TECHNIQUES EMPLOYED IN THE APPLICATION OF PHYTOHORMONES AS AN AID IN THE PROPAGATION OF FOREST TREES

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A Thesis

Presented to the Faculty

of the

School of Forestry

Oregon State College

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science

June 1941

Approved:

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Professor of Forestry

ACKNOWLEDGMENTS

The writer desires to formally express his gratitude to W. F. McCulloch for the stimulation and encouragement received since the inception of this thesis, to L. W. Zach for invaluable aid received in problem orientation, guidance and bibliography, and to H. Goodyear for helpful suggestions in the course of the field work. The writer is also grateful to G. H. Schroeder for manuscript review.

TABLE OF CONTENTS

TECHNIQUES EMPLOYED IN THE APPLICATION OF PHYTOHORMONES AS AN AID IN THE PROPAGATION OF FOREST TREES.

The purpose of this paper is to compile and present the accepted techniques, together with those of promise, which involve the application of phytohormones to cuttings, seeds, and seedlings of forest trees as a propagative aid.

The results of recent experiment (35,26,49,1,51) have tended to prove that the phytohormones have a definite and important place in modern forest practice.

Went (69), in order to eliminate the possible misconception and confusion of "hormones" as applied to plants, with those of the animal kingdom, defined phytohormones as: "Substances which, being introduced into any one part of a plant organism, are transferred to another part and there influence a specific physiological process."

Since the techniques employed are almost as numerous as are the experiments, it is imperative in the interests of future experimental work that those techniques of proven dependability be compiled and presented in one paper. At the present time, the tyro who contemplates experiment must spend tedious weeks in library research gathering sufficient technique data to enable him to initiate work. It is in answer to this need, to provide and stimulate those of experimental proclivity with a concise, usable summary of techniques now employed, that this paper is written.

Phytohormones have opened up the field of forest propagation and in many cases have literally removed it from the narrow confines of the seedbed. The fact that all plants have the potential ability to produce roots from cuttings (1), remained for years only of botanical interest. Mirov (42) presents this fact quite nicely:

> "Differentiation of cells in plants does not occur at early stages of development only, as in animals. The meristematic tissues are found in plants in all stages of their development. Accordingly, every part of a plant where meristems are present or where tissues are potentially meristematic, is capable of reproducing the whole plant."

With the advance of forest genetics and a recognition of the profound effect heredity can exert upon an individual tree, the need for propagative techniques became apparent if desired individuals were to be reproduced. Actual tree breeding practices came into being. The physical limitations of controlling pollination and seed development in themselves are almost beyond the pale of present applied forestry in this country. These, when coupled with the difficulty of tracing the ancestry of an existing tree and thereby determining the genetical probability of like or sport offspring, combine to form a barrier which is insurmountable to the forester of limited funds and time. Vegetative propagation was offered as a method of obtaining the same initial objective, that of propagating desirable strains and properties inherent to an individual tree, and at the same time result in a simplification of techniques and a reduction in expense. This passage is not meant to infer that vegetative reproduction can totally replace tree breeding in applied forestry. Vegetative propagation is essentially a method for reproducing existing strains, not a method for producing new strains. The possibility of obtaining a mutation or sport by vegetative means is extremely remote (42).

Jacobs (35), in discussing the variability of Monterey Pine, Pinus radiata D. Don, the most important softwood producer in Australia (36), believes that heredity plays no small part in governing the intrinsic wood quality, health, vigor, spiral grain, abundance and character of cones, time of bud bursting, foliage color and length, annual node production, and branch angle of this California conifer which was introduced to Australia in the late nineteenth century.

Munger, speaking of Douglas-fir, Pseudotsuga taxifolia Britt., in the Pacific northwest, credits the hereditary element as an agency affecting the vigor of trees, height increment, and time of bud bursting (43).

Hall (29), in his studies of Black Locust, Robinia pseudoacacia L., and its varieties has shown that tree form is definitely tied in with heredity. Other characteristics inherent to this species include resistance to decay and insect attack.

Assuming that it would be desirable, from a forest management viewpoint, for the forester to be able to improve the quality of the forest by increasing the percentage of of quality trees, it can be concluded that controlled heredity is a formidable tool in the hands of the silviculturist. To date silviculture has emphasized the environmental control in the form of pruning, thinning, etc. to improve the quality of the timber. It is not entirely surmise that control of "inherent characteristics" by selection of our forest individuals would do more than alleviate some of the silviculturist's problems.

It is the vegetative propagation of these desirable individuals which offers the greatest possibility of improving the general quality of the forest (35). Vegetative means are the only practical ways of reproducing the exact characteristics of any one individual. Schreiner (49) believes that the clone will become increasingly important to technical forestry and its application with the passage of time, the advantages of uniformity of growth and development together with the immediate availability of desirable individuals for reforestation are but a few of the forest practices made possible by vegetative propagation.

Of more immediate practical interest is the probability that conifers, vegetatively propagated, can produce stock large enough for planting in less time, and consequently at a lower cost, than through propagation by seed (49). Add to this saving in time the lack of seed collection, cleaning, storing, and sowing costs together with those costs which accompany seeding methods and it is not difficult to discern the economic possibilities of cuttings.

Prior to the discovery and recent application of phytohormones, it was practically impossible to propagate many of our important conifers by vegetative means.

It was found that the young buds and the leaves (to a lesser extent) produced "hormones" which stimulated root development by activating the cambium (48). These "hormones" have since been isolated and analyzed chemically which has made possible their synthesis (69).

Application of these phytohormones to various coniferous cuttings was found to have a root inducing effect (26).

Not only have the phytohormones been instrumental in bringing about the rooting of cuttings, but they have made possible the improvement of seedling stock by stimulating the production of deeper and more extensive root systems at an early age with a subsequent reduction of mortality when planted in the field (47).

Some investigators have noted that dusting or otherwise treating the seeds with phytohormones preparatory to sowing in the nursery have an effect which increases germination percent and reduces the possibility of infection from nursery fungi (19). Although this claim is at present a mooted one (28), there is evidence existing that the results obtained from some seed treating techniques is exceptionally promising (44).

Phytohormonic techniques as applied to cuttings: The greatest impediment in the propagation of coniferous cuttings has been in the difficulties of obtaining adequate root systems on the cuttings. Phytohormones have stimulated the production of roots where ordinary techniques have failed to produce roots or plantable cuttings.

There are in the main three types of cuttings, these are: (1) Stem cuttings; those which are essentially a part of the plant stem and possess the clear differentiation of various, well developed, functional tissue;(2) Fascicle cuttings; those which comprise the fascicle and its inner bud without a section of the stem tissue;(3) Root cuttings; those which possess well defined functional tissue but lack developed chloroplasts and are made by cutting or otherwise removing a section of the root system and employing the section as a cutting.

Stem Cuttings: In the making of stem cuttings several vital factors come into play as governing agencies in the rooting and successful propagation of the cutting. These factors will be discussed chronologically, commencing with the selection of the "stud"(35) or parent tree which will furnish the cutting material, and terminating with the final grading and selection of rooted cuttings for field planting.

Of the several points to be recognized in choosing a stud, aside from the possession of the characteristics which make it a desirable clone, few are more important to the assurance of success than the age of the stud (51).

Working with Eastern White Pine, Pinus strobus L., it was found by Snow (51) that the rooting percentage of cuttings fell off quite rapidly with the age of the stud.

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OREGON STATE COLLEGE
CORVALLIS, OREGON

His study shows that trees used as studs which were five years old yielded cuttings which had a rooting percentage of 55% while those made from 15 year old studs gave a 20% response. Studs 20 years old gave cuttings with zero rooting percentage. It is to be noted that the highest rooting percentage was 55%. The reader must not assume that this is the best response attainable for this species as several other factors influence the rooting.

The negative results for the older trees does not always hold true. Deuber (10) has shown that under optimum conditions of taking the cuttings together with improved techniques that it is possible to root cuttings from this species with 60 year old studs.

In general there seems to be some correlation existing between coppice vigor and rooting ability, as with many species the coppice is much more vigorous from young stools than from veteran stumps, likewise cuttings from youthful studs seem to show greater rooting percentage than cuttings from older trees. Jacobs (35) states that the general experience seems to be that the percentage strike (rooting) of a species falls off very rapidly as the tree ages.

In Australia, where Monterey Pine is extensively propagated by vegetative methods, cuttings are usually taken from trees four to seven years of age (35).

It has been the writer's experience with Redwood, Sequoia sempervirens Endl., a naturally coppicing conifer, that the shoots taken from a fresh stump make better cuttings than do the twigs from the branches of older trees or established coppice.

Selecting the cuttings: Of tantamount importance with the age of the stud is the actual age of the twig or portion of the cutting material from the stem which furnishes the cutting itself. Investigators have found that rooting of coniferous cuttings containing wood older than one year is exceptional. McCulloch (39) while working with Douglas-fir noted that in experiments with one, two, and three year old material rooting occurred only on the one year old cuttings. Copious callus did form over the cut in the older material however. The one year old stock responded to phytohormonic treatment by putting out substantial roots. These cuttings, which literally all came from but one seed, are now going on their fourth year and are in fine condition in the Oregon Forest Nursery.

With cuttings of Eastern White Pine those made from the current grown wood rooted much more readily than those from older wood (51). Monterey Pine current cuttings gave a rooting percentage 14% higher than those which had a part of the previous season's growth attached (35).

Of prime importance is the position of the potential cutting upon the stud. Experiments with Eastern White Pine revealed that the farther a cutting was made from the terminal, as a lateral twig upon a lateral as opposed to a lateral in the whorls near the leader, the greater the possibility of rooting (51). This fact is of great import to the field worker as it is these twigs which are most abundant as well as being the easiest to procure during the collection period.

Snow (51), in reasoning the relationship between the position of the cutting on the tree and its rooting percentage states:

> "These differences in rooting exhibited by cuttings of the various types may be due in part to a differential distribution of natural root inducing auxins correlated with possible electrical potential or nutrient relationships."

Commercial Monterey Pine cuttings are taken from the lower and intermediate branches of the stud (35). This is due to the higher rooting percentage as well as the facilatated collection. There is no apparant difference in the form of the plants.

Mirov (42) comments on his work with a landscape tree, Chinese-Fir, Cunninghamia lanceolata Hook., of the same family as Redwood, Taxodiaceae. He found that the position of the cutting on the parent tree exerted an effect on the form of the rooted cutting. Those cuttings taken from the lower side branches did not develop straight stems but grew in a crooked manner,while those taken from the upper part of the stud developed into straight stemmed plants.

An invaluable indicator of pine cuttings that will not root has been found by Jacobs (35). It seems that with Monterey Pine the presence of male cone primordia is a positive indication of rooting failure. The reason for this weird occurrence is not fully understood. The presence or absence of these indicators must be noted at the time of collection.

The presence of primordia can be ascertained by scrutinizing the base of the terminal bud. The small, conelike excresences are the certain indicators of the presence of male cone primordia. As a general rule, an entire whorl is either male cone bearing or not. Most of the vigorous shoots of trees over eight years of age bear the lethal primordia(35).

The writer submits the opinion that this fact, the presence of primordia on the better appearing, vigorous shoots of the older trees, might well be the reason that Snow (51) had such pronounced negative results with trees over 20 years old, while Deuber (10) had more positive results with the veteran trees. It is entirely possible, as Snow makes no mention of primordia in his rather elaborate treatment of Eastern White Pine propagation, that the cuttings which he took from the older trees, although well appearing to the casual observer not on the lookout for primordia, might well have possessed the deleterious male cones. This probability would explain some of the incongruities now existing in the propagative field of research.

Epicormic branches, which the writer has observed to be quite plentiful on Monterey Pine, do not possess the male cone primordia in their first years of life, but tend to develop~~e~~ them with age (35).

Snow (51) and Jacobs (35) agree that certain parent or stud trees produce cuttings of higher rooting percentage than do neighboring and otherwise similiar trees. This leads to the possibility of rooting potential being a function of heredity. Jacobs also points out that this characteristic is not constant, he states of Monterey Pine:

> "To date there has been considerable variability in the percentage strike obtained from different individuals which have yielded a poor strike in one year have not necessarily failed in the next. It is certain that some shooting types, if early, will fail if planted late in the season, but the investigation has not yet gone far enough to show whether any of the individuals tried offer better or worse chances of success than others."

Time of year to make cuttings: The season of the year in which the cuttings are made seems to exert a profound influence upon the rooting percentage. The writer, while working with Zach (75), in the vegetative propagation of Douglas-fir and Western White Pine, Pinus monticola D.Don, on the Oregon Forest Nursery, noted that cuttings made in April and May; phenologically expressed as after the buds had commenced to swell and after they had burst respectively; lost their foliage and were without turgor by June, less than sixty days after cutting. This is in agreement with Schaad (48) who states:

> "The difference in rooting ability between Spring and fall cuttings is dependent on factors affecting the rest period of the buds which are indirectly the result of food and water supply. If cuttings are taken in autumn the tips will remain dormant allowing the roots to form before breaking into growth, whereas spring cuttings will leaf out using up the stored food which would otherwise be available for root formation."

Jacobs (35), referring to the time of cutting in Monterey Pine, advises that the safe season for cutting varies with the early or late budding nature of the individual. Late shooting types did quite well with an August planting, (August corresponds to February in this hemisphere) while at the same time the early shooting types failed badly when planted at that time. In Australia the best months for making cuttings of Monterey Pine are: April, May, June and July. These months are comparable to our October, November, December, and January.

McCulloch (39), with his successful Douglas-fir cuttings, made his cuttings and planting in January.

Griffith (26), working with Sitka Spruce, Picea sitchensis Carr., and Douglas-fir, had maximum success with cuttings made in December, January, and February. Rooting response for cuttings made at this time was more than 50% higher than for those cuttings made during the next best months, April-May for Douglas-fir and October-November for Sitka Spruce.

Doran (12) in his propagation of Eastern White Pine cuttings had considerable success with cuttings taken from the lower branches of studs in the latter part of the winter. Snow (51), working with the same species, had 20% less rooting percentage with cuttings made in late summer.

The general experience seems to indicate that the best results are obtained from cuttings made in the fall and winter while the buds are still tight.

Making the cuttings: Bailey (2) together with the majority of commercial horticulturists prescribes rather exact methods for making the basal cut. The common procedure demands a clean-cut, even base. Workers have found that when pruning shears or snips are employed, a cut approximating 45 degrees with the longitudinal axis of the stem results in less injury to the cutting in the form of cracked or crushed tissue (48). Others (16) justify the diagonal cut on the assertion that this method is superior to the straight basal cut made at right angles with the longitudinal axis in that more of the meristematic tissue is exposed and a greater absorbtive area is presented for phytohormone application.

It has been found that in the case of Monterey Pine this meticulous cutting of standardized basal portions is of negligible import (35). Jacobs while working on the "increased absorbtive area" hypothesis conducted experiments which included the diagonal cut, the straight transverse cut, the "V" cut with apex at pith, and the pulled "cut" where the cuttings are pulled or ripped from the stud leaving rough, splintery bases. The results of his tests showed that satisfactory strikes were obtained from each of the methods of cutting so long as current wood only was taken. It was noticed that in the case of the pulled cuttings, the opportunity for securing some of the old wood was enhanced and those cuttings which were pulled at the node often possessed both the current and old wood on the exposed surface. Roots developed only from the current growth, however, which resulted in a decidedly one-sided, unbalanced root system.

In the pulling method, which is employed commercially in Monterey Pine, the branchlets are pulled from the tree with a sharp backward pull, three or four being taken at one tug. In this manner a trained collector has no difficulty in maintaining an average of 1000 cuttings per hour, whereas under the knife or snipping method a good man works assiduously to average 250 cuttings per hour (35).

Zach (75), Snow (51), Schaad (48), and other investigators have employed the knife or snipping methods in their experiments which were conducted primarily to determine the rooting percentage of various species rather than for time studies which are the outgrowth of commercial practice. For most work it may be said that any cutting method which does not injure the cutting may be used with rather uniform results so long as current wood is used.

Storing the cuttings: Although this activity, storing the cuttings, is of minor consequence to the experimenter who speedily treats and plants his cuttings; it does constitute quite a problem on large scale operations. In forest practice where the cuttings are moved considerable distances involving delay in the elapsed time from cutting to planting it is essential that the cuttings be stored properly.

The techniques employed in commercial Monterey Pine cutting operations include simple, common sense methods but are none the less important. The cuttings are temporarily stored by the collectors in shoulder bags (not unlike the bags used by American newsboys for carrying their papers) as they are made. They are transferred from the shoulder bags at convenience to large chaff bags which are located in shady places along fire-breaks and roads in the woods (35). Water storage, or storing the cuttings in tubs of water with their bases submerged is to be avoided. This practice encourages the bark to absorb great quantities of water and tends to split at the base of the cutting, leaving a wound through which decay fungi subsequently enter. Schaad (48) wittnessed this same trouble with broadleaved trees and shrubs.

Zach (75) employed containers lined with damp moss, fern fronds, sawdust or shingle tow in which the cuttings were placed as made in the field being layered or stratified with the storage medium for short (less than 24 hours) periods.

Length of cuttings: It is a question of considerable debate as to just what is the best length to which cuttings should be made. Jacobs(35) states that the longer the cutting, so long as current wood is maintained, the greater the rooting percentage and the more copious the root supply..

In commercial practice where cutting beds are used during the rooting period lifting costs increase with the depth of roots. It is apparent that long cuttings would be deeper in the ground than short cuttings and thus have deeper roots which in turn would tend to increase the lifting costs. Then too, there is the moisture problem, especially with direct field planting, where too short a cutting and consequent shallow root system might leave the newly rooted cutting literally "high and dry" as the arid season approached(35).

Analysis of Jacobs' experiments (35) shows that depth or length of cutting was highly significant. "Six and seven inch cuttings gave better results than five inch. Five inch planting was better than four inch which in turn was better than three inch."

Cuttings in general will root better if placed with a good portion of the stem covered with the medium (2). The more wood below the ground surface, the more meristematic or potential rooting surface there is from which roots can develope. Since there is a limit to the length of cuttings, when we confine them to current growth, it is advised to take the cuttings maximum length while in the field. If too long for easy handling in the subsequent treatments they can always be shortened by removing the required length from the base. This removal should precede phytohormone treatment.

McCulloch (39) used 8-10 inch cuttings with Douglas-fir and received encouraging results. The writer has found that in the field it is no easy task to find cutting material of current wood, distant from the leader, which has this length in Douglas-fir. Griffith (26) used six inch cuttings planted three inches deep in his propagation of northwest conifers. Six inch cuttings are easier to obtain and more abundant than the 8-10 inch and appear to do just as well.

Trimming the cuttings: With the development of intensive propagative work, costs preclude the making of cuttings individually with a knife or shears, pulling has been shown to be a much more economical process (35). As before mentioned in describing the pulling technique, the possibility of obtaining old wood with the cutting is omnipresent. This menace is overcome in Monterey Pine work by trimming the pulled cuttings of all old wood and to uniform length for ease of handling. The "trimmer", armed with a sharp axe, places a handfull of cuttings, keeping the buds in the palm of the hand, atop a wooden chopping block and with a single blow severs the ragged, pulled ends together with any old wood that may be present from the cutting material. Quick fingered trimmers can easily trim 2000 cuttings per hour. This is of importance when compared with the knife method of trimming, where 25% of this figure is considered good(35).

Considerable divergence of opinion exists on the feasibility of stripping the needles from the lower portion of the cutting. Some investigators advance the contention that stripping that part of the cutting to be placed in the medium promotes root development by enabling the cutting to absorb greater quantities of phytohormone (16). It is also held that greater intimacy exists between the stripped cutting and the medium allowing for the easy transfer of growth substances and nutrients from soil or medium to the cutting. Jacobs (35) finds that phytohormonized cuttings which have been stripped produce roots along the sides of the cutting where the fascicle scar tissue or callus is present at the points formerly occupied by the fascicle.

McCulloch (39) and Griffith (26) followed the needle stripping practice and obtained rooting percentages as high as 100% with some treatments for Sitka Spruce and Douglas-fir.

Jacobs (35), however, while working with unphytohormonized cuttings of Monterey Pine, observed that needle stripping acted as an inimical agent in reducing the rooting percentage, however, with those cuttings which were subsequently phytohormonized rooting percentage was markedly higher with the stripped cuttings than with the unstripped. He also remarks that the stripping produced cuttings which offered but little resistance to frost heaving when planted whereas those cuttings which still had their needles intact remained relatively free from damage due to this cause (35).

Since much of our forest land here in the Pacific northwest is located at elevations where frost heaving is the general rule both in the woods and in the nursery, it is important that we utilize every natural function of the plant to resist this decimating factor. This is especially true with Western White Pine and Sugar Pine, Pinus lambertiana Dougl., whose vegetative propagation has been advanced as a possible method of developing blister rust resistant strains by Mirov (42).

Zach (75) has noted that the stripping of the needles from the cutting is both a tedious and time consuming procedure and would tend to increase the cost of vegetative propagation, perhaps unnecessarilly.

It appears that if comparable rooting percentages can be attained from both stripped and unstripped cuttings, the latter would be preferable for both nursery and field propagation.

Treating the cuttings: This is the actual application of the phytohormones to the cuttings as a root inducing process. There are essentially three methods of application, 1. the application of the phytohormones in the direct liquid state as an aquaeous or alcohol solution in which the dissolved phytohormones are conducted up into the cutting tissue where they will stimulate rooting functions. 2. Application of the phytohormones in the form of powders or other finely divided particles in which the crystalline form of the phytohormone is in admixture with some inert bulking medium such as talc or sterile clay. This is in reality a variation of the first, or liquid, application because the phytohormones must go into solution prior to their absorbtion by the cutting. 3. Application of the phytohormones in a vaporous state as by fuming or treating the cutting by means of an atomized spray.

The isolation of those chemical compounds which possess the ability to function as phytohormones can be viewed as one of the major contributions of Chemistry to the field of plant propagation (69).

These compounds are essentially organic acids and are similiar in structure to the actual phytohormones produced by the buds and early leaves of plants as root stimulators, (44). Many ordinary organic compounds and mixtures possess traces of these auxins (44), but the synthetized material is in reality the concentrated phytohormone. The most promising of these compounds are indole-3-n-butyric acid, indole-3-acetic acid, and alpha naphthalene-acetic acid (48,26).

These compounds are available to the experimenter in either their chemically pure form from the various chemical supply houses, or are already prepared and ready for use by seed and propagator's establishments under a range of trade names. These commercial products, put out primarily for the gardening trade, are essentially mixtures of the concentrated auxins with sundry types of inert bulking media (48).

Several techniques have been designed to precede actual phytohormone application. Mirov (42) in attempting to root Western White Pine believed that the oleoresin exuded from the basal portions of the cut prevented the absorbtion of the phytohormones by the plant tissue and in that manner tended to inhibit root development. He recommended that the cuttings be soaked in luke warm water for several hours in order to drain off the oleoresin and therby prevent its accumulation.

The writer, working with Zach (75) on the same species, followed the oleoresin treatment on one set of experiments and failed to observe any difference between the cuttings so treated and the checks. It may be possible that this oleoresin exerts a favorable effect on the cutting's ability to root since considerable food is present in it and since anything tending to diminish the food supply could be regarded as unfavorable towards attaining a high rooting percentage.

The concentration or strength of the phytohormone in application is of utmost importance. It appears as though each species has its own optimum concentration for each of the seasons of the year (26).

In the application of phytohormones to the cuttings as a liquid solution several experimental advantages are obtained over the other methods of application. These advantages are: 1. The solution can be prepared in any desired concentration which enables the experimenter to work from a supersaturated solution in stock and by simple arithmetic computations and operations prepare a treating solution of any desired strength and quantity. 2. It, of the three methods, alone gives the experimenter absolute control over the time element. The worker can allow his cuttings to remain in the solution for almost any period of time. It is to be noted, however, that there is a limit to the length of time a single solution, once prepared, will retain its potency upon exposure to the air. Griffith (26) rejected all solutions more than 72 hours old. This 72 hour period gives more than ample time to treat any one set of cuttings. The reason for this transient potency is in all probability due to the unstable nature of the complicated chemical structure of the phytohormones. They are even more unstable when exposed to light and most be stored in dark colored bottles, for the light admitted by ordinary clear glass furnishes enough energy to initiate a chemical reaction which weakens the solution.

Powdered forms offer other advantages, at the expense of others. The preparation of the powder, mixing the crystalline concentrate with a bulk medium of inert materials, is a more difficult task than the mixing of liquids. In the powder, the mixture must be absolutly uniform, no one portion possessing more or less of the phytohormone than any other portion in the mixture. This means the experimenter must have many containers, each with the concentration desired, in place of the one stock solution used in the liquid method.

Although the powders fail to give the worker control of the time element, because once a cutting is treated by being dipped in the powder and set out in the frame or field nothing more can be done to regulate the absorbtion of phytohormones by the cutting, they do lend themselves favorably to mass production methods. Cuttings can be put out much more rapidly and economically in this way than in the liquid method of application.

It takes no stretch of the imagination to picture crews of propagators working in cutover, burned over Redwood lands, armed only with a sharp knife and a bag of phytohormone powder, working their way from the widely separated stumps making cuttings of the coppice, dipping the cutting in the powder, kicking a hole in the soil, inserting the cutting and tamping the soil to complete the replanting or reforestation job.

Since the cutover Redwood lands are less than 15% stocked, due to the wide spacing of the stumps (71), this method, although a conjecture of the writer's,may have potentialities.

The application of phytohormones in a vaporous or atomized state as a root inducer has, insofar as the writer knows, not been utilized. It has been used to spray orchard trees for various reasons (44) but not to stimulate root production. This method may have great possibilities in this field. Its advantages would be mainly concerned with the speed of treating the cuttings. As it is with both the powder and solution methods, each cutting requires a certain amount of handling after cutting and prior to planting which costs must be borne by the treatment activity. By the spray or atomizing method it may be possible, with increased demands for techniques, to line up the cuttings in a removable side, boxlike container as they are taken from the stud with all of the basal ends pointed in one direction towards the removable side. In treating, all of the boxes can be stacked up together, the sides removed exposing the ends to be treated, the phytohormone sprayed on as one might spray paint,and the sides slid back onto the boxes, leaving the boxes ready to be shipped on to their destination.

Media and planting depth of cuttings: The rooting media into which the cuttings are placed plays a part of varying importance in the rooting percentage of cuttings from different species and with different treatments.

For experimental work, pure sand has been employed (1). Sand alone, however, does not possess the moisture retention properties so desirable in this work which necessitates its admixture with peat moss or some other lightening and retention agent. A sand and peat mixture is used by most investigators. This preference is due to the greater moisture retention ability of the mixture together with its property to maintain a more constant temperature due to the peat's insulative nature (48).

Jacobs (35) warns that too much moisture may be more detrimental than not enough moisture to assure maximum rooting percent. Good drainage and aeration are necessities if the cuttings are to root.

Schaad (48), in prescribing the peat mixture mentions that an excess of peat in the medium may result in an excess of moisture as well as probable poor aeration.

It is also possible that an excess of peat, being organic in composition, may give rise to quantities of humic acid which through its effect may alter the pH of the medium resulting in root inhibition.

Zach (75) advocates close scrutinization of the medium preparatory to setting the cuttings. This inspection should be made in order to determine the presence of fungal or bacterial growths which may infect the cuttings by using the basal cut as a court of entry. He recommends that media of dubious sterility be thoroughly sterilized before use.

In contrast, Snow (51) points out that the presence of bacteria or fungi may exert a beneficial effect upon the cuttings through a yet undetermined symbiotic relationship.

Schaad (48) in the course of his propagative work with various cuttings took the precaution of painting the sidewalls and bottoms of the propagation flats with a copper sulphate solution.

Snow (51) obtained best root production from cuttings of Eastern White Pine which were placed in a sash bed for root development. The sash bed consisted of six inches of 2:3 peat-sand, underlain with a stratum of partially decayed horse manure and straw. He attributes part of this success to the possible "symbiotic influences" of "auxin producing" bacteria. It is a known fact that both manure and lower forms of plant and animal life produce auxins.

It may well be possible that the heat of oxidation of the decaying manure used in Snow's(51) experiments acted as a favorable stimulus to root development as temperature is somewhat of a governing factor. Phytohormones fail to function at temperatures below 41 degrees F.(48).

Snow (51) observed that cuttings propagated out of doors did not root as quickly as those left in the greenhouse. His work with Eastern White Pine showed that the outdoor cuttings took almost a year to put out plantable root systems, whereas with other conifers, Sitka Spruce and Douglas-fir employed in Griffith's (26) experiments, put out stout root systems in less than 160 days.

It is reasonable to conclude that the constant conditions made available by greenhouse shelter may favor the rooting percentage and minimize the duration of rooting (the period of time required for a cutting to produce plantable root systems) for cuttings difficult to root and for experimental work.

Jacobs (35) working on a commercial scale with Monterey Pine employs outdoor nursery beds, not unlike those used in forest nursery practice, as the propagative medium.

It has been reported (51) that when outdoor cutting beds are used mulching is necessary to prevent frost heaving and probable winter killing in the winter months. Shade frames of burlap mounted on lath supports were necessary for summer protection.

Schaad (48), in greenhouse propagation, used media composed of equal parts of clean river sand and German peat moss.

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OREGON STATE COLLEGE
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Setting out the cuttings: Commercial landscape propagators recommend setting the cuttings in the medium at an appreciable angle with the surface of the flat (2). The writer, working with landscape evergreen broadleaves, Pittosporum rhombifolium A. Cunn., Queensland Pittosporum, in California, employed both vertical and inclined (45 degrees off center) settings, and obtained equal rooting percentages in each case.

It is essential that at least half of the cutting's length be placed below the surface and into the medium (48).

Spacing the cuttings in the flats is of interest to the experimenter whose flat or bench space is limited. Zach (75) set his coniferous cuttings out in flats with the cuttings lined up in rows, spacing between the cuttings in the row averaged one inch and the rows were about three inches apart. Monterey Pine cuttings, when studied in regards to spacing, showed no significant difference in rooting percentage due to spacings of one, three, and six inches (35).

Post-setting care: The subsequent maintenance of the cuttings is a much less complicated procedure than the initial work but none the less important. Such factors as media-moisture, temperature, aeration, and exposure all exert their effect upon the rooting percentage.

Watering the cuttings is an item requiring the vigil of the propagator. The usual tendency is to put too much water on the cuttings, rather than not enough. This inhibits and has been known to prevent rooting which resulted in the failure of the cuttings(35).

Propagators have bemoaned the absence of methods of accurately measuring the "watering need" of the cutting medium, Jacobs (35) contributes the following:

> "The writer has looked in vain for a suitable method of describing or measuring the degree of watering other than common cottage garden sense. The Bureau experience may be put this way: where watering kept the soil in a condition that would favor the growth of tender garden seedlings that had a tendency to damp off, a strike of 80% of cuttings from six year old trees was experienced without shade even in the fierce summer of 1938-39. Where the watering led to drier or wetter conditions, the strike fell away. If conditions became much drier the strike gradually fell away to 10%. If conditions became much wetter, the strike very rapidly dropped to zero. Commercial success is primarily dependent upon watering, and little latitude can be allowed. Yet it appears that this most vital question of all must be left at present to common sense."

It is the writer's opinion that with the importance of this single item, it might be a controlling factor in explaining many of the incongruities in experimental work to date. The need for measuring the water need of the medium is readily apparent. Perhaps an application of the Susanville "tin can atmometer", employed at the Durbin Forest Nursery on the Lassen National Forest, R-5, may ameliorate this condition.

The method of application, so far as the writer surmises, would be to distribute tin cans or other containers among the propagating flats. These containers would be cut so as to be the same depth as the flats whose watering need it is desired to measure. The flats, together with the "meter can", would then be watered to the optimum moisture content. The next step would be to weigh the "meter can" and establish the optimum weight for the individual can. This weight would be inscribed on the can for permanent record. The meter can could be subsequently weighed from time to time to determine its deviation from its optimum weight and it in this way would act as an index to the rate of desiccation which in turn would yield an indirect measure of the need for water.

With this method the major difficulty would be to establish the optimum "moist weight" for the meter cans. This figure could be obtained by a series of experiments designed to measure the effect of different moist weights per unit of medium upon rooting. This would involve the volume of the flat and the volume of the can and the moisture content could be expressed as a percentage of the weight.

For immediate purposes a rough figure could be obtained by employing the judgment of an accomplished horticulturist on just what amount of moisture put the medium in a condition "that would favor the growth of tender garden seedlings that had a tendency to damp off." Perhaps indicator plants could be found and used to serve the same purpose.

Subsequent application of phytohormones: Along with the watering of the cuttings, the addition of a modicum of the vitamin B_1, Thiamin Chloride, as a root stimulator is recommended (66). The effect of B_1 upon garden plants and truck has been promising, but to date, little has been done to test its effects upon the propagation of forest trees. Zach (75) is at present conducting experiments along this line with various northwest trees.

Temperature of optimum rooting: There appears to be an optimum rooting temperature that varies with each species (48).

It has been found that Gerania prefer a temperature of 75 degrees F. for maximum rooting, Holly: 81 d.F., Spruce: 65 d. F. Zach (75) believes that warm temperatures, above 70 degrees F., may be too warm for the optimum production of roots on Western White Pine cuttings.

As can be seen, the experimenter or propagagator can exercise considerable control over temperature. Greenhouses, shade frames, sash beds, and mulching practices all lend themselves as tools for the use of the propagator in temperature control.

Grading the rooted cutting: After the cutting has established itself as a complete plant it is lifted from the medium or cutting bed in much the same fashion as are seedlings or transplant stock.

The cutting appears somewhat different from the seedling in that in the place of a well defined tap root it possesses extensive laterals. The root system is much more spreading in form than that of its seedling ancestor. This characteristic is both advantageous and disadvantageous in that it is a somewhat more lengthy process to plant cuttings than seedlings because the hole must be properly made before insertion. At the same time,however, the field planter does not have to stop and spread the roots by hand as is the case with seedling stock which would reduce the mortality in planted stock due to "root pack".

Other criteria employed in grading the cutting correspond with those used in seedling work, root:top ratio, stem diameter, general vigor and appearance.

Fascicle Cuttings: In most coniferous trees a rudimentary bud is present at the base of each fascicle, which, at least in theory, can produce a shoot and a supporting root system (35). Jacobs initiated work with the fascicle cuttings of Monterey Pine by cutting the fascicles from the stud, trimming the needles to a lengtheof about one inch (to reduce the transpiration area) and planting the inverted tripod appearing fascicles in glass covered frames to prevent them from being blown over by the wind. Only those fascicles having fat buds rooted regardless of phytohormone treatment. Many of the fascicles callused, at least in part, whether large budded or not.

It was noted by Thiman and Delisle (65) that roots were induced to sprout from the fascicles of Eastern White Pine. They employed similiar techniques but received puny results.

There may be a possibility that this method of propagation may offer a solution to the problems of rooting our most stubborn conifers. Experiment alone will tell. It has the advantage, of experimental interest, that the space required and handling effort is considerably less than that demanded by stem or root cuttings.

Root Cuttings: Very little has been done with root cuttings in the vegetative propagation of conifers. Bailey (2) outlines techniques for making root cuttings of deciduous plants.

The writer has experimented with root cuttings of Redwood and wittnessed considerable success in obtaining roots on these cuttings without phytohormone treatment.

The technique employed was to cut small roots, about .25 inches indiameter from the root system of an old tree and place them in a large petri dish filled with water. Small, green shoots appeared and grew in much the same fashion as those from the Redwood burls sold in the novelty trade. The water in these dishes was changed from day to day to avoid stagnation.

This method is mentioned here mainly as of possible experimental interest rather than for the development of any large scale commercial operation.

It may be that trees which would not root from one type of cutting, either stem or fascicle, would root from root cuttings or vice versa.

Phytohormone techniques in the treatment of seeds: This subject is at present a moot one. Contradictory results being obtained by investigators.

Grace (19), working with field crops, obtained highly promising results with phytohormonized seed. The phytohormone was applied in mixture with dust at minute concentrations of two or three parts per million. He assumed that the seeds after being dusted with the phytohormone powder retained a small ammount and after germination produced more abundant roots and consequently more vigorous plants. Subsequent experiments have been far from consistant, positive as well as negative results being obtained. This item may prove to be of some importance in Forest nursery work. The positive results that were obtained were so positive that experimentation is being continued. A test with tomato seeds showed that some treated seeds produced plants which bore 119 pounds of fruit in one season, more than double the yield of good, normal plants (44). This amazing difference is attributed to the phytohormone treatment prior to sowing.

Grace (19) advanced the belief, after a series of experiments, that the phytohormone dusting of the seeds, preparatory to planting, acted as a disinfectant and prevented the growth of damping-off fungi.

Gruenhagen, testing Grace's hypotheses, worked on the seeds of Red Pine, Pinus resinosa Ait., and Eastern White Pine. He states that the phytohormones exert no effect upon resistance to damping-off or towards increasing the germination percentage (28).

This field is so new and in such dire need of sound experimental evidence that few conclusions can be formulated. The meager evidence so far submitted, even though contested, points towards such great potentialities in the field, that it cannot be ignored.

Phytohormones as a root stimulator in seedling development:

Nurserymen have always been concerned with the proper development of roots on forest tree seedlings. Plank (47) engaged in reforestation activities in the Southern Pinery states:

> "If planting stock could be produced having a deeper and more extensive root system at an early age of development, it would reduce the high mortality often occurring on dry sites."

With the objective of producing stouter root systems on seedlings of Slash Pine, Pinus caribaea Morelet., Plank (47) proceeded to treat established seedlings with varying concentrations of phytohormone. Using indolebutyric acid, he found that survival was increased 20% with a single 24 hour treatment of 10 parts per million in aqueous solution.

Thus it can be seen that even though scant work has been done in this field, promising results demand further investigation.

Summary: Recapitulating, it can be said that the future of phytohormones and their relation with more productive forest practice will tend to become more intimate as phytohormone work goes on. The present stage of the game is recognizing the important place occupied by these hitherto little known agents as governing forces of nature in the production of vegetable fiber.

With forest management techniques being designed more and more towards the end of growing wood of specific properties to order, it is imperative that we as forest managers employ every tool at our command to economically satisfy this demand of industry and competition.

By vegetative means, forests of genetically selected superior individuals might be made to yield the bulk of our timber needs on small, accessible, intensively managed areas on the better sites.

The larger areas of poorer sites might well be taken over by public agencies, taking advantage of the coordinated forest uses and at the same time act as true reservoirs of timber which could act as the "emergency buffers" of war and economic strain periods stressed by modern conservationists.

From a purely economic point of view the phytohormones show exceptional promise both by producing planting stock of known characteristics and producing it more cheaply than the present methods of propagation.

The reader must remember that the phytohormones are merely governors of plant growth, not producers. Auchter (44) in a recent discussion states:

> "Despite all the striking and almost magic results being secured from the use of growth substances in controlling the growth and development of plants it must be remembered that they are in no way substitutes for the water and minerals a plant gathers from the soil or the substances it takes from the atmosphere surrounding it. They might be considered as determiners of what a plant does with such materials."

"Determiners of what a plant does!" Here are the reins of nature proffered to the forester by the productive hands of the chemist, the physiologist, and the biologist. What are we to do with them? The decision is ours to make, experiment will show the way!

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APPENDIX

Table I.

Table showing the compiled optimum concentrations, for various species of evergreen trees, of indolebutyric acid in aqueous solution for application to cuttings together with other pertinent information.

Species	Optimum Concent.	Duration of Treatment.	Root. %	Authority
Douglas-fir	8-10 mg/l.	24 hrs.	90	(39)
Douglas-fir	50 p.p.m.	24 "	80	(26)
Sitka Spruce	25 p.p.m.	24 "	100	(26)
East. White Pine	25 mg/l.	6 "	47	(51)
Monterey Pine	(Not published)		79	(35)
Colorado Spruce (*P. pungens*)	80 mg/l.	6 "	61	*
Sprawling Juniper (*J. horizontalis*)	20 mg/l.	8 "	72	*
Cryptomeria (*C. japonica*)	40 mg/l.	24 "	96	*
Plum Yew (*Cephalotaxus drupacea*)	60 mg/l.	24 "	100	*
Irish Yew (*Taxus baccata*)	100 mg/l.	24 "	90	(48)
Japanese Yew (*Taxus cuspidata*)	30 mg/l.	6 "	77	*

* By the courtesy of Pennsylvania Chemical Corporation, manufacturers of "Auxilin", Orange, New Jersey. 1938.