ROOT GRAFTS INFLUENCE DEVELOPMENT OF A RED PINE PLANTATION

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ABSTRACT

Functional root grafting between trees and stumps, studied by means of dye translocation, was found to be extremely common. Its erratic but important role in stem development is discussed along with the silvicultural implications.

BACKGROUND

Root grafting, a common phenomenon in stands of certain coniferous species, particularly pines, may be much more influential as a stand-development factor than previously suspected. This certainly seems to be the case with red pine (*Pinus resinosa* Ait.), as the following study indicates.

The investigation stemmed from an observation that in an Ontario plantation, 3 years after row thinning, more than 90 per cent of the stumps remained alive--apparently because of root grafting with live trees. Since the stand provided an interesting contrast in spacing--3 x 6-foot spacing in some areas and 6 x 6-foot in others--and since detailed stem-growth studies were already underway, it was an excellent opportunity to examine the extent and effects of root grafting.

Of particular interest was the effect that the stumps' root systems might have on stem growth of residual trees to which they were root-grafted--especially in the denser areas where crown expansion would be limited by the 3-foot spacing within the rows. Yli-Vakkuri (1954), who demonstrated that nutrients may be translocated between Scots pines (*P. sylvestris* L.) via root grafts, suggested that residual trees in a thinned stand would thus benefit.

The 40-acre plantation studied was established in Whitchurch Township in 1932 and planted by hand in furrows ploughed in an open field. Survival rate was high, so that spacing is fairly regular in most portions of the stand. Site conditions are exceptionally uniform since the plantation is located on the almost level top of a broad ridge of deep, unstratified fine sand. Every third row of trees was removed in June 1962. When the root grafting studies commenced in the spring of 1965, the stand averaged 5.1 inches in d.b.h. and 37.3 feet in height. Forty-five per cent of the total bole length was occupied by living crown on the average tree.

In preliminary excavations of upper lateral roots around selected stumps and stems, grafts were surprisingly common, occurring within and between root systems of both stumps and living trees. Grafts encountered included right-angled, polar (roots more or less parallel in the same direction), anti-polar, and collar (located near root collar). Similar types of grafts have been described by Armson and Van den Driessche (1959) who studied nine red pine plantations in southern Ontario. In addition, multiple (three- or four-way) grafts and grafts of vertical roots were found (Plate 1). Grafting occurred on roots of various ages, ranging in diameter from ¼ to 3 inches at depths from ½ to 20 inches below the surface.

USE OF TRACER DYES

Moisture movement in the grafted systems was traced mainly by dyes. Dye solutions were introduced into living stems, into stumps (both 3 year old and freshly cut), and into the proximal end of severed roots. For application to stems and stumps, leak-proof dye containers were contrived from sheet aluminum, caulking compound, and melted paraffin; for application to roots, the severed proximal ends were inserted into bottles containing the dye solution. Initially, treatments were applied with a minimum of disturbance to the roots, any exposed portions being carefully re-covered. It subsequently became evident that these measures were unnecessary, dye being freely transported even in considerably damaged and exposed root systems. Rates of dye intake were not measured.

A 0.2 per cent solution of acid fuschin in water was the main dye used; aniline blue or malachite green in similar concentrations were also employed when different colours were needed to follow possible two-way flows in grafted multiple root systems. Acid fuschin diffused most rapidly, and malachite green the least; but directions of movement were readily observable in all cases. The dyes were applied to selected stems or roots and replenished periodically for some weeks. Then dye movements were traced by excavating and cross-sectioning appropriate roots. Examples were selected to study flow directions between connected large and small trees, large and small stumps, or trees and stumps in various combinations. Treatments were applied variously in spring, midsummer, late summer, and fall. Twenty interconnected systems were investigated, and the most interesting are described below.

DYE-MOVEMENT PATTERNS

The extent of root grafting in this plantation is immediately evident in Figure 1 which shows complex and devious connections between three rows of living trees and two rows of stumps. Adjoining trees, if not directly grafted, are in most cases indirectly connected via other trees or stumps. Single root systems seem the exception in this plantation.

The general patterns of dye movement are demonstrated in Figure 1 and in subsequent figures chosen to represent the sample best. In summary the patterns are as follows:

(a) Dye introduced into living trunks during the growing season invariably flowed upward, never downward (no illustration given).

(b) Dye introduced into the proximal end of severed roots of small live trees flowed both up the tree stems *and* towards grafted trees of similar or larger size but *not* towards connected stumps (Figs. 1 & 2).

(c) Dye of different colours introduced into roots of adjoining connected stumps flowed from one stump to the other but not both ways (Fig. 3).

(d) Dyes of different colours introduced respectively into the roots of 3-year-old stumps and connected live trees flowed during the growing season from the stump root system to the tree but not the reverse (Fig. 4). During the dormant season, however, dye did not flow from stumps to connected trees.

(e) Dye applied to old stumps grafted with other stumps *and* with live trees moved up to 20 feet to one or several live trees, sometimes via root systems of other stumps (Fig. 5). This occurred in both lightly stocked (Fig. 6) and densely stocked areas (Fig. 5) and between stumps and trees of widely varying diameters.

(f) Dye applied to *freshly cut stumps* late in the growing season flowed towards connected live trees but not towards connected old stumps that were equally close (Fig. 7).

ROOT GRAFTING FEATURES

Flow of dye in most interconnected systems occurred mainly along grafted roots, and was usually absent or weak in nongrafted roots (Figs. 1, 5, 6). There were a few exceptions in which dye moved down into roots that were apparently not directly grafted to live trees, and in some cases dye flowed down vertical taproots or sinkers of stumps. It was not feasible to trace every root of each system to its end; and it may be that hidden grafts, occurring deep in the soil or near root extremities, could explain these exceptions.

Flow from stump to live tree occurred with apparently similar ease through roots originating from either system (Figs. 1, 6). In other words, grafted roots, regardless of their polarity, were conducting moisture from the "captured" root systems of the stumps to the live trees.

In every case of "captive" systems (Figs. 2, 3, 4) where dye was introduced through severed roots, it flowed towards the parent stem or stump as well as to the dominating live stem. The captured system thus retains some diminished drawing power.

Functional root grafts were common in the 6 x 6-foot spacing as well as in the 3 x 6. Grafting of red pine roots apparently occurs with ease even where roots are not excessively crowded and where the soil has no obstructions. Fusion is common where one root crosses another at a crotch. Although every degree of pressure grafting was encountered, fused functioning grafts were more numerous than nonfunctioning ones.

Summarizing, the dye patterns show that moisture flows from stump to stump in many cases, from stumps to live trees frequently, and from live trees to other directly connected trees of similar or larger size.

ROOT GRAFTING EFFECTS

This is clearly not a stand of individual trees competing independently for crown and root space. The great majority of the stems are connected directly or indirectly by root grafts with one, or more, often several other stems--and connected in an unpredictable manner in terms of both the number of grafts and their functional effectiveness.

Dye transferred more readily through some grafts than others, but no consistent tendencies relating to graft or relative root size could be discerned. Armson and Van den Dreissche (1959), who studied this matter more thoroughly, concluded that when two red pine roots graft the one that is farthest from its origin or the one of smaller diameter benefits most in subsequent growth.

Bormann (1966), from translocation experiments with maturing white pine, suggested that an effective fusion of roots occurs only between root tissues with normal physiological and anatomical alignment. He found that a "dominant tree grafted to another dominant or to a suppressed tree, cannot divert to its own use a significant quantity of water and minerals moving in the xylem of the other tree--food moves from the dominant tree to the smaller tree--when the crown of a suppressed tree dies and 'transpirational pull' is eliminated, water and minerals absorbed by the roots of the suppressed tree may move to the dominant. For the dominant tree, however, this represents a relatively inefficient method of obtaining water and minerals." When a dominant tree is grafted to a living stump, a counteracting relationship obtains--"The tree contributes minor quantities of food to the stump and gets minor quantities of water and minerals in return".

Thus dominant trees do not apparently benefit from root grafting, and suppressed stems have the effect of unimportant, dying parasites. However, an important implication remains--the intermediates or codominants could, following a thinning which removed many dominants, either gain or lose in growth, depending on the effectiveness of root grafting.

To explore this implication further, the radial increments during 1964 and 1965 of some 20 comparable codominants (6-inch diameter class) and 20 intermediates (4-inch diameter) were analysed. With these trees which, within each class, had grown comparably until the 1962 row thinning and were currently growing in similar, surrounding competition, it seemed logical to expect minimal variation in growth subsequent to thinning. Yet growth within each season, measured accurately at marked points by microdendrometers, ranged several hundred per cent between the slowest and fastest--an extremely wide variation that could result from the erratic effect of root grafting following thinning.

A similar situation was found in diameter growth of roots. Microscopic examination of rings in selected grafted roots from 3-year-old stump systems showed that growth patterns both before and after cutting were quite irregular. After thinning, the roots of most stumps continued to grow although some atrophied and a few died.

The mortality of stump roots, hence of stumps themselves, inevitably increases with time, as has been pointed out by Martin (1965) who found that 80 per cent of stumps in thinned red pine stands remained wholly or partially alive after 1 year, approximately 60 per cent after 3 years, 50 per cent after 6 years, and 40 per cent after 7 years. My higher figure of 90 per cent of stumps living after 3 years shows that rate of stump mortality must vary from stand to stand. In any case, the effect of stump root systems on residual tree growth is not by any means ephemeral but could well apply long enough to change the competitive status of many crop trees.

Armson and Van den Dreissche (1959) found "little evidence of a pronounced increase in number of grafts with age of stand but, rather, a definite increase of grafting in thinned stands as compared with unthinned." They speculated that growth increase of crown and stem through thinning would result in increased root diameter which, because of greater pressure at contact points, would induce further grafting. Adams (1940) suggested that prompt response of *P. radiata* to late, heavy thinning as contrasted with poor response to early thinning may be attributable to the increased root fusion that he found in older stands. Thus crown thinning and root grafting may be correlated and mutually beneficial to stem growth. It must be stressed again, however, that the degree of benefit to individual stems would vary widely and unpredictably because of the haphazard occurrence of grafts.

Root grafting in conjunction with stand thinning has further silvicultural implications, both good and bad. As Yli-Vakkuri (1954) and Martin (1965) have pointed out, the activities of insects and fungi, normally effective in the deterioration of stumps and their roots, are greatly curtailed by the continued viability of the stump and its impregnation by resin.

Spread of disease via root fusions is a possible deleterious factor in grafting. The root- and butt-rotting fungus *Fomes annosus* (Fr.) Cke. is perhaps the most potentially dangerous pathogen. It does occur in red pine plantations in Ontario (Jorgensen 1956), it can spread through a stand via stumps or root connections (Rishbeth 1948), and its incidence generally increases after thinning.

Another silvicultural danger in root grafting is "back-flash", indiscriminate damage resulting from chemical thinning or debarking. Cook and Welch (1957), in a chemical peeling operation in a 25-year-old red pine stand, applied sodium arsenite to selected stems and found that other stems also died, an effect attributed to the transmission of the poison through root grafts. The same effect possibly could, as as Armson and Van den Dreissche (1959) have suggested, prove useful for eliminating one species from a mixed stand by an arboricide.

Lastly an increased resistance against windthrow may be another useful effect of root grafting. This has not been clearly demonstrated; however, a strongly fused union of several root systems should be more stable than single systems, particularly in thinned stands and on shallow sites.

Considering these various pieces of evidence, I have only one conclusion--that anyone concerned with the silviculture of pine plantations, and particularly with questions of crop-tree selection, individual stem growth, chemical thinning, and sanitation cutting, should reckon with root grafting. It is equally evident that, with all these physiological and silvicultural implications, considerably more research into root grafting is warranted.

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Figure 1. Several living pines in three separate rows plus 3-year-old stumps in two intervening rows were connected by functioning root grafts. Flow patterns from different applications of dyes to stumps and to roots are shown cross-hatched.

Figure 2. A suppressed live tree was root-grafted to an adjoining dominant tree and to a healthy stump. Dye was applied to a root of the small tree.

Figure 3. Adjoining healthy stumps were connected by numerous root grafts. A vigorous root from each stump was severed and dyed.

KEY TO SYMBOLS

St 4" - stump, 3 years old, 4 inches diameter

LT 6" - living tree (red pine), 6 inches d.b.h.

LT st - stump of freshly cut tree

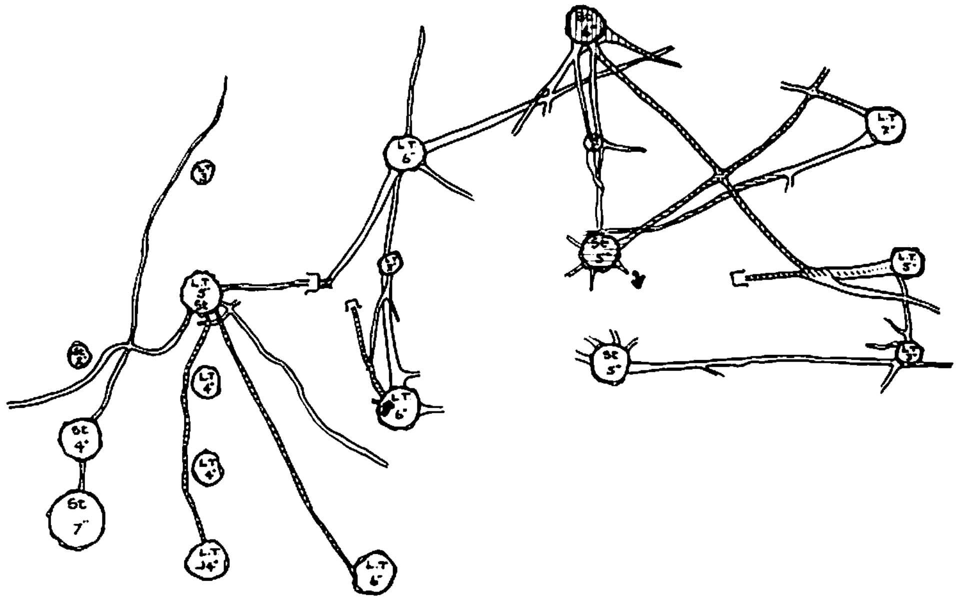
 - dye bottle applied to severed root

 - dye applied to stump surface (cross-hatchings differentiate separate dye applications)

 - dye moved up the stem

 - dye moved down taproot or sinker

Scale - generally 6 feet between rows and 3 or 6 feet between trees



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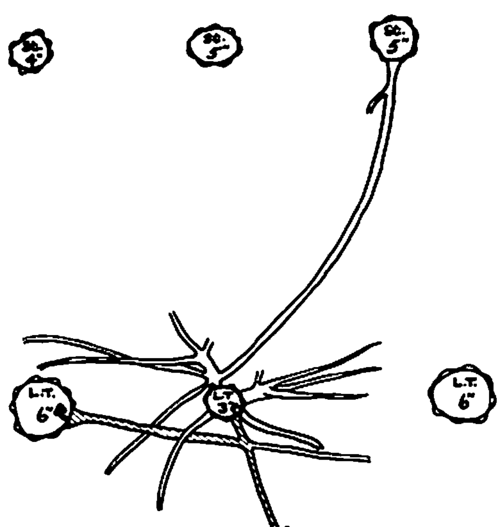

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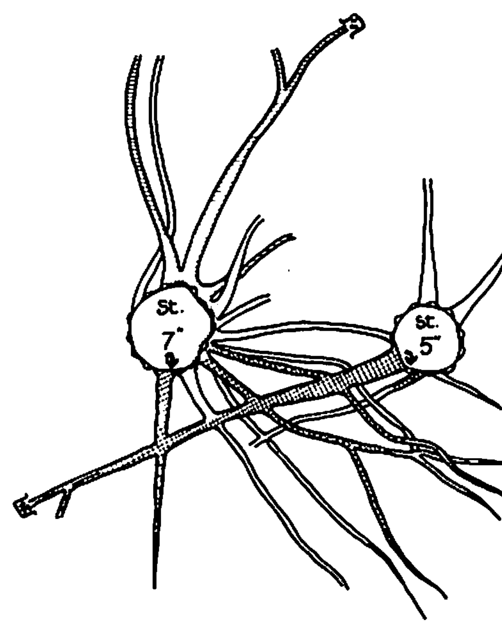

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Figure 4. An intermediate-sized stump was strongly grafted to a similar adjoining stump and to a dominant tree. Roots of the stump and the live tree were treated with different coloured dyes.

Figure 5. Healthy stumps were intimately grafted together and to vigorous live trees of various sizes up to 20 feet distant. Dye was applied to a central stump in an area where spacing was 3 x 6 feet.

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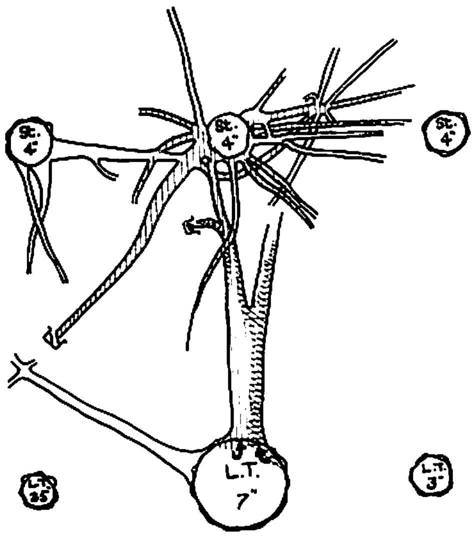

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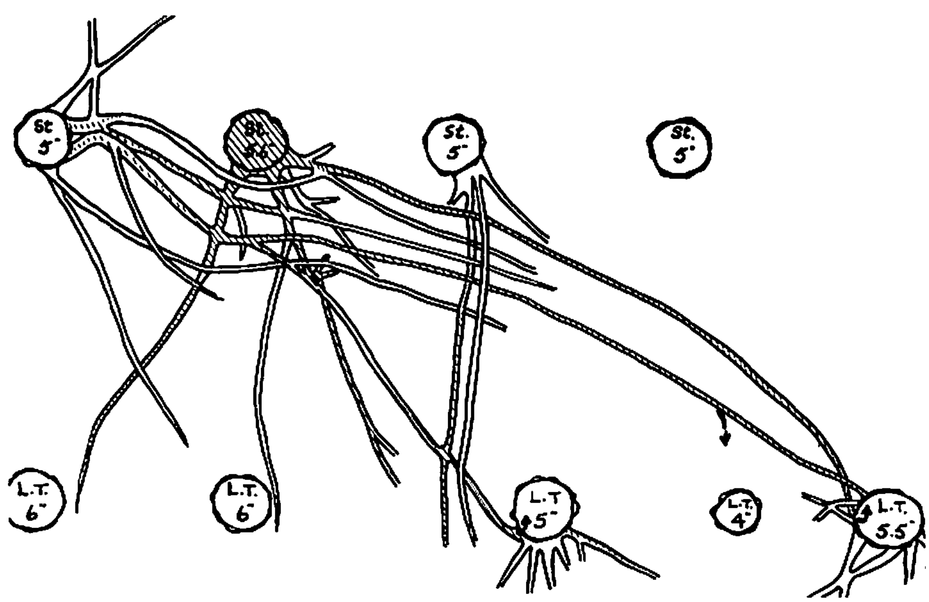

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Figure 6. Same points as Figure 5 but applied to an area where spacing averaged 6 x 6 feet.

Figure 7. A dominant live tree was grafted to adjoining vigorous trees and stumps. The tree was cut and dye was applied to the stump.

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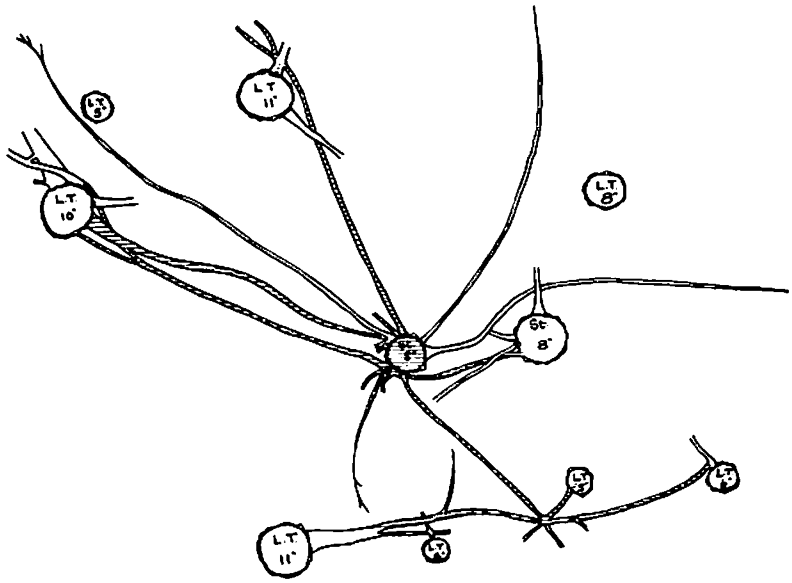

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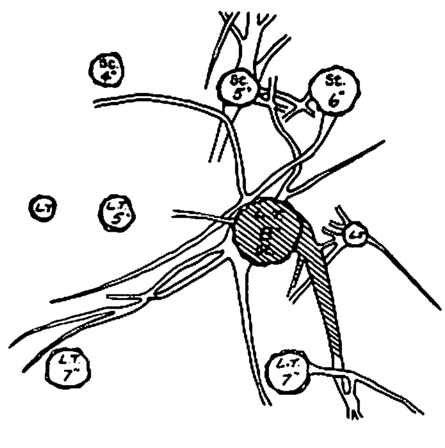

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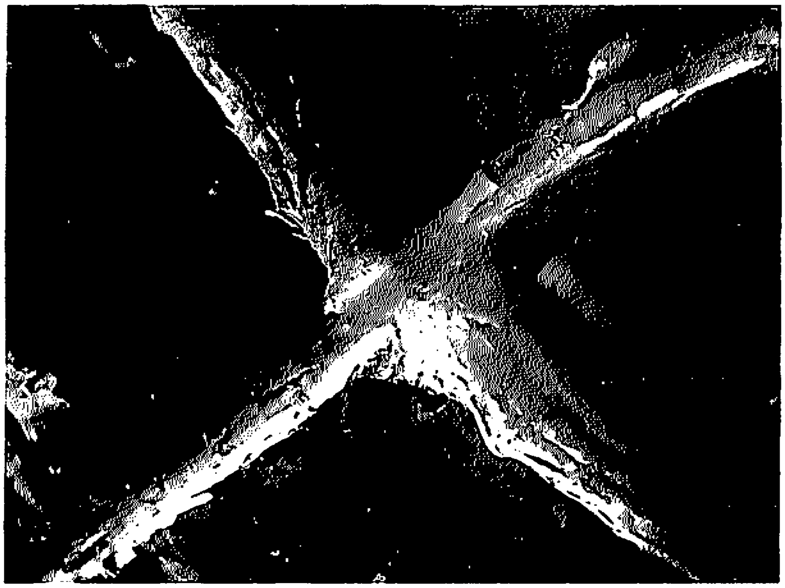
TYPES OF RED PINE ROOT GRAFTS



Above--right-angled graft

Above--cross-grafted vertical sinkers

TYPES OF RED PINE ROOT GRAFTS

Above--polar graft at crotch

Above -- 3-way graft