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# The effect of laboratory controlled artificial light; Part I On germination and early growth; Part II On plant anatomy

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# THE EFFECT OF LABORATORY CONTROLLED ARTIFICIAL LIGHT

## PART I

## ON GERMINATION AND EARLY GROWTH

## PART II

## ON PLANT ANATOMY

by

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(Signed) Carl F. Beall
Chairman Exam. Com.





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TABLE OF CONTENTS

# INTRODUCTION

For a long time light has been recognized as being one of the major factors influencing the growth, form, and distribution of vegetation.

The first studies concerned the effects of ordinary daylight on plant form and as early as 1835 Mirbel found that pores (then called stomata) would develop only on the lighted side of the leaf of Marchantia. About 1862 Sachs related the rate of photosynthesis to the intensity of light and from that time to the present the effects of light have been studied very intensively.

Later the realization developed that the different wave lengths of light might cause the plant to react differently and much work has been done demonstrating that the effects of light are caused by its component rays, each affecting the plant in a different manner.

Progress in the study of light effects probably developed at about the same pace as the developments in the physical study of light. Certainly it could not go faster. There exists even now a great need for a single instrument which will automatically record the intensity and duration of light waves of different lengths simultaneously, and it will be the part of the physicist with his knowledge of the fundamentals involved to develop such an instrument.

The nature of solar radiation is even now but little understood. It is not constant either in duration, intensity, or quality, due to alternating periods of night and day, to seasonal changes, clouds and other atmospheric conditions, aspect, and differences in elevation. Due to the filtering effects of the atmosphere the quality of light varies greatly at different elevations.

In order to study the effect of light upon plants it became increasingly evident that the illumination should be constant and of known and reproducible duration, intensity and quality. To this end the incandescent lamp has come into general use and much progress has been made in the last decade in the study of light effects.

Since the effects of light upon vegetation have formed the foundation of the practice of silviculture by foresters, laboratory studies by the use of artificial light on the germination and growth of seeds and seedlings, such as used in forest nurseries or found in the natural forest, might bring new evidence which may substantiate the present practices or show cause to materially alter them.

To date two schools of thought have developed, one led by Weaver and Clements (1929) follows the original theory that the limiting factor in forest reproduction and growth is light; while the other group led by Toumey (1928) claims that their experiments show with equal conclusiveness that moisture

is the limiting factor. Pearson (1930) is probably one of the first of the recognized authorities to show that neither one is at all times the limiting factor.

Past work has shown that the germination of some seeds may be entirely prohibited by light and others will germinate only in the presence of light. It has been the aim of the author in this paper to show two things: first, the effect of light on the germination and early growth of certain seeds and seedlings; second, the effects of the quality and quantity of light on the anatomy of the seedlings.

The writer gratefully acknowledges the personal interest of Professor Dorr Skeels of the School of Forestry under whose direction the work was done. Especial credit is due Professor J. W. Severy of the Department of Botany without whose advice and generosity in allowing the writer the full use of the histological laboratory and equipment, the anatomical portion of this work could not have been accomplished. The writer is also indebted to S. G. Hibben of the Westinghouse Lamp Company for information relative to the intensity and spectral quality of the illumination used in the experiment.

# HISTORICAL

One of the earliest references on the formative influence of light is reported by Sachs (1882) where he states that Mirbel, in 1835, found that Marchantia will develop stomata only on the lighted side of the leaf. Sachs states that light retarded growth, due perhaps to the increased transpiration and a lessened turgescence in the cells. He says further that etiolated plants in darkness transpire at a lower rate than do green plants in light and the decrease in the transpiration rate brought about when plants are kept in a nearly water saturated chamber exerts a marked influence upon the form and structure even in light. The anatomical characters of etiolated plants are quite like those of plants grown in light but in water saturated air.

According to Pfeffer (1897) Godlewski, in 1879, obtained normal plants in the presence of light but in the absence of carbon dioxide. Thus light of the shorter wave lengths and not those concerned in photosynthesis was demonstrated as being the required condition for normal form.

Goebel (1895) and Voechting in 1894 (cited by Benecke-Jost 1923) found that the members of the Cactaceae which under normal conditions produce flat, leaf-like stems and branches, form slender sylindrical internodes in continuous darkness. In this case however the internodes are shorter than those

grown in ordinary light, a reaction which is contrary to the usual trend.

Pierce (1906) definitely concludes that other things being equal light promotes growth, up to a certain intensity at least. This appears to be contrary to the conclusions of Sachs (1882) who as Peirce says made no distinction between organs of unlimited growth such as stems and organs of limited growth such as leaves. Later work shows conclusively that the dry weight of plants varies upward with the intensity of the incident light. (Bates and Roesser, 1928, Shirely, 1929). The theory of Sachs is no longer tenable except in case of some of the lower forms of vegetation which thrive in the absence of light and may even be killed by light as shown by Palladin (1914).

Clements (1910) found that Lodgepole Pine was less able to adjust itself to variations in light than to variations in either water content or temperature. No vigorous seedlings were found in forests with light values from 0.08 - 0.05 of full sunlight and seedlings of any sort were rare. Under competition for light height growth is made at the expense of growth in diameter. From the great loss sustained by wind throw when a dense stand of Lodgepole is opened up by cutting it would appear that as Burns (1914), Boerker (1916) and others have found that top growth is made at the expense of root growth, for the roots are then not extensive and insufficient to anchor the tree.

Burns (1914) found also that white pine seeds germinate best under a cover of ½" of sand but that this is not due to the presence or absence of light but to the soil moisture and temperature requirements. Shaded germination beds reduced the temperature of the soil and delayed the time of germination but did not affect the percent of germination. Shading was found to give a more uniform growth and a more even stand. Burns found great differences in the appearance of seedlings within three weeks of germination when they were subjected to varying degrees of shade. Those grown in darkness were tall, pale green, easily knocked over, and the roots were short and unbranched.

The seedlings produced in partial shade, using a cheese cloth cover for shade, were much shorter and darker green, and the roots were better developed.

The control seedlings were still shorter and sturdier than those found in either of the other two beds. The tap roots greatly exceeded the hypocotyl in length and were freely branched.

This work agrees with the later work of Boerker (1916) and Shirely (1929) and with the results of the present paper.

Palladin (1914) states that Pilobolus develops normally in a weak light but produces very long sporangiophores in darkness, where also, the spores fail to mature.

Humphrey and Weaver (1915) think that the growth of herba-

ceous plants and shrubs may frequently be so dense as to preclude the development of the young conifers. That the exclusion of the seedlings is usually due to light is a question to be determined by experiment and in the field. Repeated observations and measurements of the soil moisture content and the evaporating power of the air, together with light values show definitely that although the soil moisture may be far more than sufficient for tree growth and the humidity of the air relatively high, yet when the light values drop 1/25 of normal sunshine, the hardiest pioneer, the Western Yellow Pine, is excluded. Thus it appears that Yellow Pine, like Lodgepole (Clements 1910) is more influenced by light than by any other factor.

Boerker (1916) in a study on the germination and early growth of forest trees sums up with the statement that light plays absolutely no part in the germination of the seeds. He found that Robinia and Quercus show a decrease in height and root growth under diminishing light intensity while the conifers showed increases in height growth but decreases in root growth. The author of this paper obtained different results regarding Quercus. Seeds of Q. macrocarpa were germinated and grown for 30 days under artificial light. The stems attained a height of 6-8 inches during that time while the roots were very short and relatively unbranched as compared with those of some plants grown under natural light, which had shorter stems.

Although the work of Klebs, who in 1916 worked out the effect

of light on the germination of fern spores was not available, Benecke-Jost (1923) and Peirce (1926) give good summaries of his work. Klebs showed that under ordinary conditions fern spores will not germinate in darkness, and illumination with blue, violet, and ultra-violet, all cold rays, does not stimulate them to germinate. On the other hand cell division and differentiation are more influenced by light rays of the shorter wave lengths than by red. (Peirce 1926).

He showed also that Sempervivum, which normally flowers in June, could be forced into flowering in winter, either by means of continuous electric illumination by an Osram lamp for a few days or by increasing the daily illumination period to more than 12 hours. (Benecke-Jost 1923).

According to Toumey (1916) most, if not all, of the effect of light on the germination of seeds is due to the alternating temperature relations of night and day. Fluctuating temperatures aid germination more than constant temperatures, other requirements remaining constant. He cites no special light treatment for seeds that are difficult to germinate but is of the opinion that any such special measures are more expensive than the natural ripening process, thought this latter may require one or two years. This is probably true to a great extent, particularly with forest tree seeds, for it has been shown that light can always be replaced by some other factor and the recalcitrant seeds be caused to germinate.

Garner and Allard (1920a, 1920b, 1923, 1925) in their

experiments on photoperiodism have made an extensive and intensive study of the effects of light on growth, formation and flowering. They found that some plants could be induced to flower by lengthening the day or light period by use of artificial illumination and others could only be forced to flower if the period of illumination were shortened. In the latter case the vegetative growth of the plant would continue without the development of any flowers if the light period were longer than required. This caused the authors to arbitrarily classify the plants into two groups; long day plants and short day plants. The long day plants are those which can be made to flower by lengthening the period of illumination, while the short day plants are those which will flower only if the light period is relatively short. This work supports the earlier work of Klebs who in studying the effect of light on Sempervivum found that it could be forced into early flowering by the use of artificial light. There is in addition, a group which seems not to be influenced by the duration of the daily light period. Weaver and Clements (1929) apply to this group the name of "everbloomers". It was found that the duration of the daily light period is more potent than the intensity of the light.

Harvey (1922) in some similar experiments obtained results in the main confirming those of Garner and Allard. As a source of illumination he used nitrogen filled tengsten lamps mounted five feet above the plants. Lamps of 200 and 1000 Watt capa-

city were used, but the latter size was found to be the most economical. They were burned 24 hours daily and one set was sufficient for four months.

He, however, found that the plants grew well and set good seed or produced tubers under continuous illumination. It seemed unnecessary, as Garner and Allard stated, to have a period of darkness to accomplish all the translocation of the assimilate from the leaves. Several intensities of light were used but the plants grew in each. The lowest intensities of 25 foot candles, in the dark corners, produced better growth than in the green house in winter.

Benecke-Jost (1923) stated that it has long been known that some seeds, such as Viscum album, most of the species of Veronica, Ranunculus sceleratus and Nicotiana, will either not germinate at all or very poorly when they are in continual darkness. According to them, Lehmann found that with Lythrum, exposure to light for 1/10 second with a 730 HK Osram-Azolamp was sufficient to bring about 50% germination with seeds which in the dark would only germinate 7%.

Since those seeds which will only germinate in the light are termed "Lichtkeimers" so also there are other seeds which must be denoted as "Dunkelkeimers" or those which will germinate only in the dark. The germination of seeds of the Amarantha-ceae for example and of Veronica tournefortii are hindered by

daylight. But there are however as Toumey (1916) indicates a great many seeds that are indifferent to light.

Benecke-Jost gives one of the best reviews of the work done, particularly that done by the Germans, concerning the effects of light on plant growth.

Sayre (1923) in working out the physiology of the stomata of Rumex patientia came to the conclusion that the external factor mostly influencing stomatal opening is light, and that atmospheric humidity is less an influence than light.

Adams (1923) subjected species of Flax, Wheat, Sunflower and White Mustard to varying periods of natural daylight. The seeds were sown in pots and grown in the greenhouse where other external conditions could be maintained uniform.

In another experiment (1924) he used more species, wider range of conditions and a larger range of light exposures including electric illumination. It was found that artificial light was an aid to plant growth during the relatively short days of winter but that when the natural daylight period became 12-15 hours it had little or no beneficial effect.

The results of both experiments showed that those plants exposed to light for the longest period grew to be the tallest attained the greatest dry weight and commenced to flower earlier than the plants exposed to light for the shorter periods. He states that Garner and Allard attempt to prove too much from their experiments and agrees with them only on one point. That

concerns those plants such as Soy Bean, Wax Bean, and Tomato whose growth was not directly proportional to the period of light but who seemed to have an optimum at which their growth was greatest, light periods either of less or greater duration exerting a lesser influence in attaining height or dry weight.

- Contrary to the statement of MacDougal (1901) that etiolated stems have a greater percent of bast than normal stems, Adams states that plants grown under a diminished supply of light were deficient in mechanical tissue and had a tendency to become decumbent. The question arises however as to whether the plants of Adams were really etiolated or not for he is supported by MacDougal and Penfound (1924) who found in a later work that the percent of bast decreased with a decrease in the light intensity. The results of the present paper are at variance with Adams as well as MacDougal and Penfound. In addition Adams does not state how he arrived at that conclusion and it appears that he merely guessed at it from the fact that the plants were unable to support themselves. It is probable that one must distinguish between etiolation and diminished growth due to low light intensity which is yet ample for normal processes.

Adams believes that a restatement of the effects of light are necessary and gives quite a lengthy discussion of the physiological aspects.

Hendricks and Harvey (1924) in an experiment similar to that of Harvey (1922), grew plants in rooms, under continuous

artificial light, the plants being grown in good soil and watered with Knop's solution so there would be no deficiency in nutriment. The light intensity varied according to the distance of the plants from the light. The MacBeth illuminometer was used to measure the intensity in foot candles. The plants were subject to a range from 50 - 10,632 foot candles.

Amaranthus retroflexus and Chenopodium album bloomed at high intensities but were stockier than those plants of the same species that bloomed at lower intensities. Strawberries fruited at 1500 - 2000 foot candles, but not at 500. Plants grown in intensities below their proper range tended to become etiolated and diseased. Nicotiana tabacum grew well at low intensity and bloomed over a great range. Fagopyrum and Tropaeolum seemed to be well adapted to the lower intensities. Mirabilis produced abundant flowers at 1350 foot candles but could be induced to bloom in continuous light only by violent fluctuations in temperature or moisture conditions. The flowers would open soon after the light was extinguished. Squash produced staminate flowers abundantly at 476 foot candles but only a few pistillate flowers. Easter lilies were speeded up a month in their time of blossoming, which correlated with an increase in their carbohydrate content.

Karling (1924) following the lead of Klebs, Garner and Allard, and Adams, all of whom found that the lengthening of the day by the use of artificial light brought the plants into bloom earlier, found that with but a few hours of artificial

illumination in addition to the daylight different species of Characeae could be induced to develop antheridia and oogonia in mid and later winter. Fruiting in nature occurs in summer and early fall. Within wide limits the response was not dependent on the intensity of the illumination and a continuous illumination of only 10 foot candles was sufficient to induce the development of the antheridia and oogonia within four days.

"Growth under artificial illumination led to the lengthening of the internodes, shortening of the leaves, reduced branching, brot etiolation, and a general spindling of the plants. Very few of the eggs developed into mature oospores."

Temperature was found to be a secondary factor within the minimum and maximum limits for vegetative growth.

The light used by Karling was of low intensity (60 watt) suspended a short distance above the plants. The effects of the generated heat were eliminated by immersing the bulb in a vessel of water which also would absorb some of the light. The low intensity probably is the cause of the etiolation of his plants.

MacDougal and Penfound (1924) determined by an anatomical study, the effects of light and shade, and varying degrees of light intensity, on plants of different stories in a hardwood commune. Leaves and first year stems were collected from Acer saccharum and Ulmus americana, Asimina triloba and Benzoin melissaefolium representing the upper strata shrubs, Laportea canadensis and Impatiens pallida which are tall herbs; and

Asarum canadense and Hydrophyllum canadense, which are low herbs. In the cases of woody plants, specimens were taken from positions of both maximal and minimal light. The specimens collected were imbedded, sectioned, stained and studied microscopically. Accurate measurements were made of the differentiated portions of the stem sections and their areas were calculated as percentages of the entire stem section.

They summarized their work in the following manner:

1 - Leaves in successively lower light intensities have larger cells, more intracellular spaces, less cuticle, a relatively poor conducting system, and larger chloroplasts. They stated however that the leaves of the lower strata are not necessarily thinner.

2 - Stems in successively lower strata are characterized by a less amount of supporting and conducting tissue and an increasing amount of parenchyma..

3 - Leaves collected from the dense shade differ from those in maximal sunlight on the same plant as follows:

a - A decrease in palisade tissue, both as to the number of layers and the depth of the individual cells.

b - An increase in the percent of intracellular space and spongy parenchyma.

c.-A decrease in the amount of supportive and conductive tissue.

4 - Stems collected from dense shade differ from those in maximal sunlight on the same plants as follows:

a - A decrease in the thickness and an increase in the length of the internodes.

b - A marked decrease in the percent of sclerenchyma.

c - A notable diminution of the percent of xylem accompanied by a slight decrease in the thickness of the tracheal walls.

d - A marked increase in the percent of pith.

Plitt and Pessin (1924) found in studying the effect of the evaporating power of light on the distribution of Lichens that evaporation appears to play the most important role, and light was only an indirect factor, except in the case of Usnea and Ramalina which occured only in regions where light is intense and the high evaporation did not seem to be the controlling factor.

Shaw (1924) remarks concerning the use of brush cover for protecting seedlings in the forest that the survival is greater on the poorer sites, for less drought resistant species and for poorer stock. Naturally shade would benefit the poorer sites where the soil and moisture factors would be likely to become the limiting factors rather than light.

According to Skene (1924) Loftfield has shown that at temperatures of 1, 10, 20, and 39 degrees centigrade the time of opening of the stomata of alfalfa in light was 6, 4, 2, and 1 hour respectively, a rise of 10 degrees centigrade doubling the rate of movement which is what one would expect with the conversion of starch to sugar as the fundamental reaction.

Korstian (1925) found that the germination of Englemann Spruce showed a direct relation to the amount of shade. The lowest germination and survival occurred in the open and the highest in ¾ shade but the seedlings grown in ¾ shade were too slender to make good development. In the case of Douglas Fir the beds receiving ½ shade had the highest survival and vigor as well as the best development. Lodgepole and Western Yellow Pine were grown successfully without shade which is what one would expect from the work of Clements (1910) on Lodgepole and Humphrey and Weaver (1915) on Yellow Pine. However, continuous intense sunlight was found likely to injure small succulent seedlings.

Gilbert (1926) made some growth experiments with plants of Xanthium pennsylvanicum to determine if other environmental conditions might not have as much influence on flowering as light as shown by Garner and Allard, Harvey, Adams, and others. The plants were grown under known conditions of temperature and relative day length. Temperature was found to be a determining factor in influencing the time of flower primordia formation.

This is not a contradiction of the work of Garner and Allard (1920) but is an addition to their work and serves to demonstrate that there may be more than one cause of the same phenomena.

Moore (1926) in a study on the influence of certain soil and light conditions on the reproduction of northeast conifers found that germination and survival are slightly better in the

openings of a forest. Growth and vigor was in all cases markedly greater in the openings which he attributed to an increase in light.

A series of investigations by Pfeiffer (1926) at the Boyce Thompson Institute for Plant Research throws some light on the subject of the effect of light waves of different quality upon plant anatomy. Seedlings were grown in glass houses which transmitted light in the visible spectrum and in the ultraviolet in various ranges of wave length. It was found that the best all around development in every case was either by the full spectrum or the outdoors.

Larsen (1927) in comparing between the structures generally conceded to pertain to light found that they do not show graded changes in passing from the most tolerant to the most intolerant species. There were seeming inconsistencies which were probably due to members of species changing site, and to other causes. In general the extremes of the series do show distinctive adaptation to light conditions on the following points; leaf shape and color, relative amount of spongy parenchyma, and in the lignified parts of the leaf.

Sheard and Higgins (1927) report that the effect of ultraviolet radiation on germination was according to the wave length. Radiation of 270 - 320 uu delayed the time of germination and decreased the rate of growth, while rays of 320 - 390 uu were particularly effective in promoting growth.

Bates and Roesser (1928) grew seedlings of Redwood, Western

Yellow Pine, Englemann Spruce, Douglas Fir, and Pinion Pine for nine months on a circular table with a 200 Watt Mazda lamp suspended one foot above the center of the table. The dry weight of the seedlings was used to determine the relative growth of the seedling under light of various intensities as measured by a Coblentz thermopile. Redwood ranked first with Spruce and Fir second, the Western Yellow Pine and Pinion Pine third and fourth respectively.

Toumey (1928) found as did Fricke twenty years previous, that the increased germination of seeds and increased growth of seedlings in the openings of a forest may be attributed to the removal of root competition rather than to an increase in light. These conclusions he bases on some trenching experiments in which the root competition was removed while at the same time the light remained the same.

Shirley (1929) grew plants under four sets of light conditions:

1 - Cloth shades inside greenhouse.
2 - Cloth shades outdoors.
3 - Constant conditions indoors with artificial illumination.
4 - In a series of glass house transmitting definite regions of the spectrum.

He studied the influence of light intensity on the weight of dry matter, height, ratio of roots to shoots and found that low light intensity favors top growth at the expense of root growth which agrees with the earlier work of Boerker (1916) and the stems of the plants grown under low light intensities were weak and succulent, often too weak to support the plant.

All plants survived at less than 40 foot candles except sunflower. Redwood and loblolly pine survived six months at a light intensity barely sufficient to cause an increase in weight and he found that this intensity was less than that which Bates and Roesser (1928) found necessary, but that none of the plants so situated were able to add appreciably to their dry weight. The dry weight was found to be directly proportional to the light intensity, up to certain limits beyond which an increase in intensity had little effect. This is in agreement with the work of Adams (1923,1924).

The entire visible and ultra-violet solar spectrum was found to be more efficient for growth than any fractional portion of it. Blue was found to be more efficient than red. He concluded that light quality was not a limiting factor in forest canopies.

Pearson (1923, 1930) studied the reproduction of Western Yellow Pine in Arizona and correlated the establishment, growth, and survival of reproduction with the soil moisture and light requirements. He found that the major portion of the influence formerly attributed to light cannot be assigned to soil moisture as Toumey (1928) indicates. It was found that temperature is as much a limiting factor as moisture, particularly at the upper altitudinal limits. Low light intensity is apt to become harmful when trees are in groups. In sites having low light intensities, but having adequate soil moisture, all species tend to assume a slender and weak form. It was concluded that moisture determines the lower border of Yellow Pine.

## MATERIALS

Two sandtables, filled with unsterilized river sand to a depth of four inches, were set up. The control bed which was situated in a large laboratory was subject to room temperature and ordinary daylight. The experimental bed was in a small store room, illuminated only by a 500 watt, daylight, Mazda 'C' lamp and subjected to the heat generated by the lamp and no ventilation. A black sateen cloth was used to cover half this bed to eliminate the light.

A soil thermometer and an ordinary standard centigrade thermometer was placed in each bed. Crystallizing dishes 10 cm in diameter and 3 cm. deep were used to compare the saturation of the air over each bed.

A filtered solution from steeped stable manure was used as a nutrient solution.

Seeds of the following species were used, no record being available as to their age or origin: Avena sativa, Caragana sp., Pinus austriaca, Picea canadensis, Picea pungens var., glauca.

## METHODS

The river sand was sifted through a sieve having 10 meshes to the inch so that the growing medium would be uniform in texture assuring uniform rate of water loss and conditions for

root penetration

Two hundred seeds of each species were counted out, care being taken to select only full plump seeds. One hundred were sown on the control bed in drills 4" apart and 1/2" apart in the drill and were left uncovered. The experimental bed was divided into two sections referred to hereafter as the Light Bed and the Dark Bed, each having 50 seeds of each species sown as in the control bed. One half of the experimental bed (the Dark Bed) was kept covered continuously with a black cloth suspended 3" above the surface of the soil, from February 18 when the seed was sown to March 1 when the majority had completed germination. The other half of the bed (the Light Bed) was subjected to continuous illumination of about 250 foot candles from a 500 watt, daylight, Mazda 'C' lamp suspended 3 feet above the center of the bed. A flat white reflector was used to throw the light onto the bed. The control bed received an illumination of about 500 foot candles (3).

A soil thermometer was imbedded in each bed so that the bulb was 3" beneath the surface of the soil. A standard centigrade thermometer was placed in the control bed and one in each section of the experimental bed, all so arranged on bent wire supports that the bulb of each was 1/2" above the soil. All temperature readings were taken twice daily, at 9 am and 6 pm.

A crystallizing dish was placed in the center of each bed, the top flush with the surface of the soil and filled with

water. The amount of evaporation was measured to 0.01" each morning when the beds were watered.

From March 1 during the remainder of the experiment the black cloth was removed from 5 pm to 9 am each day thereby giving 8 hours of total darkness and 16 hours illumination by artificial light.

The growth in inches of the germinated plants was measured once daily from Feb. 26 to March 7 for oats and from March 1 to 21 for the other species. This was the period of most rapid growth and further measurements were unobtainable due to the building being locked during recess between school terms. The measurements were divided into 1" height classes, any plant being less than 1" in height was not counted except in the germination count. Any plant more than 1" but less than 2" was in the 1" height class and a plant more than 2" but less than 3" in height went into the 2" height class, etc. A white headed pin was stuck into the soil next to every seed and as the seeds germinated the pins were removed thereby assuring no error in counting.

- The areas (tables XII and XIII) of the stems were obtained by making large scale camera-lucida drawings and then running the planimeter around the perimeter of the various groups of tissues.

## DATA OBTAINED

1 - Temperature of soil twice daily.

2 - Temperature of air twice daily.

3 - Saturation of air or relative humidity expressed in the ebaporating power of the air.

4 - Percent and rate of germination.

5 - Rate of growth.

6 - Comparative health of plants.

7 - Comparative anatomy of plants grown under different conditions.

## RESULTS

The fluctuation of the temperatures as shown in the graphs and tables was caused by the variation of the heat in the building. The low temperature was in the morning and the high in the afternoon. The considerable drop over the week end was caused by the shutting off of the heat over the week end in order to save fuel. The fluctuation of temperature was less in the experimental bed because of its situation in a room not so readily affected by the temperature of the remainder of the building.

The significant data regarding temperature is summarized in the tables as given below.

As will be seen from the following summaries of the data, the greatest variation was in the Control Bed and the least in the Dark Bed with the Light Bed in between. The black cloth over the Dark Bed helped to smooth out the temperature curve over that section. It is regrettable that space was not avail-

able so that suitable and equal temperature conditions could have applied to all of the beds.

Table I

Summary of soil temperature data in degrees Fahrenheit.

| | Control Bed | Experimental Bed |
|---|---|---|
| Mean high | 66.2 | 71.4 |
| Mean low | 61.9 | 69.7 |
| Average | 64.1 | 70.5 |
| Average range | 4.3 | 1.7 |

The daily record of the soil temperatures is given in Table Ia and chart I.

Table II

Summary of air temperature data.

| | Control Bed | Experimental Bed | |
|---|---|---|---|
| | | Continuous light | Intermittent light |
| Mean high | 69.3 | 73.1 | 72.5 |
| Mean low | 64.9 | 71.0 | 70.8 |
| Average | 67.1 | 72.0 | 71.6 |
| Average range | 4.4 | 2.1 | 1.7 |

# SOIL TEMPERATURE RECORD
## FAHRENHEIT

Table 1a

| Date | | Control bed | | Light bed | | |
|---|---|---|---|---|---|---|
| | | A.M. | P.M. | A.M. | P.M. | |
| Feb. | 18 | | 65.0 | | 65.0 | |
| | 19 | 61.5 | 68.0 | 81.0 | 78.0 | |
| | 20 | 64.0 | 68.5 | 80.0 | 76.5 | |
| | 21 | 62.0 | 68.0 | 71.5 | 74.0 | |
| | 22 | 61.5 | 67.0 | 71.5 | 74.0 | |
| | 23 | 64.0 | 67.5 | 72.5 | 74.0 | |
| | 24 | 60.5 | 61.5 | 69.5 | 69.0 | |
| | 25 | 58.5 | 64.0 | 67.0 | 75.0 | |
| | 26 | 60.5 | 69.0 | 69.5 | 74.0 | |
| | 27 | 65.5 | 69.5 | 73.0 | 74.5 | |
| | 28 | 64.0 | 67.5 | 72.5 | 74 - | |
| Mar. | 1 | 65.0 | 66.75 | 71.5 | 73.0 | black cover left off |
| | 2 | 64.5 | 67.5 | 71.5 | 73.0 | 16 hours each day |
| | 3 | 60.5 | 61.0 | 68.0 | 67.5 | |
| | 4 | 59.0 | 66.5 | 66.5 | 71.5 | |
| | 5 | 62.5 | 65.0 | 69.0 | 70.0 | |
| | 6 | 60.5 | 63.0 | 67.5 | 68.5 | |
| | 7 | 62.75 | 66.- | 68.75 | 71.0 | |
| | 8 | 61.5 | 65.5 | 68.0 | 70.75 | |
| | 9 | 62.0 | 65.75 | 68.5 | 70.5 | |
| | 10 | 62.7 | 61.7 | 69.4 | 66.5 | |
| | 11 | 59.6 | 61.2 | 66.5 | 67.4 | |
| | 12 | 60.0 | 64.0 | 67.0 | 70.0 | |
| | 13 | 62.0 | 67.4 | 68.5 | 71.0 | |
| | 14 | 60.5 | 68.8 | 67.5 | 72.0 | |
| | 15 | 64.5 | 69.5 | 71.0 | 72.0 | |
| | 16 | 63.1 | 68.2 | 69.5 | 71.5 | |
| | 17 | 63.5 | 66.5 | 69.5 | 67.6 | |
| | 18 | 60.5 | 67.5 | 66.4 | 69.5 | |
| | 19 | 61.2 | 68.5 | 67.1 | 71.0 | |
| | 20 | 63.3 | 65.6 | 68.8 | 70.5 | |
| | 21 | 63.5 | 65.9 | 69.4 | 70.2 | |
| | 22 | 61.5 | 65.2 | 68.0 | 69.8 | |
| | 23 | 61.5 | 66.5 | 69.0 | 71.5 | |
| | 24 | | | | | |
| | 25 | | | | | |
| | 26 | | | | | |
| | 27 | 62.5 | 68.5 | 68.5 | 73.2 | |
| | 28 | 65.5 | 68.6 | 71.0 | 72.5 | |
| | 29 | 62.7 | | 69.5 | | |
| | 30 | 62.0 | 68.0 | 70.2 | 72.2 | |
| | 31 | 60.0 | | 67.0 | | |
| | | 2355.3 | 2451.0 | 2651.0 | 2644.1 | |

# AIR TEMPERATURE RECORD
## FAHRENHEIT

Table 2a

Taken 1" above soil

| Date Feb. | Control bed A.M. | Control bed P.M. | Light bed A.M. | Light bed P.M. | Dark bed A.M. | Dark bed P.M. | |
|---|---|---|---|---|---|---|---|
| 18 | | | | | | | |
| 19 | | | | | | | |
| 20 | | | | | | | |
| 21 | | | | | | | |
| 22 | | | | | | | |
| 23 | | | | | | | |
| 24 | | | | | | | |
| 25 | | 73.4 | | 75.2 | | 75.4 | |
| 26 | 66.2 | 76.1 | 73.4 | 78.7 | 72.5 | 76.1 | |
| 27 | 77.0 | 74.3 | 77.0 | 77.0 | 75.2 | 73.4 | |
| 28 | 60.7 | 75.2 | 74.7 | 77.2 | 75.2 | 76.1 | |
| March 1 | 71.6 | 69.8 | 73.4 | 76.0 | 75.1 | 75.2 | |
| 2 | 68.0 | 71.6 | 73.5 | 74.3 | 73.5 | 74.3 | cover off |
| 3 | 60.7 | 60.7 | 68.9 | 68.0 | 68.0 | 68.1 | for A.M. |
| 4 | 63.5 | 69.8 | 69.8 | 74.3 | 69.8 | 71.6 | |
| 5 | 66.2 | 66.2 | 69.8 | 71.6 | 70.6 | 72.5 | |
| 6 | 59.8 | 72.5 | 69.8 | 71.6 | 69.8 | 71.6 | |
| 7 | 66.2 | 69.8 | 66.2 | 73.4 | 66.2 | 73.4 | |
| 8 | 68.8 | 74.3 | 70.6 | 73.4 | 70.6 | 72.5 | |
| 9 | 63.5 | 73.4 | 69.8 | 74.3 | 70.6 | 72.5 | |
| 10 | 62.6 | 62.2 | 69.8 | 69.5 | 69.8 | 70.7 | |
| 11 | 64.4 | 63.7 | 68.5 | 67.2 | 68.8 | 68.0 | |
| 12 | 63.5 | 68.0 | 69.8 | 73.4 | 69.8 | 71.6 | |
| 13 | 67.1 | 71.6 | 71.6 | 72.4 | 71.6 | 71.6 | |
| 14 | 68.0 | 76.1 | 70.6 | 76.2 | 70.6 | 73.4 | |
| 15 | 65.3 | 67.1 | 71.7 | 72.5 | 71.7 | 73.3 | |
| 16 | 63.6 | 70.6 | 67.1 | 71.6 | 68.8 | 71.6 | |
| 17 | 62.7 | 67.1 | 69.8 | 69.5 | 69.8 | 70.0 | |
| 18 | 61.6 | 69.8 | 68.0 | 72.6 | 68.7 | 71.7 | |
| 19 | 62.6 | 73.2 | 68.9 | 75.2 | 69.8 | 73.4 | |
| 20 | 64.4 | 67.8 | 69.8 | 72.5 | 71.2 | 73.4 | |
| 21 | 64.4 | 66.2 | 70.7 | 72.0 | 71.6 | 72.5 | |
| 22 | 62.6 | 66.2 | 69.8 | 71.6 | 70.6 | 72.0 | |
| 23 | 64.4 | 69.8 | 71.5 | 74.8 | 71.7 | 75.0 | |
| 24 | | | | | | | |
| 25 | | | | | | | |
| 26 | | | | | | | |
| 27 | 65.3 | 71.6 | 70.7 | 76.0 | 71.6 | 74.3 | |
| 28 | 66.2 | 71.6 | 72.6 | 75.0 | 73.4 | 75.2 | |
| 29 | 64.4 | | 69.8 | | 71.6 | | |
| 30 | 65.3 | 64.6 | 73.4 | 73.0 | 73.1 | 74.5 | |
| 31 | 60.7 | | 68.0 | | 68.0 | | |
| | 2011.3 | 2094.3 | 2200.0 | 2200.0 | 2199.3 | 2182.9 | |

Chart 2.

Air Temperatures in Degrees Fahrenheit

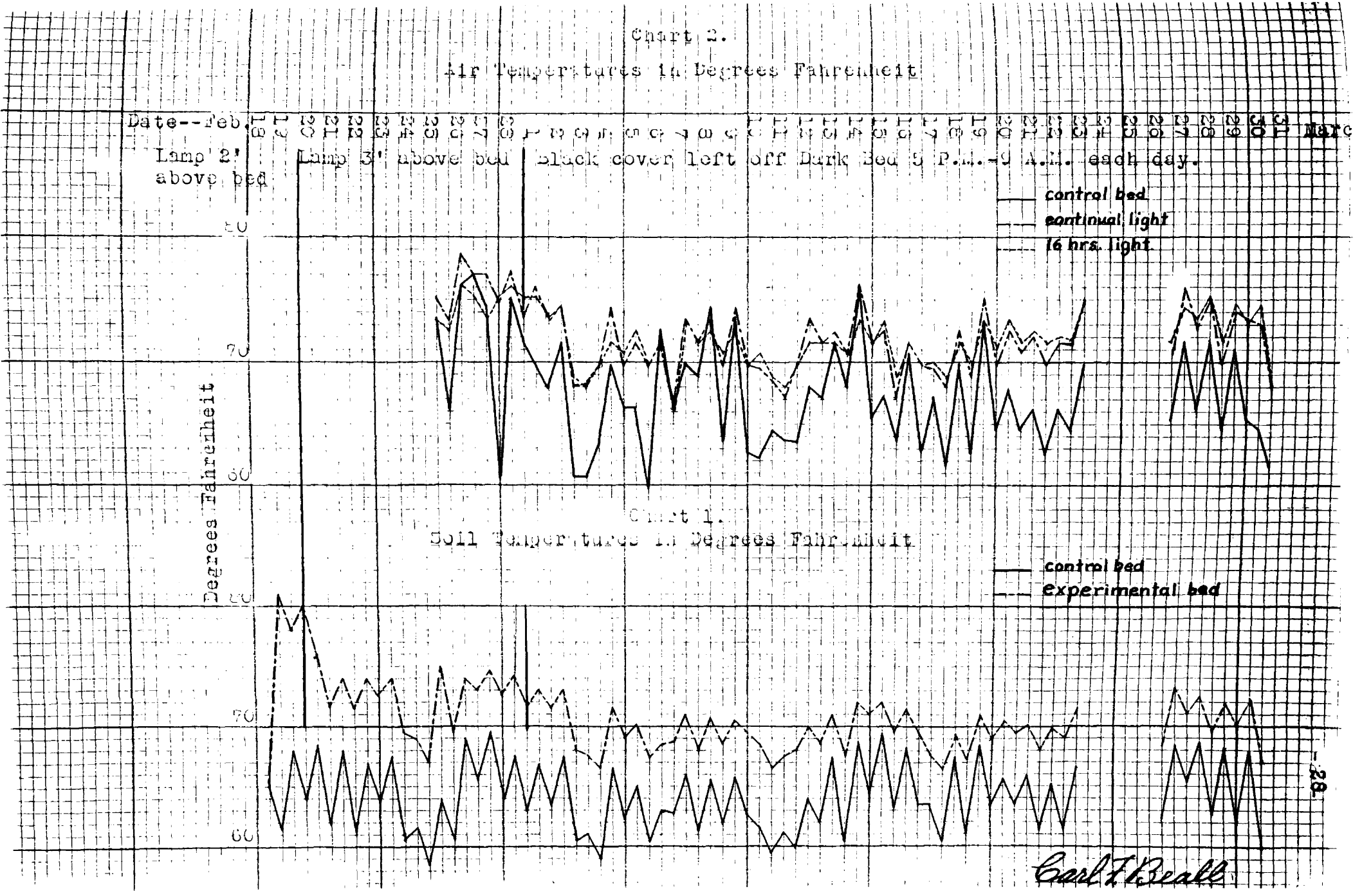



Chart 1.

Soil Temperatures in Degrees Fahrenheit




Earl T. Beals

## AIR SATURATION

This was not recognized as a factor previous to the experiment nor until it had been in progress a few days. The rapidity of germination and the moisture content of the soil as presented to visual inspection led to the conclusion that this factor of humidity had some bearing on the problem, particularly as the seeds were not in the soil but on top of it. Only sufficient readings were taken to assure the author of the differences between the three conditions.

The average rate of evaporation per day from the surface of water in the crystallizing dishes was 0.09" for the Control Bed, 0.11" for the experimental bed, Light section, and 0.03" for the Dark section, which during the time of the readings was still kept continuously dark.

# Part I

## Effect of Laboratory Controlled Artificial Light on Germination and early Growth.

### GERMINATION

Germination was considered to be complete when the hypocotyl just protruded from the seed coats.

Of the three variables, Light, Temperature, and Moisture, which influenced germination, an attempt will be made to segregate them, assigning if possible, to each one, the influence it exerted. The accompanying tables and graphs will be an aid to this end.

A summation of the percent of germination is given in Table IV.

The beds in which germination commenced first, the species and the percent of germination are shown in the following Table III.

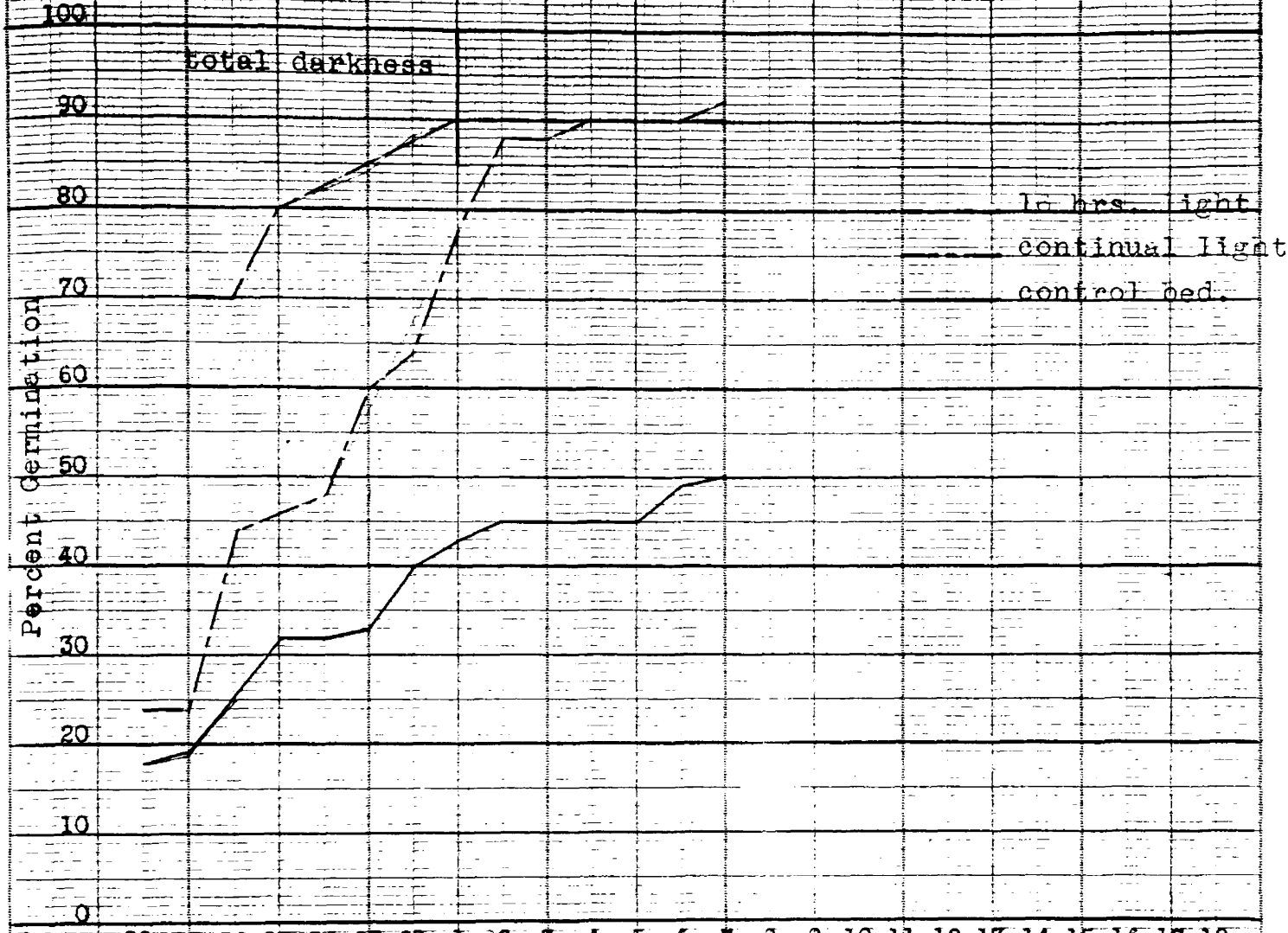
Table III

First beds to show germination and percent of germination:

| | Avena sativa | Caragana sp. | Pinus austriaca | Picea canadensis | Picea pungens glauca |
|---|---|---|---|---|---|
| Control Bed | 18 | 1 | | | |
| Light Bed | 24 | | 4 | | |
| Dark Bed | 70 | 12 | 12 | 6 | 4 |

Chart 3

Germination of Avena sativa in Percents.




Seeds sown February 18.

C. F. Beall

From this table it is seen that Avena germinated in all of the beds on the same day but in much greater per cent in the Dark Bed where the moisture content of the soil was the highest. The moisture content of the soil in the Light Bed and in the Control Bed was so nearly equal that only the difference in temperature can be the factor effecting the higher germination per cent in the Light Bed. It is therefore deductible that given equal conditions of one factor, then the variations of the other become limiting.

Oats finally attained the same per cent in the light section as in the dark section but Caragana in the light section exceeded by 2% the germination in the dark section. The difference of 2% is very slight to be of diagnostic value but combined with the fact that once germination commenced in the light section it proceeded with greater rapidity than in the dark section some inference may be made. Caragana being a very hardy plant adaptable to rather xerophilous conditions it is probable that the slightly dryer condition of the soil and the very slight increase in temperature afforded conditions more suitable to the germination of that plant.

The per cent of germination of Pinus austriaca in the Control Bed finally exceeded that of the Light Bed attaining the same per cent as the Dark Bed indicating

TABLE IV

Germination in Per cent of

| Date | Avena sativa | | | Caragana | | | Pinus austriaca | | | | Picea canadensis | | | | Picea pungens | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Feb. 18 | C. | L. | D. | C. | L. | D. | C. | L. | D. | P. | C. | L. | D. | P. | D. | L. | D. | P. |
| 19 | | | | | | | | | | | | | | | | | | |
| 20 | | | | | | | | | | | | | | | | | | |
| 21 | | | | | | | | | | | | | | | | | | |
| 22 | 18 | 24 | 70 | | | 12 | | 4 | 12 | | | | 6 | | | | 4 | |
| 23 | 19 | 24 | 70 | 1 | | 18 | 4 | 8 | 30 | | | | 10 | | | 6 | 18 | |
| 24 | 25 | 44 | 80 | 16 | 6 | 22 | 14 | 16 | 32 | | 1 | 2 | 22 | | 2 | 10 | 38 | |
| 25 | 32 | 46 | 82 | 19 | 6 | 30 | 19 | 24 | 34 | | 3 | 2 | 42 | | 4 | 16 | 54 | |
| 26 | 32 | 48 | 84 | 20 | 8 | 32 | 22 | 26 | 36 | | 3 | 6 | 50 | | 4 | 26 | 78 | |
| 27 | 33 | 60 | 88 | 22 | 22 | 38 | 32 | 34 | 40 | | 6 | 18 | 58 | | 12 | 34 | 88 | |
| 28 | 40 | 64 | 90 | 28 | 32 | 50 | 35 | 36 | 40 | | 10 | 26 | 60 | | 23 | 48 | 94 | |
| Mar. 1 | 43 | 78 | 90 | 32 | 38 | 62 | 37 | 36 | 42 | | 11 | 34 | 70 | | 32 | 54 | 100 | |
| 2 | 45 | 88 | 90 | 33 | 44 | 64 | 40 | 36 | | | 11 | 40 | 74 | | 38 | 64 | | |
| 3 | 45 | 88 | 90 | 37 | 48 | 64 | 40 | 36 | | | 11 | 40 | 74 | | 43 | 64 | | |
| 4 | 45 | 90 | 90 | 40 | 54 | 72 | 40 | 38 | | | 12 | 52 | 76 | | 43 | 64 | | |
| 5 | 45 | | 90 | 42 | 68 | 74 | 40 | | | S | 12 | 54 | 76 | S | 45 | 64 | | S |
| 6 | 49 | | 90 | 46 | 72 | 76 | 42 | 42 | 42 | | 20 | 60 | 76 | | 53 | 66 | | |
| 7 | 50 | 90 | 92 | 52 | 74 | 80 | | | | | 24 | 60 | 76 | | 56 | | | |
| 8 | | | | 54 | 82 | 82 | | | | 35 | 25 | 62 | 76 | | 60 | | | |
| 9 | | | | 55 | 84 | 84 | | | | 45 | 25 | 62 | 76 | 2 | 66 | | | 17 |
| 10 | | | | 58 | 84 | 84 | | | | 49 | 26 | 68 | 78 | 25 | 66 | | | 50 |
| 11 | | | | 65 | 84 | 84 | | | | 50 | 30 | | | 41 | 66 | | | 75 |
| 12 | | | | 66 | 84 | 86 | | | | 51 | 37 | | | 52 | 67 | | | 88 |
| 13 | | | | 67 | 86 | 86 | | | | | 38 | | | 59 | 68 | 66 | 100 | 91 |
| 14 | | | | 67 | 86 | 86 | | | | | 38 | | | 60 | | | | 91 |
| 15 | | | | 67 | 86 | 86 | | | | | 38 | | | 60 | | | | 91½ |
| 16 | | | | 67 | 90 | 86 | | | | | 38 | | | 61 | | | | 92 |
| 17 | | | | 67 | | 88 | | | | | 38 | | | 63 | | | | 94 |
| 18 | | | | 67 | | | | | | | 39 | | | 63 | | | | 94 |
| 19 | | | | 68 | | | | | | | 41 | 68 | 78 | 63 | | | | 94 |
| 20 | | | | 68 | 90 | 88 | | | | | | | | 64 | | | | 96 |
| 21 | | | | | | | | | | | | | | 65 | | | | |
| 22 | | | | | | | | | | | | | | 66 | | | | |

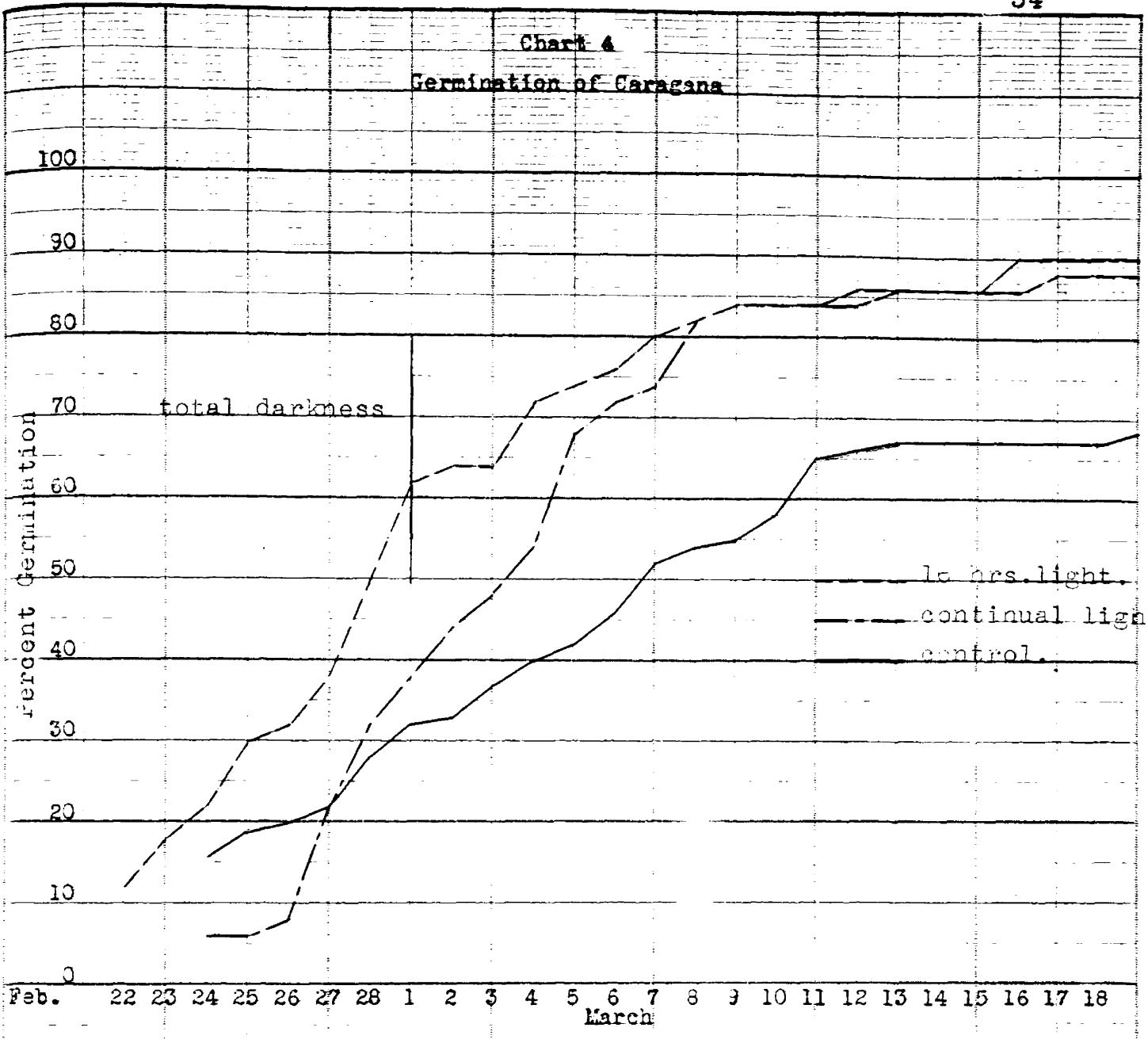
C - Control Bed
L - Light Bed
D - Dark Bed

100 seeds of each species in Control Bed

50 seeds of each species in each of the other Beds

Chart 4

Germination of Caragana

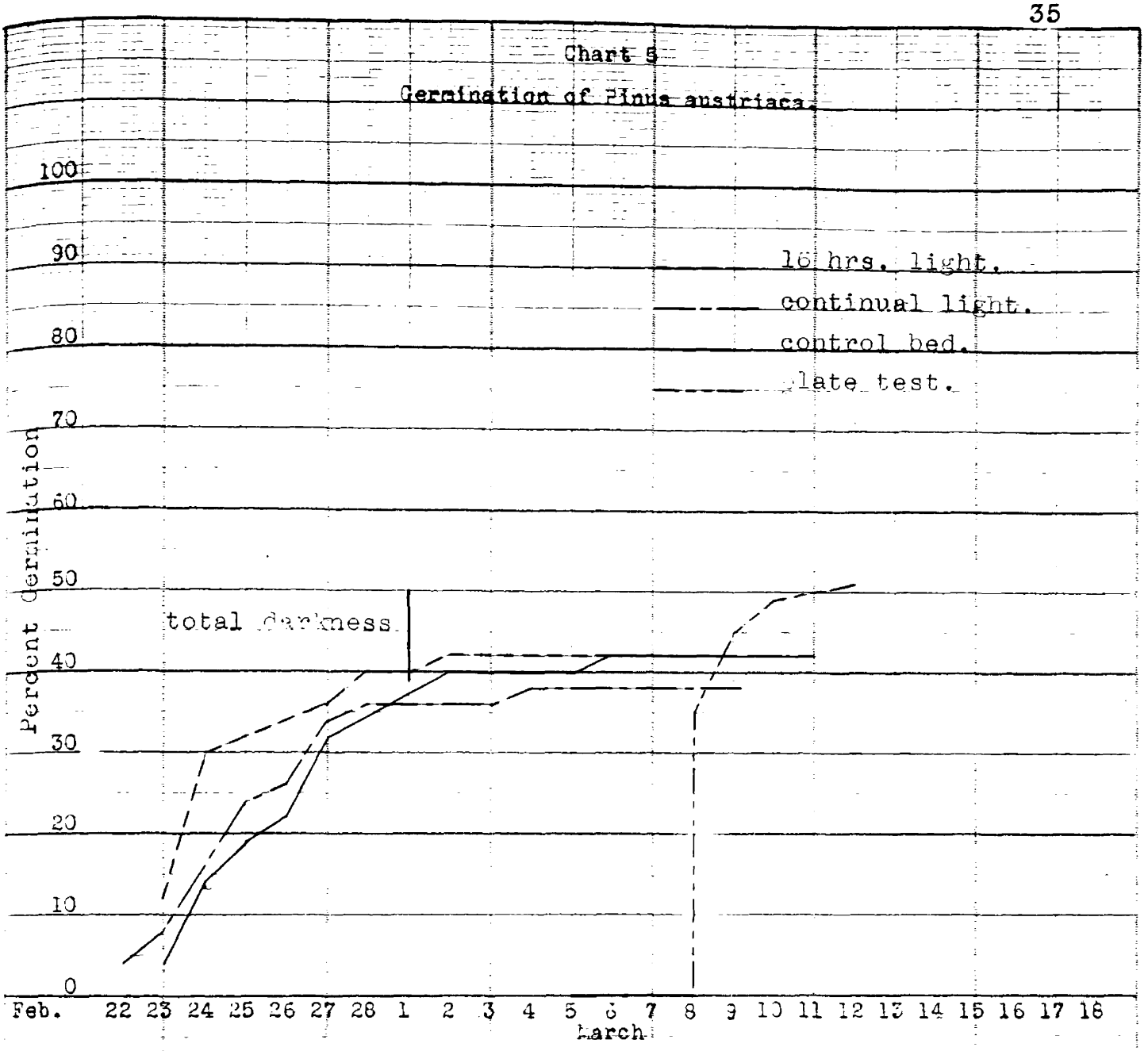



Seeds sown February 18.

C. F. Beall

Chart 6

Germination of Pinus austriaca.




Seeds sown February 18.

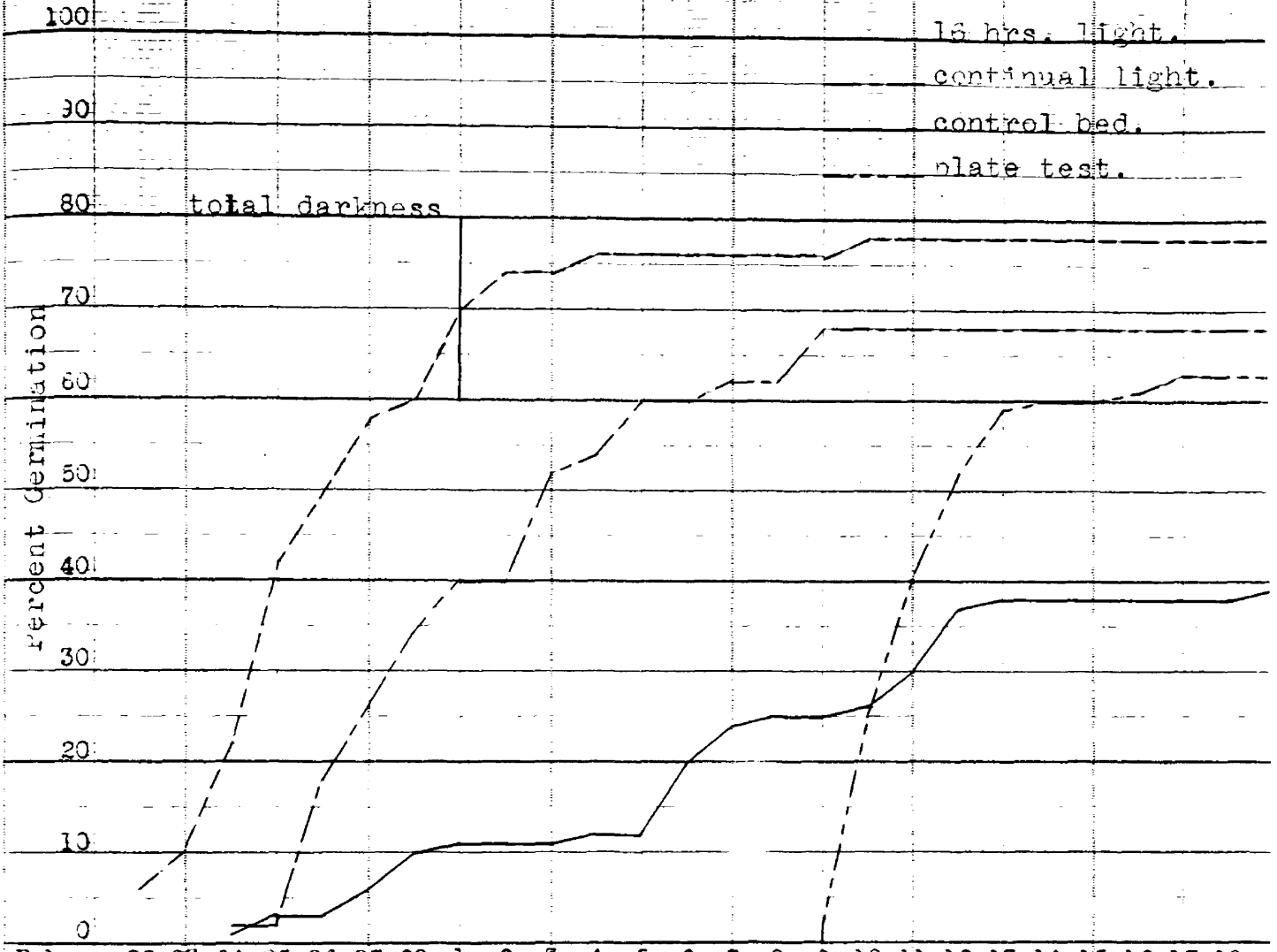
C. F. Beall

that light is not a factor in the germination of this species. The low percentage of germination of Pinus austriaca was caused by the low quality of the seeds which in plate tests germinated only 51% using 200 seeds. It is the only case where the germination in the experiment did not exceed that of plate tests. Since the plate tests provided more moisture than the experiment a clue is afforded to explain the increased germination under the control conditions over the Light Bed conditions. The Control Bed had a slightly lower evaporation rate, consequently greater saturation of the air and more soil moisture available which was approached by the Dark Bed by the fifth of March for then the Dark Bed was being exposed to the light for 16 hours each day. This indicates that within the range of 62 degrees to 73 degrees moisture is more a controlling factor than temperature or light for this species.

In the germination of Picea canadensis temperature and moisture both controlled. In the experimental bed the greater moisture in the dark section was the factor giving greater germination than in the light section, while the higher temperature in the experimental bed caused the greater germination there over the Control bed; light, aside from its heating action, being

## Chart 6

### Germination of Picea canadensis

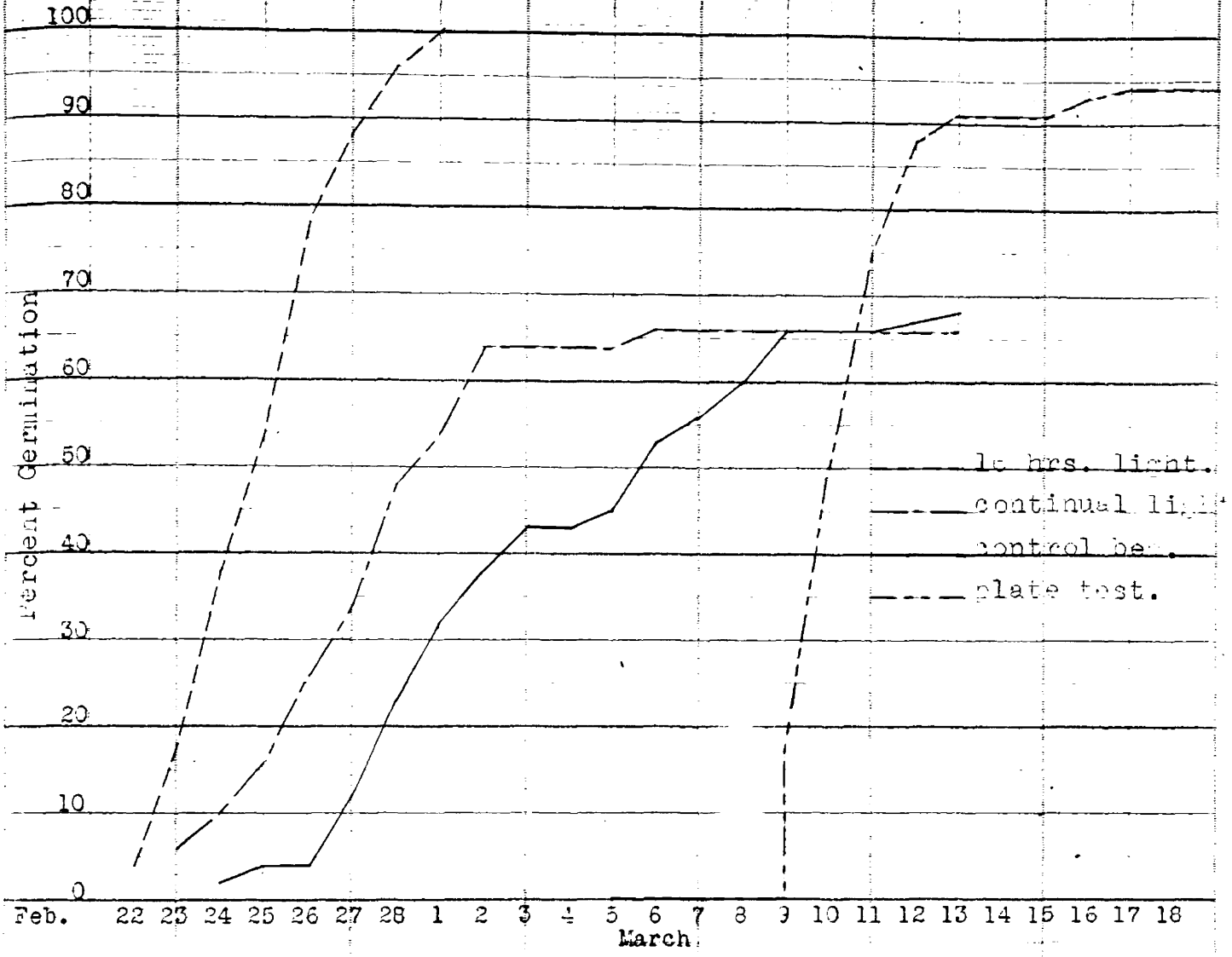



Seeds sown February 18.

C. F. Beall

Chart 7

Germination of Picea pungens var. glauca




Seeds sown February 18.

C. F. Beall

of no consequence. The germination curves are shown by chart 6.

It is indicated that in the germination of Picea pungens high moisture conditions are more important than temperature within the range of this experiment, for though both the Light and Dark Beds had nearly the same temperature the germination in the Light Bed is very much lower than in the Dark Bed, being the same as that in the Control Bed where the temperature was lower but having about the same moisture content. See chart 7.

The greatest difference being between the Light Bed and the Dark Bed whose temperature are within a degree it must be concluded that within the temperature range of the experiment moisture is the most limiting factor for Avena. In further support of this conclusion is the fact that when germination did occur simultaneously in other beds the per cent was much greater in the Dark Bed than in the other and summing up, 104 per cent germinated in the Dark Bed in contrast to the 47 per cent in all the other beds together. (Table III)

## GROWTH

As might be expected the plants in the control bed were healthier than those of either of the two other beds. The stems were shorter but thicker and the plants stood erect while in the Dark Bed the plants were etiolated to such an extent that they were unable to support themselves. The plants in the Control Bed were also a darker green than the others, with the plants in the Light Bed ranking second.

The same comparisons apply to those plants in the Light and Dark Beds, the former being more normal.

Oats in the Light Bed under continual illumination eventually attained a height of 12" at which time they headed with 2-4 sterile bracts. This was April 1, 40 days after sowing, which agrees with the work of Garner and Allard. (1920)

The root development of the plants grown in the Control Bed was much more branched than those grown in the experimental bed. None of the conifers developed branched roots. This is in agreement with the work of Burns. (1914)

The rate of growth was figured by adding up the number of inches of growth for any one day. Of course this does not give the rate for the individual plant but for

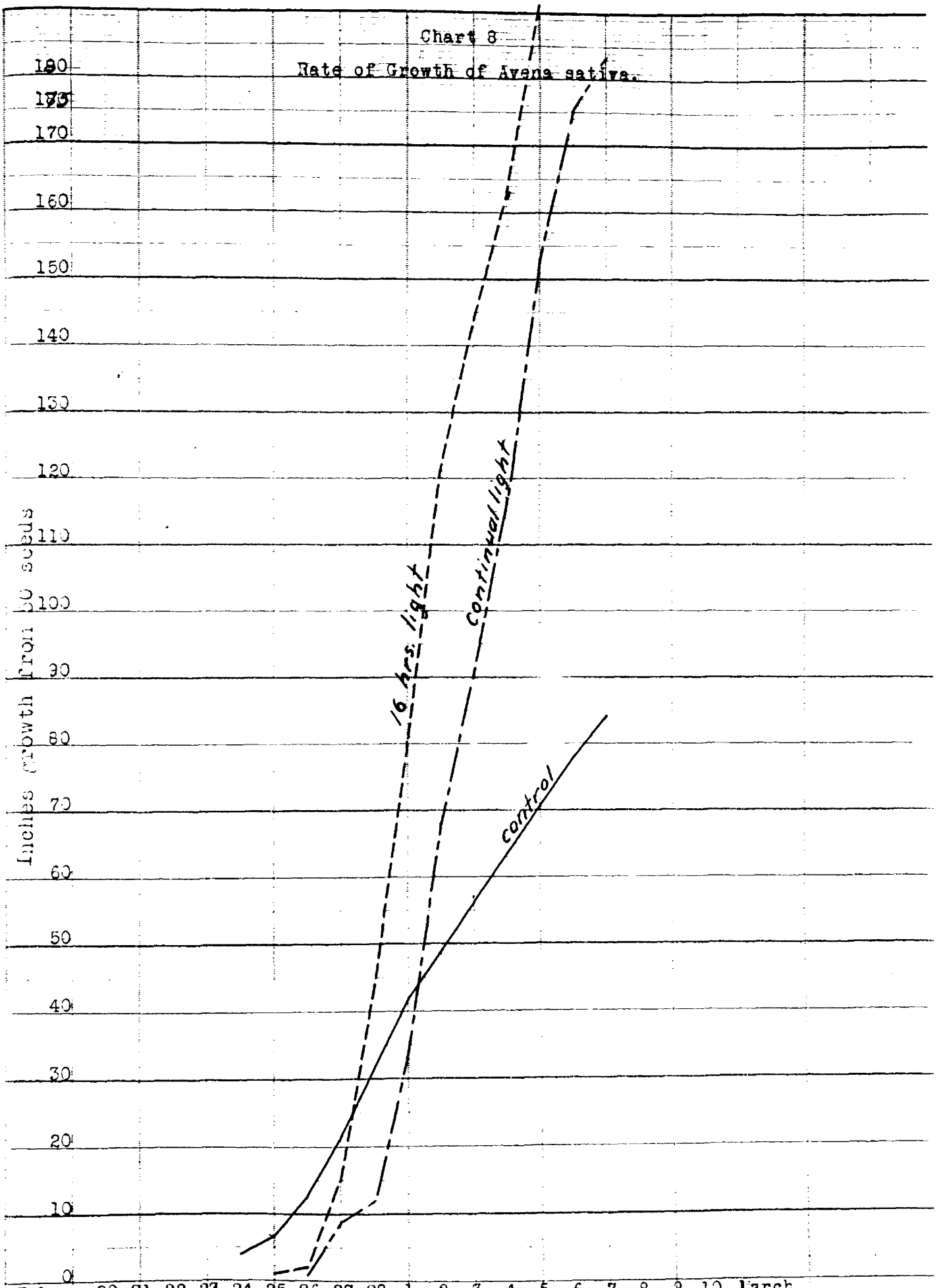
Inches of growth of Avena sativa

Table V

| Date | | Feb. 22 | 23 | March 24 | 25 | 26 | 27 | 28 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control Bed - natural day and night | | | | | | | | | | | | | | | | 100 seeds |
| epicotyl longer than | 1" | | | 8 | 8 | 11 | 15 | 16 | 18 | 20 | 24 | 26 | 28 | 29 | 30 | |
| | 2" | | | | 5 | 8 | 11 | 16 | 16 | 17 | 20 | 24 | 25 | 26 | 29 | |
| | 3" | | | | | 6 | 8 | 11 | 16 | 16 | 17 | 20 | 23 | 26 | 26 | |
| | 4" | | | | | | 6 | 9 | 14 | 16 | 16 | 17 | 22 | 24 | 26 | |
| | 5" | | | | | | 3 | 7 | 10 | 14 | 15 | 16 | 17 | 23 | 25 | |
| | 6" | | | | | | | 4 | 6 | 9 | 14 | 15 | 15 | 15 | 19 | |
| | 7" | | | | | | | | 4 | 4 | 7 | 6 | 8 | 9 | 9 | |
| continuous artificial | 8" | | | | | | | | | 1 | 1 | 3 | 3 | 4 | 3 | |
| illumination | 9" | | | | | | | | | | | | | | 1 | 12" finally |
| Light Bed | Total | | | 8 | 13 | 25 | 43 | 63 | 84 | 97 | 114 | 127 | 141 | 156 | 168 | attained |
| epicotyl longer than | 1" | | | | | 1 | 6 | 6 | 12 | 21 | 24 | 27 | 31 | 33 | 33 | 50 seeds |
| | 2" | | | | | | 3 | 6 | 7 | 17 | 21 | 24 | 28 | 31 | 32 | |
| | 3" | | | | | | | | 6 | 11 | 16 | 21 | 26 | 27 | 28 | |
| | 4" | | | | | | | | 6 | 7 | 11 | 20 | 24 | 26 | 28 | |
| | 5" | | | | | | | | 3 | 6 | 7 | 12 | 19 | 26 | 26 | |
| | 6" | | | | | | | | | 6 | 6 | 7 | 16 | 20 | 20 | |
| | 7" | | | | | | | | | | 4 | 5 | 8 | 10 | 10 | |
| | 8" | | | | | | | | | | 1 | 1 | 1 | 2 | 4 | |
| | 9" | | | | | | | | | | | | | | 2 | 12" finally |
| | Total | | | | | 1 | 9 | 12 | 34 | 68 | 90 | 117 | 153 | 175 | 183 | attained |
| Dark Bed - 16 hours artificial illumination | | | | | | | | | | | | | | | | 50 seeds |
| epicotyl longer than | 1" | | | | 1 | 2 | 13 | 22 | 31 | 34 | 37 | 41 | 43 | 44 | 45 | |
| | 2" | | | | | | 2 | 15 | 22 | 31 | 34 | 37 | 42 | 43 | 44 | |
| | 3" | | | | | | | 7 | 17 | 29 | 31 | 32 | 38 | 42 | 41 | |
| | 4" | | | | | | | | 6 | 15 | 20 | 25 | 30 | 36 | 40 | |
| | 5" | | | | | | | | 2 | 9 | 13 | 15 | 22 | 29 | 36 | |
| | 6" | | | | | | | | 1 | 2 | 7 | 9 | 12 | 13 | 24 | |
| | 7" | | | | | | | | | 1 | 2 | 3 | 4 | 5 | 12 | |
| | 8" | | | | | | | | | | | 1 | 1 | 1 | 6 | |
| | 9" | | | | | | | | | | | | | | 2 | 10" finally |
| | Total | | | | 1 | 2 | 15 | 44 | 80 | 121 | 144 | 163 | 192 | 210 | 250 | attained |

Chart 8

Rate of Growth of Avena sativa.

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Growth in inches of Caragana sp. Table VI

| Date March | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control Bed. Natural day and night | | | | | | | | | | | | | | | | | | | | | | | |
| epicotyl longer than | 1" | | | | 1 | 3 | 3 | 4 | 7 | 7 | 9 | 10 | 10 | 12 | 12 | 15 | 16 | 24 | 25 | 25 | 25 | 28 | 28 |
| 100 | 2" | | | | | | | | | 1 | 2 | 2 | 4 | 4 | 6 | 7 | 7 | 7 | 12 | 12 | 12 | 13 | 13 |
| seeds | 3" | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 |
| | Total | | | | 1 | 3 | 3 | 4 | 7 | 8 | 11 | 12 | 14 | 16 | 18 | 23 | 24 | 33 | 38 | 38 | 38 | 43 | 43 |
| Light Bed - continuous artificial illumination | | | | | | | | | | | | | | | | | | | | | | | |
| epicotyl longer than | 1" | | | | | | 1 | 2 | 3 | 4 | 5 | 5 | 7 | 7 | 9 | 9 | 10 | 13 | 14 | 14 | 15 | 15 | |
| | 2" | | | | | | | | | | 1 | 2 | 3 | 3 | 3 | 4 | 5 | 8 | 8 | 10 | 13 | 13 | |
| | 3" | | | | | | | | | | | | | | | | 2 | 4 | 4 | 4 | 5 | 5 | |
| | 4" | | | | | | | | | | | | | | | | | | | | | | |
| | 5" | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | 1 | 2 | 3 | 4 | 6 | 7 | 10 | 10 | 12 | 13 | 17 | 25 | 26 | 28 | 33 | 33 | |
| Dark Bed - 16 hours' artificial illumination | | | | | | | | | | | | | | | | | | | | | | | |
| epicotyl longer than | 1" | 1 | 2 | 4 | 5 | 5 | 5 | 6 | 10 | 12 | 15 | 16 | 16 | 16 | 16 | 16 | 16 | 16 | 17 | 17 | 17 | 17 | |
| | 2" | | | | | 1 | 4 | 4 | 5 | 6 | 7 | 10 | 12 | 14 | 14 | 14 | 15 | 16 | 16 | 16 | 17 | 17 | |
| 50 | 3" | | | | | | | | | 1 | 1 | 3 | 5 | 7 | 7 | 7 | 7 | 8 | 12 | 14 | 15 | 15 | |
| | 4" | | | | | | | | | | | 1 | 2 | 2 | 2 | 2 | 3 | 4 | 6 | 7 | 9 | 9 | |
| | 5" | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 2 | 2 | |
| | | 1 | 2 | 4 | 5 | 6 | 9 | 10 | 15 | 19 | 23 | 30 | 35 | 39 | 39 | 39 | 41 | 45 | 52 | 55 | 60 | 60 | |

Chart 9

Rate of growth of Pinus austriaca.

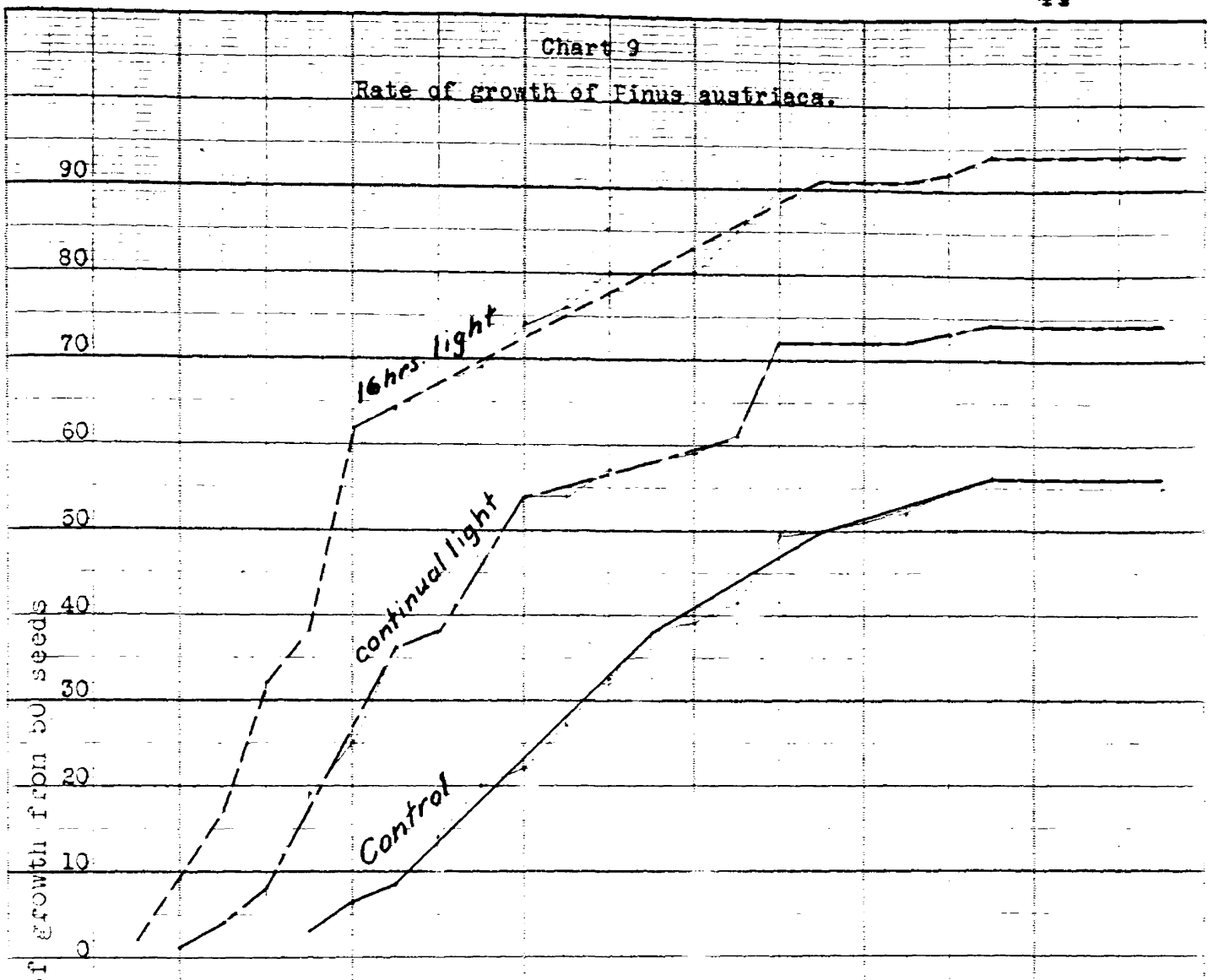
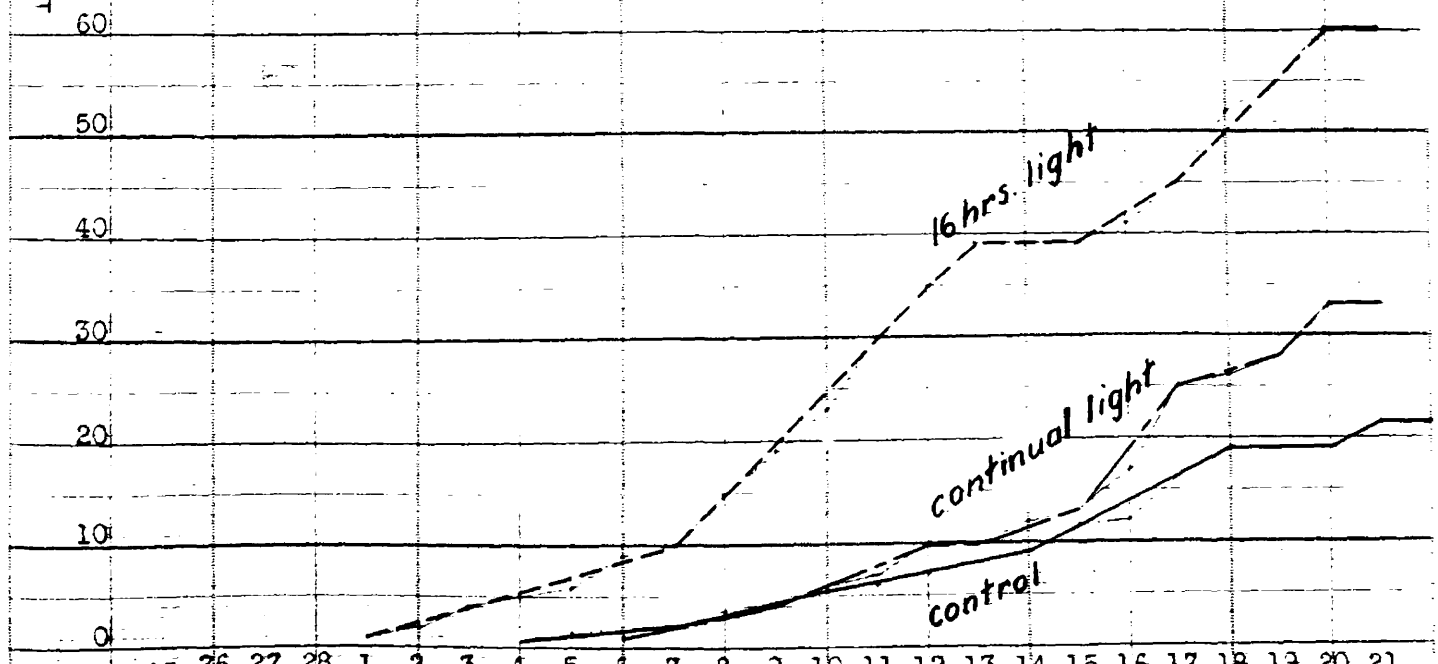



Chart 10

Rate of Growth of Caragana.

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## Growth in inches of Pinus austriaca

Table VII

| Date Feb. | | 24 | 25 | 26 | 27 | 28 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Control Bed - natural day and night** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| epicotyl longer than | 1" | | | | | | 6 | 13 | 14 | 21 | 28 | 31 | 33 | 36 | 38 | 38 | 38 | 39 | 40 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 | 37 |
| | 2" | | | | | | | | 3 | 7 | 12 | 13 | 19 | 24 | 31 | 32 | 32 | 36 | 36 | 35 | 35 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| 100 seeds | 3" | | | | | | | | | | | | 2 | 5 | 7 | 8 | 13 | 24 | 24 | 30 | 32 | 32 | 33 | 33 | 33 | 33 | 33 | 33 |
| | 4" | | | | | | | | | | | | | | | | | | | | | 4 | 6 | 6 | 6 | 6 | 6 | 6 |
| | 5" | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Total | | | | | | 6 | 13 | 17 | 28 | 30 | 44 | 54 | 65 | 76 | 78 | 83 | 99 | 100 | 102 | 104 | 109 | 112 | 112 | 112 | 112 | 112 | 112 |
| **Light Bed - continuous artificial light** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| epicotyl longerep than | 1" | | 1 | 3 | 6 | 12 | 13 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| | 2" | | | 1 | 2 | 5 | 8 | 12 | 12 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 81 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| 50 seeds | 3" | | | | | 2 | 4 | 6 | 8 | 10 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| | 4" | | | | | | | | | | | | | 3 | 4 | 5 | 7 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 | 17 |
| | 5" | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 2 | 3 | 3 | 3 | 3 | 3 | 3 |
| | Total | 1 | 4 | 8 | 19 | 25 | 36 | 38 | 46 | 54 | 54 | 57 | 58 | 59 | 61 | 72 | 72 | 72 | 72 | 73 | 74 | 74 | 74 | 74 | 74 | 74 | 74 | 74 |
| **Dark Bed - 16 hours artificial light** | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| epicotyl longer than | 1" | 2 | 9 | 14 | 16 | 16 | 17 | 21 | [illegible] | | | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| | 2" | | | 3 | 12 | 14 | 16 | 17 | 18 | 20 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| 50 seeds | 3" | | | | 4 | 8 | 15 | 17 | 17 | 17 | 20 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| | 4" | | | | | | 4 | 9 | 11 | 11 | 12 | 13 | 17 | 17 | 17 | 18 | 20 | 20 | 20 | 20 | 21 | 21 | 21 | 21 | 21 | 21 | 21 | 21 |
| | 5" | | | | | | | | | | | | | | | 4 | 7 | 8 | 8 | 8 | 8 | 10 | 10 | 10 | 10 | 10 | | 10 |
| | Total | 2 | [illegible] | 17 | [illegible] | [illegible] | [illegible] | 64 | 67 | [illegible] | 74 | 76 | 80 | 80 | 80 | 85 | 90 | 91 | 91 | 91 | 92 | 94 | 94 | 94 | 94 | 94 | 94 |

## Growth in inches of Picea canadensis

Table VIII

| Date | Feb. 28 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | Mar. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control Bed - natural day and night | | | | | | | | | | | | | | | | | | | | | | | | |
| longer than 1" | | | | | | | | | 1 | 2 | 5 | 7 | 9 | 9 | 12 | 12 | 12 | 20 | 22 | 22 | 22 | 22 | 22 | 100 seeds |
| Light Bed - 24 hours illumination | | | | | | | | | | | | | | | | | | | | | | | | |
| longer than 1" | | | | 2 | 3 | 4 | 10 | 10 | 15 | 15 | 19 | 20 | 21 | 21 | 21 | 21 | 24 | 26 | 26 | 26 | 26 | 26 | 26 | 50 seeds |
| Dark Bed - 16 hours illumination | | | | | | | | | | | | | | | | | | | | | | | | |
| longer than 1" | 4 | 6 | 14 | 20 | 21 | 26 | 28 | 31 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | |
| 2" | | | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 32 | 32 | 50 |
| | 4 | 6 | 15 | 21 | 23 | 28 | 30 | 34 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 64 | 64 | seeds |

## Growth in inches of Picea pungens var. glauca  Table IX

| Date Feb. | 28 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Control Bed - natural day and night** | | | | | | | | | | | | | | | | | | | | | | | |
| longer than 1" | | | | | | | | 3 | 5 | 8 | 17 | 18 | 26 | 29 | 30 | 32 | 38 | 40 | 43 | 43 | 43 | 43 | 43 |
| 100 2" seeds | | | | | | | | | | | | | | | | | | | | | | | |
| **Light Bed - continuous artificial illumination** | | | | | | | | | | | | | | | | | | | | | | | |
| longer than 1" | 1 | 3 | 6 | 9 | 11 | 16 | 16 | 16 | 19 | 21 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 50 seeds | | | | | | | | | | | | | | | | | | | | | | | |
| **Dark Bed - 16 hours artificial illumination** | | | | | | | | | | | | | | | | | | | | | | | |
| longer than 1" | 6 | 14 | 26 | 35 | 36 | 39 | 39 | 46 | 46 | 47 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 2" | | | | 1 | 1 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| 50 seeds | 6 | 14 | 26 | 36 | 37 | 40 | 41 | 49 | 49 | 51 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 | 52 |

the plant society, consisting of one species under one condition. A comparison of the figures secured serves as an indication of the suitability of the conditions under which the plants were grown. The number of inches growth made in each bed by species up to March 1 is shown in Table X. Since the Control Bed has 100 seeds of each species and the other two beds only 50 of each species, the Control Bed figures represent one half of the total growth in that bed.

Table X

A summary of the inches of growth made in each bed.

| Species | Control Bed | Diff. | Lt. Bed | Diff. | Dk. Bed |
|---|---|---|---|---|---|
| Avena sativa | 84 | 99 | 183 | 67 | 250 |
| Caragana sp. | 21.5 | 11.5 | 33 | 27 | 60 |
| Pinus austriaca | 56 | 18 | 74 | 20 | 94 |
| Picea canadensis | 11 | 15 | 26 | 38 | 64 |
| Picea purpens | 21.5 | 6.5 | 28 | 27 | 52 |

Six variable factors enter into the growth of the plants in the different beds. These are: temperature, light intensity, light quality, light duration, soil moisture and saturation of the air.

The lower temperature of the Control Bed would in itself be sufficient cause for the less growth in height of the plants in that bed as compared with the growth

made in the other beds, but the etiolating effect of the low light intensity and the absence of the ultra violet rays in the experimental bed, enhancing height growth without a corresponding normality in all the structures increases the difference. However a temperature difference of 4-5 degrees would not explain the great difference in growth between the plants of the Control Bed and those of the Experimental Bed for there is an much difference or more in growth between the plants of the Light and Dark beds where the temperature was practically the same. So the great increase in growth of the plants in the experimental bed over that of the control bed must be chiefly attributed to the quantity and quality of the light, and in addition, for the Dark Bed, the high saturation of the air which as Sachs (1882) shows results in plants quite like those etiolated by lack of light and combining the two causes to act at the same time would only accentuate in the effects of each. In this case, however, the quantity and quality of the light is of more importance than the saturation of the air for tho the saturation of the Dark and Light Beds was nearly the same during the grand period of

growth yet the plants in the Dark Bed made, except in Avena, a great deal more growth than did those in the Light Bed. This can only be attributed to the difference in the duration of the lighting period; a matter of eight hours less light being received by the plants in the Dark Bed thus increasing the effects of etiolation.

Thus it appears that the quantity and quality of light are of more importance in conditioning the growth of plants than are either temperature or air saturation within the limits of this experiment. Of the two factors, light quantity and light quality, it appears that from the normality of the structures that the factor light quality is the most limiting.

## CONCLUSIONS

1 - Light, aside from its heating action, has no discernable effect on germination of the species used under the conditions of the experiment.

2 - That other factors being equal, germination of the species used is conditioned by temperature and moisture, each varying in individual importance with different species, with moisture being the more important.

3 - Small fluctuations in temperature do not effect germination.

4 - Average soil temperature of 70 degrees F will effect a greater per cent and more rapid rate of germination than an average soil temperature of 60 degrees.

5 - Natural daylight gives healthier and more normal plants than the artificial light used.

6 - The quality of the light, when the latter is sufficiently intense for growth, is more a limiting factor than the quantity.

# PART II

## The Effect of Laboratory Controlled Artificial Light on Plant Anatomy.

### RESULTS

The results of this part of the problem are open to criticism in some places due to an initial lack of understanding concerning its complexities. Sufficient material was grown so that the average measurements might have been very accurate but very little material was killed and sectioned. At first the sections were cut too thin and the value of much of the work was nullified due to collapse of tissues during sectioning. The sectioning was repeated using a thickness of 15-20 microns instead of 5-10 as had been used before. Some of the material was unavailable but that which was sectioned, and small as it was in quantity, revealed conditions which on the whole check with previous work, such as that by McDougall and Penfound (1924).

Tables XI, XII, and XIII, and the plates, (photomicrographs and drawings by the author) will substantiate the text and explanations.

### DISCUSSION

It will be noticed that the usual condition of decrease in the thickness of the leaf with a decrease

TABLE XI
Cimensions given in Microns

| | Avena sativa | | | Caragana | | | Pinus austriaca | | |
|---|---|---|---|---|---|---|---|---|---|
| | Control | Light | Dark | Control | Light | Dark | Control | Light | Dark |
| Thickness of leaf | 128 | 94 | 69 | 77 | 73 | 69 | | | |
| Thickness of palisade layer | distorted | | | 43 | 32 | 30 | | | |
| Thickness of epidermis, leaf | " | | | 17 | 13 | 15 | 19 | 21 | 15 |
| Length of epidermal cells, leaf | " | | | 31 | 35 | 39 | 18 | 17 | 13 |
| Thickness of vessel walls in xylem | | | | 1.7 | 2.0 | 2.2 | 2.5 | 4.3 | 2.1 |
| Thickness of vessel walls in leaf | 1.0 | 1.7 | 1.7 | | | | 2.2 | 2.5 | 2.1 |
| Thickness of vessel walls in Avena | 1.7 | | 2.4 | | | | | | |
| Average diameter of vessels in Avena | 22 | | 17 | | | | | | |

in light intensity was repeated, as was also the decrease in the thickness of the palisade tissue. This decrease in thickness and also the relative strength of the tissues as shown by their resistance to sectioning is shown in Plate 5. In considering the figures for the average diameter of vessels in Avena as shown in Table XI where under control conditions the average diameter was 22 microns and under the conditions of the Dark Bed the average diameter was 17 microns, the relationship is easily explained thru the decreased transpiration of the plants under the Dark Bed Conditions.

No explanation is given for the irregular curve of the thickness of the epidermis of the Caragana leaf. Just below, the figures representing the length of the epidermal cells, if plotted, would fall in a straight line with the shortest occurring under the control conditions and the longest under the dark conditions. These results were to be expected.

The gradual increase of the thickness of the vessel walls in the xylem of Caragana, with a decrease in quantity of illumination, was an unlooked for occurrence. Since it also occurs in the vessels of the vascular bundles of Avena in both the stem and the leaf the quality of the light rather than its intensity must be account-

able, for the intensity was much greater under the control bed conditions than in the experimental bed, but the spectrum of the latter would show no ultra violet and a great deal of green, red, and blue. (Hibben 1930) This is in exact opposition to the results of the work of MacDougall and Penfound (1924) but the results of Pinus austriaca support their work. It must therefore be concluded that the effects of light may vary with a difference in species. They found that the average diameter of the vessels decreased with a decrease in the intensity of the illumination. The results as shown by Avena support that finding.

In Avena and Caragana the thickness of the vessel walls was increased with a decrease in light intensity as shown in Table XI, and as MacDougal (1901) found the development of the bast in per cent of the total area of the stem also increased with a decrease in light intensity, as shown in Table XII. But in spite of the greater per cent of bast in the Caragana stems raised under Dark Bed conditions these plants were somewhat recumbent while those plants grown under the other conditions were erect. This may be due to the greater turgidity of the latter plants.

Sayre (1923) says that the external factor mostly

influencing stomatal opening is light which changes the hydrogen ion concentration of the cell; and that atmospheric humidity is less an influence than light. Etiolated plants in darkness transpire at a lower rate than do green plants in light (Sachs 1882) and the decrease in the transpiration under the more humid conditions existing under the black cloth during the period of darkness for those plants grown in the Dark Bed would both tend to a suppression of the water conduction tissues. This accounts for the results depicted in Table XIII, in the photographs on Plate II, and the camera lucida drawings on Plates VIII and IX.

The results of this work are in full accord with those of Pfeiffer (1926) who showed that the differentiation of tissues in the stems of plants was greater in the full spectrum under glass than under glass transmitting only in the blue or red region. In Pinus austriaca the differentiation as evidenced by the development of the endodermis is greater under a continual artificial lighting containing considerably less than the full spectrum, than it is under the full spectrum as transmitted thru a west window in February and March. This is shown in Table XIII and pictures in Plate II. The total absence of the endodermis under Dark Bed conditions must

## Table XII

### Caragana

Areas of different regions of the stem in per cent of total area.

| | Control | Light | Dark |
|---|---|---|---|
| Cortex | 18 | 41 | 35 |
| Phloem | 39 | 30 | 26 |
| Xylem | 35 | 26 | 34 |
| Pith | 8 | 3 | 5 |
| Bast | 2 | 5 | 10 |

## Table XIII

### Pinus Austriaca

Areas of different regions of the stem in per cent of the total area.

| | Control | Light | Dark |
|---|---|---|---|
| Xylem | 3 | 5 | 2 |
| Lacunae | 6 | 4 | 5 |
| endodermis | traces | complete | absent |

be a function of the shorter duration of the light and the higher air saturation. The fact that the relationships existing in the development of the endodermis are in the same proportion as those in the development of the xylem would indicate that the same factor of transpiration played the major role in its formation. This complete formation of the endodermis under the stimulation of continual artificial light may be a reaction of the plant in shutting off excessive transpiration thru the stomata of the stem. This interesting phenomena, being based on such few specimens, is of course only conjectural.

The reason for the appearance of the lacunae in Austrian Pine, to which reference is made in Table XIII, is not known and it would be very difficult to indicate a causative agent for their origin and development. According to one theory their formation may be attributed to the necessity of the plant to increase its gas exchange, particularly with reference to the increase in respiration induced by the relatively high temperature. They appear in the photographs on Plate II as large chambers laying just inside the pericycle and situated more or less between the primary xylem elements. The construction of adjacent cell walls indicates that they are lysigenous, being formed by the dissolution of other cells. In order to more fully understand their development it would be necessary to follow it from the age of a few days to a time when the secon-

dary xylem appeared, when the lacunae would probably dissapear. No reference to the appearance of lacunae in this species has been found in botanical literature.

## SUMMARY

Altho the temperature of the Control Bed was not the same as that of the Experimental Bed and the quantity of the material was not as much as it might have been to give smooth curves if the results were plotted, nevertheless certain conclusions may be reached.

1 - The thickness of the leaves decreases with a decrease in the intensity of the illumination.

2 - The thickness of the epidermis of the leaves decreases with a decrease in illumination.

3 - The thickness and density of the palisade tissue becomes less with a decrease in light intensity.

4 - The length of the epidermal cells of the leaves increase with a diminution in light intensity.

5 - The effects of light may vary with difference in species.

6 - The thickness of the vessel walls is increased by a decrease in light intensity in these species and under the conditions of the experiment.

7 - Continous artificial illumination greatly increases the per cent of xylem.

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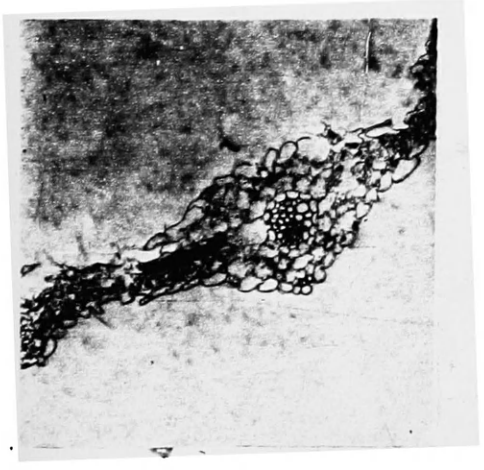
# A P P E N D I X

-PLATES-

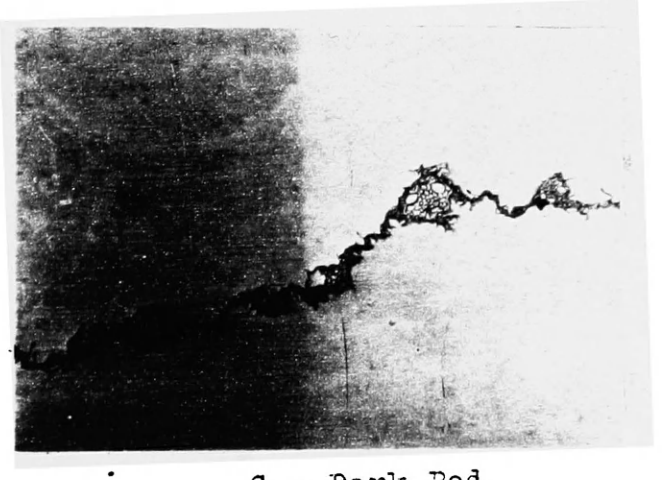
## PLATE I

Showing the relative thickness of the leaf of Avena sativa under the three conditions of light. All magnified 200 X.

A - Control Bed



B - Light Bed

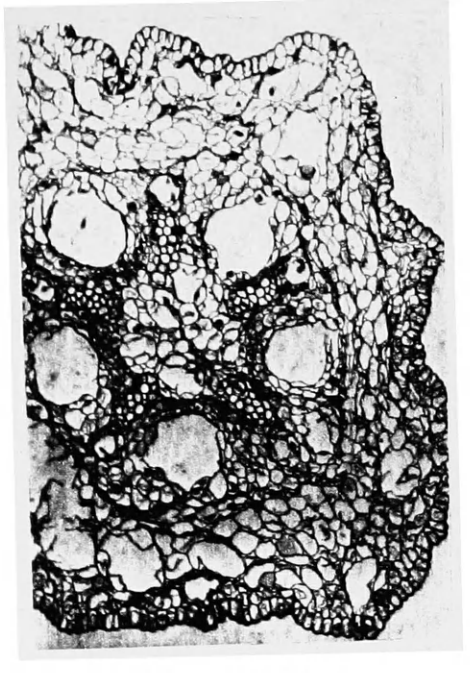


C - Dark Bed

PLATE II

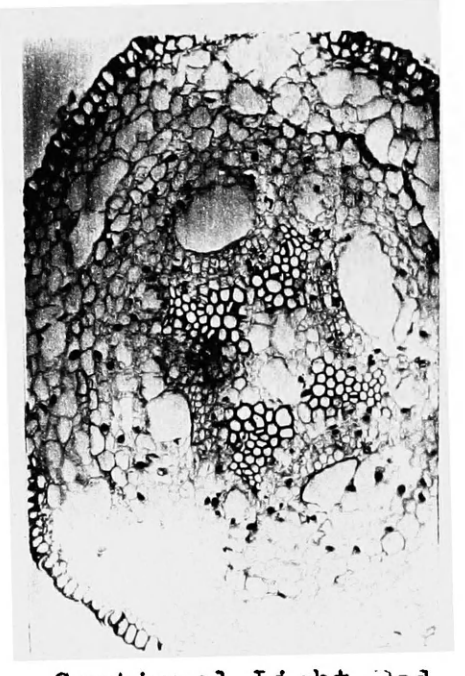
PINUS AUSTRIACA

Showing the relative development of the xylem under different conditions of growth.

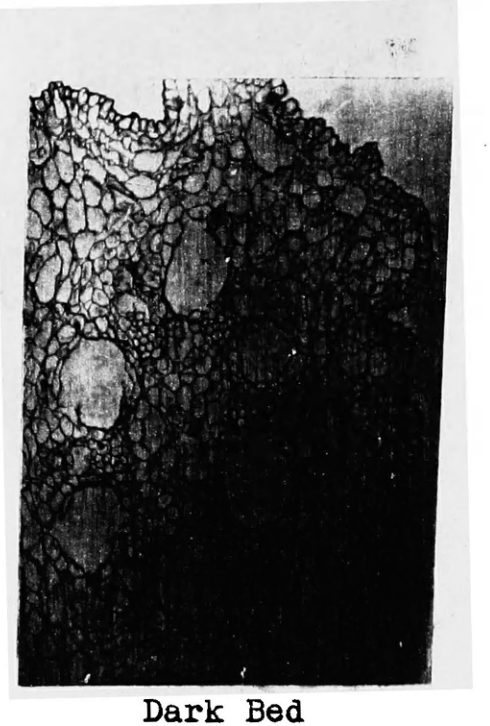


Control Bed

All magnified 200X



Continual Light Bed



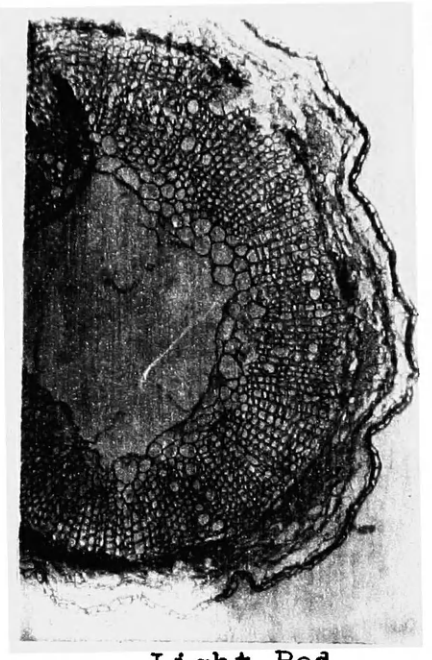
Dark Bed

PLATE III

CARAGANA

Showing development of stem tissues under different conditions of growth

Control Bed



Light Bed

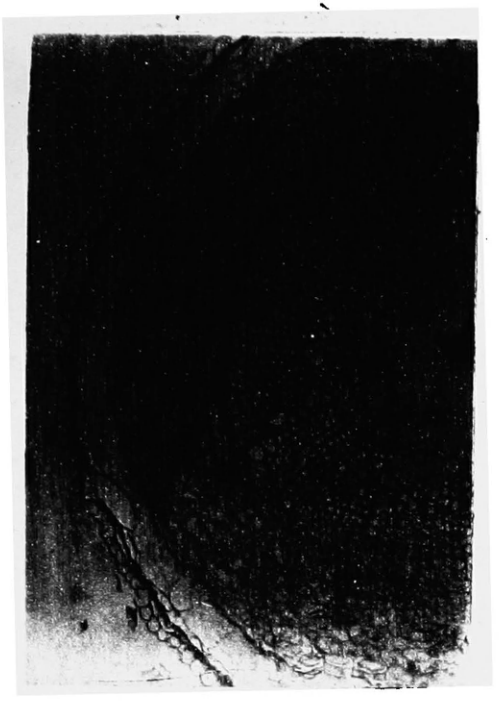
Dark Bed

1- Dark areas in phloem and cortex are groups of bast cells.

PLATE IV

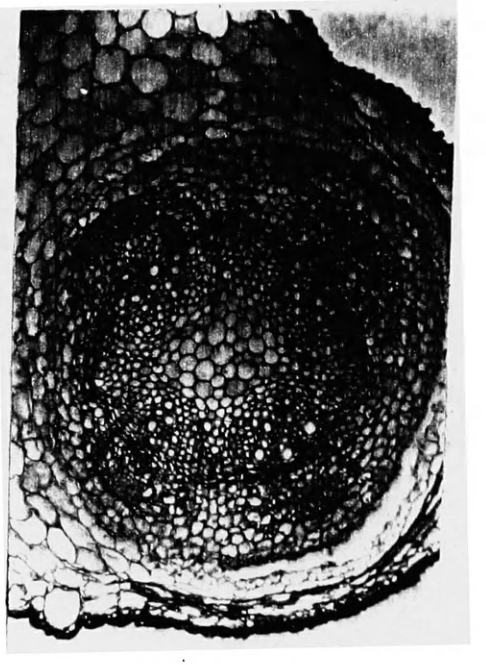
CARAGANA

Showing relative development of stem tissues
under different conditions of growth



Control Bed

Light Bed

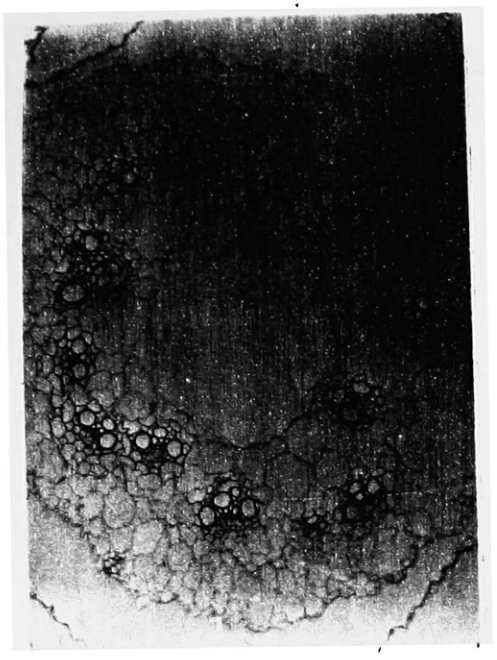


Dark Bed

PLATE V

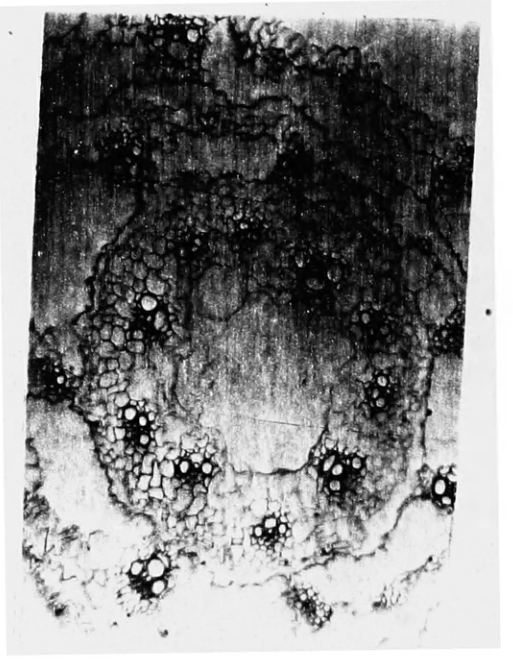
AVENA SATIVA

showing development of vascular bundles



Control Bed

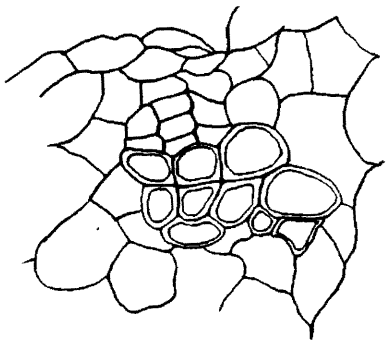
Light Bed



Dark Bed

# PLATE VI

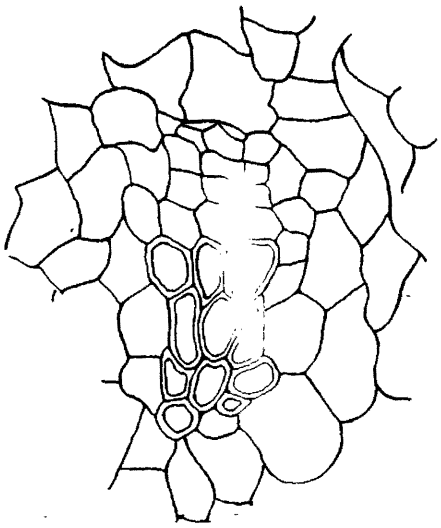
Pinus austriaca

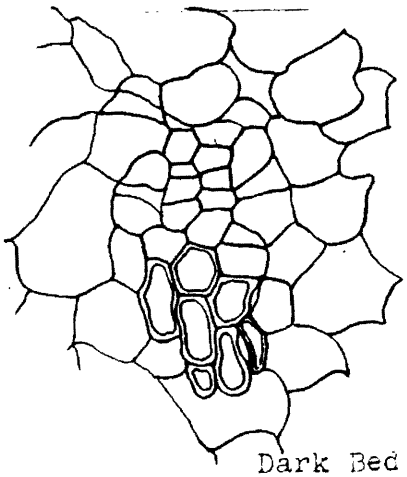


Vascular Bundle of leaf

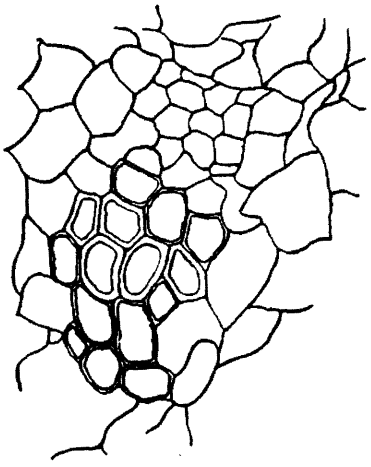
Control Bed

Light Bed

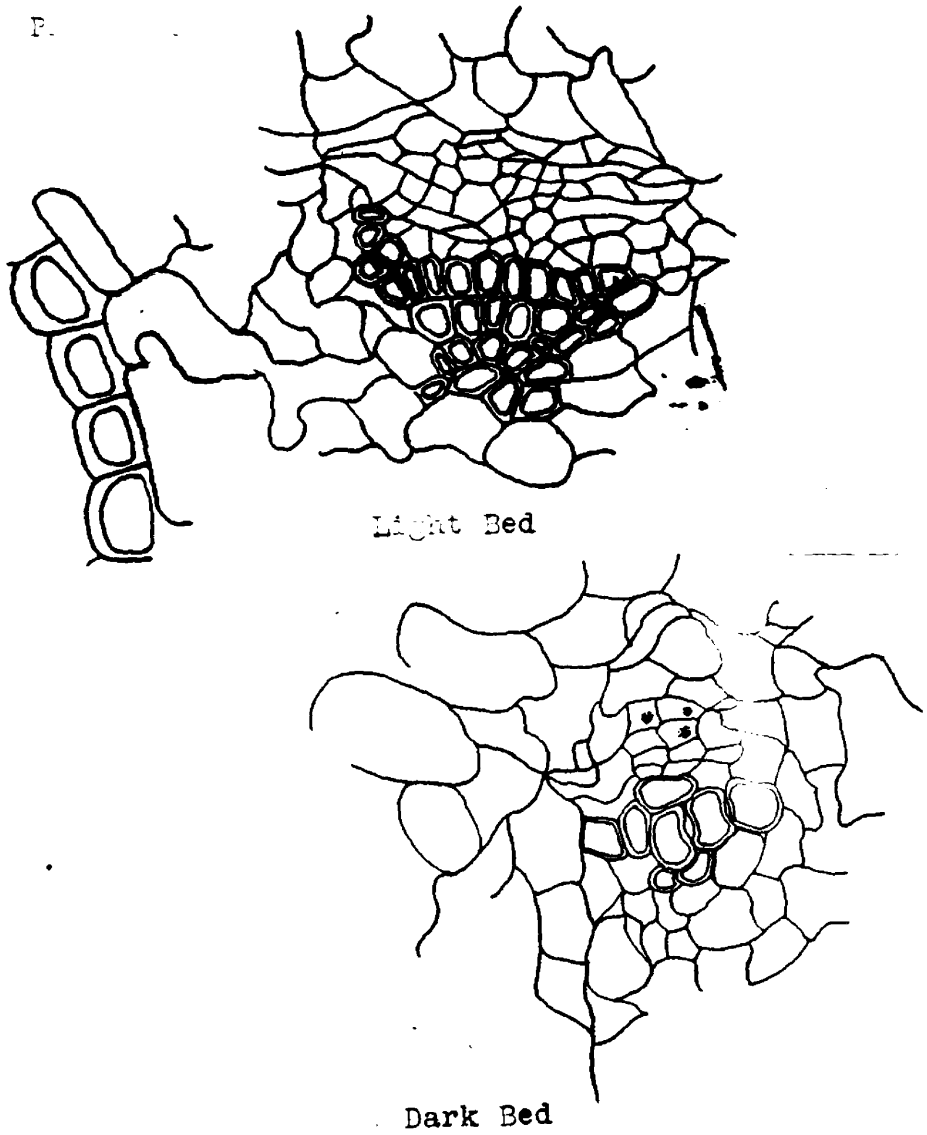




Dark Bed



# PLATE VII




Vascular Bundles of leaf of Picea