THE ROOTING RESPONSE OF VARIOUS PLANT SPECIES AS INFLUENCED BY FLUORESCENT LIGHT AND MEDIA

by

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I. INTRODUCTION

Vegetative propagation is necessary for a large number of horticultural plants since many do not come true to type from seed or with many species and varieties, seed is not produced. Commercial growers of plants such as florists and nurserymen are always seeking better methods to induce faster rooting of cuttings or to induce rooting of cuttings of species which are difficult to root under present known methods. In recent years, considerable research has been conducted to find better rooting media, to improve light relationships, to induce faster rooting by treating with hormones and to find the optimum temperatures and humidities to induce rooting for various species which are commonly propagated by cuttings.

II. REVIEW OF LITERATURE

It was mentioned by Kains and McQuesten (16) that Julius Sachs, about a decade before his death in 1897, announced that growth in plants is probably influenced by extremely small quantities of specific substances that cannot be designated as foodstuffs but which direct the activities of cells.

The above authors also stated that the term hormone, as applied to plants, was first used by Fitting in 1910. Other names since used synonymously are growth hormone, growth regulator and Wuchsstoffe.

According to Meyer and Anderson (18), Kogl, et al, were the first to isolate a growth substance "heteroauxine" as a pure chemical compound and to identify it as indoleacetic acid. Hitchcock (13) using indoleacetic acid, indolepropionic acid, phenylacrylic acid, and phenylpropionic acid dissolved in water, oil, or in lanolin, and applied locally to intact plants, caused initiation of roots, epinasty of leaves, and bending and swelling of stems of several varieties of plants. Since 1933, thirty-two growth-promoting substances have been found. Among them were fourteen acids, eleven esters, and four unsaturated hydrocarbon-containing gases. Work conducted at the Boyce Thompson Institute (14, 27), along with investigators at other institutions, has shown that the use of these growth substances would increase the rate of rooting and induce root formation on cuttings of some plants normally very difficult to root. The use of growth hormones for the production of roots on cuttings has become increasingly popular and useful to both the home gardener and the commercial grower. Dusts containing the growth substances are now available on the market under various trade names.

Although in not a few cases the growth substance treatments have given striking results, the present status still indicates that the use of synthetic growth substances is not a cure-all for the difficulties involved in the propagation of plants by cuttings. The effects of chemical treatment vary from species to species. For instance, Grace (7) found that potassium naphthylhexoate was beneficial to Lonicera cuttings but markedly injurious to those of Weigelia. Naphthylbutyric was more effective than the hexoate in respect of root length in Deutzia. Indolylbutyric acid was better than naphthlacetic as judged by number and length of roots produced on Lonicera and number of roots produced on Weigela. A reverse order of activity of these two chemicals was shown by the number of rooted cuttings and length of root of Sambucus and the number of dead Berberis and Thuja cuttings.

Cuttings taken from different varieties of the same species may respond differently to certain treatments. Chrysanthemums are among the plants which show a high degree of response to the auxin treatment. In the experiment of Cooper and Manton (4) out of fifty varieties tested, only one variety has failed to show increased rooting over untreated cuttings, yet the increase varied from just a few more roots per cuttings on certain varieties to six times as many in the case of others.

The stage of maturity of plant parts may also be a factor in causing variation in the rooting response of the cuttings to hormone treatment. Cochran (3) propagating peaches from softwood cuttings, found that only 2 per cent of the softwood cuttings taken from greenhouse-grown seedlings in July rooted in response to the same treatments that gave 100 per cent rooting of similar material during the winter.

Another substance or substances, nutritional or hormonal or both, which is usually originated in the leaves is also necessary, together with auxin, to produce roots. This is clearly manifested by Gregory and van Overbeck (12) in their experiment with Hibiscus.

According to Grace and Farrar (10), who worked on the vegetative propagation of conifers in Canada, the average rooting of talc treated and untreated cuttings of Norway

Spruce exceeded 80 per cent, a value substantially equal to that obtained with indolebutyric acid.

The injurious effects of plant hormone chemicals in a talc carrier were also noticed by Grace and Farrar in the same experiment. These injurious effects are in agreement with their previous results for propagation of conifer cuttings (6, 9). The progressive increase of injury with ascending concentration of these chemicals agreed with the results of earlier experiments on plant hormone chemicals (8, 25). In the preliminary work with naphthylbutyric acid in a charcoal carrier, the 98 per cent rooting obtained was the highest percentage reached in greenhouse propagation experiments with conifers carried on by Grace and Farrar (10). The untreated cuttings only gave a rooting percentage of 87 per cent.

Variations are bound to occur following the use of growth substances by individual propagators. Atmospheric and cultural factors will vary, leading to different results. Indeed, any single factor within a cutting may effect the rooting response of the cutting, no matter whether that factor be morphological, nutritional, hormonal, or anatomical.

Stoutemyer and Close (22) introduced a new method of propagation of plants by cuttings in 1946. In an enclosed case, not a great deal different from the old Wardian case, they installed fluorescent light and thermostatically controlled heat. As a rooting medium for cuttings and for growing seedlings, they used vermiculite. In this unit, enviromental conditions were controlled to near perfection. Their performance curves for heat, light, humidity and soil moisture are straight lines instead of curves.

According to Stoutemyer and Close (22), although rooting of some species was superior in the greenhouse, the opposite was often true. Furthermore, rooting in the propagating cases was notable for rapidity. Cuttings of various hollies and Thuja, Taxus, and Retinospora were rooted, and also other woody plants. Cuttings of many kinds of flowering plants responded well. Stoutemyer, Close and O'Rourke (24) working on the propagation of citrus, Hibiscus, and Bougainvillea, among other plants, reported obtaining exceptionally good rooting under fluorescent light, which surpassed the rooting obtained in a regular propagating house.

The above information indicates that many advantages in the rooting of cuttings can be obtained from the insulated structure providing suitable artificial light can be supplied at reasonable cost.

The most important criteria which might be used in selecting an efficient light source is concerned with the nature of the spectral distribution and the determination of whether the spectral distribution follows the photosynthetic curve. In addition one must remember that radiations other than those efficiently involved in photosynthesis may exert considerable effect upon the formation of hormones and other substances which influence plant growth. There have been many objections to the light sources used in the past; some of them were on the basis of cost of installation and maintenance. Until recently, the best source of artificial light from the stand point of quality was the carbon-arc light. Light from this source approximates that of sunlight except that its radiations are higher in blue and the ultra-violet. Also it is heavy and relatively nonportable and is both costly to install and to maintain.

More recently lamps emitting fluorescent light have become available. The quality of light obtainable from fluorescent tubes varies with the kind of phosphore which is painted on the inner surface of the tube. The spectral distribution curves for the different colored tubes, when compared with the photosynthetic curve given by Hoover (15) suggest that the daylight type would be the most efficient because the two maxima for both curves occur in the same regions. However, it should be noted that the highest maximum reached in the two curves is exactly reversed, the highest peak being in the red end of the photosynthetic curve, while the highest energy level obtained from the fluorescent tube is in the blue region. Distribution curves of all the other tubes, except the white tube, seemingly indicate that they would be comparatively inefficient in promoting plant growth.

During the latter part of the nineteenth century many papers appeared dealing with the effects of the different parts of the spectrum on plants. Extensive as the work was during this period, few of the results can be considered with certainty as being directly caused by quality of light because of the failure of the majority of the investigators to take into account the variations in light intensity and other factors that affect plant growth. In 1919, Schanz (21) reported the results of his experiments with plants grown under light consisting of definite regions of the spectrum of daylight, and concluded that light of short wave lengths, particularly ultra-violet rays, was detrimental to the growth of plants. The results of Popp's investigation (20) indicate that plants require the rays in the blue-violet end of the spectrum for good, vigorous growth. The removal of all wave length shorter than 5290 Å resulted in a condition of plants that is similar in many respects to that obtained when plants are grown in darkness or in light of very low intensity. Absence of all wave lengths shorter than 4270 Å yield similar results, though to a lesser degree. The work of Ursprung (26) showed that photosynthesis proceeds at a more rapid rate in the red end of the spectrum than it does in the blue-violet end, even when regions of equal energy value in the red and blue-violet regions are used.

According to Naylor (19), fluorescent light was found satisfactory in growing plants early in this decade. When used as the sole source of illumination, both the white and the daylight from fluorescent lamps have proved to be efficient in the growth of a number of plants such as cabbage, corn, a variety of annual red kidney bean, Biloxi soybean, dill, tobacco and tomato. When the intesnity was sufficiently high, they have flowered as rapidly as those grown under the best greenhouse conditions.

Not until 1946, however, was the effect of different light colors on the rooting response of cuttings reported by Stoutemyer and Close (22). Using many light colors, they found that the red-orange end of the light spectrum was more important in the rooting of cuttings than the blue end. None of the colors, however, had any advantage over the 3500 degrees white light. This is in agreement with the physiological effect of different light colors on plants found by previous investigators.

Stoutemyer and Close in 1947 (23) also published their results on changes of rooting response in cuttings following exposure of the stock plants to light of different qualities. In their experiment, Gordonia azillaris was used as a representative of the difficult-to-root woody plants. Plants were grown in the greenhouse, under daylight tubes, under a combination of a pink and a blue tube, under two blue tubes, and under the "E" phosphor General Electric sunlamps and used as stock plants. When cuttings from these five different sources were removed from the propagating benches, striking differences in the type of callus and of root formation were evident. By far the best rooting, together with formation of almost no callus, was found in the cuttings from the plants grown under the two blue tubes. Since the action of the "E" phosphor General Electric sunlamps was somewhat similar to that of the blue tubes although the spectral distribution was very different, it is possible that the important factor may be the exclusion of a certain band of radiation in the red end of the light spectrum, rather than the effect of a specific band in the blue end. Oddly enough, blue light was usually the least favorable light for cuttings during the rooting period in the previous experiment of the same author (22).

In the previously mentioned propagation works of

Stoutemyer and Close, they found continuous illumination most satisfactory in most cases.

The value of expanded vermiculite as a rooting medium has been demonstrated by Stoutemyer and his co-workers (22, 23, 24). Carleton (1), in his paper recommending vermiculite as a satisfactory rooting medium, soil conditioner, and seed sowing material, suggested that vermiculite may act as a regulator of humidity.

According to Grace and Farrar (5, 10, 11), the high average level of rooting attained in the rooting of coniferous cuttings was largely related to the peat-humus-sand propagation medium. Favorable effects of this medium have been shown by results obtained from both greenhouse and outdoor propagation.

Since Stoutemyer's report of the use of opaque structures in which light was furnished by cold cathode and fluorescent lamps for the propagation of cuttings, Chadwick (2) has tried to duplicate this method. In studying the effect of various light colors on the rooting response of greenhouse rose cuttings, he found that red light gave less favorable rooting response than gold and white light while the best results were obtained with daylight fluorescent tubes. Rooting was slightly more rapid under artificial light and it was also noticed that much more top growth was produced during the rooting period under fluorescent light than under greenhouse conditions.

In addition to the above, work was carried out to study the effect of light intensity on the rooting of cuttings of Better Times roses under high and low light intensities. The relatively high light intensity was 240 to 280 foot candles; the relatively low light intensity was 90 to 120 foot candles. Daylight light was used. The results indicate that better rooting response was obtained under the high light intensity.

Further experimentation by this author was arranged to study the rooting response of softwood cuttings of thirteen deciduous shrubs under white fluorescent light. Light intensity varied from 150 to 170 foot candles directly under the lights. The light intensity dropped to as low as 50 to 75 foot candles at the corners of the benches. In not a single case did cuttings respond as favorable under white fluorescent light as under normal greenhouse conditions. Light intensity in the greenhouse in the middle of the day varied from 900 to 2200 foot candles. It is probable that the unfavorable rooting under fluorescent lights is due to the low light intensity prevailing under these experiments.

Experiments with softwood cuttings of broadleaf evergreens under the same set of conditions as outlined for the softwood cuttings of deciduous shrubs were also carried out by the above author (2). The results show that easy rooting broadleaf evergreens responded favorably to artificial illumination but in no case was the rooting percentage or quality of the roots better under fluorescent lights than under ordinary greenhouse conditions.

The above author (2) also set up experiments with hardwood cuttings of narrowleaf evergreens under different light colors. Silica sand No. 7 and No. 1 vermiculite were used as rooting media. The results show that very good rooting percentages were obtained in the greenhouse, and that better rooting response of cuttings of narrowleaf evergreens can be expected under greenhouse conditions than in an opaque structure equipped with fluorescent light such as used in this experiment. Red light proved inferior to the other lights used. Gold lights proved better than white or daylight with three out of the four plants used. Cuttings under artificial illumination required somewhat less time to root than similar cuttings handled in the greenhouse.

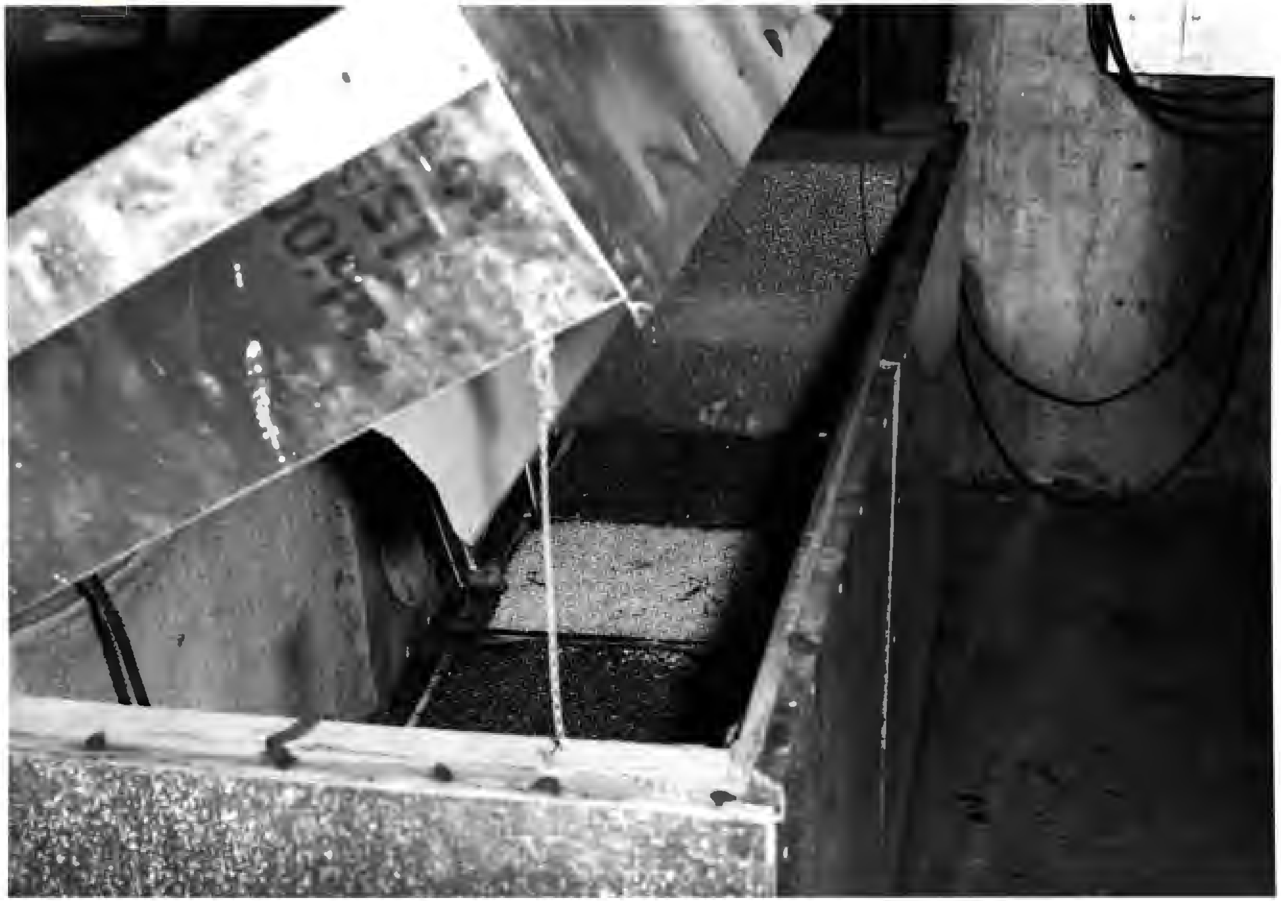

Fig. I. The aluminum propagating cabinet, showing the hinged cover and the arrangement of flats and psychrometer inside of the cabinet.

Fig. II. The aluminum propagating cabinet, showing the ventilation window at one end. The two doors are opened and the second and fourth flat are removed to give a clear view of the interior.

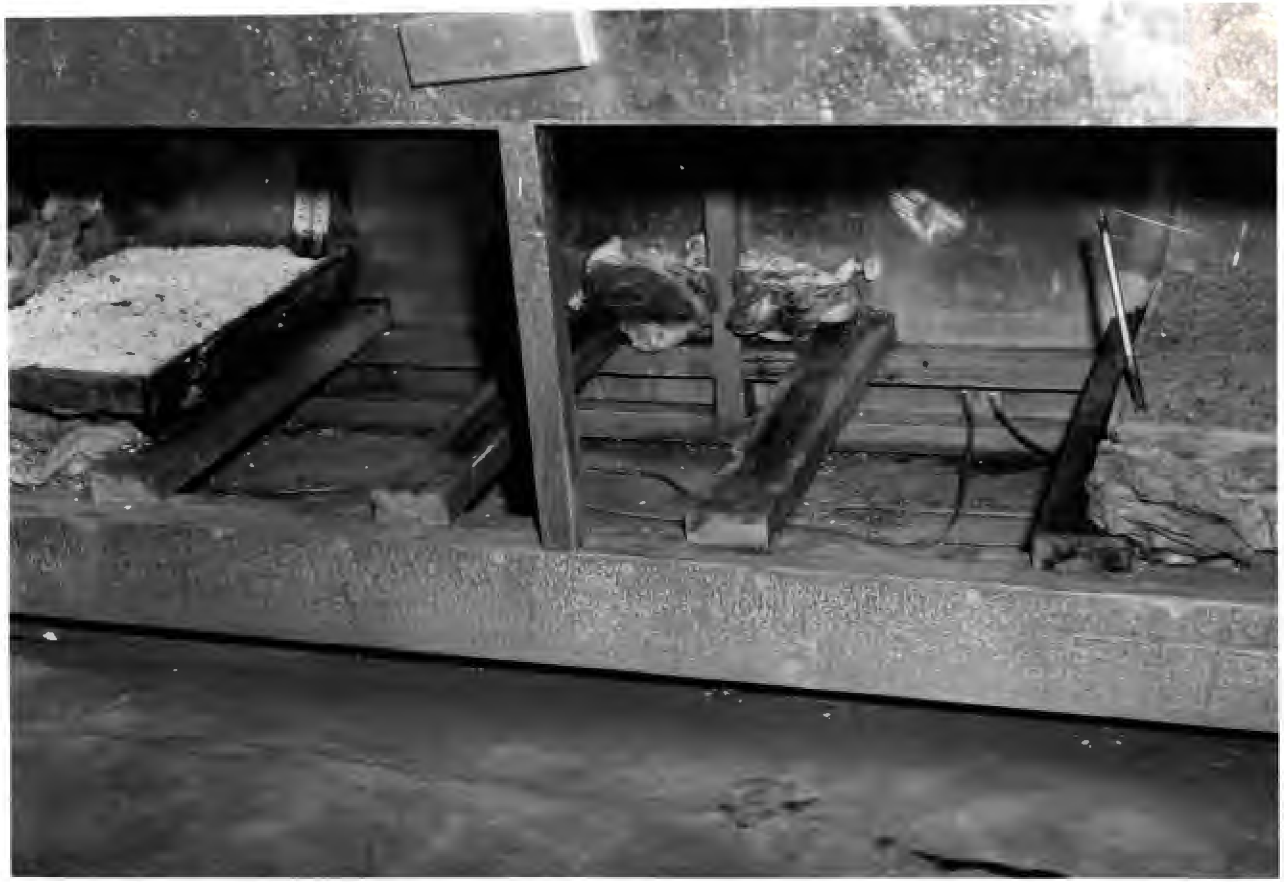

Fig. III. The aluminum propagating cabinet with the three middle flats removed to show arrangement of the heating cable at the bottom.

III. MATERIALS AND METHODS

Environmental Factors. The experimental work for this thesis was started in the winter of 1948. To test the value of fluorescent light, an aluminum propagating cabinet six feet long, 21 inches wide, and 31 inches high, was constructed to accomodate five flats. Ventilation was provided by opening the movable cover that was hinged on the top of the cabinet (Figure I).

In the spring of 1949, an additional aluminum propagating cabinet was constructed. The size and construction of this new cabinet and that of the previously mentioned one were essentially alike, except that the former had a window at each end and two doors on the side instead of a hinged top (Figure II).

The light source in each of the two cabinets was two 5-foot 3500° white fluorescent tubes attached to the cover of the cabinets 20 inches above the cuttings. According to Stoutemyer and Close (22), white light was generally superior to the other colors and was often used as the control. Continuous illumination was provided in the experiments. Light intensities varied from 425 foot candles directly under the middle of the lamps to 175 foot candles at the corners of the cabinets.

Air temperatures in the cabinets were maintained at 65 to 75 degrees F for the most part of the year and about

10 degrees F warmer during the summer. Temperatures of the rooting media were supplied by heating cables (Figure III) and were maintained at 70 to 75 degrees F by a thermostat. The humidity was influenced markedly by air temperatures and varied from 55 to 65 per cent in summer to 75 to 85 per cent in winter. Watering the walls of the cabinets and burlap stuffed around the flats helped to increase the humidity.

Experiment A

Six species of Junipers were used in this experiment. They were J. plumosis, J. sabina, J. virginiana horizontalis, J. chinensis pfitzeriana, J. procumbens, and J. excelsa stricta. The first five species were chosen from the lists of difficult-to-root coniferous evergreens provided by three commercial nurseries. Juniperus excelsa stricta was used as control since it was in the lists of less-difficult-to-root conifers provided by the same nurseries. All the cuttings were made about six inches long and with ½ to ¾ inches of 2-year-old wood at the base.

A mixture of one-third peat moss and two-thirds vermiculite was used as the rooting medium in this experiment. Stoutemyer and Close stated that this combination had produced exceptionally heavy rooting of acid soil plants. The pH of vermiculite is somewhere between 6.66 and 6.7 (1). According to Carleton (1), aborvitae seemed to root satisfactorily in straight vermiculite without any adjustment of pH. All varieties of Taxus, on the other hand, seemed to do better in a 50-50 mixture of sand and vermiculite or the sand-peat-vermiculite combination. Chadwick (2), propagating Taxus cuspidata, found medium silica sand (grade No. 7) a favorable rooting medium.

The cuttings were planted on December 21, 1948. There were five replicated flats containing twelve cuttings each of each species. The rows for the species in every flat were randomized.

Data collected included the quality, the callus formation, and the rooting of cuttings. These were obtained by drawing at random three samples from each row at weekly intervals from the fourth week after planting until the conclusion of the experiment.

Experiment B

Cuttings of J. chinensis var. Ames, J. chinensis var. Story, J. chinensis var. Iowa, J. chinensis var. Maney, Taxus cuspidata, and Thuja occidentalis were used in this experiment. These cuttings were made according to accepted commercial methods.

The rooting media used were sand, vermiculite, and a mixture of half peat and half vermiculite. Each kind of rooting medium occupied three flats. The experiment was arranged in a split plot design.

Data collected included (1) qualities of cuttings of different species and of different varieties within species in different media, (2) callus formation of cuttings of different species and different varieties in different media, and (3), rooting of cuttings of different species and different varieties in different media. Data were collected every week since the fourth week after planting by drawing at random three samples out of each row. These samples were planted back immediately after data were taken.

Experiment C

The cuttings used in this experiment were made from Juniperus chinensis var. Maney, Taxus cuspidata var. Hicksii, and Thuja orientalis. These materials were obtained from the Horticultural farm on October 23, 1949, and were made into cuttings six inches long with a heel of 2 year wood and planted on October 25, 1949.

Four kinds of rooting media were used. They were sand, vermiculite, 50-50 sand and vermiculite, and expanded silica sand sold under the trade name of "Permalite".

Sand was used as the control.

There were 160 cuttings of each species and two flats of each medium. Twenty cuttings of each species were planted in two randomized rows in every flat, making a total of four treatments, four replications per treatment and ten cuttings per replication for each species. One comparable set of cuttings was placed in the regular propagating bench in the greenhouse.

Data on (1) quality of cuttings of different species in different media, (2) callus formation of cuttings of different species in different media, and (3) rooting of cuttings of different species in different media were collected every week from the fourth week after planting until the conclusion of this experiment by drawing at random three samples out of each replication. These samples were planted back immediately after data were taken.

Experiment D

Softwood cuttings of carnation (Dianthus caryophyllus) and dusty miller (Senecio leucostachys) were used in this experiment. No chemical treatment was applied. The rooting media used were sand and vermiculite. Sand was used as the control. According to Laurie and Kiplinger (17), a number of investigators have found that in general, sand is a very satisfactory rooting medium for most plant species. Other media may be used, and for certain plants they are superior to sand.

In this experiment, one flat of sand and one flat of vermiculite were used. Three random rows of twelve cuttings each of carnation and dusty miller were planted in both flats. These made up a total of two treatments, three replications per treatment and twelve cuttings per replication for each species. A comparable set of cuttings was handled under greenhouse conditions.

All cuttings were dug every fifth day and the callus formation and rooting recorded.

Experiment E

The stock plants used were one year old peach seedlings growing at the Horticultural Farm. One hundred semi-hardwood cuttings with two to three nodes were taken on October 1, 1949. All but the top pair of leaves on the cuttings were stripped off. Because of insufficient material, cuttings made from both main branches and lateral branches were used. These cuttings showed differences in the diameter of stem and the stages of development of leaf buds.

These peach cuttings were divided into two groups of fifty cuttings each. One group was untreated, and the bases of the cuttings in another group were treated with Hormodin No. 2. Vermiculite was used as the rooting medium. The treated and untreated cuttings were planted in five rows of ten cuttings each in two separate flats. Data on the vegetative growth and callus formation as well as the rooting of the treated and untreated cuttings were collected every fifth day after planting.

IV. RESULTS AND DISCUSSION

Experiment A

The first collection of data on the rooting and callus formation of cuttings was made on January 11, 1948, the beginning of the fourth week after planting. One sample of J. plumosis was found rooted and with medium amount of callus formation, while the rest of the samples had neither roots nor callus.

No rooting or callus formation was observed during the four succeeding weeks. On the other hand, the number of dead cuttings of every variety had been increasing gradually during this period. On the ninth week after planting, the bases of most cuttings showed symptoms of wood rot.

The whole experiment was concluded February 23, 1949. No rooting or callus formation was found. The number of living cuttings of different species was counted and listed in Table I. The analysis of variance of number of cuttings alive (Table II) shows that the number of cuttings alive is characteristic of the plant species.

Since the dead cuttings and some living cuttings showed symptoms of wood rot at the bases, the poor aeration in the medium could be partially responsible for the death

Table I

Number of Juniper Cuttings Alive Two Months After Planting

Dec. 21, 1948 to Feb. 23, 1949

Replication	Species					
	Juniperus plumosis	Juniperus sabina	Juniperus virginiana horizontalis	Juniperus procumbens	Juniperus chinensis pfitzeriana	Juniperus excelsa stricta
1	9	5	10	6	11	9
2	12	3	9	11	11	4
3	11	5	10	7	9	5
4	10	1	10	7	11	5
5	12	1	4	4	4	3
Total	54	15	43	35	46	26
Mean	10.8	3	8.6	7	9.2	5.2

Difference required for significance:

at 5% level = 2.59
at 1% level = 3.52

Table II

Analysis of Variance of The Number of Juniper Cuttings

Alive Two Months After Planting

Dec. 21, 1948 to Feb. 23, 1949

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Total	29	336.30	
Species	5	202.7	40.54 **
Replicates	4	56.13	14.03
Error (Species x Replicates)	20	77.47	3.87

** Significant at 1% level

of the cuttings. A mixture of one-third peat and two-thirds vermiculite has a water holding capacity of about 185.7 per cent (a value more than ten times that of the water holding capacity of fine sand), so that over-watering may easily occur when using it as rooting medium.

Experiment B

Among the six species of coniferous evergreens used in this experiment, Taxus cuspidata showed the least favorable response. Cuttings of this species in the two flats at the middle of the cabinets showed yellowing of their leaves on the tenth day after planting while cuttings of the same species in the other flats and cuttings of other species were still healthy. Two factors may account for this; first, the higher light intensities and consequently possible toxicity of fluorescent light or inability of the Taxus cuttings to utilize this light source in photosynthesis, and secondly, the relatively greater leaf surface of Taxus cuspidata which permitted greater water loss. Most cuttings of Taxus cuspidata in the other flats also showed yellowing of their leaves a few days later, and by the end of the sixth week after planting over 80 per cent of them wilted and died.

Thuja occidentalis also responded unfavorably under the same conditions. No callus formation was found on the cuttings of this species. Some of them showed browning of shoot tips at about one month after planting. The number of dead cuttings increased slowly and steadily throughout the period in the rooting media. At the conclusion of this experiment the percentages of living cuttings in sand, vermiculite, and 50-50 peat and vermiculite were only 11.7, 16.7, and 28.3 per cent respectively. No cuttings rooted in the sand, while cuttings in vermiculite and the mixture of 50-50 peat and vermiculite rooted 5 and 3.3 per cent respectively.

Cuttings of Ames, Iowa, Maney, and Story Junipers had all started callus formation at the fourth week after planting. A negligible increase in callusing was observed during the following several weeks. Then came the period by the end of May when the callus formation was very active, and medium to heavy callus formation was attained in about a month's time. New top growth also developed.

Rooting of these four varieties was first observed on September 26, 1949, after twenty-nine weeks in the rooting media. All cuttings were dug and the rooted cuttings were counted and then potted and placed in the greenhouse. The cuttings not rooted but alive were planted back into the media in the cabinets.

It was observed that during the two succeeding weeks the remaining cuttings showed considerable increase in root formation. After that no more rooting took place; and the whole experiment was concluded on that date. The final readings were based on the total number of rooted cuttings on October 10, 1949.

The number of rooted cuttings of these four varieties of Junipers in different media were recorded in Table III. According to the data, they all responded poorly under white fluorescent light. The mean number of rooted cuttings for Ames, 0.55, was the lowest, while the mean number of rooted cuttings for Story, 4.44, was the highest mean number rooted. The rooting responses of Iowa and Maney were intermediate between the rooting response of Ames and Story, with a mean number of rooted cuttings of 1.22 and 2.55 respectively.

The rooting of Ames, Iowa, and Maney was quite uniform in different media, while the rooting of Story varied from 5 per cent in sand to 38.3 per cent in the mixture of 50-50 peat and vermiculite; however, according to the analysis of variance (Table IV), the rooting in different media did not differ significantly.

Table IV reveals significant differences among the rooting responses of the cuttings of the four varieties

Table III

Number of Rooted Cuttings of Four Varieties of Junipers in Different Media Under White Fluorescent Light

March 7, 1949 to October 10, 1949

Medium	Variety	Replication A	B	C	Total	Mean
Sand	Ames	1	0	0	1	
	Iowa	0	0	6	6	
	Maney	1	0	8	9	
	Story	1	2	0	3	
		3	2	14	19	1.58
Vermiculite	Ames	1	0	2	3	
	Iowa	0	1	1	2	
	Maney	1	1	5	7	
	Story	5	2	7	14	
		7	4	15	26	2.16
50-50 Peat and Vermiculite	Ames	1	0	0	1	
	Iowa	1	0	2	3	
	Maney	4	2	1	7	
	Story	12	0	11	23	
		18	2	14	34	2.83

Variety mean:

Ames	0.55
Iowa	1.22
Maney	2.55
Story	4.44

Difference required for significance:
for varieties
at 5% level = 2.20
at 1% level = 3.02

Table IV

Analysis of Variance of The Number of Rooted Cuttings of Four Varieties of Junipers in Different Media Under White Fluorescent Light

Mar. 7, 1949 to Oct. 10, 1949

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Replicates	2	51.389	25.695
Media	2	70.305	35.153
Error (a)	4	45.945	11.486
Varieties	3	79.416	26.472 **
Varieties x Media	6	1.251	0.208
Error (b)	18	89.333	4.962
Total	35	337.639	

** Significant at 1% level.

of Junipers. Since there are many zeros in Table III and the rooting does not seem to have come from a normal population, the data in Table III were corrected by using the correction factor $\sqrt{x+0.5}$ (Table V) and the corrected data analyzed (Table VI). No significant changes were noted in the two analyses (Tables IV and VI). It is also indicated in Table VI that the rooting responses shown by the four varieties were characteristic of the varieties used.

According to the data in Table III, the highest percentage of rooting was 38.3 per cent by J. chinensis var. Story in the 50-50 peat and vermiculite. From the data collected there is not sufficient evidence to judge the merits of using white fluorescent light for rooting narrowleaf evergreen cuttings. Other factors may influence the rooting response of evergreen cuttings. In this experiment the rooting media were maintained at a high moisture level and rotting was found at the basal end of many dead and living cuttings. If a lower moisture level of the media had been maintained, better aeration might have been conducive to better rooting. If fluorescent lighting for propagation is to be made more efficient and practical, some means are necessary by which air temperature can be maintained at the optimum level.

Table V

Number of Rooted Cuttings of Four Varieties of Junipers in Different Media Under White Fluorescent Light (The data in this table were corrected by using the correction factor $\sqrt{x+0.5}$).

Mar. 7, 1949 to Oct. 10, 1949

Medium	Variety	Replication A	B	C	Total
Sand	Ames	1.224	0.707	0.707	2.638
	Iowa	0.707	0.707	2.549	3.963
	Maney	1.224	0.707	2.915	4.846
	Story	1.224	1.581	0.707	3.512
		4.379	3.702	6.878	14.959
Vermiculite	Ames	1.224	0.707	1.581	3.512
	Iowa	0.707	1.224	1.224	3.155
	Maney	1.224	1.224	2.345	4.793
	Story	2.345	1.581	2.738	6.664
		5.500	4.736	7.888	18.124
50-50 Peat and Vermiculite	Ames	1.224	0.707	0.707	2.638
	Iowa	1.224	0.707	1.581	3.512
	Maney	2.121	1.581	1.224	4.926
	Story	3.535	0.707	3.392	7.634
		8.104	3.702	6.904	18.710
Total		17.983	12.140	21.670	51.793

Variety mean:

Ames	0.97
Iowa	1.18
Maney	1.61
Story	1.98

Difference required for significance:

For varieties at 5% level = 0.67

Table VI

Analysis of Variance of The Corrected Number of Rooted Cuttings of Four Varieties of Junipers in Different Media Under White Fluorescent Light

Mar. 7, 1949 to Oct. 10, 1949

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Replicates	2	3.848765	1.924382
Media	2	0.678697	0.339348
Error (a)	4	1.491339	0.372834
Varieties	3	5.436941	1.812313 *
Varieties x Media	6	2.699664	0.449944
Error (b)	18	8.296073	0.460892
Total	35	22.451479	

* Significant at 5% level.

Experiment C

Cuttings of Taxus cuspidata var. Hicksii appeared to be superior to the cuttings of either Thuja orientalis or Juniperus chinensis var. Maney in speed and amount of rooting under either white fluorescent light or greenhouse conditions. All Japanese Yew cuttings under white fluorescent light remained healthy in the different media. Rooting was first observed in the mixture of 50-50 sand and vermiculite on January 3, 1950, and rooting percentages of 95 per cent and up were obtained by April 4, 1950 in the different media. Cuttings of the same species under greenhouse conditions suffered from serious damping-off and a faulty heating cable, and the number of dead cuttings on April 4, 1950, ranged from 10 per cent in Permalite to 50 per cent in both vermiculite and 50-50 sand and vermiculite. These factors may have been the cause of the low rooting percentages of the cuttings of this species in the greenhouse in comparison with the high rooting percentages of those in the cabinets. Chadwick (2), in his experiment with hardwood cuttings of four species of narrowleaf evergreens, stated that better rooting response of cuttings of narrowleaf evergreens can be expected under greenhouse conditions than in an opaque structure equipped with fluorescent light.

The progress of rooting of Japanese Yew cuttings under white fluorescent light and normal light are recorded in Table VII. According to the data, the earliest rooting was obtained in the mixture of 50-50 sand and vermiculite under white fluorescent light; however, rooting percentages of the cuttings in sand and Permalite increased much faster during the following six weeks and attained 90 and 80 per cent rooting respectively. The rooting percentage in 50-50 sand and vermiculite by that time (Feb. 14) was only 52.5 per cent. On April 4, 1950, rooting percentages of above 95 per cent were obtained in all media (Table VIII). The final rooting percentages in different media were not significantly different (Table IX).

In the greenhouse, rooting of Japanese Yew was first obtained in Permalite (Table VII). On February 14, 1950, cuttings in Permalite still showed the highest rooting percentage, 45 per cent, while the rooting percentages in sand, vermiculite, and 50-50 sand and vermiculite were 25, 25, and 20 per cent respectively. On April 4, 1950, the rooting percentage of cuttings in Permalite ranked first, while cuttings in vermiculite and the mixture of 50-50 sand and vermiculite gave the two lowest rooting percentages (Table X). According to the analysis of variance of the number of rooted cuttings in the different media (Table XI),

Table VII

Progress of Rooting of Cuttings of Japanese Yew in Different Media

Under White Fluorescent Light And Greenhouse Conditions

Oct. 25, 1949 to April 4, 1950

Date of Examination	White Fluorescent Light				Greenhouse			
	Sand	Vermiculite	Permalite	50-50 Sand and Vermiculite	Sand	Vermiculite	Permalite	50-50 Sand and Vermiculite
Jan. 3	0	0	0	7	0	0	2	0
Jan. 10	8	7	10	7	2	4	6	0
Jan. 17	15	19	13	18	6	7	9	2
Jan. 24	17	19	25	18	6	8	14	3
Jan. 31	24	19	30	20	9	8	16	6
Feb. 7	35	23	30	21	10	9	18	8
Feb. 14	36	24	32	21	10	10	18	8
Feb. 21	36	27	32	23	13	12	21	11
Feb. 28	36	32	32	33	13	14	21	11
Mar. 7	38	34	32	35	15	14	26	11
Mar. 14	38	36	32	36	15	15	26	14
Mar. 21	38	37	37	36	18	15	28	16
Mar. 28	38	38	38	38	19	16	28	16
April 4	38	40	40	38	22	16	28	18

Table VIII

Number of Rooted Cuttings of Japanese Yew in Different Media

Under White Fluorescent Light

Oct. 25, 1949 to April 4, 1950

Medium	Replication A	B	C	D	Total	Mean
Sand	10	10	9	9	38	9.5
Vermiculite	10	10	10	10	40	10.0
Permalite	10	10	10	10	40	10.0
50-50 Sand and Vermiculite	10	10	10	8	38	9.5
Total	40	40	39	37	156	

Table IX

Analysis of Variance of Rooted Cuttings of Japanese Yew in Different Media Under White Fluorescent Light

Oct. 25, 1949 to April 4, 1950

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Replicates	3	1.50	0.50
Media	3	1.00	0.33
Error	9	2.50	0.28
Total	15	5.00	

Table X

Number of Rooted Cuttings of Japanese Yew in Different Media

Under Greenhouse Conditions

Oct. 25, 1949 to April 4, 1950

Medium	Replication				Total	Mean
	A	B	C	D		
Sand	6	7	3	6	22	5.5
Vermiculite	5	4	5	2	16	4.0
Permalite	8	7	6	7	28	7.0
50-50 Sand and Vermiculite	5	6	5	2	18	4.5
Total	24	24	19	17	84	

Difference required for significance:

at 5% level = 2.16

Table XI

Analysis of Variance of The Number of Rooted Cuttings of Japanese Yew in Different Media Under Greenhouse Conditions

Oct. 25, 1949 to April 4, 1950

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Replicates	3	9.5	3.16
Media	3	21.0	7.00 *
Error	9	16.5	1.83
Total	15	47.0	

* Significant at 5% level.

the number of cuttings rooted was characteristic of the rooting media used.

Cuttings of Aborvitae had no callus formation under either white fluorescent light or normal light. When the experiment was concluded on April 28, 1950, no rooting was found in the greenhouse. Under white fluorescent light there was only one rooted cutting in vermiculite and Permalite. The number of dead cuttings was large in both the propagating cabinets and the greenhouse. In the cabinets, percentages of dead cuttings ranged from 2.5 per cent in Permalite to 32.5 and 47.5 per cent in 50-50 sand and vermiculite and pure vermiculite respectively. Generally speaking, in the greenhouse the percentages of dead cuttings were even higher. The cuttings in both vermiculite and 50-50 sand and vermiculite showed 50 per cent mortality. Cuttings in sand had the lowest percentage of dead cuttings, 10 per cent. Owing to the fact that a greater number of dead cuttings was found in the two media that have the greatest water holding capacities, that rotting was generally observed at the basal ends of the dead cuttings, and that high mortality also occurred in the greenhouse, it would be reasonable to assume that the high percentage of dead Aborvitae cuttings in the cabinets was due to the unfavorable water relationship resulting from over-watering the media rather than to any harmful effect exerted on the cuttings by the white fluorescent light.

Maney Juniper cuttings responded very poorly in the greenhouse. There was no callus formation or rooting. The percentages of dead cuttings ranged from 30 per cent in both sand and 50-50 sand and vermiculite to 70 per cent in vermiculite. Cuttings of the same species responded much more favorably in the cabinets. By the middle of February they had active callus formation which was accompanied by new shoot growth shortly afterward. Upon the conclusions of this experiment most of the cuttings had heavy to very heavy callus. Only one cutting in sand and three cuttings in vermiculite were rooted. These rooted cuttings had only medium callus formation. This was in accordance with the general belief that cuttings of woody species usually fail to strike root due to excessive callus formation. It may be possible to improve the rooting response of Maney cuttings by the common practice of pealing off the callus.

Experiment D

The progress of rooting of cuttings of dusty miller and carnation in two different media under white fluorescent light and greenhouse conditions is recorded in Table XII and XIII. When sand was used as the rooting medium for dusty miller (Table XII), earlier rooting was obtained

Table XII

Progress of Rooting of Cuttings of Dusty Miller in Sand and Vermiculite Under White Fluorescent Light and Greenhouse Conditions

Jan. 12, 1950 to Mar. 13, 1950

Date of Examination	White Fluorescent Light		Greenhouse	
	Sand	Vermiculite	Sand	Vermiculite
February 6	0	0	13	0
February 11	0	0	35	9
February 16	0	0	35	9
February 21	27	4	35	19
February 26	27	4	35	19
March 3	30	15	36	26
March 8	32	21	36	27
March 13	32	25	36	29

Table XIII

Progress of Rooting of Cuttings of Carnation in Sand And Vermiculite Under White Fluorescent Light And Greenhouse Conditions

Jan. 12, 1950 to Mar. 13, 1950

Date of Examination	White Fluorescent Light		Greenhouse	
	Sand	Vermiculite	Sand	Vermiculite
February 6	0	0	0	0
February 11	0	0	30	0
February 16	0	0	30	0
February 21	35	0	30	17
February 26	35	0	32	19
March 3	35	0	36	19
March 8	36	4	36	24
March 13	36	16	36	24

in the greenhouse. Under greenhouse conditions, rooting was first observed on February 6, and 97.2 per cent rooting was observed by February 11 in sand. On the other hand, under white fluorescent light, rooting of dusty miller cuttings had not begun until February 21, 1950. However, this initial rooting was 75 per cent (27 of 36 cuttings rooted); and by March 8, 1950, the rooting percentage of dusty miller in sand under white fluorescent light had risen to 88.9 per cent and did not differ significantly from the 100 per cent rooting of the same kind of material in sand under greenhouse conditions (Table XIV and XV). In Table XIV, the data of rooting responses of dusty miller in sand and vermiculite under white fluorescent light and greenhouse conditions were combined because the variances were tested and found to be homogeneous.

Earlier rooting was obtained in the greenhouse when vermiculite was used as the rooting medium in the propagation of dusty miller (Table XII). Under greenhouse conditions an initial rooting percentage of 25 per cent was obtained on February 11, while rooting was not observed under white fluorescent light until two weeks later. By March 8, 1950, rooting of dusty miller in vermiculite was 58.3 and 75 per cent under white fluorescent light and greenhouse conditions respectively. The rooting response

Table XIV

Number of Rooted Cuttings of Dusty Miller in Sand And Vermiculite Under White Fluorescent Light And Greenhouse Conditions

Jan. 12, 1950 to Mar. 8, 1950

Location	Medium	Replication			Total	Mean
		A	B	C		
White Fluorescent Light	Sand	10	12	10	32	10.66
	Vermiculite	5	7	9	21	7.00
	Total	15	19	19	53	
Greenhouse	Sand	12	12	12	36	12.0
	Vermiculite	10	6	11	27	9.0
	Total	22	18	23	63	

Difference required for significance:

For media at 5% level = 3.22

Table XV

Analysis of Variance of The Number of Rooted Cuttings of Dusty Miller in Sand And Vermiculite Under White Fluorescent Light And Greenhouse Conditions

Jan. 12, 1950 to Mar. 8, 1950

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Locations	1	8.33	8.33
Replicates within Locations	4	12.34	3.085
Media	1	33.33	33.33 *
Media x Locations	1	0.34	0.34
Error	4	12.33	3.0825

* Significant at 5% level.

of dusty miller in vermiculite was consistantly inferior under white fluorescent light. According to Table XIV and XV, vermiculite seemed to be inferior to sand as a rooting medium for dusty miller under either white fluorescent light or greenhouse conditions.

When sand was used as the rooting medium for carnation, earlier rooting was obtained under greenhouse conditions; however, the final rooting percentages (100 per cent) were obtained in both treatments a little less than two months after planting (Table XIII). The good rooting response indicates that sand is a favorable rooting medium for carnation under either white fluorescent light or greenhouse conditions.

According to the data in Table XIII, earlier rooting was obtained in the greenhouse when carnation cuttings were propagated in vermiculite. In the greenhouse, 47.2 per cent of the cuttings were rooted on February 21, while no rooting was observed under the white fluorescent light. By March 8, 1950 the rooting percentages of carnation in vermiculite under white fluorescent light and greenhouse conditions were 11.1 and 66.6 per cent respectively. When this rooting percentage (11.1 per cent) is compared with the rooting attained (100 per cent) by the cuttings of the same species in sand under white fluorescent light (Table XVI and XVII), it may be said that sand was a much better

Table XVI

Number of Rooted Cuttings of Carnation in Sand And Vermiculite Under White Fluorescent Light

Jan. 12, 1950 to Mar. 8, 1950

Mean	Replication A	B	C	Total	Mean
Sand	12	12	12	36	12.00
Vermiculite	1	2	1	4	1.33
Total	13	14	13	40	

Difference required for significance:

at 1% level = 3.97

Table XVII

Analysis of Variance of The Number of Rooted Cuttings of Carnation in Sand And Vermiculite Under White Fluorescent Light

Jan. 12, 1950 to Mar. 8, 1950

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Replicates	2	0.20	0.10
Media	1	170.53	170.53 **
Error	2	0.47	0.24
Total	5	171.20	

** Significant at 1% level.

rooting medium than vermiculite for carnation when white fluorescent lamps were used as the source of illumination. Although the rooting response of carnation in the greenhouse was found not to be as favorably in the vermiculite as in the sand (Table XVIII), the analysis of variance (Table XIX), shows that the difference was not significant.

Experiment E

Leaf dropping was first observed on the untreated peach cuttings on the sixth day after planting. Abscission of leaves proceeded so rapidly that over 50 per cent of both treated and untreated cuttings defoliated within the following few days. An effort was then made to check the abscission by spraying the aerial portions with a 1 ppm solution of napthaleneacetic acid but without results. By the end of the following week all untreated cuttings and all but seven treated cuttings had defoliated. Obviously this hormone solution was either applied after the abscission layer had already progressed too far or an effective amount was not absorbed into the tissues.

On the sixteenth day after planting, leaf buds on two untreated and many treated cuttings were opening. Two treated cuttings were rooted and had light callus formation and new shoots. It was noticed that these two cuttings had greater diameters of stems than most of the other

Table XVIII

Number of Rooted Cuttings of Carnation in Sand

And Vermiculite Under Greenhouse Conditions

Jan. 12, 1950 to Mar. 8, 1950

Medium	Replication A	B	C	Total	Mean
Sand	12	12	12	36	12.0
Vermiculite	9	5	10	24	8.0
Total	21	17	22	60	

Table XIX

Analysis of Variance of The Number of Rooted Cuttings of Carnation in Sand And Vermiculite Under Greenhouse Conditions

Jan. 12, 1950 to Mar. 8, 1950

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square
Replicates	2	7.00	3.50
Media	1	24.00	24.00
Error	2	7.00	3.50
Total	5	38.00	

cuttings, had better developed axillary buds, and were among the few that were taken from the main branches. The two treated cuttings probably had more food and hormone for root initiation than the other cuttings taken from the side branches.

On the twenty-first day after planting two of the treated cuttings that had foliage were rooted. By this time, all of the defoliated cuttings, either treated or untreated, which had not broken dormancy were dead. No callus formation was observed on these dead cuttings. The leaf buds of the remaining cuttings developed into shoots about one-half inch in length. Three of the treated cuttings were found rooted. The remaining cuttings that had new shoots, but no roots, wilted and died. Since there were no symptoms of either diseases on these cuttings, their death might better be explained as the result of the inability of the cuttings to absorb water, or that the cuttings were taken after the abscission layer was initiated in the leaf petiole. According to Cochran (3), the softwood cuttings of peach have a great tendency to plug the xylem vessels with wound gum and thus check the uptake of water. This tendency had made his experiment of propagating peaches from softwood cuttings in summer a failure in comparison with the good results given by the same kind of material under the same treatment in winter. By treating the cuttings with indolebutyric acid and then holding them in continuous mist he was able to get favorable rooting response during March, April, and May.

V. SUMMARY

The Juniper cuttings responded unfavorably in various media under white fluorescent light. The best rooting obtained in the experiments was only 38.3 per cent, while the cuttings of every species showed high mortality. In these experiments, the rooting media were maintained at a high moisture level and basal rot was found at the ends of many dead and living cuttings.

The number of cuttings of Junipers alive two months after planting was characteristic of the species, and was not influenced by the kinds of media used.

When the four varieties of Juniperus chinensis were propagated under white fluorescent light, the number of rooted cuttings was significantly different among varieties. The kinds of media had no effect on the rooting.

Medium to very heavy callus formation was observed on the Juniper cuttings under white fluorescent light. Active callus formation appeared to be associated with new shoot growth, however, neither the amount of shoot growth nor callus formation appeared to be indicators of root formation. In these experiments, the rooted Juniper cuttings had only medium callus formation.

Cuttings of Thuja orientalis and occidentalis also responded poorly under white fluorescent light. Low rooting percentage and high mortality were observed in different media.

The cuttings of Juniperus chinensis var. Maney and Thuja orientalis showed no rooting in the greenhouse. The mortality of Maney ranged from 30 per cent in both sand and the mixture of 50-50 sand and vermiculite to 70 per cent in vermiculite. With Thuja orientalis a mortality of 50 per cent was observed in both vermiculite and 50-50 sand and vermiculite. The lowest mortality, 10 per cent, was observed in sand.

The cuttings of Taxus cuspidata responded very differently under white fluorescent light in different season. Rooting of 95 per cent and up was attained in a little more than five months in four different media during winter and spring. This rooting was a contrast to the complete failure of the same species when propagated during the summer months. The number of rooted cuttings of this species under greenhouse conditions was influenced by the media. The highest mean number of rooted cuttings, 7.0, and the lowest mean number of rooted cuttings, 4.0, were observed in Permalite and vermiculite respectively. Damping-off that prevailed in the greenhouse is thought to be partially responsible for the lower rooting compared to that obtained in the cabinets.

An experiment with two herbaceous plants, dusty miller and carnation, was also carried out under white fluorescent light and greenhouse conditions, using sand and vermiculite as the rooting media. The results indicated that earlier rooting of these two species can be expected in the greenhouse, whether sand or vermiculite be used. As for the final rooting, the number of rooted cuttings observed in the two locations showed no significant difference.

The cuttings of dusty miller and carnation responded favorably in sand under both white fluorescent light and greenhouse conditions. The rooting percentages of 75 to 97.2 per cent were observed at about five weeks after planting; and the rooting percentages of 88.8 to 100 per cent were attained half a month later.

Sand seemed to be superior to vermiculite as a rooting medium for the propagation of carnation under white fluorescent light as was indicated by comparing the 11.1 per cent rooting in vermiculite with the 100 per cent rooting in sand under white fluorescent light. The rooting of carnation in sand and vermiculite, however, did not differ significantly under greenhouse conditions.

In the experiment of propagating peaches by semi-hardwood cuttings the results were very poor. Over 50 per cent of the cuttings dropped their leaves in a few days after planting. The napthaleneacetic acid spray was unsuccessful in preventing the dropping of leaves either because the spray was applied after the abscission layers had already progressed too far or had dried out before an effective amount was absorbed into the tissues.

The few rooted cuttings obtained in this experiment were the treated ones. Among them five were rooted after their leaves had dropped and their leaf buds had opened.

Most of the untreated cuttings wilted without breaking dormancy, while the majority of the treated cuttings had their leaf buds developed into shoots about one-half inch long. These new shoots usually wilted at this stage if there were no roots to support them, and finally the cuttings died.

VI. CONCLUSIONS

1. The cuttings of Junipers and Aborvitae responded unfavorably under white fluorescent light. The high mortality of cuttings due to damping-off could be partially responsible for the low rooting percentages.
2. In all the experiments, poor medium aeration and high air temperature in the cabinets had been two of the important causes of the high loss of cuttings. If fluorescent lighting for propagation is to be made more efficient and practical, some means by which air temperature can be maintained at the optimum level is necessary.
3. Rooting of the four varieties of Juniperus chinensis differed significantly. Within each variety, the rooting in different media did not differ significantly.
4. Juniper cuttings callused heavily under white fluorescent light. The rooted cuttings had only medium callus formation. Presumably better rooting could be expected if the excessive callus on the cuttings was peeled off.
5. Active callus formation on Juniper cuttings appeared to be associated with new shoot growth. The amount of new shoot growth, however, could not be used as an indicator of rooting.
6. Normal light did not favor callus formation or new shoot growth of Juniper cuttings.

7. Seasonal variation in rooting response was manifested by Taxus cuspidata cuttings under white fluorescent light. Favorable results with this species were obtained in different media during winter and spring; while using the same kind of material during the summer months resulted in complete failure. This may be due to the seasonal variation of the cuttings themselves or to the better environmental conditions in the cabinets, particularly the lower air temperature and higher humidity.

8. The propagating cabinet was comparable to the greenhouse as a place for propagating dusty miller and carnation. Although in all cases rooting under greenhouse conditions was notable for rapidity, the final rootings in these two locations showed no significant difference.

9. Sand was superior to vermiculite as a rooting medium for the propagation of dusty miller and carnation under white fluorescent light.

10. Under greenhouse conditions rooting of dusty miller in sand was also higher than that obtained in vermiculite. With carnation, however, the two media used did not cause significant differences in rooting.

11. Chemical treatment seemed to be advantageous in the propagation of peaches by semi-hardwood cuttings.

12. Rooting cuttings under white fluorescent light had no

deleterious effect upon the subsequent growth of these cuttings when potted and grown in the greenhouse.

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