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

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

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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.

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

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 (<u>Nicotiana tabacum</u>) 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.

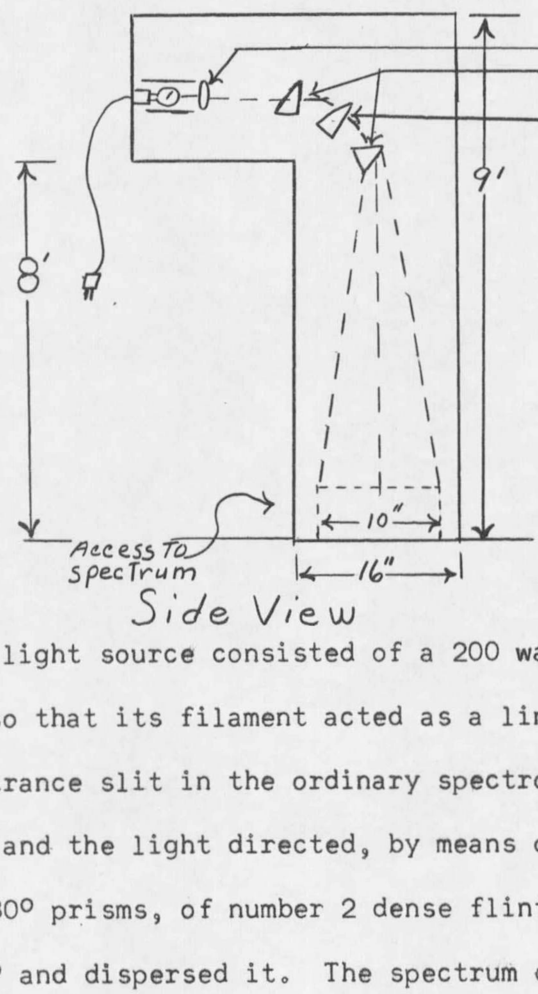
Along with their work on lettuce seed germination, Borthwick and associates have done considerable work on the action spectrum for barley flowering (5) and for inhibition of the second internode (4) under various light regimes with energies varying 10,000 fold and time of irradiation 100 fold. In treatments 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