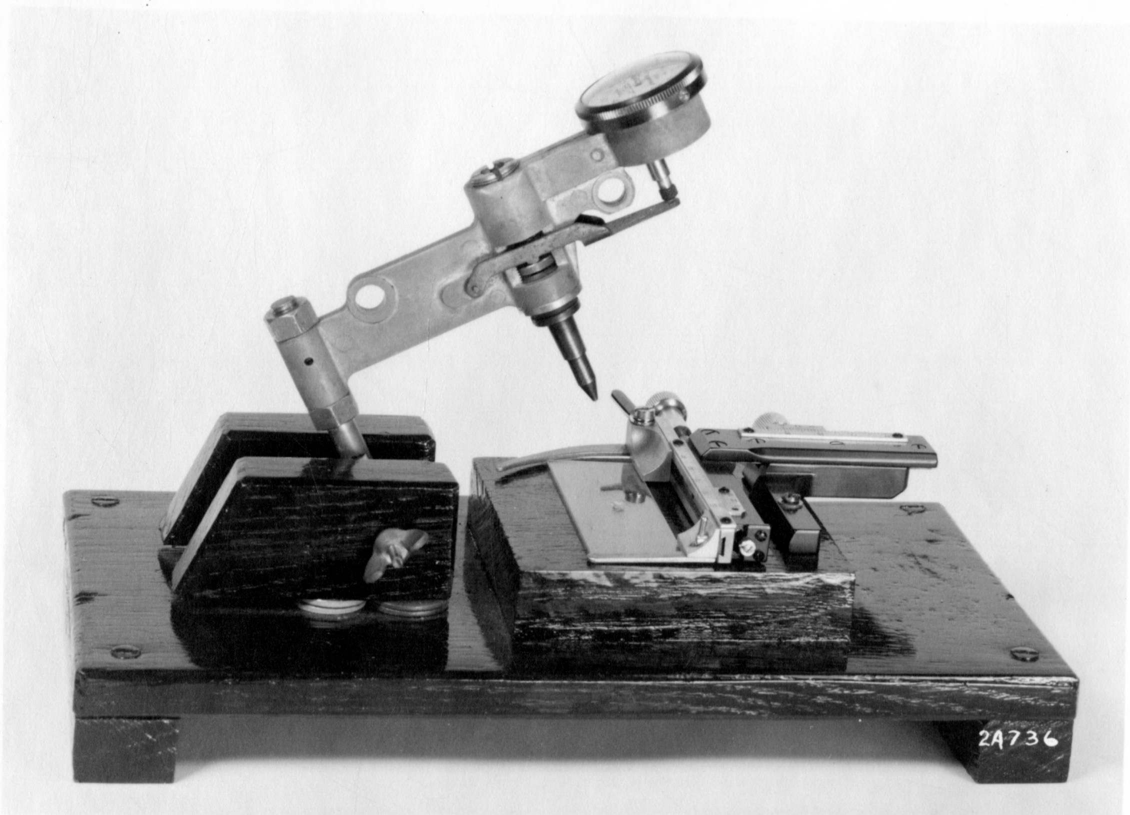
which it was moved back to the zero point. The knives were sharpened before the cutting of each rootstock.

Hardness - Compression Test

Transverse wood sections about 15 mm in length were taken from the middle internode of the twigs. Following the technique of Grosh and Milner (15), a section was placed on the stage of a freezing microtome and covered with aqueous gelatin. The gelatin was frozen by blasting with carbon dioxide. A portion from one end of the frozen specimen was removed with a knife, the gelatin was melted with a hot soldering iron pressed to the stage and the specimen was inverted in its place. A piece of balsa wood, 0.8 mm thick, was frozen to the stage beside the specimen as an indicator of the final thickness of the section itself. The inversion was made to secure two parallel faces of the section. The section was mounted to a glass slide and the slide was then placed on the microscope stage of the hardness testor devised by Katz et al. Plates III and IV. The section was moved in a straight line by adjusting the microscope stage and four measurements were taken, two on either side of the pith. The hardness measurements were made by pressing down on the framework of the Impressor with the hand until the flat part of the Impressor spindle was in contact with the specimen. The hardness number of a particular point was read after the maximum number was reached on the dial, a number which remained unchanged as long as force was applied. Ten sections of each rootstock were tested.

EXPLANATION OF PLATE III

Photograph of the Compression Impressor Tester.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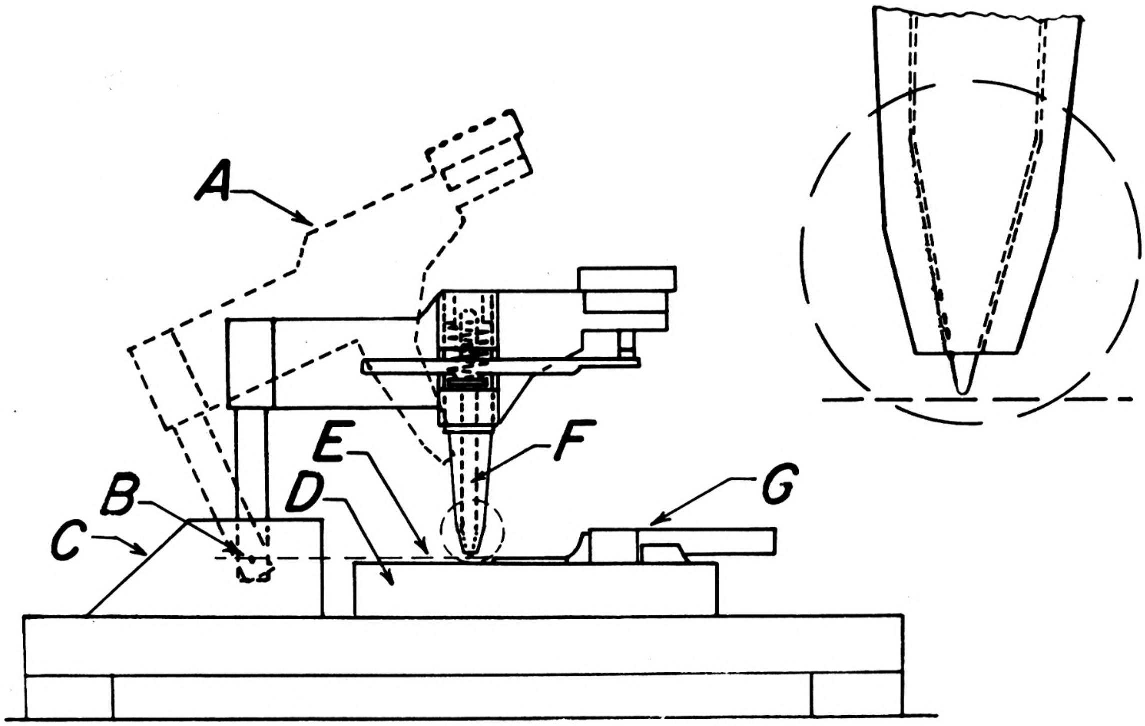
EXPLANATION OF PLATE IV

Diagram of Impressor Testor. The lettered parts on the diagram are as follows: A. Tester in lifted position, B. Axis about which the tester swings, C. Oak support, D. Oak platform which supports the sections to be tested, E. Plane which contains the upper surface of the sections and the axis mentioned in B, F. Penetrator, G. Two-way movement stage, H. Slotted nut.

PLATE IV



Density Determinations

Sections of wood, 1-2 cm long and of various diameters were taken from internodes nearest the median of the twigs. Thirty twigs of each of the 10 apple stocks were used.

The sections were placed separately in petri dishes in an oven at 100°C. for two days. The petri dishes were placed in a dessicator in which calcium chloride was used, in order to keep the wood specimens dry.

The principles involved for density determinations were adopted, with few modifications, from a method used to determine the density of wheat grains (28). Essentially, it is a liquid displacement method in which cyclohexane was used as the liquid. Cyclehexane was chosen because it has a low specific gravity of 0.779 at 20°C., and it did not effect the wood constituents when soaked in it. Twenty-five and 50 millimeter Gay-Lussac pycnometers were filled with cyclehexane. The twig sections in covered petri dishes, and the pycnometers were placed in Thelco automatic incubator at 25°C. After 30 minutes, 10 flasks containing the liquid were weighed separately, 10 lots of wood sections of a rootstock weighed and each placed in a flask. The flasks were returned to the incubator. Thirty minutes later, when most of the air in the intercellular spaces of the wood was displaced by the liquid, the volume was adjusted and the flasks containing the cyclehexane and the wood were weighed.

Ten determinations were taken for each stock. In each treatment the following measurement had been obtained: Weight of flask containing the liquid, weight of wood specimen, and the weight of the flask after the wood was dropped in the liquid.

The following equation was used to obtain the density of cyclohexane at 25°C. Density = $\frac{\text{Weight}}{\text{Volume}}$ Ten determinations were made, and the density mean was 0.7663.

The density of the wood was computed by the following equation:

$$\text{Density} = \frac{(\text{Weight of Wood})\ \ (\text{Density of liquid})}{(\text{A plus Weight of wood}) - \text{B}}$$

Where A is the weight of flask containing the liquid and wood. Ten determinations were made and the means were used to represent the density of a rootstock variety.

Anatomical Structure

Specimens about 15 cm in length were taken from internodes nearest the middle of the twigs. Five twigs of each stock were picked from the material previously described.

Sections were prepared for microscopic examination according to methods outlined by Sass (27) and Johansen (18). The specimens were killed in FAA solution, then dehydrated by passing the material through series of different concentrations of tertiary butyl alcohol. Celloidin was dissolved in equal amount of anhydrous methyl alcohol and anhydrous ether. Concentrations of 2, 4, 6, 8 and 10 per cent were prepared. Infiltration of the wood specimens was started in the low concentration and continued through the 10 per cent celloidin solution. During each treatment the wood sections were added to the celloidin solution in a jar which was closed tightly and placed in an electric oven at 53°C.

for 36 hours. Following infiltration in the 10 per cent solution chips of celloidin were added at 24 hour intervals until the solution was thick enough to flow at room temperature. Infiltrated pieces of wood were removed from jars with a mass of enveloping celloidin and immersed in chloroform until they hardened. Finally, specimens were mounted on wooden blocks and stored in a mixture of equal amounts of 95 per cent ethylalchol and glycerine.

Sections 15-20 microns thick were cut with a sliding microtome. The sections were stained with safranin and fast green, then mounted in Canada Balsam.

About 15-20 sections of each rootstock were examined with a microscope. The various tissues and the characteristics of these tissues were observed and photomicrographs were taken.

RESULTS

Bark-Wood Relationship

The data obtained were examined statistically using the analysis of variance on the bark percentages as shown in Table 1.

Table 1. Analysis of variance of bark percentage of one-year-old stems of selected apple stocks. Diameters were measured with callipers at the middle internode before and after removing a ring of the bark.

Source of Variation	Difference	Ms	F	Significance
Variety	9	126.2398	15.02	***
Samples, same variety	90	8.4040		

***Significant at the 0.001 level.

It is indicated above that the variations in the percentage of bark among the rootstock varieties are highly significant.

In Table 2 mean percentage of bark of the stocks are arranged in descending order.

Table 2. Ordered array of mean bark percentages of the median internode of one year stems of different apple rootstocks.

Rootstock	Mean per cent bark	Rank	Rootstock	Mean per cent bark	Rank
Malling-8	29.790	1	MM-106	23.544	6
Clark	29.028	2	K-62	22.312	7
K-4	27.587	3	MM-104	21.607	8
K-41	26.548	4	Hibernal	20.382	9
Virginia Crab	24.520	5	Muzalma	19.985	10

L.S.D.* = 2.580 at the five per cent level.

It can be seen from Table 2 based on percentages of bark the rootstocks fall into three loose groups. The stocks Malling-8, Clark and K-4 have the highest percentage of bark. Twigs from K-41, Virginia Crab and MM-106 had nearly equal bark percentages. The rootstocks K-62, MM-104, Hibernal and Muzalma made a group by themselves possessing the lowest bark percentage. Individual differences can be determined from the same table.

Analyses were carried further using correlation and multiple regression computations to examine any interaction or correlation between the diameter, the length of the twig, the length of internode and the percentage area of bark (Table 3). In general, relationships

Table 3. Analysis of relationship of mean bark percentages, length of internodes, diameter and total length of one year old stems of some apple rootstocks. Bark percentage, internode length and diameter measurements were taken near the middle of each twig.

	M 8	MM 104	Clark	MM 106	K 4	Muzalma	K 41	Hibernal	K 62	Va. Crab
Diameter x Internode Length	-.0476 ns	.1517 ns	.2495 ns	-.2673 ns	-.1706 ns	-.3256 ns	.2370 ns	-.2539 ns	-.4342 ns	.2394 ns
Diameter x Twig Length	.5107 ns	.3377 ns	-.0394 ns	-.0503 ns	.1517 ns	.2820 ns	.1958 ns	-.0602 ns	.8254 **	.5254 ns
Diameter x Percent Bark	.1252 ns	.0037 ns	-.7088 *	-.0677 ns	.4834 ns	-.5426 ns	-.3493 ns	.0166 ns	-.5143 ns	-.2320 ns
Internode Length x Twig Length	-.2043 ns	.0913 ns	.0513 ns	.2346 ns	.0744 ns	-.3082 ns	-.2812 ns	.8606 **	-.6523 *	.6496 *
Internode Length x Percent Bark	-.7461 *	.2622 ns	-.2550 ns	-.1432 ns	.1153 ns	.6875 *	-.3788 ns	-.7341 *	.0406 ns	.1863 ns
Twig Length x Percent Bark	-.2083 ns	.1425 ns	.0322 ns	-.7424 *	-.3276 ns	-.3416 ns	-.2416 ns	-.8728 ***	-.4808 ns	.2559 ns

* Significant
** Highly Significant
*** Very Highly Significant
ns Not Significant

did not fall in a certain pattern. Only significant relationships are presented in the text.

The diameter and the length of twig internode, and the diameter and the total length of twigs seemed to be independent characteristics, with the exception of the K-62 variety where length was found to be highly dependent on the diameter of the twig.

A positive significant correlation between the diameter and the bark area was noticed in Clark wood.

An increase in length of internodes was associated with an increase in the total length of the twigs of Hibernal, K-62, and Virginia Crab.

There was a negative significant correlation between the length of internode and the percentage of bark in twigs of Malling-8 and Hibernal, while in the Muzalma variety, an increase in internode length was associated with the bark area.

Bark percentage in MM-106 and Hibernal was negatively correlated with the length of the twig.

While not significant, it was indicated that a correlation may exist between the diameter and bark percentage in K-4, Muzalma and K-62, and further observations may be worthwhile in this respect.

Toughness - Cutting Test

The results on the amount of pressure required to cut the various stocks were first subjected to an analysis of variance. (Table 4).

Table 4. Analysis of variance of the toughness of different apple rootstocks twigs expressed in pounds pressure required to cut the twigs.

Source of variation	Difference	Ms	F	Significance
Variety	9	1132.79	16.81	***
Samples	90	67.37		
Total	99			

*** Significant at 0.001 level

This analysis revealed that the varieties differed greatly in resistance to cutting.

On the basis of this analysis the rootstocks ranked according to toughness as seen in Table 5.

Table 5. Ordered array of mean pressure, expressed in pounds required to cut one year old twigs of 10 apple stock varieties.

Root-stock	Mean pressure (lbs)	Rank	Root-stock	Mean pressure (lbs)	Rank
Hibernal	52.66	1	K-41	27.58	6
K-4	44.18	2	MM-104	26.39	7
K-62	40.85	3	MM-106	25.46	8
Muzalma	33.35	4	Malling-8	23.88	9
Virginia Crab	29.15	5	Clark	17.98	10

L.S.D.* = 7.30 at five per cent level

From the values obtained an arbitrary grouping of the rootstocks on the basis of toughness was made as follows:

Extremely tough:		Hibernal
Tough	:	K-4, K-62
Intermediate	:	Muzalma, Virginia Crab, K-41, MM-104, MM-106
Tender	:	Malling-8, Clark

A striking variation was noticed between the upper two and the lower group. Individual differences between varieties were considerable as indicated by the highly significant F value obtained on the analysis of variance.

Statistical analyses were extended to include the other two variables considered in this study, the diameter and the length of the twig. Correlations and multiple regression computations are presented in Table 6.

With the exception of Hibernal and Malling-8, an increase in the diameter of the twig was associated with its toughness. The two exceptions, having a correlation of more than 0.50, deserve further testing.

Where a positive correlation was established between the length and diameter of the twig a positive correlation between the toughness and length was also noted for the varieties MM-104, Clark, MM-106 and K-62. Where length and diameter behaved independently, toughness was not correlated with length. However, Virginia Crab was an exception in both cases.

Table 6. Correlations between total length, diameter and toughness of twigs of some apple rootstocks. Diameter measured at the internode nearest the middle of the twig and toughness was expressed in pound pressure required to make the cut at that position.

	M 8	MM 104	Clark	MM 106	K-4	Muzalma	K 41	Hibernal	K 62	Va. Crab
Twig Diameter x pounds pressure	.5777 ns	.8847 ***	.9575 ***	.9544 ***	.7654 **	.9425 ***	.6854 *	.5371 ns	.9518 ***	.8889 ***
Twig Length x Twig Diameter	.5258 ns	.8967 ***	.7704 **	.9323 ***	.1985 ns	.1738 ns	.5973 ns	.3711 ns	.9124 ***	.5118 ns
Twig Length x Pounds Pressure	.3210 ns	.7050 *	.8231 **	.8062 **	.3177 ns	.3414 ns	.4008 ns	.1976 ns	.9183 ***	.6778 *

* Significant
** Highly Significant
*** Very Highly Significant
ns Not Significant

Hardness - Compression Test

An analysis of variance indicated significant variation of hardness means as determined with the compression tester for varieties and locations in the tissues. Analysis is shown in Table 7.

Table 7. Analysis of variance of the hardness means of transverse sections of one year wood of some apple stocks. Relative values were obtained by use of an Impressor Testor, at each of two test locations.

Source of variation	Difference	Ms	F	Significance
Variety	9	133.28	19.72	***
Location	3	39.65	5.87	***
V. x L.	27	13.04	1.93	***
Samples	360	6.76		
Total	399			

*** Significant at 0.001 level

The hardness means ranked in descending order are shown in Table 8.

Table 8. Order array of hardness means of transverse sections of one year old wood of different apple stocks. Values were obtained by use of an Impressor Testor.

Rootstock	Hardness means	Rank	Rootstock	Hardness means	Rank
MM-106	81.48	1	MM-104	78.71	6
Clark	81.39	2	Va. Crab	78.42	7
Muzalma	80.43	3	K-4	77.86	8
K-62	80.25	4	Malling-8	76.90	9
K-41	78.78	5	Hibernal	74.12	10

L.S.D.* = 1.14 at the five per cent level

Four fairly distinct groups based on hardness of wood were observed, the hardest group included MM-106, Clark, and Muzalma. K-62 comprised a second. The third group included the varieties K-41, MM-104, Virginia Crab and K-4. Wood of the stock varieties Malling-8 and Hibernal possessed the softest wood and constituted groups four and five, respectively.

The mean hardness of the various locations of the hardness tests are listed in Table 9.

Table 9. Hardness means at two locations of transverse sections of one year old wood of different apple stocks.

Rootstock	Test location next to bark	Test location next to pith	Variation
Hibernal	79.03	75.23	3.80*
K-62	81.60	78.90	2.70*
Virginia Crab	79.60	77.25	2.35*
Malling-8	75.95	77.85	1.90*
Clark	82.15	80.63	1.52 ns
K-4	78.60	77.13	1.47 ns
MM-104	79.38	78.05	1.33 ns
MM-106	81.15	81.80	0.65 ns
Muzalma	82.08	81.45	0.63 ns
K-41	78.43	79.13	0.60 ns

L.S.D.* = 1.61 at the 5% level
* Significant at 0.05 level
ns Not significant

These results indicated that the wood next to the bark was harder than the wood around the pith in Hibernal, K-62 and Virginia Crab. The opposite was noted in Malling-8. The wood of the rest of the rootstocks did not differ significantly in hardness at the various test locations.

Density Determinations

A highly significant variation in the density of wood was detected among the various stock varieties. (Table 10).

Table 10. Analysis of variance of the densities of one year wood of 10 apple stocks as determined by displacement in cyclohexane.

Source of variation	Difference	Ms	F	Significance
Rootstocks	9	0.03349	4.98	***
Within Stocks	90	0.00673		
Total	99			

*** Significant at 0.001 level

Density means were ranked in the order shown in Table 11.

Table 11. Ordered array of density means of twigs of different apple stocks as obtained by displacement in cyclohexane.

Rootstock	Density means	Rank	Rootstock	Density means	Rank
Hibernal	0.9493	1	Malling-8	0.8411	6
K-62	0.9326	2	Virginia Crab	0.8270	7
K-41	0.9309	3	MM-104	0.8147	8
Clark	0.8851	4	MM-106	0.7990	9
K-4	0.8700	5	Muzalma	0.7958	10

L.S.D.* = 0.0730 at the five per cent level.

Three classes emerged when the density means were compared. The rootstock Hibernal, K-62, K-41 and Clark had the greatest densities. The K-4 variety could be placed in an intermediate grouping. The rootstocks Malling-8, Virginia Crab, MM-104, MM-106, and Muzalma made up a third group with the lowest densities.

Anatomical Structure

Photomicrographs of parts of transverse sections of wood and bark of stems of 10 apple stocks are presented in plates V - XIV. Examination of these figures show a wide variation in the anatomical structure of the twigs among the different stock varieties.

Considering the wood sections first, an appreciable variation among the stocks was noticed in the amount and distribution of the wood elements, fibers, rays, parenchyma cells and vessels. Despite the fact that individual stocks showed particular wood structure, close comparison may reveal similarities between two or more of the rootstocks. On the basis of similarities, the 10 wood structures can be conveniently divided into six distinct groups as seen in Table 12.

In groups 1, 2, and 3, the bark appeared to possess relatively smaller proportion of fibers than groups 4, 5 and 6 as compared to living tissues. It was noticed that the bark of K-41 and MM-106 resembled the bark of the dwarf groups 1, 2 and 3 whereas the wood of these semidwarfing stocks showed wide variability similar

Table 12. Relative comparison between the amount of wood elements as seen in photomicrographs of transverse sections of wood, of twigs, of selected rootstocks.

Group	Rays	Parenchyma cells	Fibers	Vessels
1. Malling-8 K-4	numerous, wide, narrowly spaced and occupy large area	numerous	occupy small area	very abundant small in size
2. Clark	wide and occupy large area	prominent and numerous	occupy smaller area than fibers	medium in number, small in size
3. K-41 MM-106	medium in number and width	intermediate in number	occupy large area	not abundant medium in size and scattered
4. Muzalma K-62 MM-104	narrow few in number	few	occupy the largest area	not abundant large in size
5. Va. Crab	wide and numerous	few	more than group 1	abundant and large in size
6. Hibernal	few, narrow and widely spaced	numerous	occupy the largest area	medium in number, very large

EXPLANATION OF PLATE V

Fig.I Hibernal rootstock wood as shown in transverse section taken from one year old stem.

Fig.IITransverse section of a portion of Hibernal bark obtained from one year old stems.

PLATE V

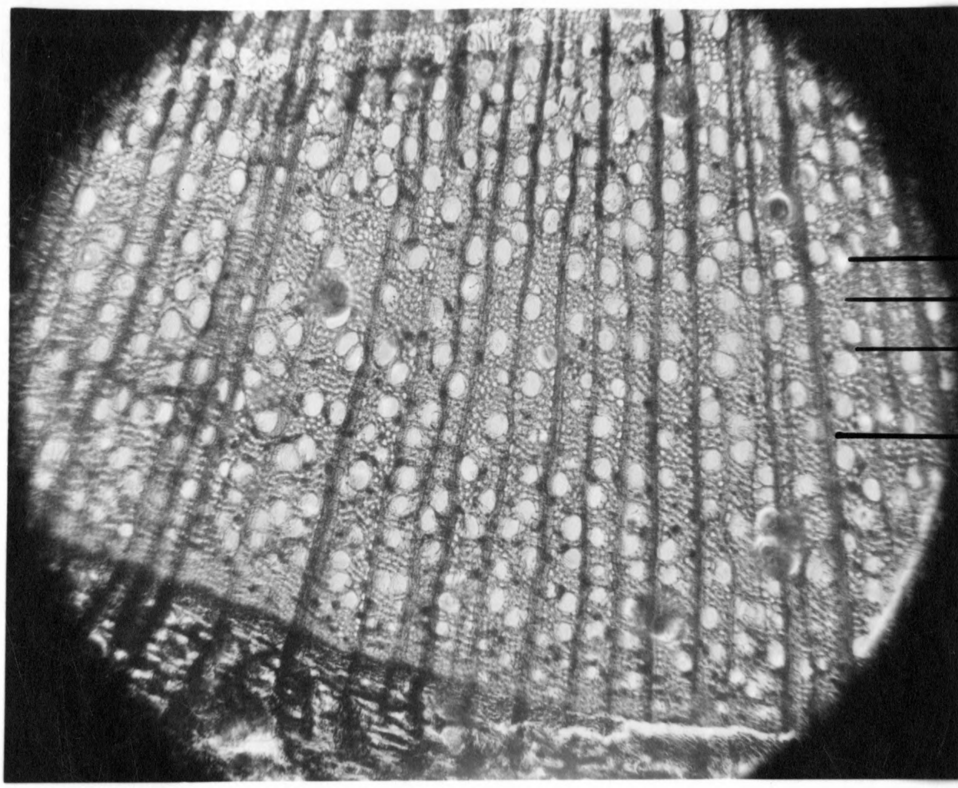


Fig. I

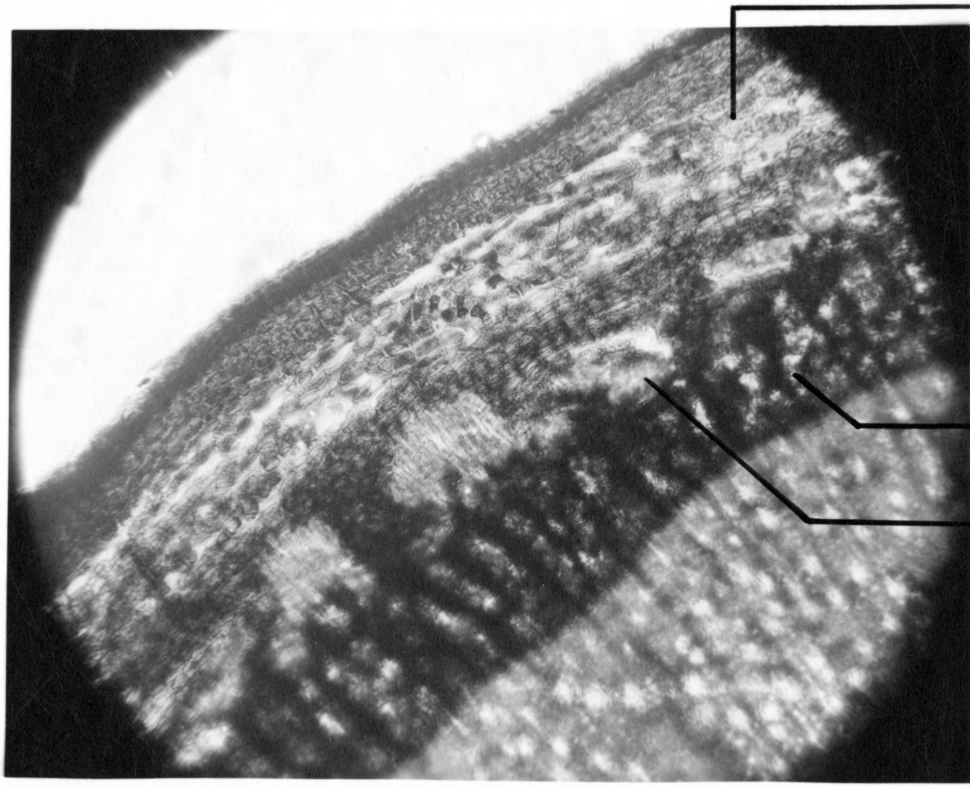


Fig. II

EXPLANATION OF PLATE VI

Fig. Structure of wood of K-62, a very vigorous rootstock, as seen in transverse section of portion of one year wood.

Fig. Portion of bark of K-62 rootstock twigs as seen in transverse section.

PLATE VI

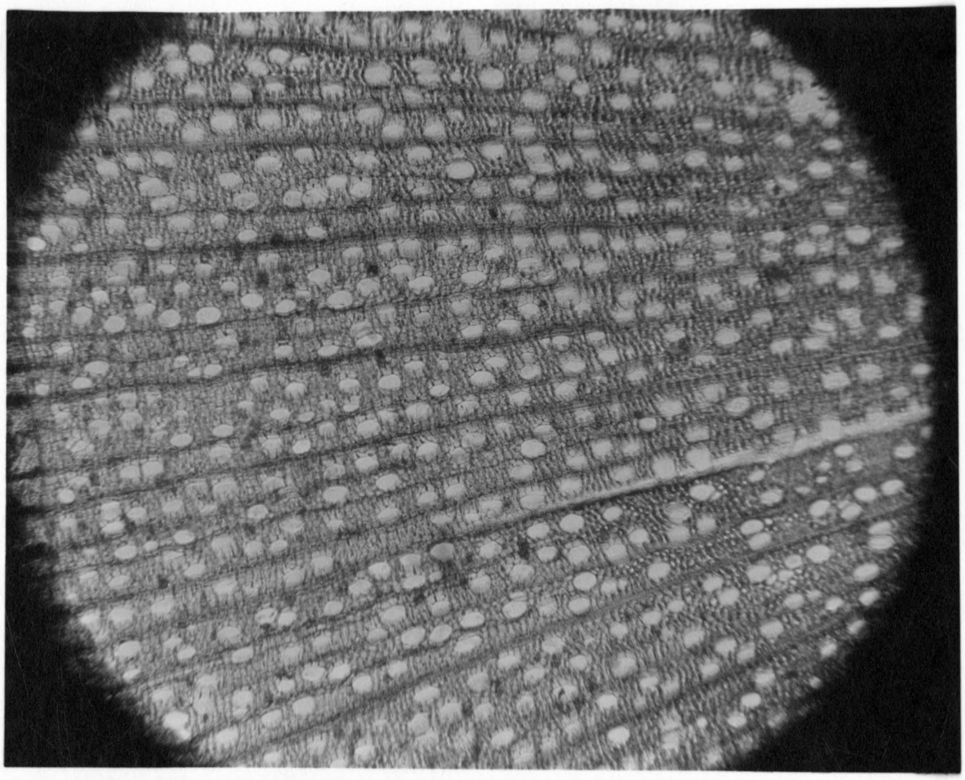


Fig. I

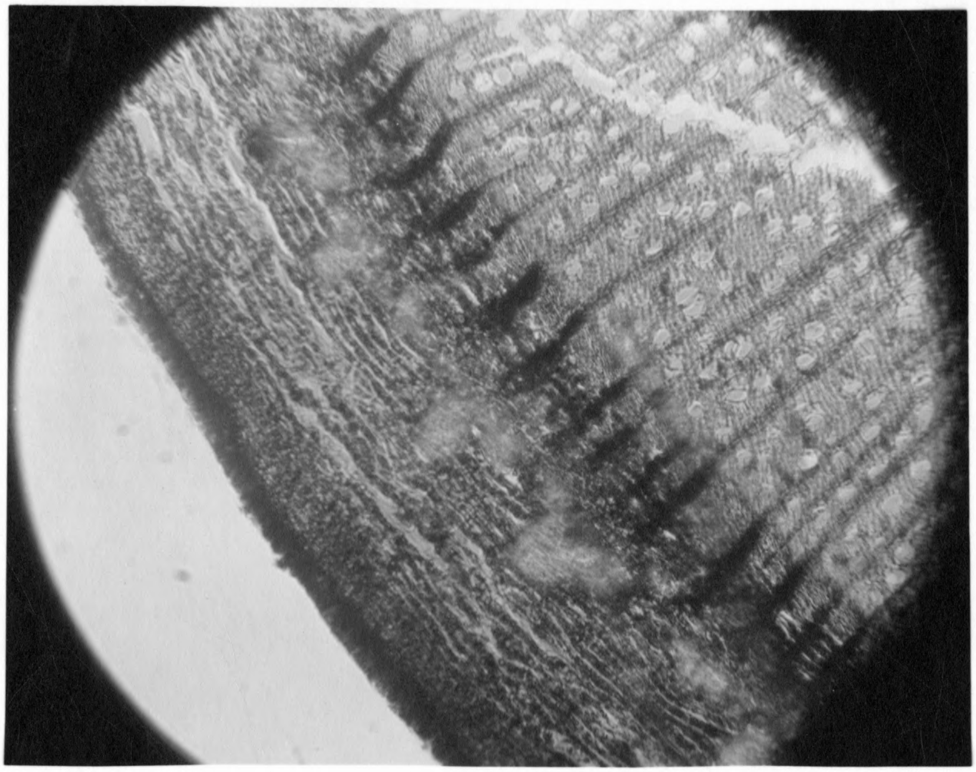


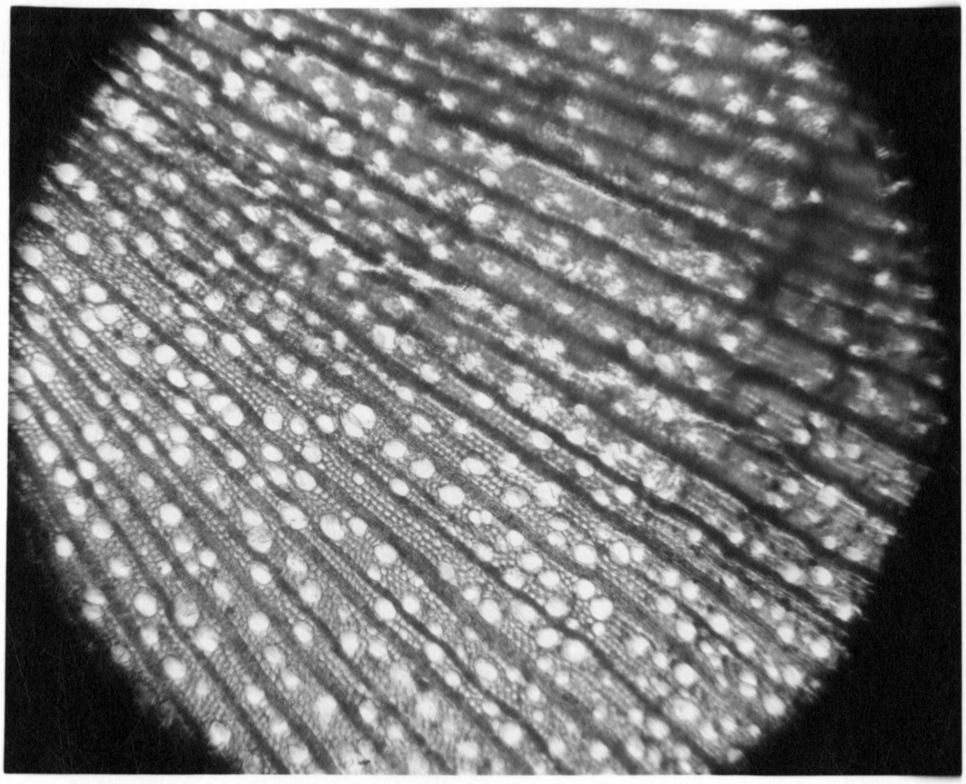
Fig. II

EXPLANATION OF PLATE VII

Fig. Wood of Virginia Crab rootstock shown in cress section. A portion of one year wood is seen.

Fig. Portion of Virginia Crab bark from twigs as shown in transverse section.

PLATE VII



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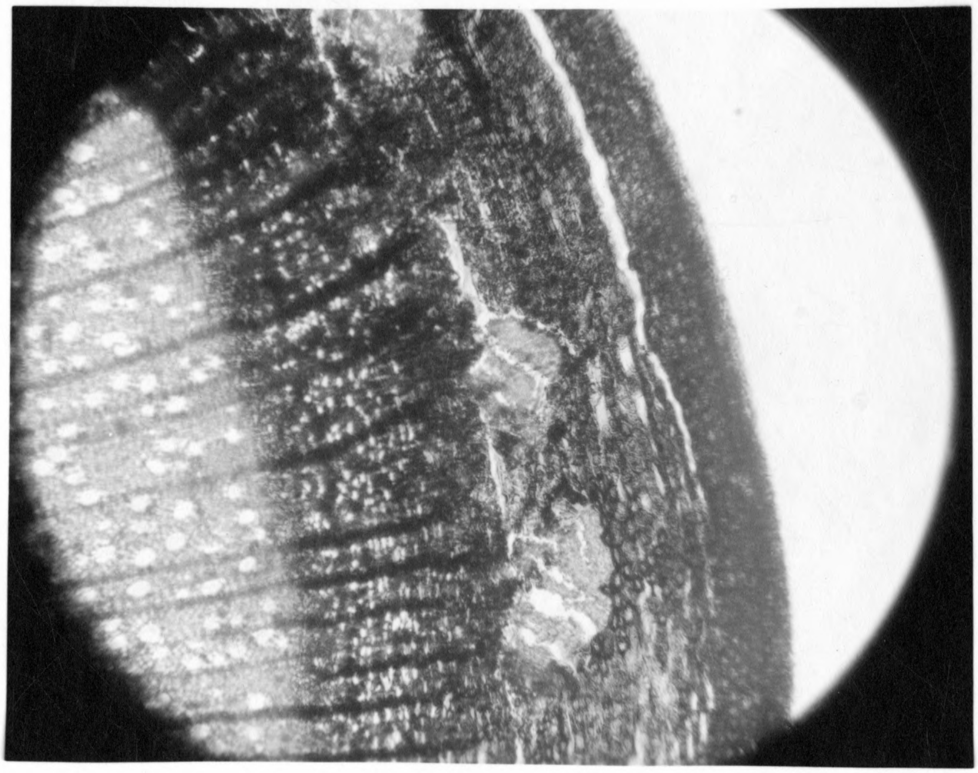

Fig. II

EXPLANATION OF PLATE VIII

Fig. Transverse section of MM-104 apple rootstock. A portion of one year old wood is shown.

Fig. Portion of bark of MM-104 twigs as seen in cross section.

PLATE VIII

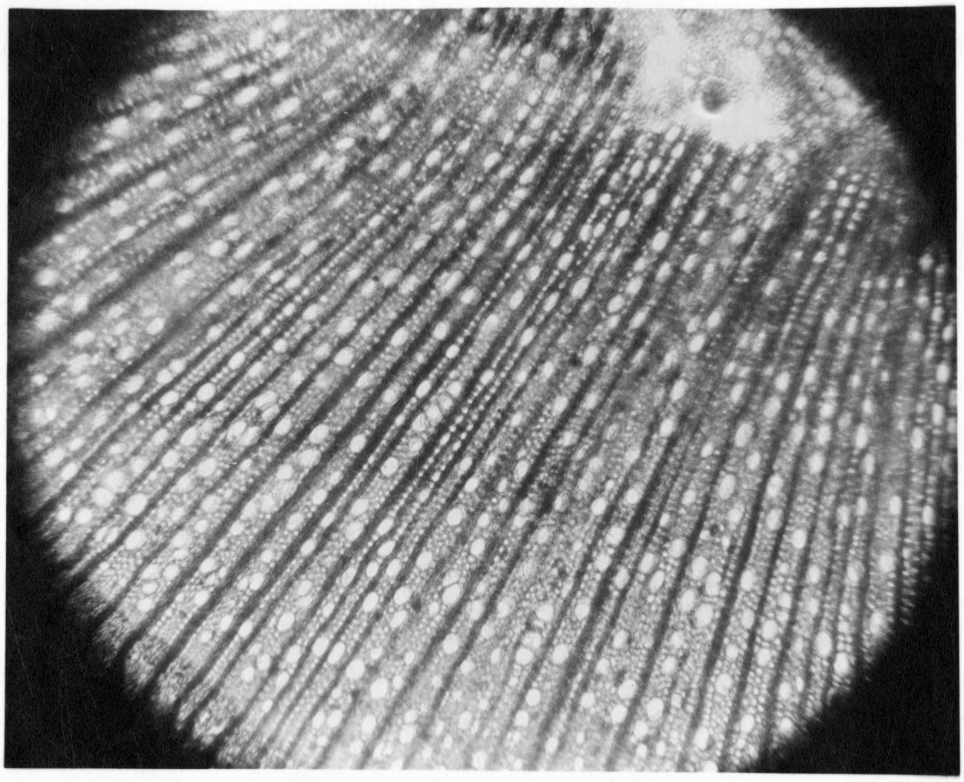

Fig. I

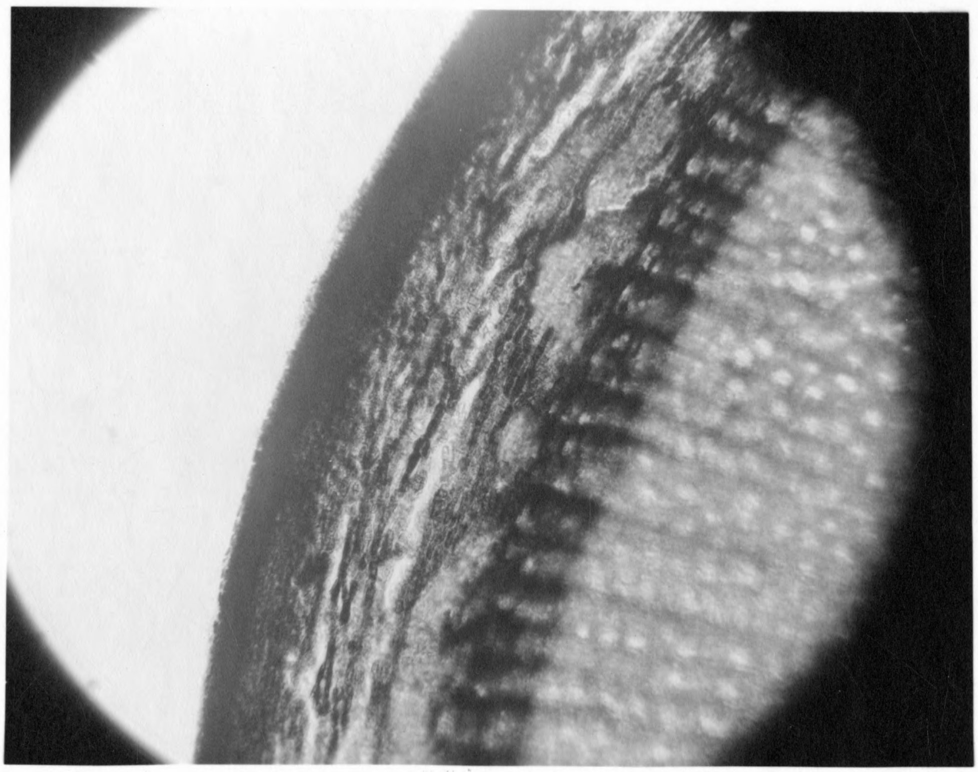

Fig. II

EXPLANATION OF PLATE IX

Fig. Portion of Muzalma rootstock obtained from wood of twigs.

Fig. Transverse section of bark of Muzalma rootstock. The portion shown was taken from one year old stems.

PLATE IX

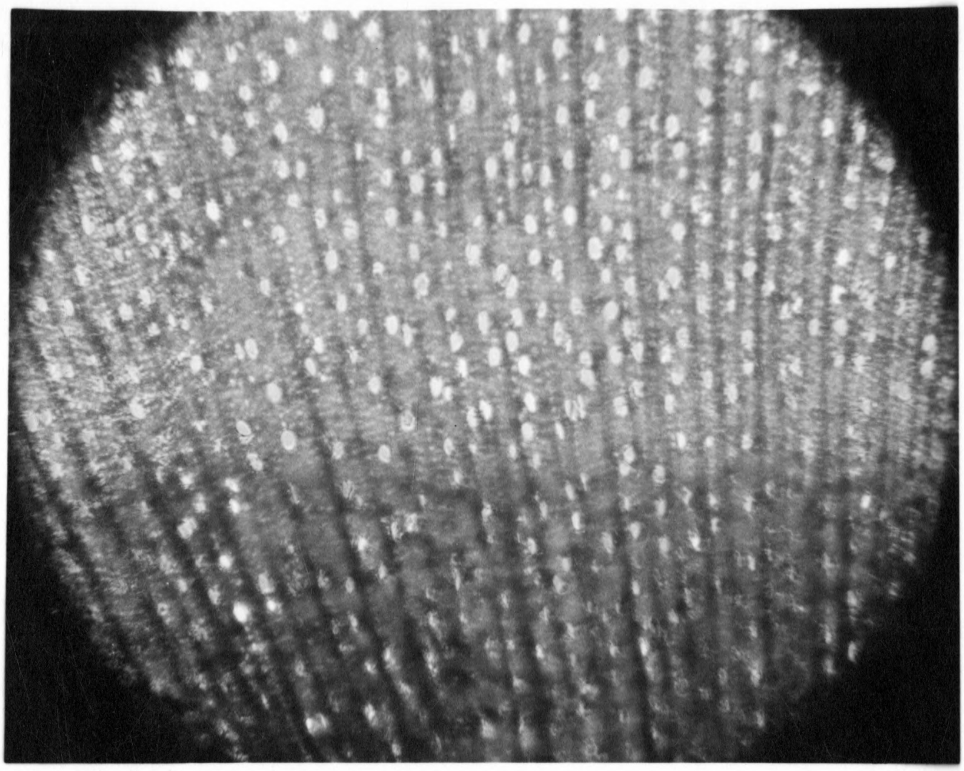

Fig. I

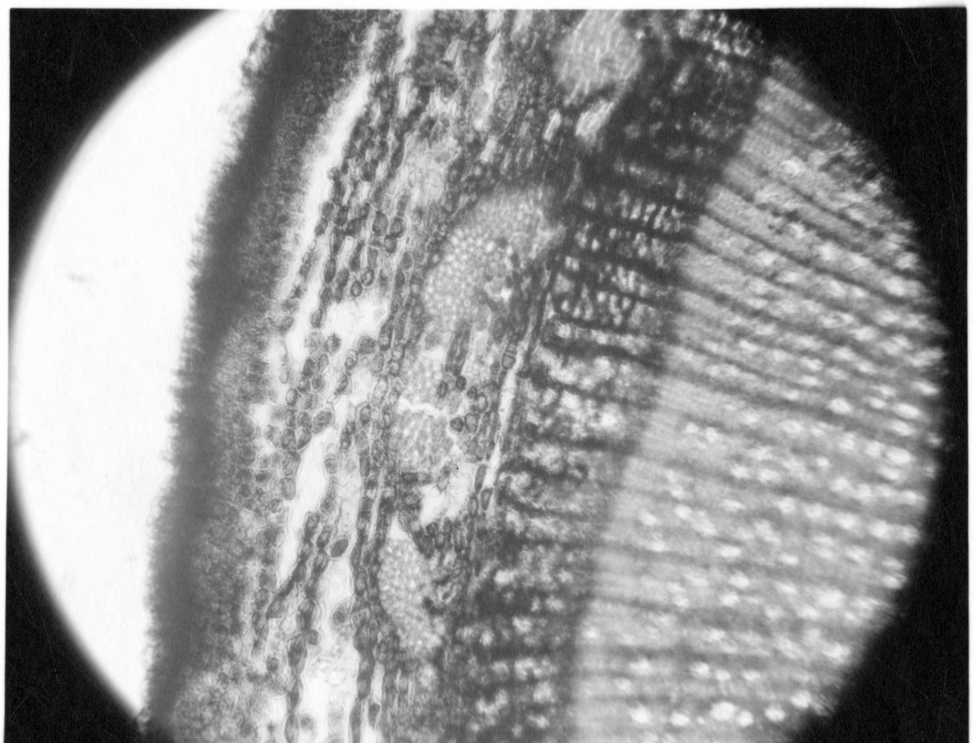

Fig. II

EXPLANATION OF PLATE X

Fig. Portion of one year old wood in transverse section taken from K-41 a semidwarfing rootstock.

Fig. Transverse section of a portion of K-41 rootstock bark as taken from twigs.

PLATE X

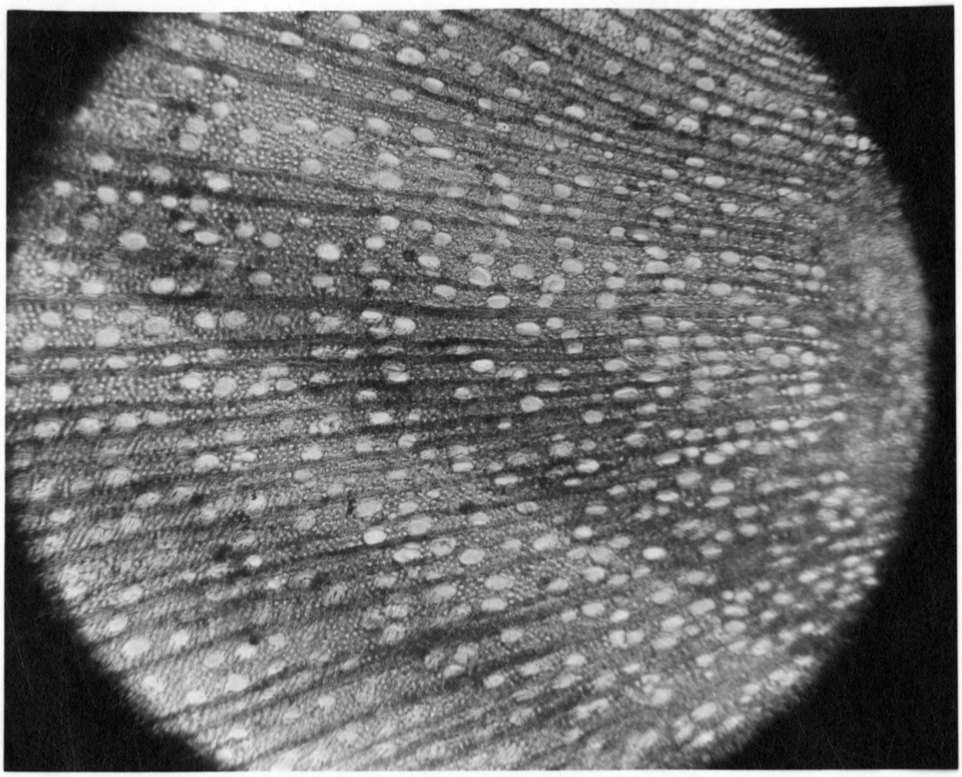

Fig. I

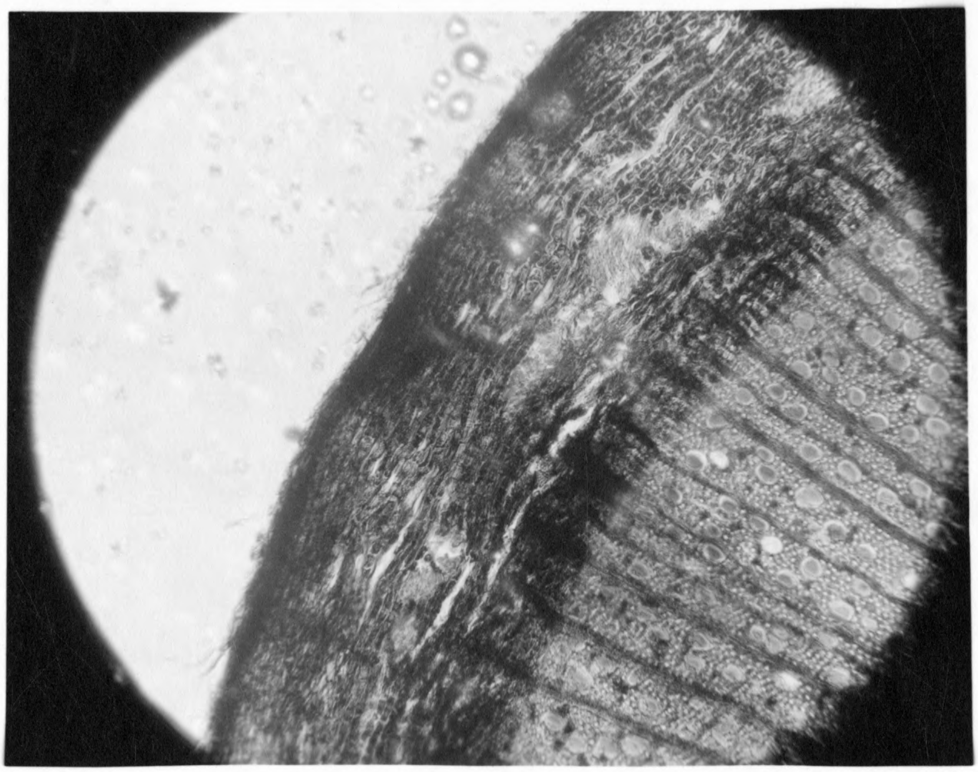

Fig. II

EXPLANATION OF PLATE XI

Fig. Transverse section of portion of one year wood of MM-106 a semidwarfing rootstock.

Fig. Portion of bark of one year twig of MM-106 apple rootstock shown in cross section.

PLATE XI

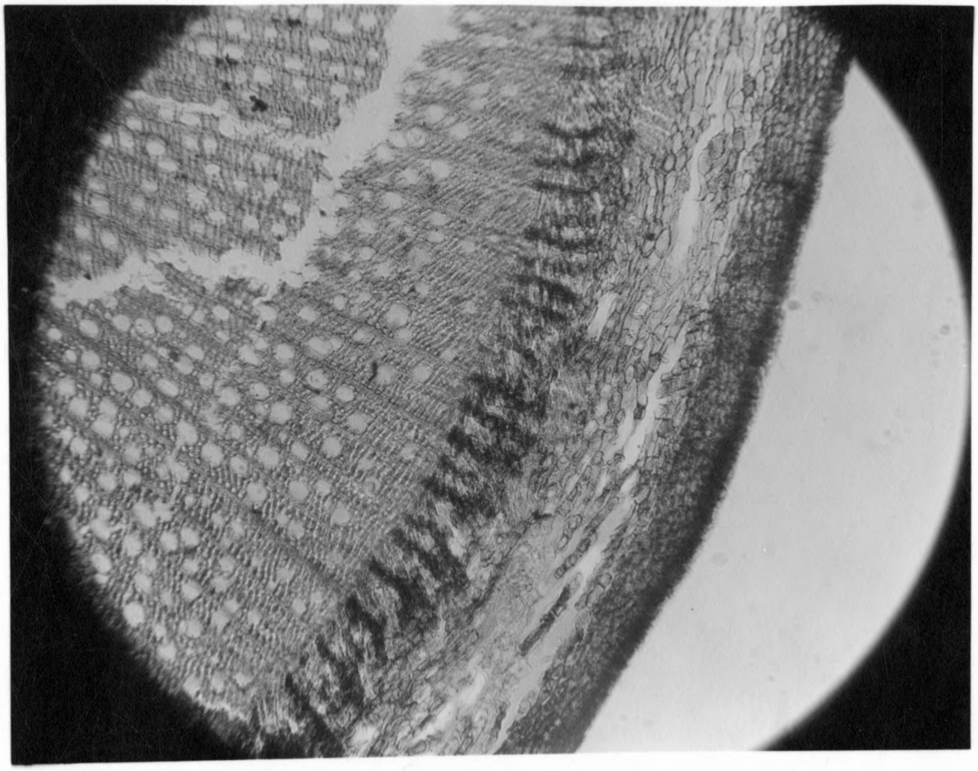

Fig. I

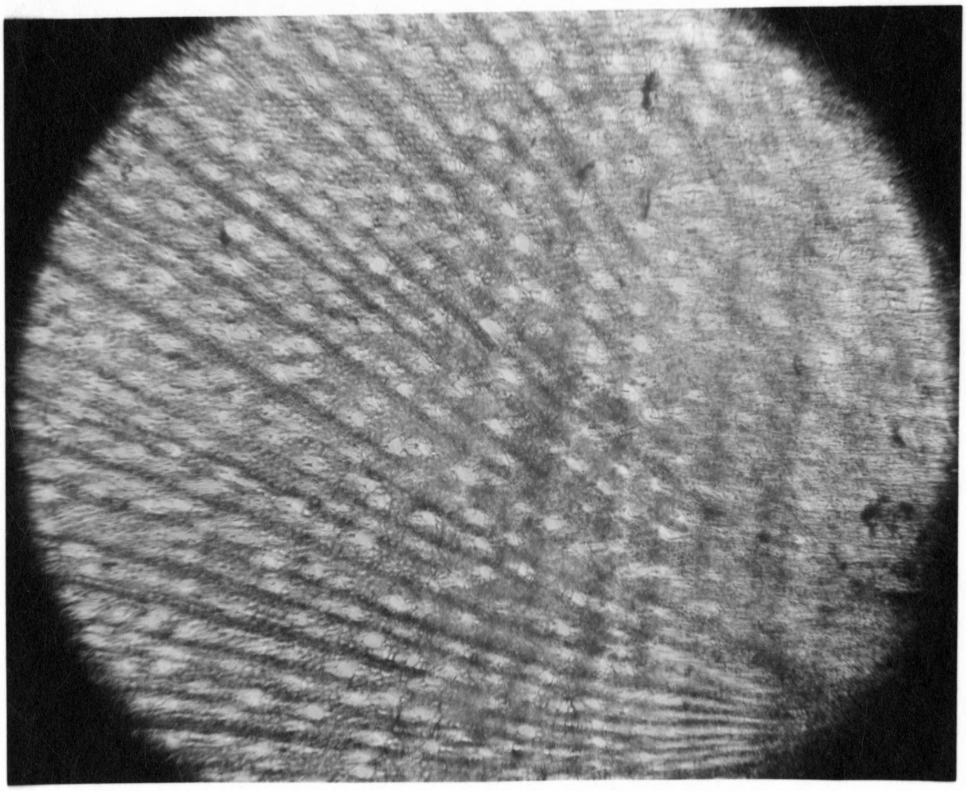

Fig. II

EXPLANATION OF PLATE XII

Fig. Transverse section of a portion of one year old wood of semidwarfing K-4 rootstock.

Fig. Transverse section of a portion of twigs of K-4 stock variety.

PLATE XII

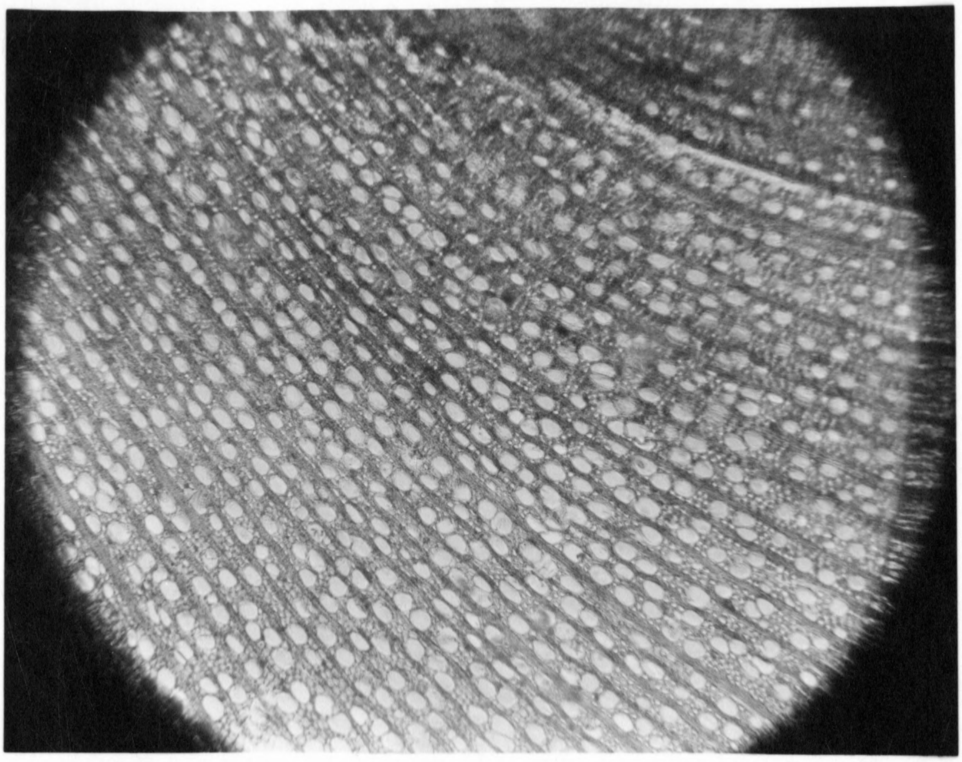

Fig. I

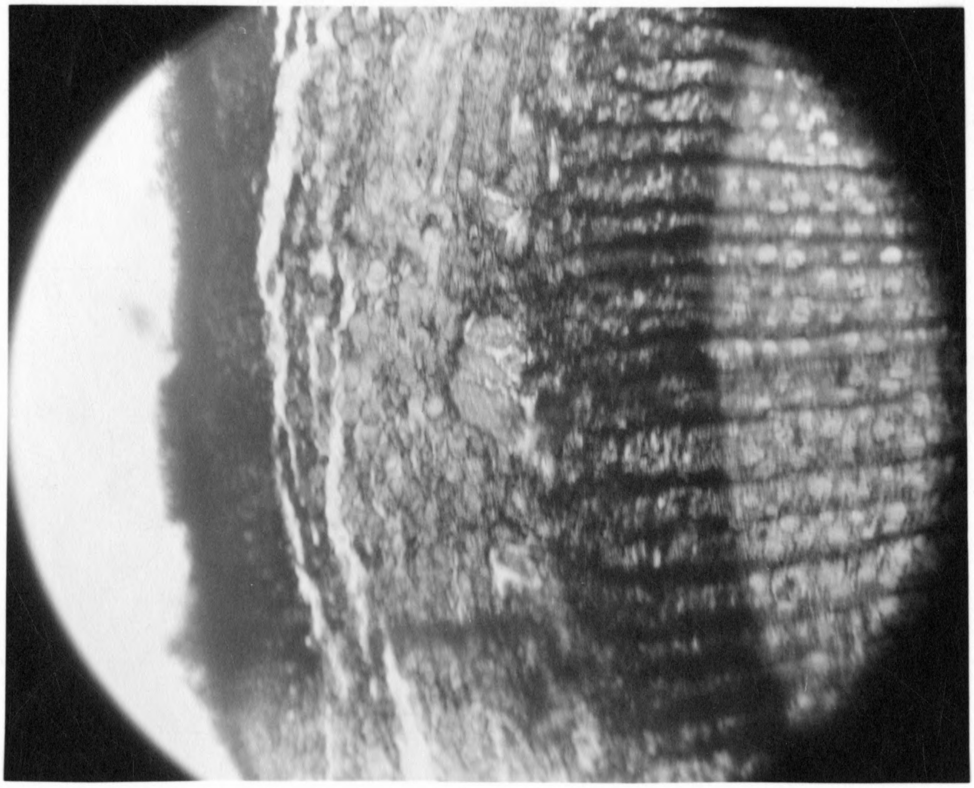

Fig. II

EXPLANATION OF PLATE XIII

Fig. Transverse section of a portion of a twig of Clark a dwarf rootstock.

Fig. Transverse section of a portion of bark of a twig of Clark rootstock.

PLATE XIII

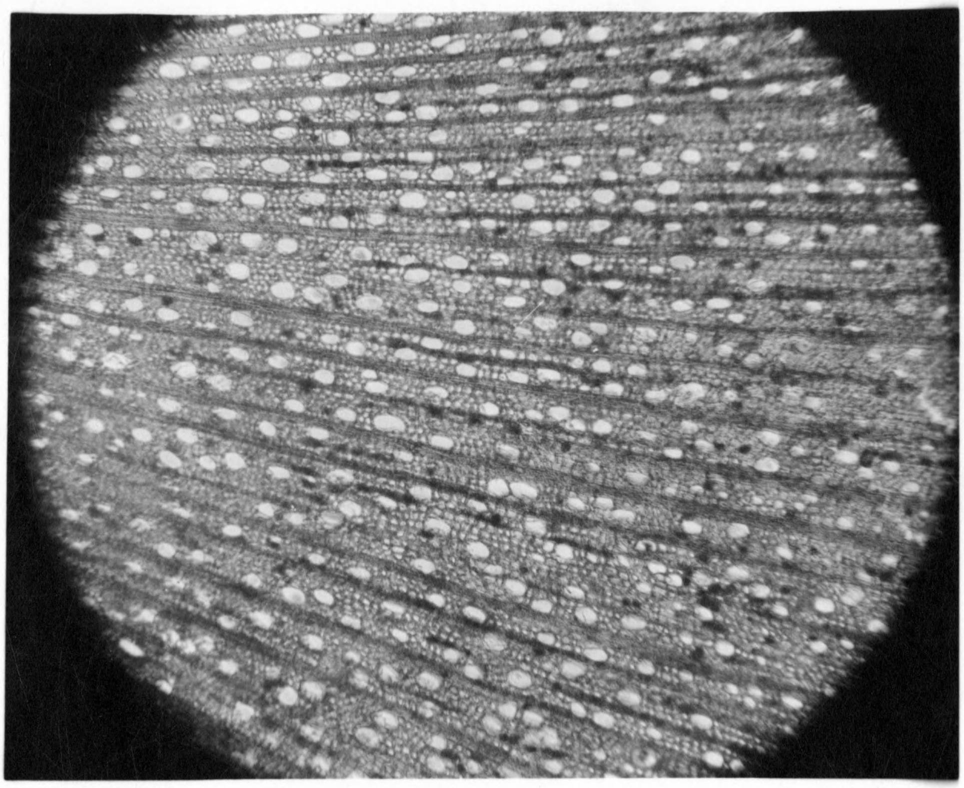

Fig. I

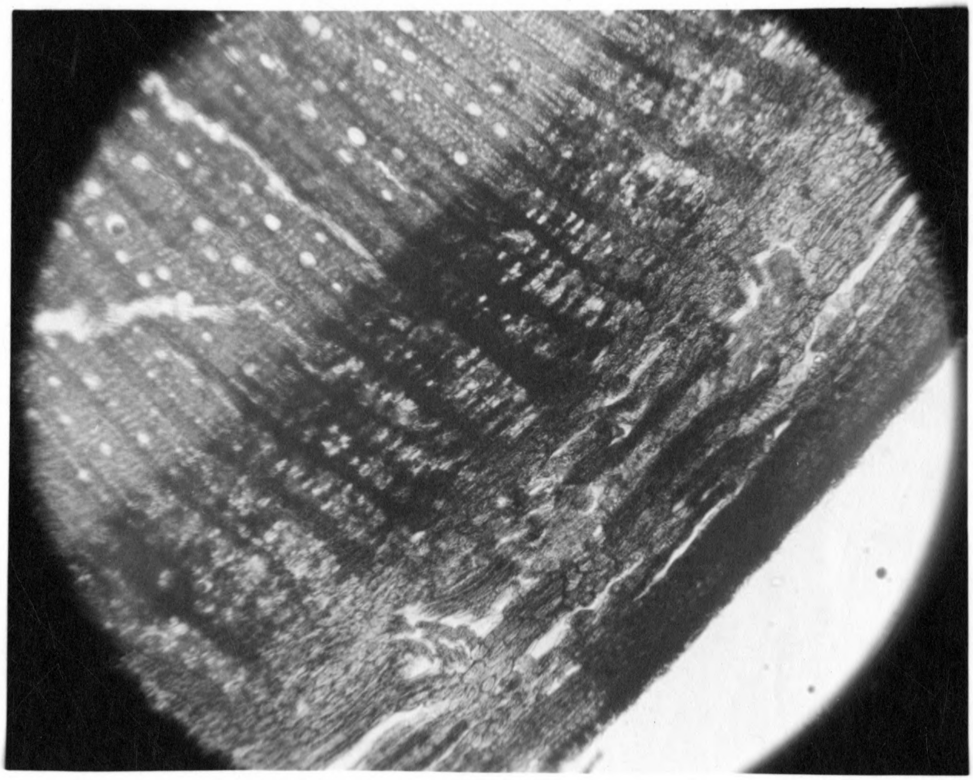

Fig. II

EXPLANATION OF PLATE XIV

Fig. Transverse section of portion of one year wood of Malling-8 a dwarf apple rootstock.

Fig. Transverse section of portion of Malling-8 bark taken from one year old stems.

PLATE XIV

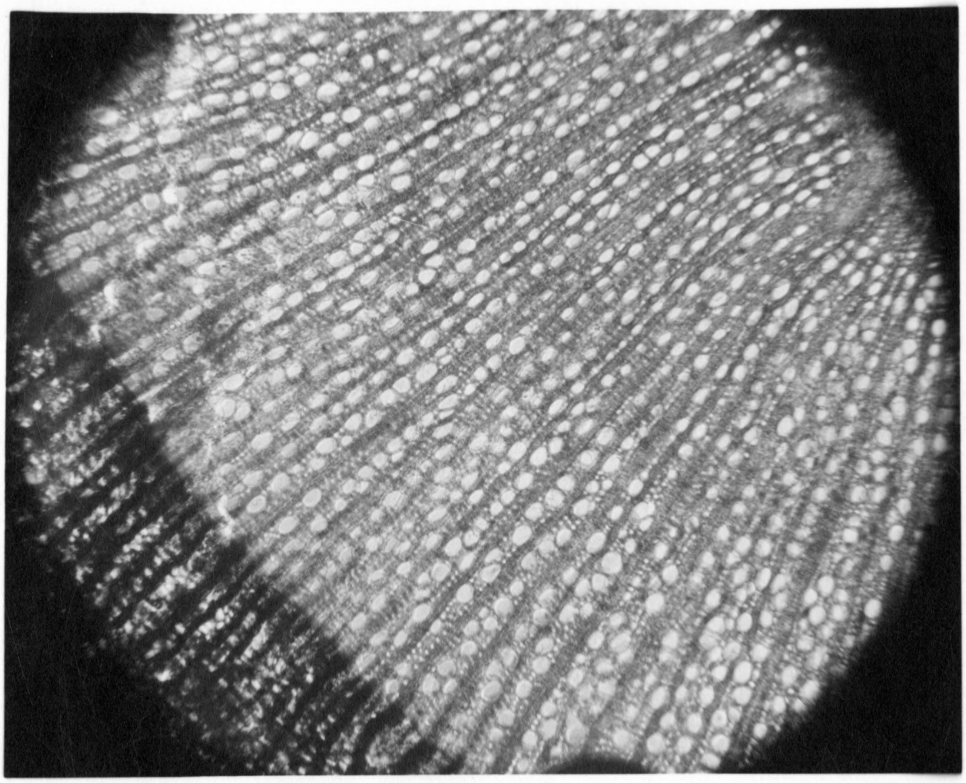

Fig. I

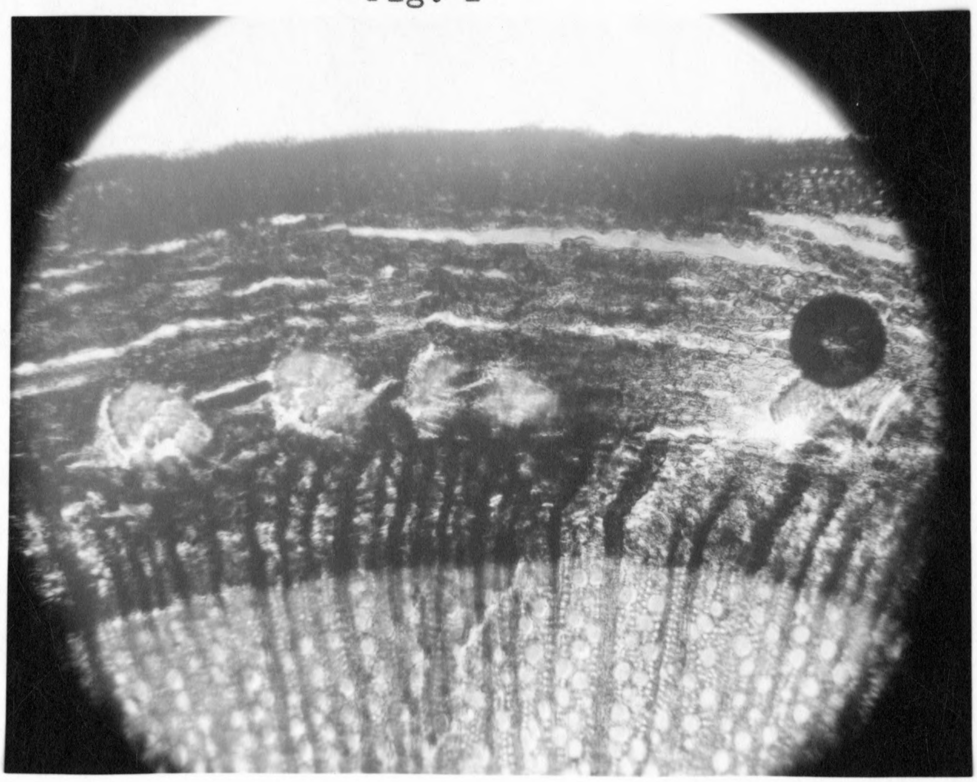

Fig. II

to the wood of the vigorous groups, 4, 5 and 6.

DISCUSSION

Results of the study of bark-wood relations of the different apple rootstocks showed a close relationship between the proportion of bark to wood of a twig and the rate of growth. It was found that twigs of the strong-growing stock varieties showed a lower bark to wood ratio than the weak-growing varieties. Those varieties intermediate in vigour were also found to be nearly midway between the strong and weak-growing varieties in bark-wood relationships. By this procedure, the vigour traits of new rootstocks could be fairly predicted.

These findings were in agreement with the results of studies of roots and stems of some Malling rootstocks (2) (3) (30). The same bark-wood ratio reported for the different apple rootstocks have also been observed to have been induced in the wood of the scion varieties worked on the rootstock. This influence was detected by measuring the rate of growth, bark-wood ratio and the effects on precocity of fruting of scion varieties. Where dwarfing stocks were used, the scion variety worked upon them exhibited slow vegetative growth, a higher bark-wood ratio and came into production earlier than the same scion variety on a vigorous rootstock.

The photomicrographs of transverse sections of one year old wood, Plates V - XIV indicated differences in the relative amount of xylem elements of the 10 apple rootstocks. Stock varieties which possess dwarfing traits showed a relatively greater proportion of living tissues to dead. The rays were wide and abundant, and parenchyma cells were numerous, whereas the fibers were not abundant. In case of the more vigorous rootstocks, Hibernal, K-62, Muzalma and MM-104, the dead tissues or the fibers appeared to occupy a relatively larger area than the living tissues. The rays looked narrow and the parenchyma cells were often sparsely scattered. However, sections cut from twigs of Virginia Crab, a relatively strong-growing stock, indicated a higher living to dead proportion of tissue. The fibers percentage appeared to be small in the bark of the dwarfing stocks, Malling-8 and Clark as well as in the more semidwarfing K-4, and variable in the bark of vigorous stock varieties. The rootstock with intermediate vigor K-41 and MM-106, seemed to possess some characteristics of both dwarf and vigorous stocks. The bark-wood ratio and relative area of fibers in the bark of the intermediate stocks varieties were closer to those of the dwarfs, whereas the proportion of living to dead tissues in the xylem resembled the xylem of vigorous rootstocks.

It may be concluded that bark-wood ratios, and the proportion of living to dead tissues in wood and bark of twigs are fairly good criteria for predicting the rate of growth of rootstocks. Furthermore, the ultimate modifications in scion variety traits based on rootstock influence on variety, may be fairly well predicted as suggested by (3) (23) (30).

An attempt was made to discover any relationships that might exist between size of the twigs as determined by the diameter, the length of internode or the length of the twig and the bark-wood ratio. Since diameter, internode length and the length of the twig may be considered indicative of the growth rate of the twig, and because bark-wood ratio have been associated with the differences in vigor, attempts were made to discover what relationship, if any, exists between both criteria of vigor. The results obtained suggested that the diameter, internode length and length of the twig had no bearing on each other with the exception of the stock K-62 in which the twig showed an increase with an increase in diameter. The length of twig in the strong-growing stock varieties, Hibernal, Virginia Crab and K-62 was found to increase with increased length of internode. The reason this relationship was established in twigs of these rootstocks may possibly be attributed to longer and greater number of internodes which appeared to have greater homogeniety in length along the twig, characteristics that were not prevalent in other rootstocks. Bark percentage was found related, in some rootstocks, to internode length. In case of Malling-8 a dwarf rootstock, a decrease in the bark percentage was found to accompany an increase in internode length. A similar decrease in the bark-wood ratio was observed in Hibernal, a vigorous variety. However, in the Muzalma variety the bark-wood ratio was observed to increase with increase in internode length. It was noticed with the Clark variety that the larger the diameter of the twig the higher the bark percentage. The length of twigs of Hibernal and MM-106 appeared to be related to the bark-wood ratio. As variable and inconsistant as they were, these results suggest individualistic differences rather than definite patterns for rootstock varieties possessing the same degree of vigor.

The significance of the toughness-cutting test of one year wood of the selected apple rootstocks is better appreciated when toughness effects are known. In grafting, a common method of apple propagation, one year wood is often used. Chances of a successful union between a compatible rootstock and a scion variety are best when a considerable portion of the cambium layer in both varieties are matched. Smooth and strong graft union and a straight grafted tree, are most likely to be obtained where surfaces of contact between the stock and scion varieties are even. Eveness of the cut can probably be more secured with tender-wood twigs. Ease encountered in cutting tender-wood twigs, as in K-41, rootstock has been commented on by Luce (22). Thus, it may be deduced that working with tender-wood material in grafting may produce a high percentage of desirable trees. Savings in time and wood might be achieved with soft wooded scions and stocks. Investigations of cider apple varieties have indicated greater success in propagation where tender-wooded scion varieties were worked on tender-wooded rootstocks and where tough-wooded varieties were worked on tough-wooded stock varieties, than where toughness of rootstocks and varieties were different (19). These findings may contribute to the explanation as to how toughness exerts its influence on the graft union. Toughness of the wood of some apple rootstocks and varieties was found to be correlated with winter hardiness in many instances (1). Furthermore, the mechanical strength of the trunk and the scaffold system of the top worked rootstocks under loads of fruit production can be explained by the degree of toughness of wood and wide crotches.

The results obtained from the cutting tests have shown that twigs of Hibernal, a vigorous and hardy rootstock, offered greatest resistance to cutting, whereas Malling-8 and Clark which are dwarfs appeared to be the most tender. In between the two extremes various degrees of resistance was noticed among twigs of the different stock varieties. Differences in toughness or resistance to cutting may be attributed to the relative amounts of fibers in the twig compared to the other wood elements, the thickness of the walls of the fibers and the length and the degree of overlaping according to (4) (10) (12).

Relationships between diameter and length of the twig and its toughness have indicated, in general, that with an increase in diameter of the twig an increase in toughness was noted. This was possibly due to the increase in amount of fibers and lignification of the wood cells. Toughness was increased with length only to the extent by which the length increased the diameter of the twig, as indicated by MM-104, Clark, MM-106 and K-62 twigs. Length did not influence toughness where it did not affect the diameter of the rest of the stock varieties.

The hardness-compression test used in this investigation was an attempt to find measurable differences which may exist among some apple rootstocks possessing various vigor. Compressions were based on relative values obtained from readings on transverse sections of wood with an Impressor tester, and from studying the anatomical structure as shown by photomicrographs. Considerable varietal differences were detected. The stock varieties were divided into groups according to their hardness. Sections of wood of MM-106, Clark and Muzalma recorded the highest values of resistance to the compression test, whereas Hibernal and Malling-8 showed the least resistance. Intermediate values were recorded for the rest of the rootstocks. For example, it was noted that Hibernal and Malling-8, Clark and Muzalma, exhibited similarities in hardness but they were grouped differently with respect to toughness-cutting test.

The size and number of vessels present in wood tissues tested would be expected to influence hardness and toughness of wood. The greater the numer of vessels present the lower the expected values obtained with any hardness and toughness test. Such criteria have been used for identification of hard and soft wood (10). This characteristic may be used in comparing varieties of the same species.

This could possibly explain the differences in hardness values obtained for sections of Hibernal and Clark rootstocks. The hardness values of the first variety were quite low and could be related to the great number of large vessels present as seen in Plate V. This may also explain low hardness values obtained for K-4 where vessels are numerous, and intermediate values recorded for the rest of the stock varieties where vessels are relatively medium in size and number.

Contrasted with Hibernal sections the sections of Clark wood showed the highest hardness values and Plate XIII indicated that sections of these varieties possessed smaller vessels and fewer than any of the 10 rootstock varieties. The other varieties were intermediate in hardness value and vessel number and size which suggested some vessel influence on the results.

In other experiments the compressive strength of wood cut parallel to the fibers was found to be several times greater than samples cut at right angles to the fibers in the common American woods. It has been reported (12) that endwise compression tests to determine strength of wood are easy, simple and inexpensive; however, these tests are not necessarily representative of other strength properties and the results may be misleading. As stated above considerable differences in hardness values were obtained for sections of the various rootstock varieties. There were differences also between values obtained at the two locations in the same wood section of the varieties Hibernal, K-62, Virginia Crab and Malling-8. When examined under a microscope it was noticed that test locations in Hibernal, K-62 and Virginia Crab next to the bark had a denser structure of smaller cells than the areas next to the pith, this may also be detected in Plate V, Fig. 1. Probably these differences account for the variability in results. It may be that these anatomical differences were caused by fast growth of the twigs in spring and a slowing of growth rate in the summer. However, in Malling-8 the wood next to the pith was denser and harder than wood next to the bark. No differences were detected between test location in the rest of the rootstocks as a result of the hardness test. This was confirmed by microscope examination which revealed homogenous structure throughout the various wood sections.

Strength properties of wood have been considered to be correlated with the density of wood (8) (12). Therefore, several methods of density determination have been practiced (4) (11) (12). The majority of the methods used were concerned with the actual density of wood, that is the amount of cell wall substance per unit of volume. Since the wall substance varies with the size of the cells, the thickness of the cell wall and the number of various kinds of cells, the anatomical structure of wood has an important role in predicting density. The differences in density among the different rootstocks studied indicated fairly good agreement with their anatomical characteristics. For example, Hibernal, K-62, and K-41 were found to have the highest densities. Varieties Malling-8, Virginia Crab, MM-104, MM-106 and Muzalma had the lowest densities. When the photomicrographs of these two extreme groups were examined, a greater amount of thick-walled fibers per unit volume could be detected in wood sections of the group with highest density, than in the group possessing the lowest densities. Number and size of the vessels did not seem to have any bearing on density. These observations are in line with other investigations (12) who concluded the following: "Note should be made at this time of the fact that unusually light woods do not necessarily have a high pore count (vessel volume); in fact the reverse is usually the case." It should be mentioned that density determination of Clark wood did not result in the densities anticipated from the study of structure of the wood of thid rootstock variety. It is not unlikely that eroneous readings of density may be responsible for this. The wood of K-4 possessed intermediate density values and showed structural characteristics that are different from both extremes, in that the area occupied by thick-walled cells is not much less than the area occupied by vessels per unit volume. It is likely that the pith, which is made of parenchyma cells, may have some influence on the density of certain volume of twigs. This influence is expected to be greater in small twigs where the proportion of pith to wood is relatively large which tends to decrease densities obtained. Whereas in larger twigs the proportion of pith to wood becomes negligible, due to the fact that pith is a primary tissue which does not increase in size throughout the life of the stem, hense pith influence on density is negligible.

SUMMARY

A close relationship was found between the proportion of bark to wood in twigs and the rate of growth of selected apple rootstocks. Weak-growing stock varieties possessed higher bark-wood ratios than strong growing rootstocks. Moderate-growing varieties in general indicated a decreased bark-wood ratio with increased

vegetative vigor. Few exceptions were noticed.

Microscopic examination of transverse sections of wood and bark from twigs of 10 apple rootstocks showed a wide variation in the anatomical structure of the twigs among the different stock varieties. Distinct differences were noted in amount and distribution of fibers, rays, parenchyma cells and vessels. On the basis of similarities noted the 10 rootstocks were divided into six groups. In general a positive relationship appeared between the amount of living tissue in wood and bark and growth rate; the greater the proportion of living tissue the lower the vigor of the variety. However, in some moderate-growing stocks the wood structure tended to resemble that of the strong-growing varieties whereas the bark structure resembled that of the weak-growing varieties.

It was concluded that the bark-wood ratios, and the proportion of living to dead tissue, in wood and bark of twigs are fairly good criteria for predicting the rate of growth of these rootstocks.

No definite pattern emerged when the relationships between the bark-wood ratios and twig diameter, length and internode length were studied. The results were variable suggesting individualistic differences between varieties.

Significant differences in toughness of wood were found among twigs of the various rootstocks. With some exceptions, strong-growing varieties exhibited greater resistance to cutting than the weak-growing varieties, with moderate-growing varieties ranking between the other two groups. Examination of photomicrographs of transverse sections of wood of the different rootstocks showed thicker cell walls and relatively greater proportion of fibers to other wood elements in the tough-wooded varieties as compared to more tender-wooded varieties. The sections prepared did not show the length and arrangement of fibers, yet other workers have reported that where the fibers were relatively long and overlaping greater toughness resulted than when the opposite conditions were found (7). For the most part an increase in toughness of wood was associated with increased diameter of the twigs. However, two exceptions were noted. Increased toughness accompanied an increase in both length and diameter of the twig.

When cross sections of wood taken from one year old stems were tested for hardness at various location with an Impressor tester. The relative values obtained indicated great varietal differences in hardness among the various stock varieties. The size and the number of vessels present appeared to influence the hardness factor. Examination of the photomicrographs of wood sections of the different rootstock suggest the lower hardness values to be associated with relatively numerous and/or wider vessels. However, other investigators (12) have concluded that results of endwise compression test do not necessarily represent the strength properties of wood. This idea may explain in part the disagreement detected between toughness and hardness properties of the various stock varieties. Hardness readings obtained near the canker of wood sections and at the edges were essentially equal for some rootstocks. Fast growing stock varieties showed hardness values next to the bark than from tests on tissues next to the pith. Microscopic examinations revealed small thick wall of cells next to the bark in wood sections of the vigorous rootstock. Where no differences between test locations were detected in the structure of cells throughout wood sections was fairly homogenous. It can be concluded that growth rate may have been fast early during the growing season then slowed down during the summer in the strong-growing stock variety. Weak-growing rootstocks may have a slow and steady rate of growth throughout the entire season with the exception of Malling-8 where a flush of increased growth may have occurred late in the growing season.

When densities of portions of apple rootstock twigs were determined displacement in cyclohexane, highly significant differences were detected among the various rootstocks. Fairly good relationship was found between density and the structure of wood. Higher densities were associated with greater number of cells and thick-walled cells per unit volume. An increase in number and size of vessels observed did not result in lower densities. The volume of pith of the specimens taken was not considered in the study, but its influence on the density of small twigs may be substantial.

Findings of these studies may be valuable in explaining ease and success of grafting in the production of desirable grafts. Reasons for variability of winter hardiness, vigor of apple rootstocks, and the differences in mechanical strength of trunk and the scaffold of top worked trees may in part be explained by these findings. Further implications of these results in horticulture research may be discovered.

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SOME ANATOMICAL RELATIONSHIPS OF ONE YEAR WOOD OF SELECTED APPLE ROOTSTOCKS

by

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Ten apple rootstocks were selected for the study. An arbitrary grouping made on the basis of relative vigor among the rootstocks selected is as follows:

Very dwarfing:	Malling-8, Clark
Semidwarfing:	K-4, K-41, MM-106
Vigorous:	Muzalma, MM-104
Very vigorous:	Hibernal, Virginia Crab, K-62

The purpose of this study was to study the anatomical relationships of the one year old wood of selected apple rootstocks.

Twigs of the various rootstocks were collected during the dormant season and stored at 40°F. in sphagnum moss. The internode nearest the middle of the twigs was chosen for this study.

Bark-wood relationship was studied by removing a ring of the bark from the internode nearest the middle of the twigs. Percentage of total bark as compared to the woody cross sectional area of the twig was computed. Length of internodes, diameter and length of twigs were determined. Dwarfing rootstock varieties were found to possess higher bark-wood ratio than those of the very vigorous group with the exception of the variety Virginia Crab. Intermediate ratios were observed for the intermediate groups. Relationships between internode length, diameter and length of twigs and bark-wood ratio did not follow a definite pattern.

Microscopic examinations of transverse sections of twigs of each of the stocks revealed the proportion of living to dead tissues in wood and bark of the twigs may be used in predicting rootstock behavior.

Mechanical test were used to determine toughness and hardness of wood of the different rootstocks. Toughness expressed in pounds of pressure required to make a cut through the twig was found to be greatest in the twigs of the varieties classified as vigorous and very vigorous while the very dwarfing rootstocks offered the least resistance to cutting. An increase in the twig diameter, in most of the rootstocks, resulted in greater resistance to cutting. Examination of microscopic transverse section of the different rootstocks indicated that higher number of fibers compared to other wood elements per unit volume, and the thicker cell walls may result in increased toughness.

An impressor tester was used for testing hardness of transverse sections of wood of the different rootstocks. Two locations on each section were tested, one next to the pith, the other next to the bark. Highly significant differences were detected among the various stock varieties, among locations and between locations in the same variety. Hardness differences among varieties seemed to be related to the wood structure. As shown by examination of wood sections, in tissues possessing large cells and numerous, large vessels the hardness values tended to be lower than where cells structure was dense and vessels were fewer and smaller. In the vigorous rootstocks, Hibernal, Virginia Crab and K-62 hardness values were greater next to the bark than next to the pith. It may be concluded that fast growth early in the growing season may have produced loose cell structure next to the pith, whereas the slower growth in summer resulted in denser cell structure, hence the greater hardness next to the bark. Malling-8 showed a reversed order of hardness between the two locations. The rest of the rootstocks showed homogeneous structure of cell throughout the whole section.

Density of wood on an oven dry basis was determined by using the displacement method in cyclohexane. Highly significant differences in wood density was noticed among the various rootstocks. When transverse sections of wood were examined a fairly good relationship between the anatomical structure and density values were obtained. The presence of large numbers of fibers possessing thick walls and small lumens per unit volume may explain the higher densities obtained for Hibernal, K-62, K-41. The lowest densities shown for Muzalma, MM-106, MM-104, Virginia Crab and Malling-8 may also be related to fewer fibers with thinner walls. The number and size of the vessels did not seem to have a great influence on density determinations.