The response of winter wheat coleoptiles to light of narrow spectral regions
by Bruce Alexander McCallum

A THESIS Submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of Master of Science in Agronomy
Montana State University
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Abstract:
Karmont winter wheat seedlings were germinated for four and five days and exposed to a spectral range from 4175 Angstroms' to 6400 Angstroms for one, two and three days for each germination period at growing temperatures of 68° F. and 45° F. Exposure to the spectrum resulted in a retardation in coleoptile elongation for all wavelengths studied. Wavelength, pre-irradiation germination time and exposure time main effects and their resulting interaction, with the exception of the pre-irradiation germination time x exposure time interaction for the 68° F growing temperature, were significant at the one percent level for both temperatures.

THE RESPONSE OF WINTER WHEAT COLEOPTILES TO LIGHT OF NARROW SPECTRAL REGIONS

by

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ABSTRACT

Karmont winter wheat seedlings were germinated for four and five days and exposed to a spectral range from 4175 Angstroms to 6400 Angstroms for one, two and three days for each germination period at growing temperatures of 68° F. and 45° F. Exposure to the spectrum resulted in a retardation in coleoptile elongation for all wavelengths studied. Wavelength, pre-irradiation germination time and exposure time main effects and their resulting interaction, with the exception of the pre-irradiation germination time x exposure time interaction for the 68° F. growing temperature, were significant at the one percent level for both temperatures.

INTRODUCTION

Many factors play important roles in the development of any crop from the initiation of germination to the maturation of the plant. In some plants like the perennials, this period covers many years while in other cases development is limited to one year. These factors include depth of seeding, temperature, moisture availability, nutrients and light. The change in any one away from the optimal region, causes adverse effects upon the plant, and may even result in death.

When winter wheat is subjected to unfavorable environmental conditions, and as a result the growing point or coleoptile (1) fails to reach the soil surface within a reasonably short time, an unusual phenomenon occurs. The primary leaf emerges from the coleoptile prior to the emergence of the coleoptile from the ground. When this occurs the primary leaves grow out and ball up due to their inability to push through the soil to the surface. Since the plant is therefore unable to reach above the surface to obtain enough energy for life, it dies. This phenomenon seems to be directly associated with unfavorable growing conditions which do not allow the coleoptile to reach the soil surface within a relatively short period of time. With these facts in mind it was decided to determine which factor or factors, listed above, were responsible for the early breakthrough of the primary leaves from

(1) Coleoptile in this paper refers to what many authors call the mesocotyl plus the coleoptile. In other words, the entire shoot from the face of the germ to the tip of the growing point.

the coleoptile. Earlier tests have shown that while the rate of elongation was reduced, temperature and moisture stress alone caused no shortening in the maximum obtainable length of the coleoptile. Even seeds planted at a six inch depth attained the same coleoptile length as those which were germinated on blotter paper. An interesting difference existed between seeds grown in light and seed grown in darkness. The coleoptiles of the seeds grown in light stopped elongating as they reached the soil surface. Coleoptiles developing from seeds grown in darkness elongated to heights well above the soil surface.

After having found that moisture stress, temperature, and depth of seeding were not the major factors of the pre-emergence phenomenon, it seemed probable that light was a major factor in coleoptile elongation inhibition and premature primary leaf emergence.

REVIEW OF LITERATURE

The response of plants to light has been observed for years and extensive literature has been written on the subject. For the purposes of this paper, only those reports dealing closely with the cereals will be considered.

There are several terms used in the literature which require explanation: One watt equals 621 lumens at a wavelength of 5560 Angstroms. One Angstrom (A) equals 10^{-4} microns. The range of the visible spectrum is from 4000 A to 7500 A. The point of maximum visibility is at 5560 A.

One erg = 10^{-7} watts x sec. or one erg/sec. = 10^{-7} watts.

Inhibition percentage equals $\frac{\text{check (dark control) - treated}}{\text{check}}$

Action spectrum is the reciprocal of the energy required to induce a given reaction at a given wavelength.

W. W. Garner and H. A. Allard (8) should be credited for the disclosure and demonstration of the phenomenon of photoperiodism. In 1906, they observed a strain of Maryland Narrowleaf tobacco (Nicotiana tabacum) which would not flower and produce seed in a normal growing period, no matter what physiological stresses were applied. The only means by which seed could be produced was to transplant the plants in the greenhouse during the winter months during which time the plants would flower and produce seed. After many experiments with various plants and light intensities, Garner and Allard introduced two words which would, along with the definition of each, explain what they had

found; Photoperiodism to designate the response of an organism to the relative length of day and night and photoperiod to designate the favorable length of day for each organism. From their work they concluded that "sexual reproduction can be attained by a plant only when it is exposed to a specificially favorable length of day, and exposure to a length of day unfavorable to reproduction but favorable to growth tends to produce giantism or indefinite continuation of vegetative development, while exposure to a length of day favorable to sexual reproduction and to vegetative development alike, extends the period of sexual reproduction and tends to 'induce the everbearing' type of fruiting".

Current research is disclosing more and more startling effects of light upon plants.

In his work with timothy (Phleum pratense), Gordon (11) found that light stimulated germination. However, between 25 and 30°C. timothy became relatively light insensitive. There are many other species which require light to germinate. Tobacco seeds show a significant increase in germination percentage when exposed for 0.01 seconds to direct sunlight (6). They are so photosensitive that strong moonlight applied for 15 minutes will stimulate germination (14).

Borthwick and Hendricks (3) found that lettuce seed, which germinates better in the presence of light, could be stimulated by exposure to red light. Far-red or infa-red radiation, however, would inhibit germination. The amount of energy necessary to inhibit

germination is 70 times greater than that required to induce germination. Black and Wareing (2) found that the inhibitory effects of the far-red radiation had an effect on Betula pubescens up to 10 hours after exposure.

The response of oats, Avena sativa, to light has been studied for many years. Some of the earliest work with monochromatic light was that done by Johnson (12) on the first internode and coleoptile of oats. He found, using intensities of 1.2 ergs/cm^2/sec for each wavelength studied, that the mesocotyl, that region from the scutellar node to the coleoptilar node, was inhibited by exposure to monochromatic light. The coleoptiles, that region from the coleoptilar node to the tip, were stimulated by the monochromatic light. However, due to the shortness of the mesocotyl, which seems to have the greatest effect on the total length attained by the seedling, or shoot, the total seedling length was shorter under the treatment than under darkness.

When the energy level was raised to 13 ergs/cm^2/sec the inhibition of the first internode was increased correspondingly over that of the lower intensity.

Avery (1) discovered this to be true also. He found that, at equal intensities, red light had the greatest effect on inhibiting the first internode, green and blue were next with violet being the least effective.

Schneider (15) in his work at Harvard, showed that both the coleoptile and the mesocotyl of oats were capable of acting as their own receptor of light stimulus. He found that the coleoptile of the

young oat plant was stimulated by red light at intensities of 0.5 to 8 ergs/mm^2/sec. All of his work was with apical segments of the coleoptile. Went (18) found that the extreme 0.1 mm of the coleoptile tip was the most sensitive to light. From that point downward, the sensitivity dropped about 5000 times to a rather constant value for all regions more than 2 mm distant from the tip.

Oat plants grown under continuous exposure at low intensities, reacted much the same as the plants receiving high intensities for short periods. In this work Weintraub (16) showed that the inhibition was dependent upon the quality and quantity of light. For any given wavelength, inhibition was proportional to the logarithm base 10 of the intensity and when he compared several intensities the angles of slope were equal. The inhibition effects cover a wide range of intensities for each wavelength. The low light intensities affect cell division and the high intensities retard elongation. Goodwin (9) in his work further confirmed this.

In later work, Weintraub (17) and his associates found that red light (6234 A) initially inhibited at 10^{-9} ergs/mm^2/sec while blue inhibited (4358 A) at $10^{-6.5}$ ergs/mm^2/sec. Complete inhibition was obtained at 10^{-2} ergs/mm^2/sec for red light and 10 ergs/mm^2/sec for blue. The percent inhibition on final mesocotyl length was about parallel at different intensities of the same order of magnitude. It was also found that temperatures had no effect on the action curve.

The light range effective for Avena internode inhibition was found by Goodwin (10) to be from 6230 to 7100 Angstroms. The action spectrum for 10% inhibition, (those wavelengths at a given intensity which will result in a reduction in mesocotyl length of 10% of the check) was at a minimum at about 5000 A, with a slight rise at 4050 A, a shoulder between 5700 and 5900 A, a rise between 6000 and 6200 A and a minimum effectiveness at 6230 A. "The total amount of incident energy required to give threshold inhibitions using 1 to 15 second exposures and 100 hour exposures is within the same order of magnitude for the wavelengths studied". Inhibition of the mesocotyl is a complex phenomenon involving at least two processes, one much more light sensitive than the other. These are probably the ones affecting cell division and cell elongation, respectively. Each process has a different action spectrum.

Along with their work on lettuce seed germination, Borthwick and associates have done considerable work on the action spectrum for barley flowering (5) and for inhibition of the second internode (4) under various light regimes with energies varying 10,000 fold and time of irradiation 100 fold. In treatments with equal energy in which intensity was varied from 0.25 to 25 foot candles and 100 to one minute exposures, an equal reduction was obtained. When energies varied, the inhibition varied linearly with the logarithm to base 10 of the energy. As the treatments moved from the green region of the spectrum out toward either end, the amount of energy required to obtain a given response increased. The energy required to inhibit elongation is 100 times that required to

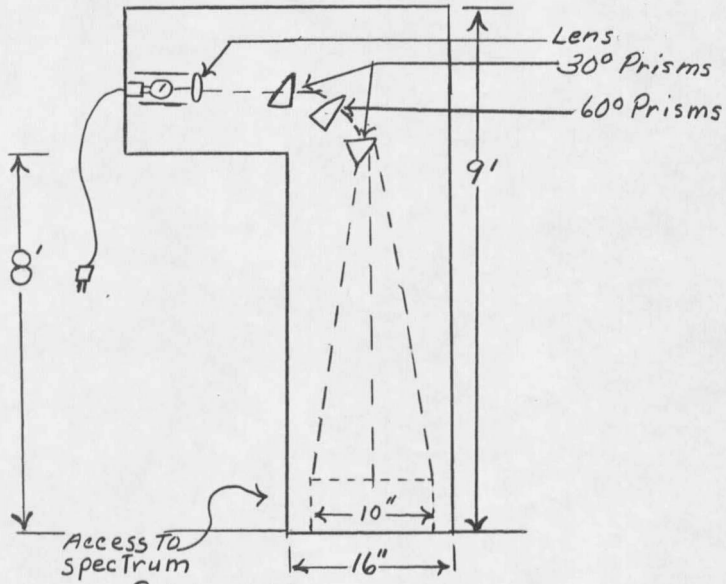
inhibit flowering.

Flint (7) with his work on the mesocotyl of corn, found results which were almost opposite to those found by the above authors. He found the greatest inhibition resulted from exposure to blue light with red giving no response over white light. His results are quite similar to those reported in this paper.

MATERIALS AND METHODS

All tests were conducted using Karmont winter wheat which is a bearded, white chaffed, winter hardy variety.

To establish a source of light which would be reasonably monochromatic, a box was constructed with the following demensions:



Side View

The light source consisted of a 200 watt clear Westinghouse bulb mounted so that its filament acted as a line source replacing the usual entrance slit in the ordinary spectrograph. The bulb was shielded and the light directed, by means of a lens, through one 60° and two 30° prisms, of number 2 dense flint glass, which bent the light 90° and dispersed it. The spectrum covered an eight by ten inch area at a focussing distance of eight feet (Figure 1). Access to the spectral region was gained through an opening at the blue end of the spectrum. Wavelengths were determined visually by a grating

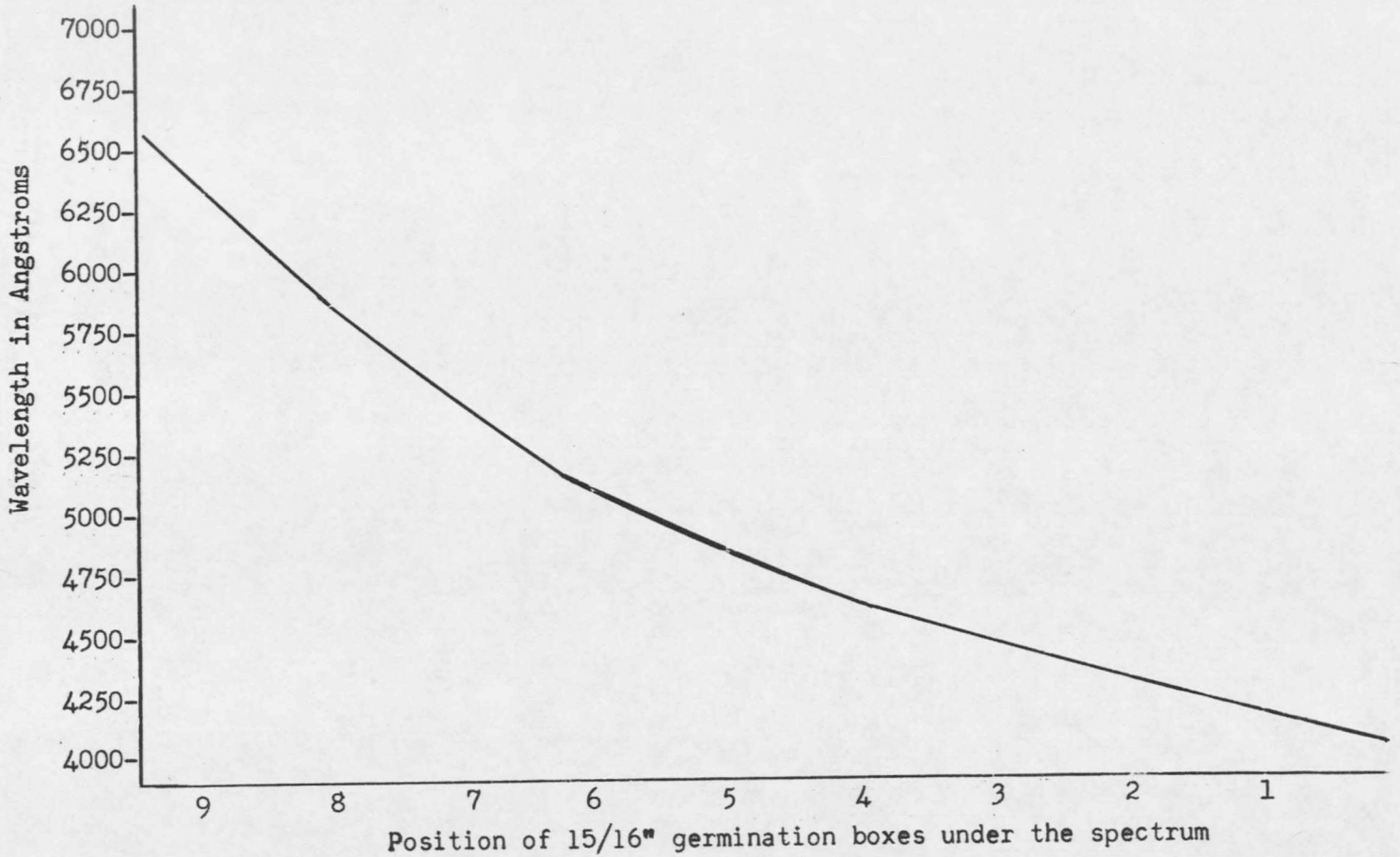


Figure 1. The location of the spectral regions for each box in the spectograph at a focal distance of eight feet.

spectroscope. The spectrum covered a distance of from 4100 to 6500 Angstroms (A). An intensity of three foot candles was measured at 5560 A the region of maximum visibility, with a General Electric photoelectric light meter. The entire apparatus was placed in a double door darkroom so that no light other than the spectrum was available to the seeds. Copper coils, 3/8," were placed around the outside at six inch intervals to a height of 3.5 feet. Cold water was run through the coils to maintain the growing region at a constant temperature. The minimum temperature which was attainable from such a system was 60° F. Four seeds were placed in each of two 15/16" plastic germination dishes and placed in the holding box. Ten double rows of boxes covered the spectral region, two boxes per region. The bottoms of the germination boxes were removed and replaced with blotter paper so that enough moisture was available to the plant throughout the entire growing period. All seed was treated with 10% Phygon-flour mixture before testing. The 15/16 inch plastic germination boxes were placed inside wooden boxes 11.5 x 2.5 x 5.5 inches, on top of a one inch layer of sterilized Zonolite insulating material. All of the wooden boxes were painted with a black water resistant paint.

To maintain complete darkness, the wooden boxes were fitted with sliding light-tight lids. This was necessary since the material had to be transported from the growth chamber to the light source for treatment and back to the growth chamber after treatment.

Two temperature-light trials were conducted, one at a germinator

temperature of 68° F, light source temperature of 70° F and another with the germinator temperature of 45° F, light source temperature 60° F. The tests covered three light periods and three germination periods. The germination periods were maintained constant and the light period was varied for each test. The test ran as follows:

Three days germination plus one, two, and three days under light, followed by six, five and four days in the germinator to make a total test period of ten days. Ten days was the amount of time required for the primary leaves to emerge from the coleoptile at the warm temperature (70° F.). The cold (45° F.) test was conducted in the same manner as the warm treatment except that the germination period following light was 23,22, and 21 days respectively. At the end of the holding period there was still no appreciable growth so all boxes were placed at a 70° F temperature for seven additional days.

To determine from what depths the coleoptiles would emerge under conditions of normal day light and complete darkness, a depth of planting trial was conducted. Ten seeds were placed at depths ranging from one to six inches in cylindrical ice cream containers. On half of the containers were covered to prevent light passage and the other half were covered with clear Cellophane. These containers were placed in the greenhouse in a randomized complete block design of three replications. Date of emergence and final coleoptile length were recorded.

Significant mean differences for main effects and interactions were obtained by Scheffé's method of multiple comparison (14).

RESULTS

Greenhouse depth of planting experiment.

The coleoptiles of seedlings which were grown in containers which excluded all light, elongated above the soil surface at one, two and three inch plantings (Figure 2). The coleoptiles of the seedlings which were grown in the clear plastic covered containers, elongated only to the soil surface. At the four inch depth of planting the coleoptiles in both the dark and light conditions did not elongate to the soil surface. The average coleoptile lengths of the seedlings grown in the light excluding containers exceeded the average length of the coleoptile in the light exposed containers.

Coleoptile elongation responses to pre-irradiation germination and light exposure at 45° F. growing temperatures.

Examination of the analysis of variance data, Table I, shows statistical differences for all treatments and treatment combinations. Using Scheffé's method of multiple comparisons (14) statistically significant differences were calculated for all main effects and first order interactions (Table II). A comparison of the data for main effects (Table III) using the calculated differences from Table II, shows that significant differences at the 1 percent level exist between the dark treatment, and all light treatments for the wavelength means. The pre-irradiation germination means differ significantly when the four day germination is compared with both the three and five day germination. When the exposure time

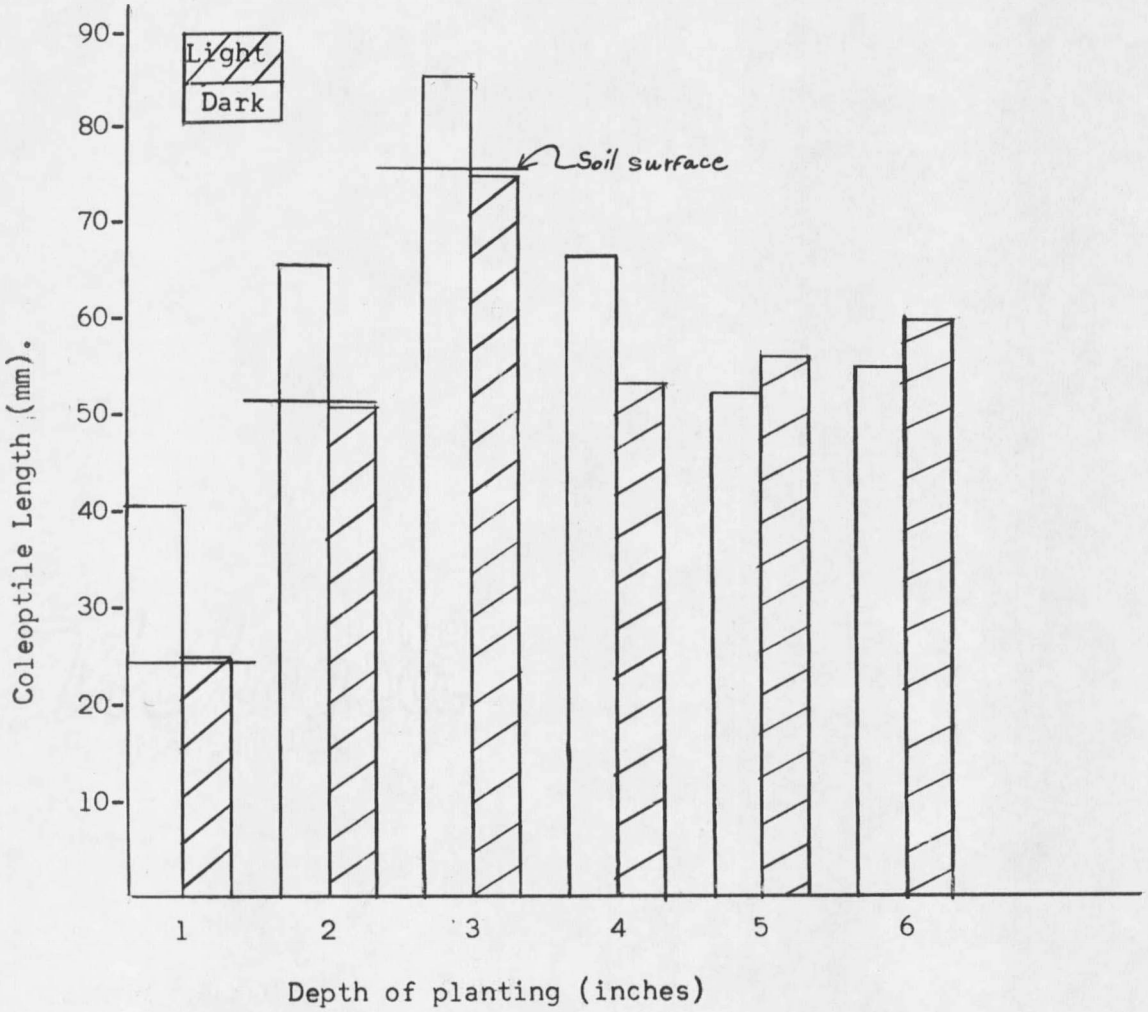


Figure 2. Coleoptile lengths, at various planting depths under conditions of normal daylight and darkness, of seedlings grown in the greenhouse.

Table I. Analysis of variance for the response of Karmont winter wheat coleoptiles to wavelength, pre-irradiation germination time and exposure at a germinating temperature of 45° F.

Source of variation	Degrees of freedom	Mean square
Wavelength	9	6,571.54**
Pre-irradiation germination time	2	19,182.60**
Exposure time	2	4,237.07**
Wavelength x pre-irradiation	18	3,190.50**
Wavelength x exposure time	18	1,560.91**
Wavelength x pre-irradiation x exposure	4	3,230.79**
Error	630	712.79
Total	719	

** significant at the 1 percent level

Table II. Differences between means of main effects and interactions necessary for significance using Scheffe's method of multiple comparisons

Effect or interaction	Mean difference necessary for significance (mm)			
	45° F.		68° F.	
	1% level	5% level	1% level	5% level
Wavelength	20.87	18.38	17.19	15.15
Pre-irradiation germination time	7.39	5.93	6.07	4.92
Exposure time	7.39	5.93	6.07	4.92
Wavelength x Pre-irradiation time	54.20	50.40	44.77	41.60
Wavelength x Exposure time	54.20	50.40	44.77	41.60
Pre-irradiation time x exposure time	19.24	16.71	15.87	13.80

Table III. Average coleoptile lengths of Karmont winter wheat for the main effects, wavelengths, pre-irradiation germination time and exposure time and the wavelength x pre-irradiation germination and wavelength x exposure time interactions at the 45° F. and 68° F. growing temperatures.

	Average coleoptile lengths in millimeters													
Wave-	45° F. growing temperature							68° F. growing temperature						
length	Germination			Exposure				Germination			Exposure			
(A)	3 days	4 days	5 days	1 day	2 days	3 days	Mean	3 days	4 days	5 days	1 day	2 days	3 days	Mean
4175	57.4	18.2	64.2	44.7	61.0	34.0	46.6	3.6	19.7	10.5	21.2	10.5	2.2	11.2
4310	60.2	28.2	46.8	58.6	42.2	34.4	45.1	16.7	13.7	3.0	16.6	2.0	14.6	11.2
4460	65.4	24.2	54.8	50.0	51.5	44.0	48.2	8.4	15.0	4.0	11.3	6.8	9.2	9.3
4625	56.5	42.1	62.1	55.7	48.4	56.7	53.6	48.5	21.3	4.9	26.6	26.6	19.2	24.1
4800	56.7	34.2	46.1	42.2	39.4	55.4	45.7	12.1	16.0	3.3	13.0	14.0	4.4	10.4
5040	64.0	56.2	43.6	53.9	62.0	47.0	54.3	17.0	14.6	18.5	16.6	27.8	5.6	16.7
5375	55.8	51.2	46.1	54.0	51.0	47.7	51.0	18.5	39.1	21.2	24.2	29.0	25.8	26.3
5840	53.2	47.4	34.5	44.6	59.4	31.0	45.1	13.6	42.5	10.4	16.3	25.6	24.6	24.5
6400	55.4	61.9	37.0	48.2	47.8	58.2	51.4	14.0	43.4	32.9	36.8	39.4	14.2	30.1
Dark	75.2	70.1	81.7	72.4	75.0	79.5	75.7	50.8	68.7	58.2	69.5	57.4	50.7	59.2
Mean	60.0	43.4	51.6	52.4	53.8	48.8		26.1	36.4	25.7	33.2	31.9	23.0	

means are compared there is no significant difference at the five percent level using the S- method of comparison.

The significance exhibited by the wavelength x light exposure time interaction (Table I) can be seen from the graphic presentation of this interaction in Figure 3. The divergent responses exhibited by the coleoptiles at 4175 A, 4310 A and again at 5840 A would account for this significance. The greatest statistical difference is between 4175 A, 4310 A and 5840 A and the dark treatment at the three day exposure. This same divergence is seen again in Figure 4, where the wavelength x per-irradiation germination time interaction is presented. The wide separation between points in the 4175 A to 4800 A region and again in the 5840 A to 6400 A region is again statistically significant. Further significance is shown by the opposite slopes of the four and five day pre-irradiation lines.

The exposure time x pre-irradiation germination time interaction is presented in Table IV. Table II shows a difference, at the 1 percent level, of 19.24 necessary for significance. This significant difference is found between the three day exposure, four day germination mean and the one and two day exposure, three day germination means and the three day exposure, five day germination mean. A significant difference exists between the two day exposure, four day germination mean and the two day exposure, four day germination mean.

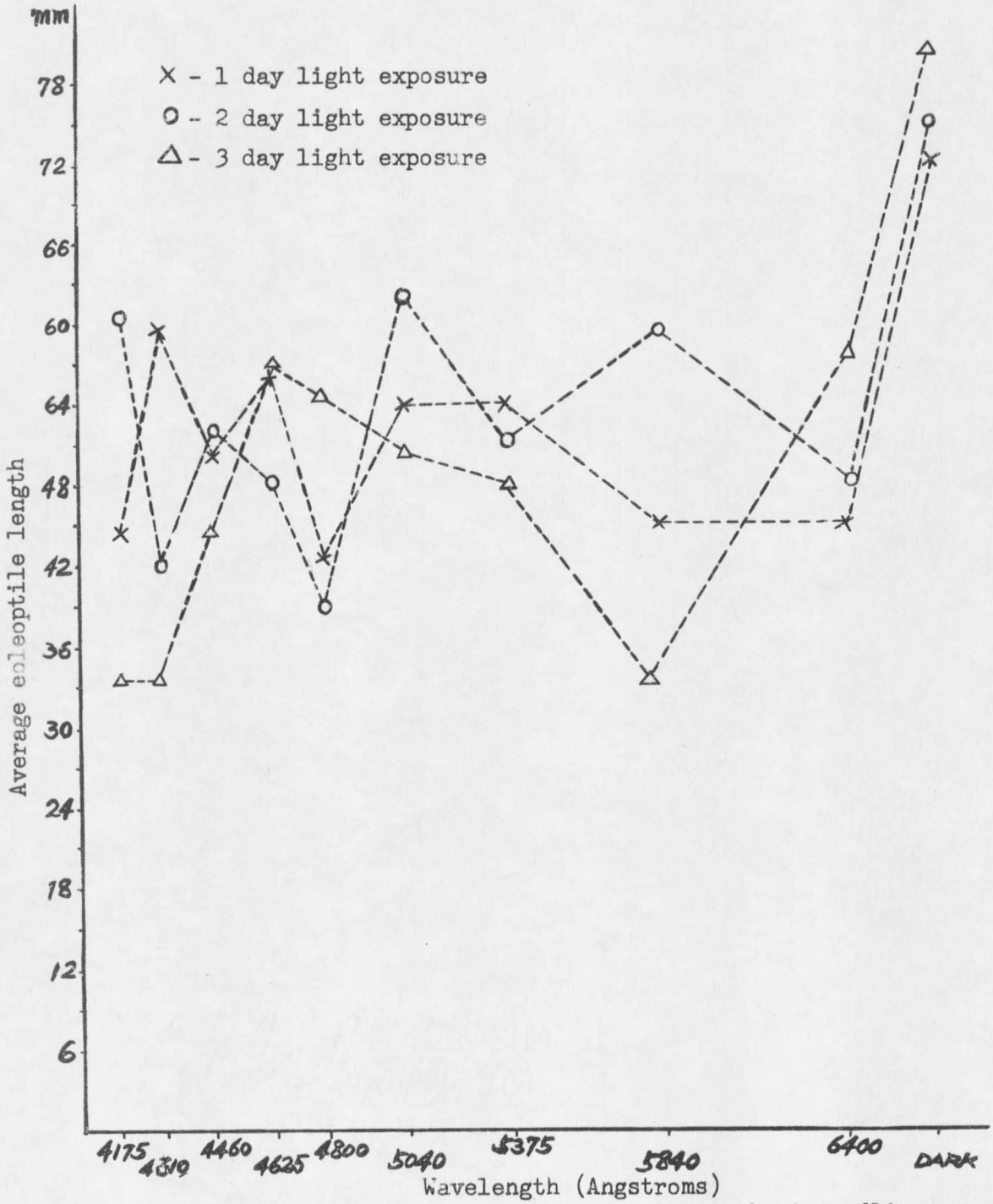


Figure 3. Average coleoptile lengths of Karmont winter wheat seedlings at the different wavelengths when grown exposed to, one, two, and three days of continuous irradiation at the growing temperature of 45° F. The coleoptile length values are an average of the three pre-irradiation germination treatments.

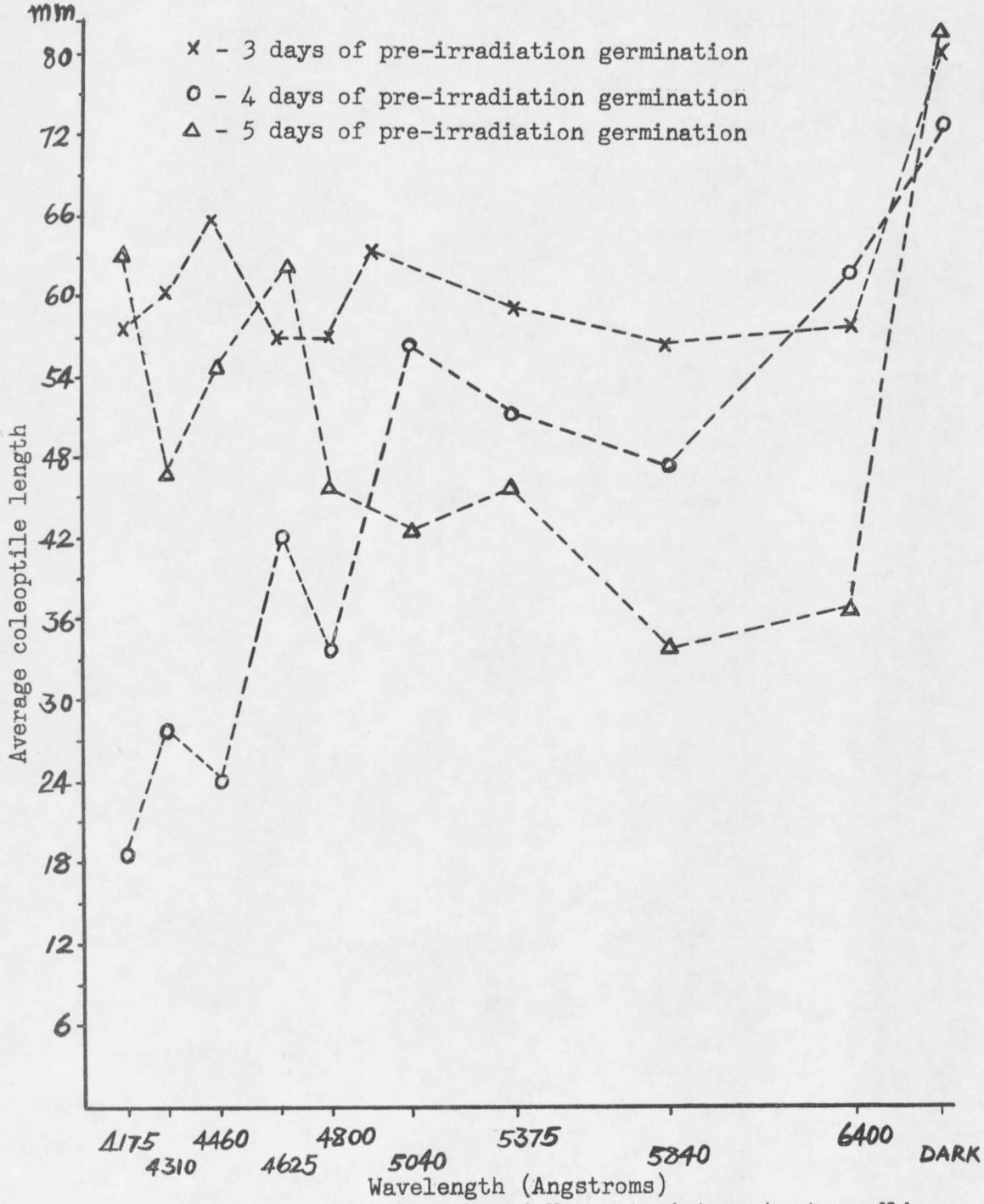


Figure 4. Average coleoptile lengths of Karmont winter wheat seedlings at the different wavelengths when germinated for three, four and five days prior to irradiation at the growing temperature of 45° F. The coleoptile length values are an average of the three light levels.

Table IV. Average coleoptile lengths of Karmont winter wheat for the pre-irradiation germination time x exposure time interaction at the 45° F. and 68° F. growing temperatures.

	Average coleoptile length in millimeters							
	45° F. growing temperature				68° F. growing temperature			
	Germination			exposure	Germination			exposure
Exposure	3 days	4 days	5 days	Mean	3 days	4 days	5 days	Mean
1	60.3	51.6	45.2	52.4	27.5	41.8	30.4	33.2
2	66.5	41.8	53.1	53.8	29.0	39.8	27.0	32.0
3	53.2	36.8	56.4	48.9	21.8	27.5	19.8	23.0
Germination Mean	60.0	43.4	51.6		26.9	36.4	25.7	

Coleoptile elongation responses to pre-irradiation germination and light exposure at 68° F. growing temperatures.

The analysis of variance table, Table V., points out that all main effects and the first order interactions, with the exception of the pre-irradiation germination time x exposure time interaction are significant at the one percent level.

The differences between means for the main effects and interactions necessary for statistical significance using the S - method are presented in Table II. Using these differences in Table III these main effects differences are observed. The difference between the dark treatment and all light treatments is significant as is the difference between the red (6400 A) wavelength treatment and 4175 A, 4310 A, 4460 A and 4800 A treatments. A five percent significant difference exists between the 5375 A treatment and the 4310 A, 4460 A and 4800 A treatment.

Figure 5 illustrates the stastistical significances of the wavelength x exposure time interaction. A statistical significant difference is observed at 4175 A between the one and three day exposure, at 4310 A between one and two and the two and three day exposures and at 4625 A between the two and three day exposures at 5040 A. The one and three and two and three day exposures at 6400 A are also significantly different.

The wavelength x pre-irradiation germination time is presented in Figure 6. Statistical significance is illustrated at 4175 A

Table V. Analysis of variance for the response of Karmont winter wheat coleoptiles to wavelength, pre-irradiation time and exposure time at a growing temperature of 68° F.

Source of variation	Degrees of freedom	Mean square
Wavelength	9	16,868.35**
Pre-irradiation germination time	2	8,878.27**
Exposure time	2	7,419.26**
Wavelength x pre-irradiation	18	972.30**
Wavelength x exposure time	18	1,122.57**
Pre-irradiation x exposure time	4	449.96
Wavelength x pre-irrad. exposure time	36	1,384.50**
Error	630	486.19
Total	719	

** Significant at the 1 percent level

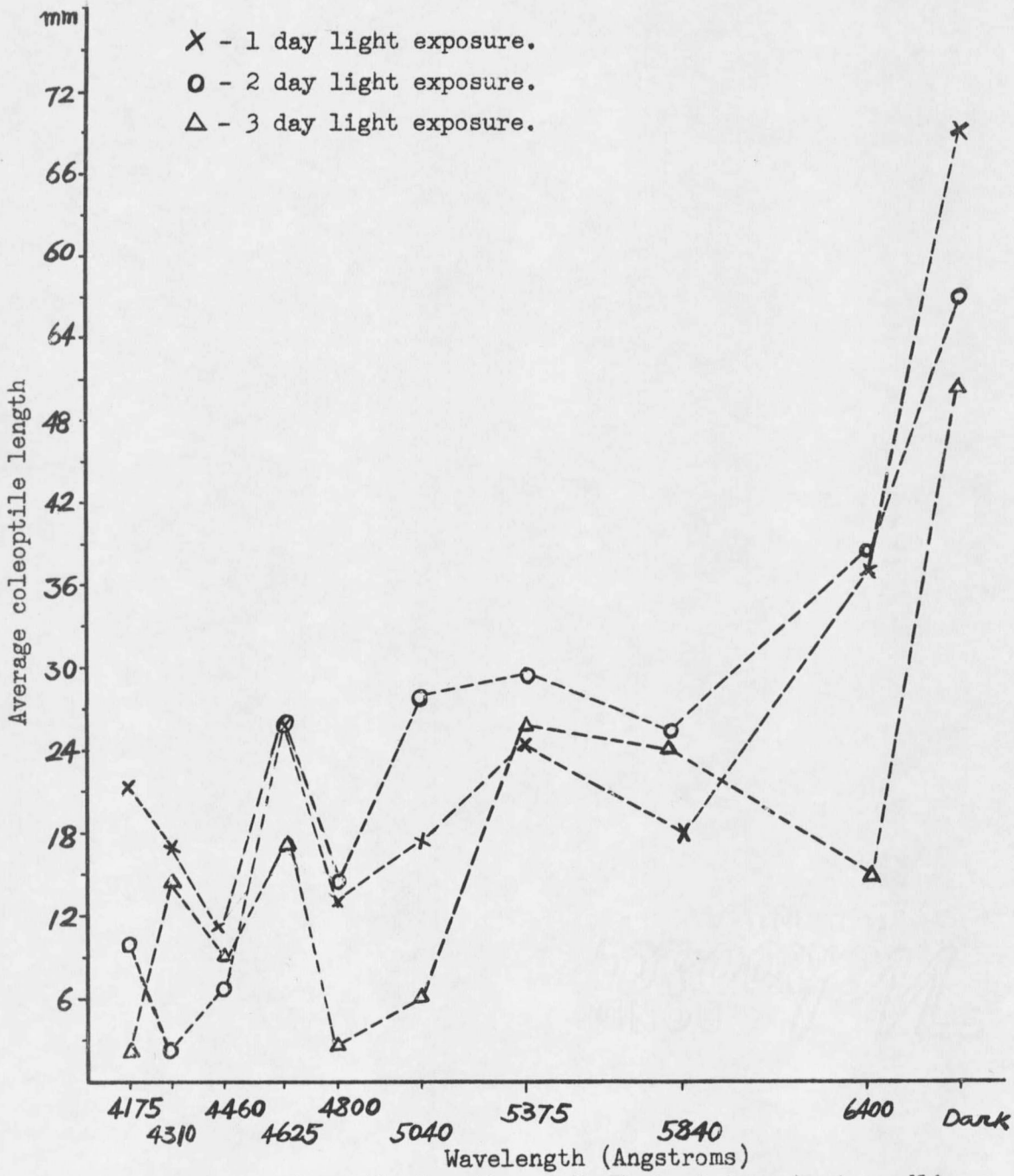


Figure 5. Average coleoptile lengths of Karmont winter wheat seedlings at the different wavelengths when exposed to one, two and three days of continuous irradiation at the growing temperature of 68° F. The coleoptile length values are an average of the three pre-irradiation germination treatments.

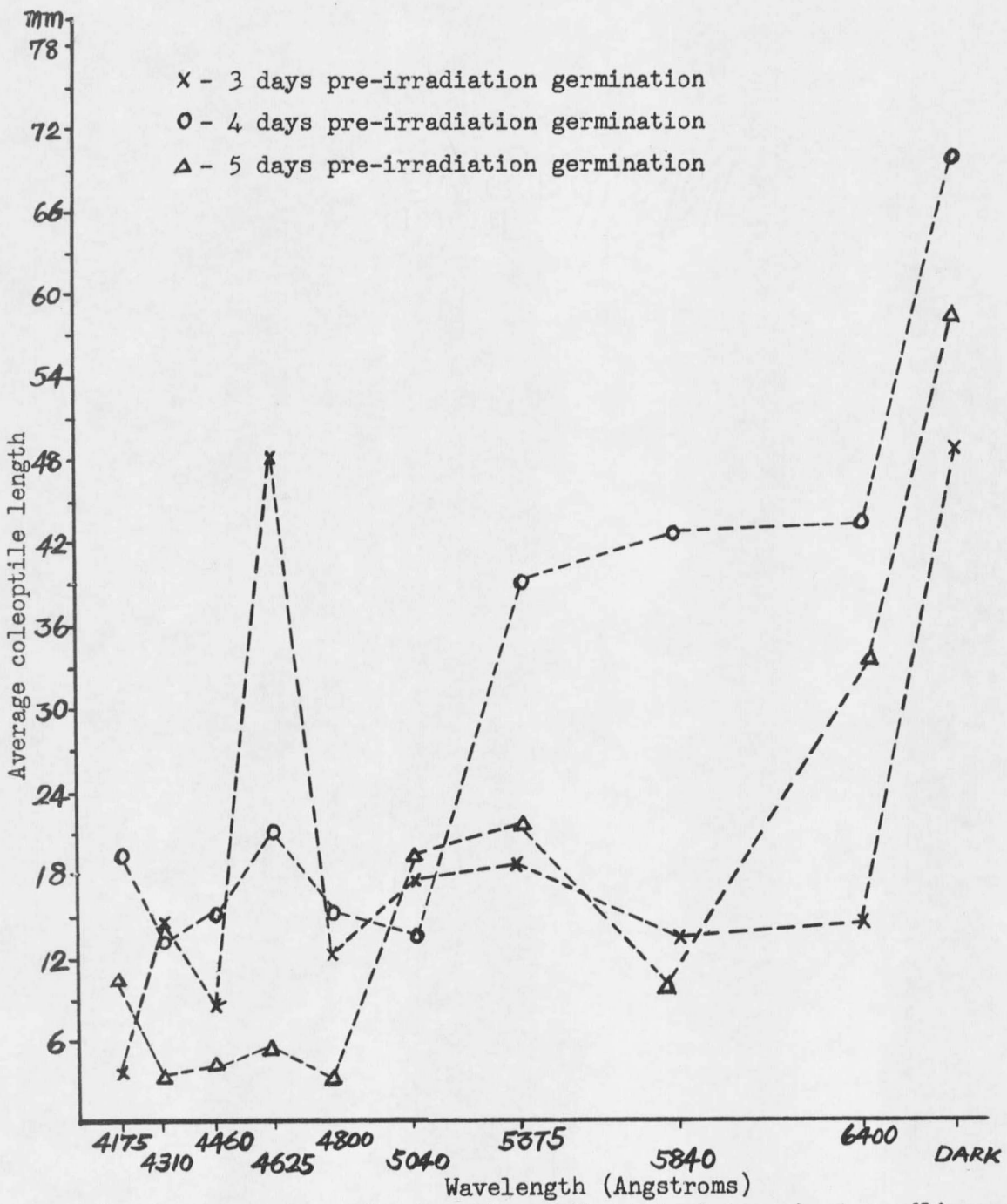


Figure 6. Average coleoptile lengths of Karmont winter wheat seedlings at the different wavelengths when exposed to one, two and three days of continuous irradiation at the growing temperature of 68° F. The coleoptile length values are an average the three pre-irradiation germination treatments.

between the three and five and the four and five day germination time. Significance is also shown at 5375 A between the three and four and the four and five day germination time. This same difference is seen at 5840 A. The three and five and three and four day germination time at 6400 A are also significant.

Average effect of wavelengths upon coleoptile elongation at the 45° F. and 68° F. growing temperatures.

A comparison between the wavelength means at the growing temperatures of 45° F. and 68° F. is presented in Figure 7. The two temperatures tended to exhibit parallel effect at all wavelengths with major differences existing at 4460 A, where the 45° F. test shows an increase in response while the 68° F. test shows a decrease in response. Another difference exists at 5375 A where the 45° F. test decreases in effect over the preceeding wavelength and the 68° F. test increases in effect over the preceeding wavelength. From 5375 A through the check the effects appear parallel in nature.

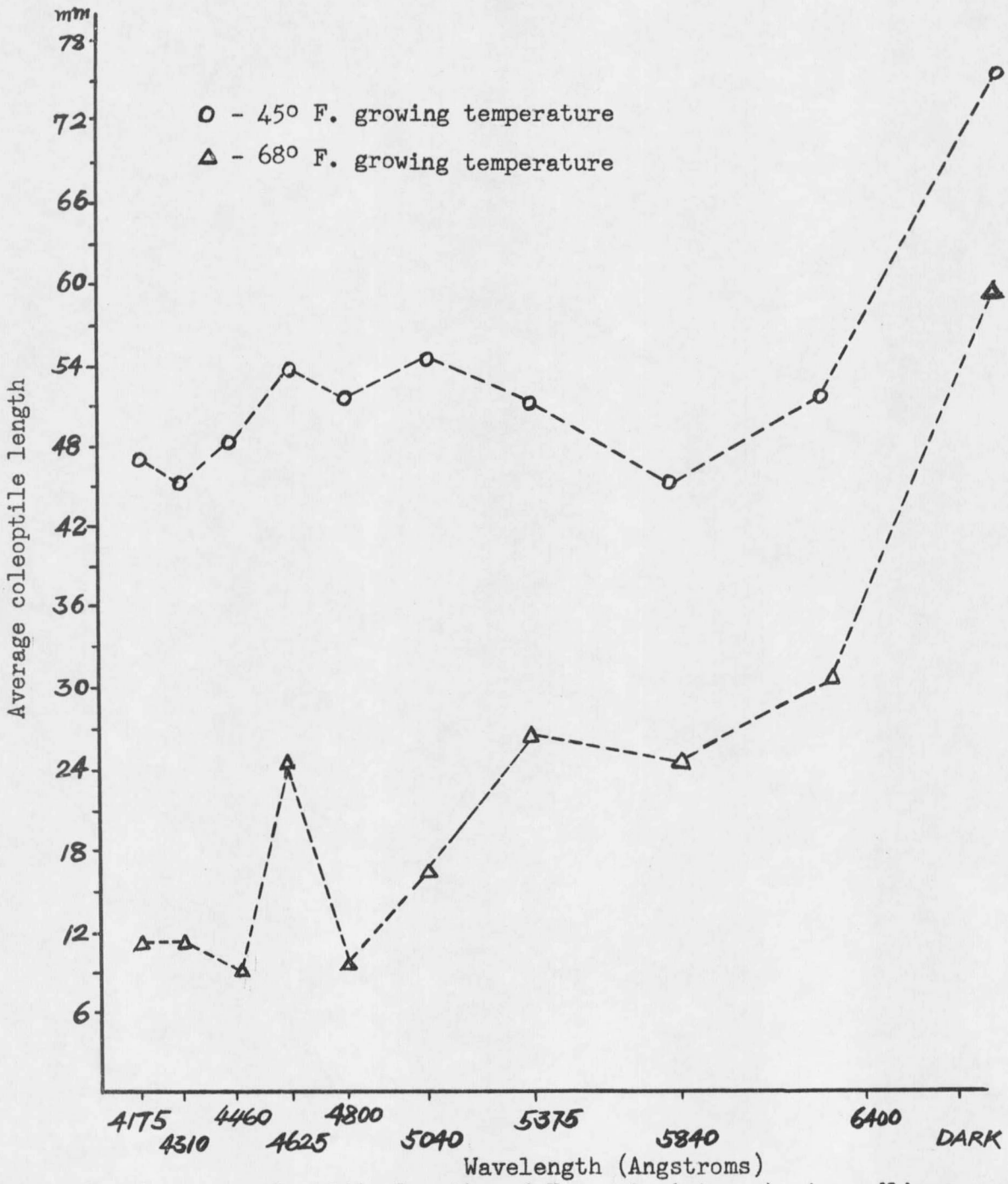


Figure 7. Average coleoptile lengths of Karmont winter wheat seedlings at the different wavelengths when grown at 45° F. and 68° F. The coleoptile length values are an average of the three light exposure periods and the three pre-irradiation germination treatments.

DISCUSSION

Preliminary observations.

In preliminary tests to determine the range of inhibition which was possible with the apparatus described in materials and methods, some interesting responses were observed.

When exposed for periods greater than five days, the seeds under the spectrum did not develop as the exposure time advanced. When seed was exposed for nine days, only the seed which was exposed to the red region of the spectrum (6400 A) recovered from the treatment.

When seed was exposed for eight days, vernalized, and planted in the greenhouse for further observation, the plants which developed from the red exposed seed required seven more days to head than did the plants from the seed which had been exposed to the blue (4175A) region of the spectrum. The seed from the red exposed plants was shriveled, while the seed from the blue exposed plants appeared normal.

Greenhouse depth of planting experiment.

The ability of the coleoptiles of Karmont winter wheat to emerge from the soil surface from depths up to three inches under conditions of absolute darkness and normal daylight, is seen in figure 2.

The apparent inhibiting effect that light has upon the coleoptile lengths is shown by the growth of the coleoptiles above the soil surface when grown in the absence of light. The coleoptiles from seedlings grown under conditions of normal daylight stopped elongating upon

reaching the soil surface. At the four inch planting depth, which was greater in depth than the average maximum obtainable length of the coleoptiles, the coleoptiles of the dark grown seedlings elongated to greater lengths than the coleoptiles of the seedlings grown under normal daylight. This would indicate a possible inhibiting effect of light penetrating the soil surface. The reduction in coleoptile length at the four, five and six inch depths would indicate an apparent depressing effect of soil depth upon the coleoptile.

This experiment also indicated that there is some other factor which stops the elongation of the coleoptile. At the one, two, and three inch dark planting, the coleoptiles elongated to approximately one inch above the soil surface and stopped. These coleoptiles were far short of their maximum potential which is approximately 80 mm, when the seedlings are grown in darkness on blotter paper. It is therefore apparent that some factor, other than light, temperature, and depth of seeding has an effect upon the length attainable by the coleoptiles when grown in soil in the absence of light.

Coleoptile elongation responses to pre-irradiation germination and light exposure at 45° F. growing temperatures.

The general response of the coleoptiles to wavelengths at the colder (45° F.) growing temperature, was less than the response at the warm (68° F.) growing temperature (Figure 7). This difference is apparently due to the earlier stage of development that the seedlings were at, at the time of exposure, due to the slower rate of development

brought about by the cold temperature.

At this colder temperature, the effect of the wavelengths is for an overall depression in the coleoptile length, and no statistically significant differences exist between any of the wavelength means. The germination time prior to exposure seems to be a definite factor in the response of the coleoptiles to irradiation. The shortest (three day) pre-irradiation germination time, resulted in the least coleoptile inhibition, while the four days of germination prior to exposure resulted in the greatest coleoptile inhibition.

The significance of the wavelength x exposure time interaction (Figure 3) is the result of the inconsistent responses of the coleoptiles to the wavelength.

When the amount of pre-irradiation time was plotted against the wavelength, a negative linear relationship between coleoptile length and wavelength was indicated for the four day germination period. This was opposite to the response of the three and five day germination periods. The validity of these responses is questioned and further tests will be necessary.

Coleoptile elongation responses to pre-irradiation germination and light exposure at 68° F. growing temperatures.

The general inhibitory effect of all wavelengths used in this investigation was greater at the 68° F. growing temperature than at the 45° F. growing temperature as shown in Figure 7.

The inhibitory effects at each wavelength studied varied considerably, resulting in the significant interactions in Table V.

The greatest mean coleoptile inhibition was at 4460 A followed by 4800 A, 4310 A and 4175 A. All of these wavelengths lie within the blue region of the spectrum (Figure 1).

The general trend was for an increased coleoptile inhibition as the shorter wavelengths were reached (Figure 5). At 5840 A, the sharp increase in inhibition would suggest that this region of the spectrum is capable of reducing the coleoptile elongation at low energy levels. These data clearly show the inhibiting effect that light has upon the coleoptiles of Karmont winter wheat.

The amount of pre-irradiation germination is also an important factor in the inhibitory effect of the wavelengths upon the coleoptiles (Figure 6). The greatest responses resulted from three and five days germination with the four day germination showing the least effect. This would suggest that at this particular stage of development, the seedlings became less light sensitive than at the three and five day germination periods.

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SUMMARY

Light of all spectral regions studied has an inhibiting effect upon the coleoptiles of Karmont winter wheat.

At growing temperatures of 45° F. the overall effect was a general inhibition in the coleoptile lengths of the irradiated plants over the dark treatment. No significant difference existed among wavelength means. The four day germination mean was significantly lower than the three and the five day means. There were no significant differences among the exposure time means.

Statistically significant differences existed between the dark treatment and wavelengths at the 68° F. growing temperature. The statistically significant difference between the 6400 A region and the 4175 A, 4310 A, 4460 A and the 4800 A region shows that the blue light is more inhibiting than red light at the intensities obtained in the study. The three and five day germination means were statistically significantly different than the four day germination mean. The one and two day exposure times were significantly different than the three day exposure time.

Almost parallel responses to the wavelengths studied were obtained for the 45° F. growing temperature and the 68° F. growing temperature with the 68° F. showing the greatest coleoptile inhibition response.

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