A study of the comparative value of Juniperus scopulorum and Juniperus virginiana as understock for four juniper clones
by Neil J Van Sloun

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Horticulture at Montana State College
Montana State University

Abstract:
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A STUDY OF THE COMPARATIVE VALUE OF JUNIPERUS SCOPULORUM AND JUNIPERUS VIRGINIANA AS UNDERSTOCK FOR FOUR JUNIPER CLONES

by

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ABSTRACT

No significant difference appears to exist between Juniperus scopulorum and Juniperus virginiana as understocks for J. chinesis pfitzeriana, J. horizontalis lividus, J. sabina tamariscifolia, or J. scopulorum Montana No. 1. Successful unions were established for all grafts in which the bark of the scion and stock was close enough to permit the establishment of a callus bridge. Two somewhat different developmental sequences occur, depending upon the distance separating scion from stock. When scion and stock are relatively near one another the sequence involves (1) the formation of a callus bridge followed by (2) the development of a cambial bridge, and (3) the subsequent production of new secondary xylem and secondary phloem. When scion and stock are relatively far apart a union of the vascular tissues of scion and stock precedes cambial activity through the differentiation of some callus tissue into tracheids and sieve cells on either side of the newly formed cambium. Parenchyma cells of the cortex, phloem, and xylem, including the phloem and xylem rays, contributed to callus formation; the cambium contributed little, if at all.

INTRODUCTION

Junipers are propagated by seeds, layers, cuttings, and grafts. Species that root with difficulty or do not grow true to parent type from seed are propagated by grafting. Grafting is also used when a salable plant is desired more quickly. At present, two understocks are commonly used in juniper grafting, Juniperus virginiana and Juniperus chinensis. Juniperus scopulorum is native to the Rocky Mountain area and offers more hardiness and drought resistance than J. virginiana or J. chinensis. The aim of this investigation was to determine whether J. scopulorum compares favorably with J. virginiana as an understock in the commercial propagation of junipers.

LITERATURE REVIEW

Grafting of plans is a very ancient art, dating back to 1560 B. C. (34). There are many methods of graftage (1, 17, 19, 27) and many uses and reasons for grafting (34). Grafts have been successful on algae, mosses, lower vascular plants (Selaginella), herbaceous monocots and dicots, and woody gymnosperms and angiosperms (34). Many inter-specific and inter-generic grafts have been successful but successful grafts between families are quite rare (34).

Grafting of junipers has been done for many years. Mallinson (28) in 1926 described the grafting procedure for junipers and mentioned J. virginiana as the understock. Since then J. chinensis, J. excelsa stricta, J. communis hibernica, J. horizontalis plumosa, and Thuja orientalis have been noted in the literature (5, 6, 7, 15, 21) as understocks in juniper propagation. At present J. virginiana and J. chinensis are most highly recommended (19, 21, 22, 27, 39, 40) as understocks.

Although grafting is a very ancient art, anatomical studies of graft union development date back merely to the mid-eighteenth century (12). Since then, interest in grafting has proceeded along two lines: (a) applied usages in agriculture and (b) anatomical and physiological studies, with neither area contributing significantly to an understanding of all factors involved in the union of stock and scion.

The chronological sequence of ontogenetic phases in the establishment of the graft union has been summarized by Hartmann and Kester (19) as: "(a) establishment of intimate contact of a considerable amount of the cambial region of both stock and scion under favorable environmental conditions, (b) production and interlocking of parenchyma cells (callus tissue) of both stock and scion, (c) production of new cambium across the callus 'bridge', and (d) formation of new xylem and phloem from the new vascular cambium in the callus bridge".[1]

A slightly different developmental sequence has been reported as occurring in Nicotiana (10). Here sieve elements and xylem elements differentiate within the callus bridge concomitantly with the development of cambial tissue, thus giving rise to a union of the younger vascular tissues of scion and stock prior to cambial activity. Sass (35) suggested that a similar process occurs in apple when poor matching results in excessive callus formation.

Frequent statements are made in theoretical and practical grafting literature that only the cambium possesses proliferative capacities. Eames

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[1]Hartmann, H. T., and D. E. Kester. 1959. Plant propagation, principles and practices. Prentice-Hall, Inc. Englewood Cliffs, N. J. Pp. 273-275.

and MacDaniels (13) state ". . . budding and grafting have as their basis the ability of the cambium of both stock and scion to develop callus. . .".[2] This is contrary to the evidence forwarded by a majority of investigators (3, 4, 24, 31, 35, 36) indicating that the cambium often plays a subordinate role or is not the only tissue region involved in callus initiation. Parenchyma cells of the cortex (10, 24, 37), phloem (4, 24, 26, 41, 36, 10) phloem rays (4, 24, 31, 36), medullary rays (18, 36), xylem (10, 36), immature xylem rays (4, 36, 37), xylem rays (4), and pith (24, 37, 10), have been mentioned as contributors to callus tissue. At least one investigator stated that the cambium contributed very little to callus initiation (35). It is obvious that controversy exists with regard to the relative roles played by the cambium and other tissues in callus formation.

Some disagreement appears to exist also, as to the relative roles played by the scion and stock in the formation of callus tissue. Kostoff (25) reported that in the Solanaceae callus tissue joining the scion and stock is chiefly the product of the stock. This statement is not in agreement with observations on other plants reported by the majority of workers, who stated that contributions from stock and the scion are approximately equal.

In addition to a consideration of the sequence of events in the formation of successful graft unions, one must attempt to determine why certain unions fail. Several factors have been suggested in the literature as being responsible for graft union failures. They are: wood discontinuity

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[2]Eames, A. J., and L. H. MacDaniels. 1947. Introduction to plant anatomy. McGraw-Hill Book Co., Inc., New York. Pp. 201.

(2, 8, 32, 38), xylem distortion (33), excessive callus formation (8, 32, 33), seasonal regrafts resulting in excessive callus formation (often suberized) (3), cambium destruction (20), bark interruption (20), phloem discontinuity (3), and uneven starch balance (8, 20, 25, 30, 33).

MATERIALS AND METHODS

This investigation was conducted at Montana State College from November 1958 to November 1959.

The plant materials used were J. scopulorum (Common Rocky Mountain juniper) and J. virginiana (Eastern Red Cedar) as understocks, and J. chinensis pfitzeriana (Pfitzer juniper), J. horizontalis lividus (Lividus juniper), J. sabina tamariscifolia (Savin juniper, "Tam" variety), and J. scopulorum, Montana No. 1 (Montana No. 1 juniper*) as scionwood.

Juniperus scopulorum understocks were obtained from the Forest Nursery of Montana State University at Missoula, Montana. These understocks averaged 3/16 inch in diameter at the base and five inches in height. Juniperus virginiana understocks were obtained from the Plumfield Nurseries at Fremont, Nebraska. These understocks averaged 1/4 inch in diameter at the base and eight inches in height. The J. scopulorum understocks were 2-1 (2 year old, once transplanted) seedlings, the J. virginiana non-transplanted 2-year old seedlings. The scions were obtained from plants growing on the Montana State College campus and in the Bozeman area. The J. chinensis pfitzeriana scions averaged 11 inches in length, the other three varieties six inches

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*Special clonal section having upright form and blue color made and propogated by Plumfield Nurseries, Fremont, Nebraska.

in length. All the scions were of the current year's growth. The scions were cut two days prior to grafting (early January, 1959) and kept refrigerated for this period under conditions of high relative humidity.

The same soil was used throughout the investigation. A mixture of 3 parts loam top soil, 1 part sand, and 1 part manure was used.

Four hundred J. scopulorum seedlings were potted on 21 November, 1958 in 4-inch plastic pots. The plants were stored in a cool greenhouse (minimum temperature of 55° F) until they were grafted in January 1959. Four hundred and fifty J. virginiana seedlings were potted on 18 December, 1958 in 4-inch plastic pots and handled as the other seedlings. Roots of the J. virginiana seedlings were trimmed before potting. Those of the J. scopulorum seedlings were not trimmed because their root systems were not so large as those of the J. virginiana seedlings.

On 10 January, 1959 the understocks were sorted to achieve an "even" understock. One hundred and forty J. scopulorum and fifty J. virginiana seedlings were discarded because of low vitality and crooked stems.

The side graft was used throughout this investigation. An oblique incision 1½ inches long and penetrating 1/3 of the diameter of the stem was made on the lower two inches of the understock. Into this incision was inserted the lower end of the scion that had been cut to form a wedge 1½ inches long. The scion was placed as far as possible into the understock. Care was taken to line up as closely as possible the cambial regions of scion and stock. The graft was then bound securely with rubber budding strips. The time of grafting and the numbers of each graft combination are listed in Table I.

Table I - Graft combinations and time of grafting.

Graft combinations		Number	Date
Scion	Stock	made	made
Pfitzer	J. virginiana	100	12 Jan 59
Pfitzer	J. scopulorum	80	13 Jan 59
Lividus	J. virginiana	100	16 Jan 59
Lividus	J. scopulorum	60	16 Jan 59
Montana No. 1	J. virginiana	100	18 Jan 59
Montana No. 1	J. scopulorum	60	18 Jan 59
Savin	J. virginiana	100	23 Jan 59
Savin	J. scopulorum	60	24 Jan 59

On the same day the grafts were made, the plants were placed under intermittent mist in a greenhouse at a minimum temperature of 65° F. The automatic mist system was of an "In-Bed" type with Type A-6 "Humido-mist" nozzles (self-cleaning). The mist was controlled by an "electronic leaf". The J. chinensis pfitzeriana grafts were kept under the mist at 65° F. for ten days, the other grafts for fourteen days. After this treatment the grafts were placed in a different greenhouse at 55° F. At this time moist sphagnum moss was packed around each graft to prevent the grafts from drying out. On 26 February, 30 J. horizontalis lividus grafts on J. virginiana were moved back to the 65° F. house and forced. Also moved back to the 65° F. house were five each of the other graft combinations. All of the above scions were alive and quite green. On 15 February, one-half of the top of the understock was removed on all the plants. The remaining half was removed on 25 March. On 27 July, the growing grafts were counted and the plants set out in nursery frames. An analysis of variance test was conducted to determine any significant differences between the two understocks.

The collection of material for an anatomical study of the graft unions was begun on 26 February 1959. At this time, one graft of each stock-scion combination was removed and placed in Craf III solution (23). An additional J. horizontalis lividus on J. virginiana graft was placed in FAA solution (23). Thereafter two J. horizontalis lividus on J. virginiana grafts were fixed (one in Craf III and one in FAA) at weekly intervals until 21 May. One each of the seven other combinations were fixed in Craf III at monthly intervals. After this treatment, all samples were softened in a mixture of one part fuming hydrofluoric acid and one part 50 percent ethyl alcohol for one week. They were then dehydrated and embedded in celloidin (23).

Longitudinal and transverse sections were cut at 15 microns with a sliding microtome. They were then stained with anilin blue and iodine-potassium-iodide and mounted in glycerine.

RESULTS

Grafting Success.

The analysis of variance (Table IIB) indicates that no significant difference existed between the two understocks, J. scopulorum and J. virginiana. Because of the slow growth of junipers, total linear growth of the different stock-scion combinations was not measured. The grafted plants were separated into two groups; dead and surviving (surviving being defined as those plants showing visible signs of growth).

A tabulation of survival percentages is presented in Table IIA. The Savin on J. scopulorum exhibited 68 percent survival while Savin on J. virginiana resulted in 43 percent survival. Lividus on J. virginiana and J. scopulorum was approximately equal with 52 and 43 percent, respectively.

Table IIA - Percentage of growing stock-scion combinations on 27 July, 1959.

Graft combinations		Percent
Scion	Stock	Surviving
Lividus	J. scopulorum	43
Lividus	J. virginiana	52
Savin	J. scopulorum	68
Savin	J. virginiana	43
Pfitzer	J. scopulorum	0
Pfitzer	J. virginiana	1
Montana No. 1	J. scopulorum	21
Montana No. 1	J. virginiana	13

Table IIB - Analysis of variance for data in Table IIA.

	D.F.	S.S.	M.S.	F.*	
				Calc.	Tab.
Treatment	1	75.33	75.33	.106	5.99 13.75
Error	6	4259.16	709.86		
Total	7	4334.49			

*F value is not significant.

There was little difference in growth among the several graft combinations (Plate I). It was noted that some grafts which appeared to have healed and formed callus tissue remained green and alive for some time but eventually died.

Montana No. 1 united almost twice as well with J. scopulorum than with J. virginiana, although both percentages were quite low (Table IIA). Pfitzer did very poorly on both understocks.

General Description of the Stem.

The complete stem (both J. scopulorum and J. virginiana) consists of periderm, cortex, obliterated primary phloem, several increments of secondary phloem, the cambial region, several increments of secondary xylem and pith.

The cortex is composed entirely of starch- and/or resin-containing parenchyma cells and possesses numerous intercellular spaces.

The elements in the vertical system of the secondary phloem are arranged tangentially and alternate with one another in the sequence; sieve cells, parenchyma cells, sieve cells, parenchyma cells, parenchyma cells, fibers, etc. (Plate II, A). The parenchyma cells of the parenchyma strands and of the rays contain starch and/or "resinous" material (9). Tangentially elongated resin canals surrounded by epithelial cells are found in the non-functional phloem.

The vertical system of the secondary xylem consists of tracheids and gum-containing parenchyma cells. The xylem rays (horizontal system) are made up exclusively of starch- and/or resin-containing parenchyma cells.

All parenchyma cells (of cortex, phloem, xylem, and pith) possess primary walls.

The Successful Grafts.

Twenty-four of forty-two grafts studied anatomically exhibited successful unions. In each of the twenty-four successful grafts the scion had been inserted into the stock in such a manner that the bark of the scion either came into contact with that of the stock or nearly so. All

parenchyma cells of the stem seem to be equally capable of proliferation and formation of callus tissue, with the possible exception of those in the pith. No notable differences appear to exist in the behavior of the various combinations of scion and stock, nor in their starch content.

The sequence of events in the union of scion and stock was simplest in those grafts with a more accurate alignment of tissues of scion and stock, that is, with outer bark adjacent to outer bark, inner bark adjacent to inner bark, etc. (Plate III, A). The ontogenetic sequence includes (1) the proliferation of parenchyma of the cortex (both phloem and ray parenchyma) of the bark followed by (2) the development of a cambium (Plate III, A, at c) in the newly formed tissue resulting in the union of the cambia of scion and stock, and (3) the subsequent production of new secondary phloem and secondary xylem.

The sequence of events in the grafts that possessed a less accurate alignment of tissues of scion and bark (e.g., with outer bark of the scion adjacent to inner bark of the stock and inner bark of the scion adjacent to secondary xylem of the stock) is similar to that mentioned above. In the second type graft, however, the parenchyma (both xylem and ray parenchyma) of the secondary xylem (Plate III, B) of the stock, in addition to the parenchyma of the bark of both scion and stock, proliferate and contribute to the formation of the callus tissue in which a cambial bridge eventually differentiates. This type union of scion and stock results in the formation of a U-shaped cambial union (Plate III, C at c).

If scion and stock are in actual contact with one another or nearly so, a cambial union is achieved with a relatively short period of time,

all new vascular elements (sieve cells and tracheids) result from cambial activity and thus have their long axes oriented vertically. If on the other hand scion and stock are relatively far apart and thus require a relatively large callus bridge, tracheids and sieve cells with their long axes oriented horizontally may differentiate on either side of and prior to activity of the newly formed cambial bridge (Plate IV, C). Under such circumstances a union of the xylem and phloem of the scion and the stock precedes cambial activity within the cambial bridge.

In most of the successful grafts the bark of only one side of the scion was aligned with that of the stock. This is due to the fact that most of the scions are smaller than the area of the stock in which they were inserted. As a result, not only is there a space between both sides of the scion and the stock, but also between the two halves of the stock not separated by the scion (Plate IV, A). If the distance between scion and stock is not very great, these areas become occupied by callus tissue that remains parenchymatous. If, on the other hand, a relatively large gap exists between scion and stock, the callus tissue bridging these areas may give rise to a cambium that runs parallel to the scion and another that runs parallel to the stock (Plate IV, B). The cambium lying adjacent to the scion eventually unites with the cambia at either end of the scion, and the cambium lying adjacent to the stock with the pre-existing cambium of the stock. If the distances are relatively great between both halves of the stock and the scion, a complete ring of cambium may develop around the scion and around each half of the stock. These cambia subsequently give rise to secondary xylem and secondary phloem. Very commonly groups of

more or less obliquely oriented tracheids differentiate from the callus tissue that bridges the scion and stock resulting in a union of the xylem of the two parts of the graft (Plate II, B).

The Unsuccessful Grafts.

In seventeen of the eighteen unsuccessful grafts studied anatomically, the scion was embedded entirely in the secondary xylem of the stock (Plate IV, D); in other words there was no alignment of the bark of the scion with that of the stock. Callus tissue produced by both scion and stock gave rise to either scar tissue or a periderm before a bridge could be achieved thereby preventing the union of the scion with the stock. The other unsuccessful graft examined anatomically (Pfitzer on J. scopulorum) had a nearly perfect alignment of the tissues of scion and stock, but little or no proliferation of parenchyma had occurred (see comments on Pfitzer combinations in Discussions and Conclusions).

DISCUSSION AND CONCLUSIONS

As indicated in the introduction, the aim of this investigation was to determine whether Juniperus scopulorum compares favorably with J. virginiana as an understock in the commercial propagation of junipers. J. virginiana and J. scopulorum are almost identical anatomically and both have the same chromosome number, 2n=22 (11, 29). For these reasons one might expect both species to prove equally suitable as understocks for diploid junipers.

The statistical analysis of all data indicates that no significant difference exists between the performance of J. scopulorum and J. virginiana

as understocks for the materials studied. Obviously continued observations over a longer period of time would be desirable to determine with certainty the true value of these two understocks. During this period such factors as root formation, winter injury, hardiness, drought resistance, general growth habits, disease resistance, and possible dwarfing effects should be considered.

If one were to consider the Montana No. 1 combinations apart from the other stock-scion combinations, one might question the value of J. virginiana as an understock. Montana No. 1 united almost twice as well with J. scopulorum as with J. virginiana. A possible, but perhaps poor explanation for these results might be in the fact that Montana No. 1 is actually a variety of J. scopulorum and therefore might be expected to do better with J. scopulorum than with J. virginiana. However, in view of the close similiarities in structure and chromosome number of the two understocks this hardly seems a valid reason for the differences observed. The number of takes of both Montana No. 1 combinations are low when compared with those of Lividus and Savin and are perhaps too low to be considered of any significance in this investigation. The low percentage takes with Montana No. 1 as compared with the relatively high percentages of Lividus and Savin may possibly be attributed to the different growth habits of Montana No. 1. Montana No. 1 is upright, Lividus and Savin horizontal.

Any one of a combination of several factors may be responsible for the exceedingly poor performance of the Pfitzer combinations. Incompatibility may have resulted from the difference in chromosome number of the scion and stock in these combinations. Pfitzer is tetraploid (11), whereas J.

virginiana and J. scopulorum are diploids (29). (Lividus, Savin and Montana No. 1 are diploids.) The failure of the Pfitzer combinations might also be attributed to the fact that the Pfitzer scions were almost twice as large as the scions of the other combinations. Excessive transpiration by the large Pfitzer scions may have created a water relations problem. And finally, the Pfitzer combinations had a four-day shorter period under the mist and warm temperature than did the other combinations.

In the present investigation successful unions were established for all grafts studied anatomically in which at least a part of the bark of the scion and stock was in contact or nearly so. In other words, as long as the bark of scion and stock was close enough to permit the establishment of a callus bridge, a cambial union followed and a successful union resulted. In all but one of the unsuccessful grafts, the bark of the scion and stock were so far apart that the callus tissue of one or both halves of the graft had produced either scar tissue or a periderm before a union could be accomplished.

When scion and stock are relatively near one another, the sequence of events in the graft union consists of (1) the formation of a callus bridge (with equal contributions by scion and stock) followed by (2) the development of a cambial bridge, and (3) the subsequent production of new secondary xylem and secondary phloem. The developmental sequence differs somewhat, however, in those grafts in which scion and stock are relatively far apart and thus, in which a relatively large callus bridge is required. Here, tracheids and sieve cells differentiate from callus tissue on either side of and prior to activity of the newly formed cambial bridge. This pattern

of development results in a union of the vascular tissues of scion and stock prior to cambial activity rather than afterward, and is similar to the phenomenon reported by Sass (35) as occurring in apple when there is excessive callus formation.

The length of time required for a complete union of scion and stock varies considerably depending upon the distance between scion and stock, and the degree of accuracy in alignment of the tissues of the scion and stock. It is apparent that a greater amount of callus tissue will be necessary to fill in a larger space than a smaller one. Likewise more time will be required for cambial formation in a wider bridger of callus tissue than in a narrower one. The second factor is clearly understood if one recalls that a less accurate alignment of tissues of the scion and stock results in a greater radial separation of the cambia of scion and stock, thus requiring the formation of longer cambial bridges than in those grafts in which the cambia lie adjacent to one another.

It is apparent from the review of literature that controversy exists with regard to the relative roles played by the cambium and other tissues in callus formation. In the present investigation the cambium appeared to contribute little, if at all, to callus formation. The grafts in this study were made during winter dormancy. At this time of year the cambial zone of the juniper is one to three cells wide. During the same time of year the cambial zones of other species may possess as many as ten overwintering elements (16). One might logically expect the cambial zone of a species with many overwintering elements to play a greater role in callus formation than one with only a few. It would be interesting to examine

juniper material that had been grafted during the growing season, that is, at a time when the cambial zone would consist of more than merely the layer of cambial initials and one or two derivatives. During a period of cambial activity one would expect the cambial zone to contribute much more to callus formation than during the dormant period. Under any circumstance, the role played by the cambium in callus formation during the dormant period probably varies from species to species, in part at least, according to the number of elements overwintering in the cambial zone.

With regard to the relative roles played by other tissues in callus formation, practically all tissues of the stem have been cited, at one time or another, as having contributed (see review of literature). In the present investigation it was observed that the parenchyma cells of the cortex, phloem, and xylem, including the phloem and xylem rays, are capable of undergoing considerable proliferation. Of these, the parenchyma cells of the xylem and the xylem rays are particularly important when the tissues of the bark of scion and stock are not in alignment. It is interesting to note that, except for immature elements, these cells are rarely mentioned in the literature as the precursors of callus tissue. Very likely the reason for this lies in the fact that in many species the parenchyma cells of the xylem and xylem rays possess secondary walls and are, therefore, unable to undergo reversible changes (14). In other words, it is impossible for these cells to become meristematic. The parenchyma cells in the xylem and xylem rays of the juniper possess primary walls and thus can become meristematic. Since the pith was rarely involved in the unions studied, no data was gathered with regard to its role in callus formation.

The little additional care and time required to be certain of alignment of the two barks would greatly increase the efficiency of the grafting.

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PLATE I

A. Photograph showing comparative growth of Lividus on *J. scopulorum* and *J. virginiana*.

B. Photograph showing comparative growth of Savin on *J. scopulorum* and *J. virginiana*.

C. Photograph showing comparative growth of Montana No. 1 (also called Rocky Mountain No. 1) on *J. scopulorum* and *J. virginiana*.


LIVIDUS
ON
J. SCOPULORUM
LIVIDUS
ON
J. VIRGINIANA
A


SAVIN
ON
J. SCOPULORUM
SAVIN
ON
J. VIRGINIANA
B

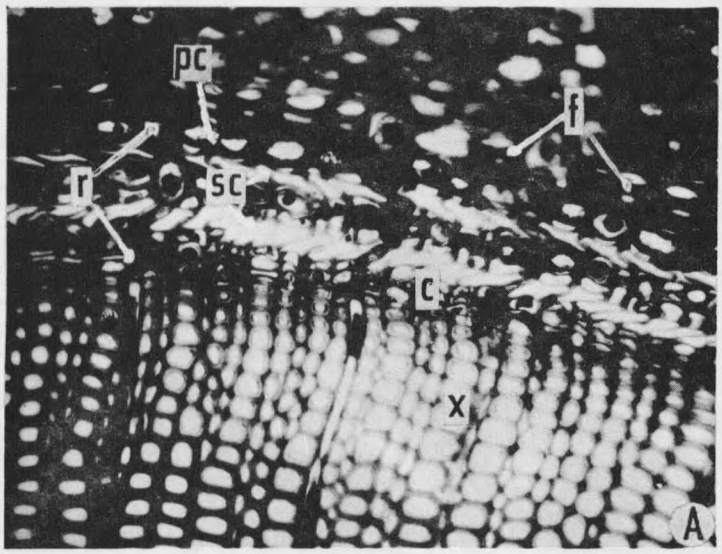

ROCKY MTN.
NO. 1
ON
J. SCOPULORUM
ROCKY MTN.
NO. 1
ON
J. VIRGINIANA
C

PLATE II

A. Transverse section showing outer part of the xylem (x), the cambial zone (c), and the inner area of the phloem (above the cambial zone). The parenchyma cells of the rays (r) possess primary walls in both the phloem and xylem. The vertical elements in the phloem are fibers (f), parenchyma cells (pc) and sieve cells (sc). X320.

B. Longitudinal section shwoing obliquely oriented tracheids (t) that have differentiated from callus tissue (cal) bridging scion (sn) and stock (st). X80.

Details: c, cambial zone; cal, callus tissue; f, fibers; pc, parenchyma cells; r, rays; sc, sieve cells; sn, scion; st, stock; t, tracheids; x, xylem.


pc
f
r
sc
c
x
A

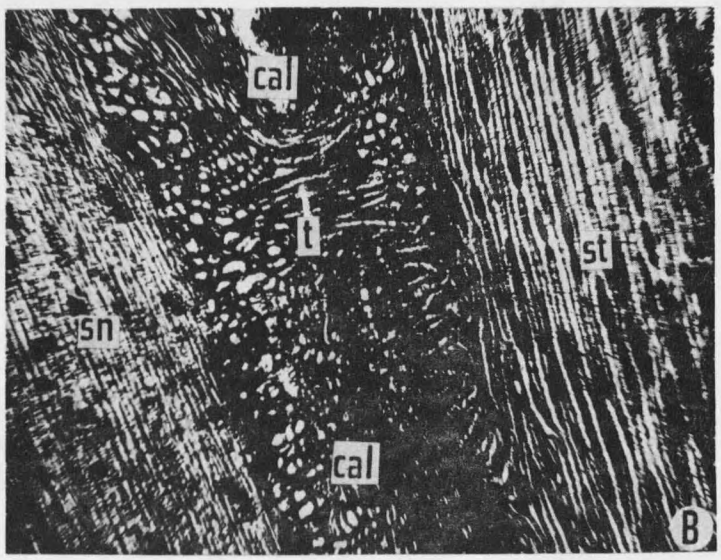

cal
t
st
sn
cal
B

PLATE III

A. Transverse section showing outer part of the xylem (x), the cambial zone (c), the phloem (ph), and cortex (ctx). The tissues of scion and stock are very accurately matched (the stock is to the left of the broken line, the scion to the right). X80.

B. Transverse section showing part of the stock (st) and scion (sn) including callus tissue (cal) produced between them from proliferating xylem parenchyma and xylem ray parenchyma. X80.

C. Transverse section showing a U-shaped cambial union between stock (st) and scion (sn). X80.

Details: c, cambial zone; cal, callus tissue; ctx, cortex; ph, phloem; sn, scion; st, stock; x, xylem.