

AN ABSTRACT OF THE THESIS OF

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Title: Utilization of the Night-Interruption Phenomenon to Hasten

the Seed Increase of Long-Day Cereals During Short-Day Regimes in

California and Arizona

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Tests were carried on in growth chambers and in the field to determine if the harvest of daylength-sensitive long-day cereals grown during the winter in Arizona could be hastened 30 days by the use of night interruption.

Two durum lines which were near-isogenic for sensitivity to daylength were used throughout the study. The average day and night temperatures and daylengths for the Yuma, Arizona area during the period November to May and for the Santa Ana, California area from August through November were simulated in the growth chambers. Light for the night interruption was provided by incandescent lamps. Various intensities of light were tested and different durations of night interruption were applied. The night interruptions were initiated approximately one month after planting.

From the studies it was learned that the date of harvest could be hastened 30 days by the use of incandescent lighting on the plants.

To induce heading and hasten the harvest date by 30 days through the use of night interruption the following conditions had to be met:

1. The light intensity had to be at least 6 foot candle.
2. A night interruption of 6 foot candle intensity requires 5 hours of light (9:30 p.m. - 2:30 a.m.) each night.
3. Night interruption has to continue for approximately 85 days after it is initiated.

Utilization of the Night-Interruption
Phenomenon to Hasten the Seed Increase
of Long-Day Cereals During Short-Day
Regimes in California and Arizona

by

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UTILIZATION OF THE NIGHT-INTERRUPTION
PHENOMENON TO HASTEN THE SEED INCREASE
OF LONG-DAY CEREALS DURING SHORT-DAY
REGIMES IN CALIFORNIA AND ARIZONA

INTRODUCTION

One of the policies of the Seedstocks Project at the North Dakota State University is to make seed increases of new and potential crop varieties as rapidly as possible. This policy is now of particular importance in view of the low inventories of food grains world-wide.

For many years annual seed increases have been made during the North Dakota winter near Yuma, Arizona, from mid-November to mid-May. A second increase site has been established near Santa Ana, California, by the North Dakota State University Seedstocks Project. Use of this site permits seed increase of daylength-insensitive cereals during the August 1 to mid-November period. For the daylength-insensitive cultivars, this allows an interim seed increase between a July harvest in North Dakota and a mid-November planting at Yuma, Arizona. Thus, three field increases during a 12 month period are possible.

An interim seed increase of daylength-sensitive cereals at Santa Ana, California, is not now feasible because the crop is too immature to harvest for seeding at Yuma, Arizona by mid-November. Thus, seed production of promising lines of daylength-sensitive cultivars cannot now be accelerated by an interim increase at Santa Ana, California.

Late planting dates in North Dakota have been found to result in reduced yields. Studies reported by Jensen et al. (37) have shown that the sowing in North Dakota of wheat (Triticum aestivum L.) and barley (Hordeum vulgare L.) about April 20 has produced 13 to 40 percent higher yields than plantings made in mid-May.

The purpose of this study was to investigate the economic and practical feasibility of producing seed of spring type cereals one month earlier during the fall and winter months in California and Arizona, respectively, by use of night interruption with incandescent lights. A 5 bushel increase on one acre resulting from the 30 day earlier return of seed to North Dakota can mean an additional 400,000 bushels 3 years later.

LITERATURE REVIEW

Photoperiod

Over fifty years ago Garner and Allard (27) demonstrated the response of higher plants to daylength. They termed the biological measurement of the relative lengths of day and night photoperiodism. Subsequent research referred to by Hillman (35) and others (32, 36, 60) indicates that the length of the dark period is equally as important as length of day.

Plants have been categorized according to their response to different daylengths by Lang (41) and many others (1, 2, 5, 18, 29, 35, 40, 41, 49, 60, 62) as long-day, short-day, and day-neutral. Hillman (35) added the categories, short-long-day and long-short-day with the qualification that all classifications are either qualitative or quantitative in reaction to daylength. All of the classifications relate to the prerequisite for sexual reproduction. Currently plants that respond to photoperiod are termed daylength-sensitive and those that are day-neutral are referred to as daylength-insensitive according to Lebsack et al. (42).

Effect of Photoperiod on Spring-type Wheat (*Triticum durum* Desf.) and *Triticum aestivum* L.)

Spring wheat is a long-day plant by accepted definition (60) but

will flower at any daylength given sufficient time and conducive temperatures (8, 9, 10). This type of response, though time to flowering decreases with increase of daylength, classifies spring wheat as quantitatively a long-day plant (8). Hillman (35) states that some wheat varieties are short-long-day plants.

Vegetative Stage

For maximal vegetative growth and reproduction in long-day plants, studies by Aspinall et al. (2, 3, 4, 47, 48) and reports on other studies referred to by Kirby (38) showed that short days preceding long days were necessary. Heslop-Harrison (34) quoted Ryle (1965) as having found that the daylength experienced before initiation of the inflorescence determined the spikelet number in perennial ryegrass (Lolium perenne L.), a quantitative long-day plant. Short days increased the number of primordia formed. Heslop-Harrison (34) also stated that comparable results are available for other species, and that data are sufficient to support the generalization that daylength conditions delaying inflorescence initiation increase primordium number.

Chinoy and Nanda (8, 9, 10) and Kirby (38), along with others (2, 13, 26, 31, 39, 72), on studies involving spring wheat, reported that the greatest leaf area development takes place during short days. Friend et al. (19, 21, 22, 26) reported that the total number of leaves and tillers present on wheat plants after four weeks' growth also increased

with increasing daylength. Friend et al. (24) found that the absolute and relative growth rate of the whole plant increased with light intensity and was maximal at ear emergence. The relative growth rate increased with light intensity in early stages of growth. In addition, Friend et al. (22) found that increasing the photoperiod by supplementary light during the vegetative stage of growth had no significant effect on any of the growth parameters, root, stem, relative growth rate, net assimilation rate, leaf weight ratio, leaf area ratio, and ratio of leaf area to leaf weight.

Kirby and Eisenberg (39) indicated that the number and size of leaves of a plant species is inherited. Consequently there is variation in varietal response. Chinoy and Nanda (8) reported that under natural conditions the vegetative period of a variety appeared to determine stem elongation. Chinoy and Nanda (9) also reported that darkness is not essential to the development of long-day plants. Paleg and Aspinall (48) reported that night interruption with a light period accelerated spikelet development, primordium production, and stem elongation and reduced the number of leaves on the main stems and of grains on the ear.

Tillering

Conflicting data are reported on the primary causative agents inducing tillering. Kirby (38) stated that, in work done by others,

short days with natural light increased tillering. However, in controlled environments barley varieties varied in rate and pattern of tiller development, but generally tillering was greatest under long days. Thorne et al. (66) reported increased tillering of wheat under short-day regimes. Williams and Williams (72), reported that light intensity also is a factor in tiller development. They stated that wheat tillered most during short days with a high light intensity.

Forster et al. (15) stated that Maximov showed that where floral development is inhibited vegetative growth continues without flowering. Thus, researchers differ on the effect of daylength on tillering, dry-weight production and leaf production. Kirby (39) in 1969 summed up the contradictory findings as follows:

"There is no general hypothesis about the effects of daylength on tillering, dry-weight growth and leaf production, as contradictory results have been obtained in different experiments, due partly to experimental conditions. The recent work of Williams and Williams (59) indicate that the low tillering obtained in short-day treatments in some controlled environment experiments may be due to the low temperature income."

Floral Initiation and Ear Emergence

Of many investigations (1, 7, 8, 15, 38, 41, 65, 72), Lang (41) best expressed the need of long days to induce flowering in wheat, stating that flowering will cease or be delayed if daylength is reduced to ten hours at 22.5° C. Chinoy and Nanda (8) reported that stem elongation accelerates under long days and was markedly increased under post

photo-inductive treatments. Stem elongation is considered part of the flowering process. Friend et al. (20) reported that floral initiation was earlier with each increase of light intensity under continuous illumination. Levy and Ross (43) stated that photoperiod is the prime factor in controlling maturity in a study involving photo-period and vernalization.

Most plant species must attain a certain age before they can respond to forces activating floral initiation. The exact age depends upon the species.

Yield and Yield Components

Kirby (39) stated that in both field and pot experiments short days have generally been reported to increase numbers of ears, number of spikelets per ear, and in the case of wheat number of florets per spikelet, although 1000-grain weights show no change. Marked interactions between variety and daylength in respect to yield components has been frequently related to the response of the varieties involved, Kirby (39) reported of studies by Griffith (1961).

Heslop-Harrison (34) states that the limitation of grain number is imposed during ear initiation by the numbers of plastochron cycles executed and in small grains by the numbers of ear producing tillers. In the cereals, as in most species, there is a sharp decrease in plastochron with inflorescence initiation.

Paleg and Aspinall (48) stated that yield of barley was affected by night interruption at an early phase of plant growth because of an earlier cessation of primordium production. Night interruption produced the long-day effect rather than the short-day. Paleg and Aspinall (48) stated that because of the cessation of primordium production, yield of grain from plants in a breeding program may be reduced by an attempt to accelerate flowering with an artificial photo-period extension. Further, Paleg and Aspinall (48) stated that in their work with effects of photo-period on barley it would appear that the number of grains per ear produced on commercial crops of barley would be, at least in part, a function of latitude of the planting site, the date of planting, and the photo-periodic sensitivity of the crop. Heslop-Harrison (34) stated that the ultimate potential of yield in cereals is governed by determinations made early in the life of the plant. For the small grain cereals no generalizations beyond this seem feasible, because of the complexity of temperature, daylength and nutritional interactions and the existence of species and varietal differences.

Heslop-Harrison (34) stated that it is well established that foliage below the flag leaf makes little contribution to grain yield in barley and wheat. Heslop-Harrison (34) also stated that the number of leaf bearing nodes is not a highly important factor in itself in cereals, and accordingly that little significance attaches to this aspect

of the functioning of developmental controls concerned in transition to flowering. Studies by Thorne et al. (66) suggested that grain yield is more closely related to duration of leaf area above the flag leaf node than to total leaf area duration.

Factors Influencing Floral Induction in the Spring-type Wheat Plant

Hillman (35) has stated that yearly responses of plants are rarely directly coerced by weather. Plants respond to several factors which may be subtle yet dependable. Temperature, light intensity, duration of light, critical length of day, critical length of night, and genetics can and may all be involved. Pugsley (51) has reported that genetic control is implicated also.

Critical Day

Salisbury and Ross (60) stated that in all cases of photoperiodism studied under the usual conditions of light-dark cycle totaling twenty-four hours, it is possible to speak of both a critical day and a critical night. The sense of the terms always depends on whether we are dealing with short-day plants or with long-day plants. If flowering will occur at any daylength but more rapidly at long days, then we say that the plant is a quantitative or facultative long-day plant. In an absolute or qualitative long-day plant no flowering will occur when the days are shorter than a specific length. This daylength depends upon the species and is equivalent to the critical daylength. Days shorter than this

will not result in flowering whereas longer days will cause flowering. Hillman (35) stated with respect to long-day plants that in the typical long-day plant, flowering occurs most rapidly when the plant receives more than a certain number of hours of light per day--that is, when the length of illumination exceeds the critical daylength of the plant in question. Garner and Allard (27) stated that sexual reproduction can be attained by the plant only when it is exposed to a specifically favorable length of day. The requirements in this particular vary with the species and variety.

Salisbury and Ross (60) showed that the critical day for winter wheat is twelve hours. However it was shown by Gries et al. (29) and others (15) that spring varieties are accelerated to a greater degree by increased photoperiods than are winter varieties. Lang (41) stated that long-day plants will cease to flower or flowering will be delayed if daylength is further reduced to ten hours at 22.5° C or will begin to flower or flower more rapidly if it is extended to sixteen hours. There are differences within species and between varieties. Evans (14) noted that one strain of darnel (Lolium temulentum L.) has a critical daylength of nine hours while another strain requires fourteen hours to flower. Kirby (39) stated that the concept of critical daylength cannot be applied to long-day plants such as wheat, oats and barley. Varieties with a steep slope between the 9-10 hour and the 14-16 hour segment of the curve are said to show strong response to

photoperiod, while those where the time to ear emergence varies little with daylength are said to be insensitive or day-neutral. Kirby (39) also quoted work by Van Doben, Doroshenko, and Dantuma which showed that those varieties from higher latitudes have greatest response to daylength, hence have a more critical daylength. Sampson et al. (62) also inferred on their studies with oats (Avena sativa L.) that oats from higher latitudes have greater response to daylength. Ormrod (46) and Guitard (31) found marked differences among varieties of wheat in sensitivity of head differentiation as affected by photoperiod. Barley varieties differed only slightly in photoperiodic sensitivity of culm elongation at any one photoperiod and there were only small differences among photoperiods.

Ormrod (46) in his studies in British Columbia, Canada deduced that the eleven-hour photoperiod seemed to be a critical indication of sensitivity to short photoperiods for both early and late varieties of wheat.

Critical Night

Critical night is that period of darkness which must be exceeded before the first sign of flowering can be observed in short-day plants. The critical night represents a maximum period in the long-day plant. If flowering is to occur, the dark period must be shorter than the critical night as stated by Salisbury and Ross (60).

In the case of long-day plants a night-interruption period by sufficient light induces flowering because the night period is now shorter than the critical night. This phenomenon has led many investigators to emphasize the role of the dark period in photoperiodism. They suggest calling long-day plants short-night plants.

Temperature

In studies on spring wheat, spring barley, timothy and perennial rye grass several investigators (20, 21, 24, 26, 31, 54, 57, 59) have shown that changes in temperature alter normal response to photoperiod. Friend et al. (20) found that higher temperature between 10-25° C along with night interruption increases rate of floral initiation. This effect could result from either an increased rate of production of flower-inducing substances or from an increased sensitivity of the meristematic cells to a given level of flower-inducing substance, but is not caused by an increase in leaf area. This conclusion was reached because a high proportion of leaf area of wheat and darnel can be removed with little effect on time of floral initiation. After floral initiation the growth of the apical meristem of spring wheat is more rapid in early heading. Low temperatures strongly retarded the later stages of ear development and emergence.

A change of temperature under a given photoperiod has been reported by Salisbury and Ross (60) to alter completely the reproductive

response of poinsettia (Euphorbia pulcherrima L.) and morning glory (Ipomeoea purpurea L.). The plants become absolute short-day plants at high temperatures and absolute long-day plants at low temperatures. These species are day-neutral only at intermediate temperatures. Salisbury and Ross (60) suspect that both the long-day and short-day responses exist in all plants, and peculiarities can be accounted for by specific interactions and overlapping of the critical minimum and maximum lengths of day and night for various species.

S. G. Wellensiek of Holland, stated Salisbury and Ross (60), discovered that a given temperature will substitute for a given photo-periodic treatment or vice versa. This relationship has come to be referred to as Wellensiek's phenomenon. Hillman (35) stated that it may take considerable care to separate general effects on growth from specific effects on flowering.

However, it has been generally concluded that high temperatures, up to 30° C, favor flowering. Hurd-Karrer (36) demonstrated that with the Hard Federation variety of wheat an increased daylength decreased time to flowering to a much greater degree when plants were grown at 69.8° F than when grown at 53.6° F.

Light Quality and Intensity

Williams and Williams (72) reported that growth processes are slower during the short-day periods when light intensity is low. They

concluded that light intensity and quality are important as well as duration. Aspinall and Paleg (2, 3, 4), found that increased light intensity increased primordium production and floral development. Ryle (56) reported a direct relationship between light intensity and seed yield per plant. Treshaw (67) reports that too high a light intensity has deleterious effects. Friend et al. (22) in their work reported that the increase in the net assimilation rate and relative growth rate with increasing daily total radiation was similar to that obtained by raising the intensity of light given to plants under continuous lighting. Friend et al. (20) further found that under continuous illumination floral initiation of Marquis wheat was earlier with each increase in light intensity from 200 to 2500 f. c. The effect of light intensity was attributed to promotion of floral initiation by energy in the far-red (730 mμ). They found, further, that low intensity light (10-15 f. c.), although insufficient to provide an energy substitute for growth, has marked morphogenic effects and accelerates floral initiation when used to extend a short daylength or interrupt a dark period. Floral initiation was not related to leaf numbers as the experiment was carried further, and only the removal of first and second leaves showed a delay in floral initiation.

According to Lane et al. (40) extended night interruptions and 8 hour extensions of the photoperiod were effective for inducing floral initiation, particularly with light from dark red incandescent, ruby

red or incandescent lamps. For all lamp types 8 hour extensions prior to each daylight period were more effective than those given at the end of each day. Four hour light breaks were most effective when given in the middle of each night. Lane et al. (40) stated that flowering of a number of long-day plants can be induced by brief exposure to light near the middle of long nights.

Borthwick (7) reported the action spectra for long-day and short-day plants with regard to flowering. The study showed that the maximum effectiveness of the red region was 6500 A, ranging from 5800 A-7000 A. The maximum for the far-red region centered at about 7300 A with a range of 7000 A to 7600 A. After many experiments on long-day plants and short-day plants with varying effects on timing of light application, Borthwick concluded that in long-day plants red promotes flowering and in short-day plants red inhibits flowering, but in both types far-red counteracts the red. Some investigators have found that plants have a spectral dependence on both the red region and the far-red region for flowering. Evans (14) in his work on the long-day plant, daniel, found that night interruption to induce flowering was most effective with an equal mixture of red and far-red. Floral induction decreased progressively with increase of either red or far-red.

Hillman (35) found that in cocklebur (Xanthium strumarium L.), a short-day plant, flowering was improved by high intensity light

preceding and following the dark period. Under favorable conditions it has been found that carbohydrates fed to the leaves provide the same inductive effect provided by high intensity lights. This response indicates that the photosynthetic action may influence movement of hormones in the stream of assimilates.

According to Hillman (35) several laboratories have found that the spectral quality of the main light period strongly affects photoperiodic response. In a test by Stolwijk and Zeewaart (1955) on henbane (Hyoscyamus niger L.) it was found that the species was photoperiodic only under violet, blue or far-red and was more or less photoperiodically insensitive to red, orange and green. Hillman (35) further states that opposite results have been obtained with a number of plants, notably the duckweed (Lemna purpurea L.). He stated that this plant shows a typical short-day response under red light but is essentially daylength-insensitive under either blue or far-red, and flowers under continuous lighting with these colors.

Plant Age

Plant age is a variable that is important in reaction to photoperiods. Evans (14) found that older plants of dandelion were fully responsive to one long-day cycle whereas 2 week old plants were much less responsive. It was thought in this case that leaves produced later were more sensitive to photoperiods. Most plants will not respond to

photoperiod as very small seedlings, and some species of trees will not respond until 5-40 years old. The age of the plant necessary to respond to photoperiod depends upon species. George Klebs, according to Salisbury and Ross (60), recognized this diversity of response and suggested a name, "ripeness to flower", for the condition a plant must achieve before it will flower. Individual leaves also must reach an apparent ripeness to flower before the plant will respond.

Photo-inductive Treatments

Although the induction of flowering is an "all or none" phenomenon, the effectiveness of photoperiodic treatment as measured by number of flowers or rate of flower bud development is a modulated response, and this modulation persists over weeks or months, states Bonner (5).

Galston and Davies (28) reported that Garner and Allard determined that some plants flower under short-day regimes and some under long-days, but other researchers found that the reproduction is governed by the length of the dark period. These findings led many researchers to study the effects of artificially making long days by extending short days with artificial lights, and simulating short night periods by interrupting a long dark period with light. For these plants requiring short days Bonner (5) states that giving many successive long dark periods which are just infinitesimally longer than the

critical value will induce rapid flowering. He further states that this is a classical way to determine the critical night length.

As stated previously, researchers have found that altering the daylength can induce flowering of plants in vegetative stage. Having found the critical daylength to induce flowering is accomplished by either lengthening the day or breaking the night with a period of light. Different durations and intensities of light are necessary to affect, photoperiodically, the different species of long-day plants. Different species of long-day plants also respond differently to the duration and intensity of light used for the night interruption scheme.

Plant species respond differently to variable ambient temperature and to duration, quality and intensity of light. Usually the higher the temperature, to approximately 30° C, the less duration and intensity of light required. The reciprocity law referred to by Salisbury and Ross (60) applies when heat and light treatments are applied. That is, as long as the product of light intensity and exposure time remains constant, the photochemical effect of the light also should remain constant.

The quality or wavelength of the light used for altering photoperiod is of considerable importance (12, 23, 25, 67). Borthwick (7) reported that red light has an inhibitory effect on flowering in short-day plants and promotive effect in long-day plants. He further found that induction of flowering in the short-day plant by far-red

light could be reversed by later exposure to red light. This response was not found in all plants, and the reversible effect does not occur in the cereals, where terminal initiation resulting in flowering, once initiated, cannot reverse. Or as stated by Heslop-Harrison (34) plants like the cereals with terminal inflorescences, vegetative growth and flowering are strictly alternative processes in any one axis.

Chinoy and Nanda (8, 9, 10) found that in long-day plants darkness is not essential at any stage of development. Numerous researchers (11, 15, 32, 43) have found that extension of short days with artificial light has caused the long-day plants to flower.

Riddell et al. (53) stated that photoperiod regardless of light intensity is the primary factor in accelerating the rate of development of spring wheat.

Cooper (11) and Wanser (69) first demonstrated the effect of increased daylength on the flowering of spring wheat varieties. Hurd-Karrer (36) demonstrated the influence of temperature on the response of wheat to photoperiod.

Liverman and Bonner (44) found that cocklebur which qualitatively requires at least 8 1/2 hours dark period for flowering can be made to flower by supplying sugar to the plant. Researchers, according to Salisbury and Ross (60), have found that the dark period must be continuous for short-day plants. A light break, even a flash, during the dark period prevents flowering.

Borthwick (7) reported that red light is inhibiting to flowering of short-day plants but far-red reverses this effect; however, the plant responds to the light color of last exposure. Long-day plants are opposite to short-day plants in that red light induces and far red inhibits flowering. Hillman (35) states that a night period is required in preparing the plant to flower as the Pfr pigment must change to a non-inhibitory form.

Friend et al. (22) reported that flowering of quantitative long-day wheat is most rapid in continuous illumination. Plants grown in a daylength of 8 hours preceded by 8 hours of supplemental light will have a flowering behavior comparable to that experienced in a 16 hour day.

Lane et al. (40) also found that extending the light period prior to natural day is more effective than providing supplemental light at the end of each day. This effect was the same for all long-day species tested provided the proper spectrum of light was used.

Night Interruption

Interruption of the night with a brief period of light (length of interruption dependent on plant species involved) is equivalent to exposure to a long day. Day-interruption by darkness has little or no effect on short-day plants.

Borthwick (7) states that, "according to their action spectra the flowering of long-day plants on short days is promoted by interrupting the dark periods with red light". The intensity of light that is effective is dependent upon the light duration. The time during the dark period when the light is applied is also important. At certain times the plant is more sensitive to the light break than at others (60). No simple hypothesis by which photoperiod depends simply on the length of either the light or dark period can be made since studies by Claes and Lang according to Hillman (34) showed that the long-day plant henbane normally has a critical daylength of 11 hours in a 24 hour cycle but if the light-dark cycle is 48 hours the critical daylength is 9 hours.

Paleg and Aspinall (48) found that a promotion of floral development by night interruption with low energies of light, frequently (Aspinall, 1966) though not invariably (Evans, Borthwick and Hendricks, 1965), accompanies floral initiation in response to a long photoperiod. This characteristic has been of great experimental value in investigations of the physiology of floral initiation but the potentialities of the response in other areas has been little explored. In addition, Paleg and Aspinall (48) stated that in view of low energies and brief periods of illumination required for this response it would appear that manipulation of cereal development on a field scale by these means is at least feasible.

Paleg and Aspinall (48) described the responses under field conditions of four barley varieties to night interruption. They reported that all varieties demonstrated an acceleration of floral development with the most intense illumination giving the greatest response. Intensity was from 1 f. c. to 10 f. c. and the duration of illumination was for 2 hours in the middle of the dark period. Illuminated plants began elongation and vegetative growth earlier when illuminated but ceased earlier. Ear emergence on some varieties was advanced up to 3 weeks. Yield of grain was generally decreased by night interruption. Each increase in light intensity caused a further decrease in grain yield. Ear size was generally reduced and in every case control plants had the largest number of grains. Paleg and Aspinall (48) stated further that these results were supported by the findings of Hoensel (1951). Hoensel (1951) suggested that yield of grain may be improved without an undue delay in flowering by subjecting the plants to short photoperiods for the first few weeks of growth and then transferring them to long photoperiods to accelerate flowering. Kirby (38) reported that Aspinall and Paleg (1966) found that with long days achieved by the night interruption treatment, the primordium development was most rapid but ceased before the control with fewer primordia developed.

Number of spikelets per ear increased with decreasing daylength. Two hours of night interruption with incandescent lights showed no

effect on rate of primordium development, but more primordia were formed under short days. Kirby (38) states that daylength effects on yields tend to be contradictory. He also stated that field experiments usually are confounded by variety and plant density interaction. This effect was overcome in recent experiments yet the night break gave a significant reduction in yield related almost entirely to a reduction in spikelet number. 1000 grain weight was not affected.

Chemicals as Inducers of Floral Initiation

Salisbury and Ross (60) state that as long as 35 years ago Chailakhyan and Zhdanova investigated the possibility that auxins in the plant played an important role in flowering. From these studies Chailakhyan and Zhdanova concluded that it was unlikely that flowering was due to a change in auxin content of the plant. There are exceptions. Clark and Kerns (1942) reported, according to Salisbury and Ross (60), that application of certain synthetic auxins to pineapple will stimulate flowering. Apparently application of auxin stimulates ethylene production which in turn induces flowering in pineapple, a long-day plant.

In short-day plants auxin usually inhibits flowering, especially when added during florigen synthesis or florigen translocation. Salisbury and Ross (60) concluded that endogenous auxins normally may not play a decisive role in flowering but they may influence compounds that control flowering.

Gibberellins

Anton Lang (1957) according to Salisbury and Ross (60) demonstrated that GA_3 substituted for the vernalization required by several biennials. Certain long-day plants also flowered in short days when similarly treated, but short-day plants were not appreciably influenced.

Many plant physiologists have extended Lang's work and more than thirty long-day species from at least seventeen families are known to be induced to flower with GA_3 treatment. Some plant species require other known gibberellins. In a few cases auxins have stimulated flowering of long-day plants but only after photoperiods were extended nearly long enough to induce flowering, anyway. Quoting from Salisbury and Ross (60),

"A few long-short-day plant species have been investigated, and it appears that gibberellins can substitute for the long-day requirement but not for short days. No qualitative short-day plants have yet been induced in unfavorable day-lengths by application of any gibberellin, so we may conclude that their florigen is not a gibberellin, at least not one of those presently known."

Galston and Davies (28) summarize the effect of gibberellin by stating that "Gibberellin enhances stem and leaf growth, promotes bolting and flowering in some long-day plants. Many of the responses to gibberellin application are in systems normally controlled by phytochrome or induced by chilling."

Absciscic Acid

Salisbury and Ross (60) report on work by several investigators showing varying responses to abscisic acid by both long-day and short-day plants. They concluded that although abscisic acid does sometimes exhibit flower-promoting ability, it is probably not a florigen but may influence the production or action of florigen.

Mechanism of Response to Photo-period

Perception

Photoperiodic conditions usually are perceived by the leaves which have reached a certain stage of growth. However, the sensitivity of the response to long days increases with increase in plant age. Evans (14) observed that the age of dandelion plants rather than increased leaf area increased the sensitivity to induction. He thought that increased photoperiodic sensitivity could be due to greater responsiveness of later formed leaves.

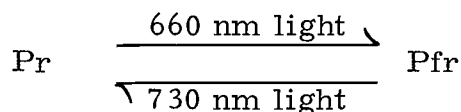
Bonner (5, 6) found that if any single leaf on a cocklebur, a short-day plant, is exposed to long nights, the plant flowers in response to the long-night treatment. Long-day plants will also flower if but one leaf is exposed to night interruption by adequate light. A bud flowers in response to the photoperiod treatment of the leaf so the flowering stimulus must be transmitted from leaf to bud.

Species and strains within species vary considerably in the length of inductive treatment required to induce flowering. Classical examples (ones often used by researchers) are the Ceres strain of darnel, a long-day plant, and cocklebur, a short-day plant. The Ceres strain of darnel at 34 days of age requires only one long day to induce flowering. The cocklebur can be induced to flower with exposure to a single long dark period if individual leaves have reached a stage termed "ripeness to flower".

Phytochrome

A mechanism is necessary to control initiation of reproductive activity or of plant dormancy prior to winter. The phytochrome system is one such mechanism. Galston and Davies (28) describe it as follows:

"One of the most prominent mechanisms involves a pigment, named phytochrome, which exists in plants in at least two different forms, one active and the other presumably inactive. Both forms absorb in the visible region of the spectrum, one in the red region at 660 nm (nanometers), the other in the "far-red" region at 730 nm. The form absorbing at 660 nm (Pr) is considered to be the inactive form. When Pr absorbs a quantum of light, it is transformed to the 730 nm absorbing form (Pfr). The latter, which is the active form of the pigment, may be transformed back to Pr either by absorption of a quantum of light near 730 nm, or by thermal processes proceeding slowly in the dark.



Slower nonphotochemical Temperature-sensitive reversion

Since visible light emanating from the sun is a mixture of wavelengths causing the net transformation of Pr to Pfr, the alternation of light and dark periods in a normal day constitutes a system for the diurnal transformation in the state of phytochrome."

Galston and Davies (28) speculate that phytochrome resembles a bile pigment or phycobilin. Hillman (35) states that some studies indicate that phytochrome closely resembles phytocyanin.

Galston and Davies (28) state that although the properties of phytochrome satisfactorily explain the action of light on the control of growth and form in many plants, there are some paradoxes yet unresolved. For example, in some plants that are known to respond to red and far-red light, no phytochrome has been detected. Where the above has occurred it is generally considered by most experts in the field to be due to a trivial technical problem.

Florigen

Experiments carried out by Chailahjan and Moshkov, according to Hamner and Bonner (17), suggested that a floral hormone was produced when the leaves perceived the inductive photoperiod. A given leaf exposed to proper photoperiod would induce buds some distance away to flower. Chailahjan believed that a hormone was involved and called it "Florigen" (flower maker). There is some skepticism concerning the existence of florigen because no substance has yet been

extracted or synthesized that will induce flowering in all types of plants or even in all response types within a single family. Evans (14) adds, however, that Lincoln et al. (1962) reported that extracts from either flowering Xanthium or flowering Helianthus (daylength-indifferent) are able to bring about induction in Xanthium even under continuous light if prepared and applied in proper manner. Evans (14) states further that most studies indicate that when floral stimulus has been produced it is translocated from the leaves to the shoot apex. It has been determined that the translocation is by way of the vascular system presumably in living cells of the phloem. Although many studies have sought to determine the chemistry or nature of florigen, it remains a physiological concept rather than a chemical reality.

Endogenous Rhythms

Galston and Davies (28) and others (61, 71) report that many experiments have suggested that all higher plants contain in their cells endogenously oscillating systems or 'biological clocks' that govern rhythmic alterations in behavior. Some of these rhythms, which are approximately 24 hours long are referred to as 'circadian'. The sleep movement of leaves is an example. Galston and Davies (28) state that the photoperiod does not control floral induction directly, but rather it alters the endogenous rhythm, which changes at a photoperiod near the critical for flowering. Thus, the endogenous rhythm

in some way governs the flowering response. Withrow (71) however, states that there is evidence of a time lag between the stopping of the photoreaction and the response of the endogenous rhythmic system. The nature of the control appears to reside in an interaction between the states of phytochrome present and the endogenous rhythm.

Hillman (35) states that although light responses other than those mediated by phytochrome may be involved, it is at least a reasonable hypothesis that there are only two basic controlling factors in photoperiodism. One would be the rate of the still unknown reaction in which Pfr participates, and which in turn would be affected by the amount of Pfr, the time which it is presented, and the level of the substrate. The second would be the phase of the endogenous circadian rhythm according to which the product of the Pfr action might have differing effects. Alternatively, the rhythm might control the availability of the substrate in question. At least the idea that photoperiodism is a simple function of either the light period or the dark period must be discarded; a mechanism is required that explains interactions across time.

MATERIALS AND METHODS

In the choice of plant materials consideration was given to known responses to daylength. Two durum (Triticum durum Desf.) lines known to be near-isogenic in response to daylength were used throughout much of the study. The durum lines, similar to material used by Lebsock et al. (42), J70D/Z/B/'Lakota'/3/Leeds/Sel. 191-6 classed as daylength-insensitive, and J70D/Z/B/'Lakota'/3/Leeds/Sel. 190-5 classed as daylength-sensitive were obtained from the North Dakota State University-U. S. D. A. breeding programs and were considered F_9 generation from F_6 bulks of the cross. Z/B ('Zenati'/'Bouteille') is a daylength-insensitive durum line from Israel. Lakota (LK.) and Leeds (Lds.) are daylength-sensitive durums **also developed in the N. D. S. U. - U. S. D. A. program.** Hereafter, for brevity, these near-isogenic lines will be referred to as sensitive and insensitive. Later in the study the durum varieties Leeds, Ward, Rolette, and Rugby were added along with an oat line. Ward, Rolette, and Rugby also were developed in the North Dakota State University-U. S. D. A. program, subsequent to the beginning of this study. Later observations were made of Ward and Rugby in large field trials under winter-time seed increase.

GROWTH CHAMBER STUDIES

In studies from August 1971 through March 1975, 3 clay pots

of each variety or experimental line with 2 plants per pot were grown in the growth chambers. Three seeds per pot were planted but seedlings were thinned to two plants per pot. The soil mixture for the study was composed of two parts Fargo clay, one part sand and two parts compost. No fertilizer was used. The plants were watered daily. The illumination in the growth chambers was measured and found to be uniform. The plantings were always arranged so that pots of similar lines or varieties were never contiguous.

Two growth chambers were used for each test. Both chambers were adjusted for the daylength, effective day temperature and effective night temperature of the area desired, namely; Yuma, Arizona or Santa Ana, California. One chamber was maintained as the normal or control chamber. The second chamber had the night interruption lights imposed in it. The intensity varied from 1800 f.c. to 5 f.c. with the several tests.

The growth chambers were lighted by "cool-white" VHO fluorescent tubes and frosted incandescent lamps. The fluorescent tubes provided approximately 88% of the light, which was the main source of the "red" light. The incandescent lamps, which were the main source of the necessary "far-red" light, provided approximately 12% of the total light available.

The intensity of the light provided for the daylight period was kept equal and constant for the two growth chambers used in each test.

The intensity was 1300 foot candles (f. c.) or 1800 f. c. at plant height, depending on types of growth chambers that were available. This difference in f. c. , where temperature remains constant, has little influence on the growth cycle according to Friend et al. (24). The tops of the plants were kept in the original f. c. region, while growing, by lowering the platform on which the potted plants rested.

The Santa Ana, California, environment and the Yuma, Arizona, environment were selected because the author had previously found that daylength-insensitive small grains could be increased in the Santa Ana area from the period August 1 to November 12, and harvested in time to be replanted in Yuma, Arizona. Yuma is the usual site for November to May production of North Dakota winter increases. The effective day and night temperatures, from California weather records of the Santa Ana, California environment, for the period August 1 to November 12 are listed in Table 1, subsequently referred to as the Santa Ana regime.

Table 1. Effective day and night temperatures and daylength at Santa Ana, California.

Calif. increase period	Daylength		Effective temperature	
	Sunrise AM	Sunset PM	Day C	Night C
August	5 ⁰⁴	6 ²⁰	26.1	18.3
September	5 ²⁶	5 ³⁹	25.6	17.2
October	5 ⁴⁷	5 ⁰³	22.8	14.4
November	6 ¹⁰	6 ⁴⁵	20.6	10.6

The daylength and effective day and night temperatures of the Yuma, Arizona, environment for the growing period November 15 through May 15 are shown in Table 2. The formula for calculating effective day and night temperatures is given by Griffith (30). The temperatures and daylengths representing the Yuma, Arizona, environment will be referred to hereinafter as the Yuma regime.

Table 2. Effective day and night temperatures and daylength at Yuma, Arizona.

Arizona increase period	Daylength		Effective temperature	
	Sunrise AM	Sunset PM	Day C	Night C
Nov 15	7 ⁰⁸	5 ³⁸	22.8	12.2
Dec 15	7 ³³	5 ³⁴	17.8	6.7
Jan 15	7 ⁴¹	5 ⁵⁵	18.3	7.8
Feb 15	7 ²²	6 ²⁴	20.0	8.9
Mar 15	6 ⁴⁹	6 ⁴⁶	23.3	12.2
April 15	6 ⁰⁹	7 ⁰⁸	23.9	13.9
May 15	5 ⁴⁰	7 ³⁰	30.0	20.0

For the entire study the daylength, for either the Yuma or the Santa Ana regime, was considered as that period from sunrise to sunset. Official sunrise and sunset data were obtained from U. S. Naval Observatory Records. Francis (16) reported that using sunrise to sunset as length of day was satisfactory.

The "effective" day and night temperature changes were synchronized in the growth chambers with the controlled daylengths. The plant response of the daylength-insensitive durum line was checked against the response of quite similar durum germplasm (ZxB)xLk X Leeds F₄ used in 1966-1969 at Santa Ana in a search for a feasible August 1-November 15 increase site. The heading dates of the two were similar and days to heading were comparable to the 1966-1969 field tests at Santa Ana. This result ensured that the temperature and daylength regime established in the growth chambers was satisfactory. The night interruption periods imposed every 24 hours were from 1 hour duration to 5 hours with varying degrees of light intensity (Table 3).

Table 3. Schemes of night interruption.

Lamps	Foot candles	Time and duration of night interruption
Fluorescent and incandescent	1800 f. c.	1 hr. 11-12 PM
"	1800 f. c.	2 hr. 10-12 PM
Incandescent	100 f. c.	1 hr. 9-10 PM
"	10 f. c.	5 hr. 9:30 PM--2:30 AM
"	10 f. c.	2.5 hr. 10 PM--12:30 AM
"	5 f. c.	5 hr. 9:30--2:30 AM

The different durations of night interruptions and different light intensities imposed were to determine the quality and quantity of light required for the successful use of night interruption on long-day cereals. Light intensity was measured in foot-candles (f. c.). A light meter was used to measure light intensity in the field and growth chamber.

The 5 hour (9:30 p. m. --2:30 a. m.) night interruption scheme was imposed for 7, 14, 30, 60 or 90 days in different experiments to determine the number of night interruptions required to hasten heading and ripening of spring-type cereals by 30 days, during the short-day period of winter. After initial trials most of the night interruption periods were of 5 hours' duration commencing at 9:30 p. m. and ending at 2:30 a. m. Thus each 24 hour period consisted of approximately 10 hours light, 4 hours of darkness, 5 hours of light (incandescent) and 5 hours of darkness. The light and dark periods were planned so that the 10 hours of the fluorescent-incandescent light period approximated the 10 hours of daylength that is prevalent at Yuma, Arizona from November to February. This practical night interruption scheme is quite comparable to the simulated light-dark period of Riddel et al. (53) as shown in Table 4.

The night interruption with light was begun one month after planting, Paleg and Aspinall (48) allowed the same growth period before applying night interruption. Plants were dissected periodically in two experiments.

Table 4. Comparative night interruption schemes.

Experimenter	Day	Darkness	Night interruption	Darkness
Riddel et al.	8 hrs	4 hrs	8 hrs	4 hrs
Ebeltoft	10 hrs	4 hrs	5 hrs	5 hrs

Except for the growth chamber experiments in the summer of 1973 each test was terminated on completion of heading of all entries in the growth chamber in which night interruption was imposed. Only daylength-insensitive entries in the control (normal environment) would have headed. General heading response under normal conditions for sensitive materials was already known. Therefore, each test was terminated when the effects of night interruption had been learned. This was done because there was critical need of the growth chambers by others. Days to heading was the principal observation made on the plants in the growth chamber studies.

Days to heading was considered from date of sowing to head emergence from the boot. One emerged head per pot constituted date of heading for a given pot. The mean of the 3 pots was used for average date of heading. (In field nurseries in North Dakota, "heading" has occurred when 50% of the heads of a line are out of the boot.)

Field Studies

Studies in the field were carried on for one season in Santa Ana, California and four seasons at Yuma, Arizona. The North Dakota Agricultural Experiment Station has made winter increases at Yuma since 1954. Because of short days and cool temperatures about 150 days are required to produce a crop of barley, and 165-180 days to mature a crop of durum or hard red spring wheat.

For night interruption in the field two 1500 watt, 240 volt Quartz-Flood floodlights were mounted on poles and directed at the center of the plot area. The distance of the lights from the plots varied for different locations as shown in Figures 1 and 4. The light treatments (night interruption) were imposed 4 weeks after sowing and were terminated at swathing time (soft-dough stage) in all tests but one. In the one test the night interruption was terminated after 60 days. This was done to determine if night interruption influenced ripening. The time of night interruption and duration varied with the several tests.

The night interruption experiments in the field in Arizona began before review of literature. The last two years of testing included field increases of daylength-sensitive durum varieties. Hybrid wheat (Triticum aestivum L.), oats (Avena sativa L.), and barley (Hordeum vulgare L.) were included in the studies in 1972-73. The first two seasons, 1970-71 and 1971-72, of studies in Arizona included an 8

hour extension of daylength and a 1 hour break of the night period, respectively. All other studies imposed a night interruption period of 5 hours.

The small plot and lighting arrangement for the Yuma site is shown in Figures 1 and 2. Lights also were mounted and placed in an increase field of Ward durum. The arrangement for lighting the large field 145 meters away from headquarters was made possible through use of "Romex" light cord laid on the ground surface, and used for two years.

The 1972 Santa Ana, California experiment included 1 potential durum variety (D6674), 2 North Dakota durum varieties (Leeds and Rolette), and the near-isogenic daylength sensitive and insensitive lines previously described. Two replications of 3 meter rows 30 cms apart were sown in the plot where night interruption was imposed (Figure 3). The planting scheme was duplicated in the control plot which was 100 meters distant from the treated plot and not receiving any light other than normal daylight. Two 1500 watt 240V quartz lamps were mounted on a pole 3 meters above the ground. The pole was 2 meters from the plot area (Figure 4). The power was controlled by a time clock with lights going on at 9:30 PM and off at 2:30 AM. Much more intensity was achieved than necessary in the main plot area. Uneven illumination was expected. Planting was made August 2nd and night interruption began September 12.

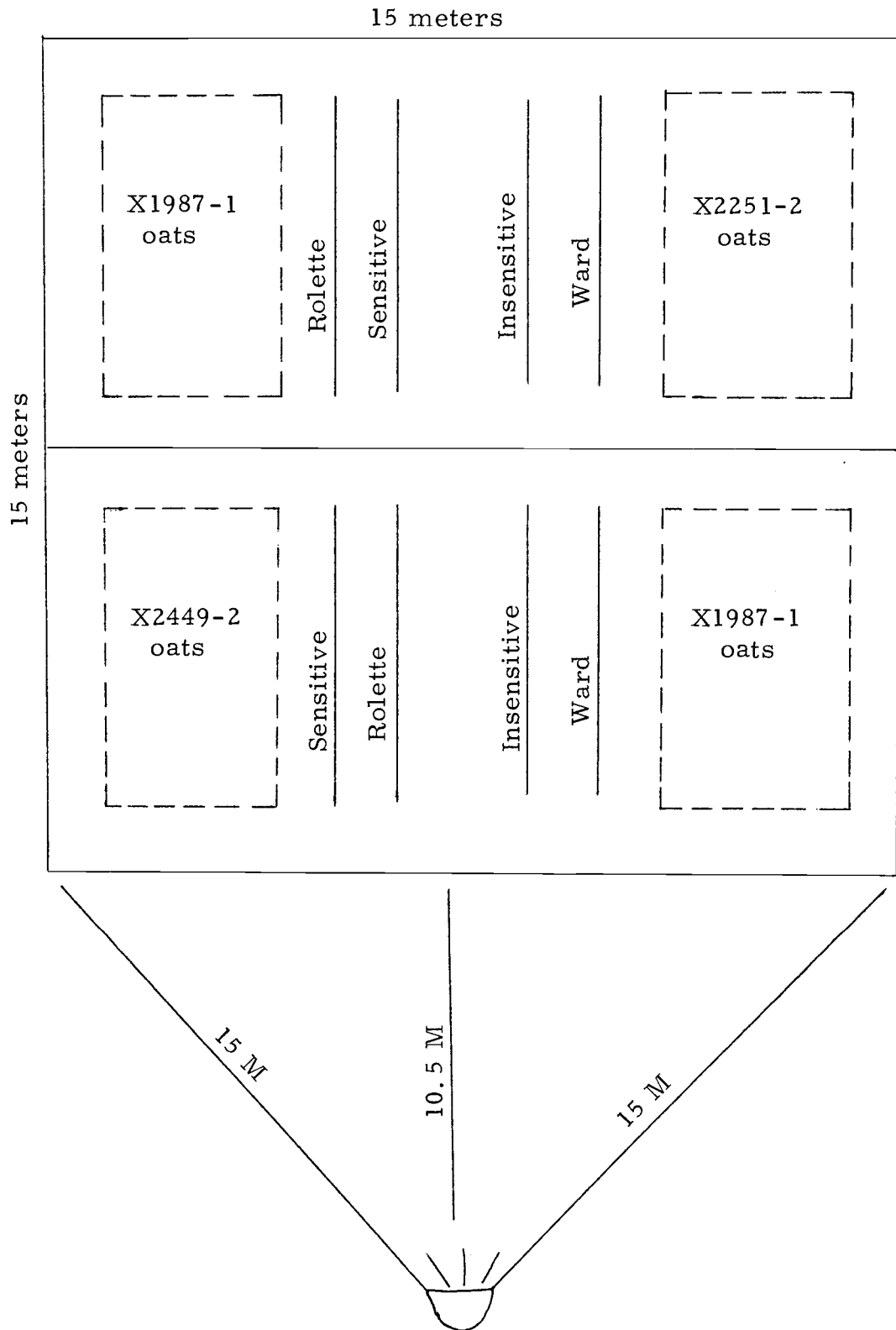


Figure 1. 1972-73 Arizona plot plan.

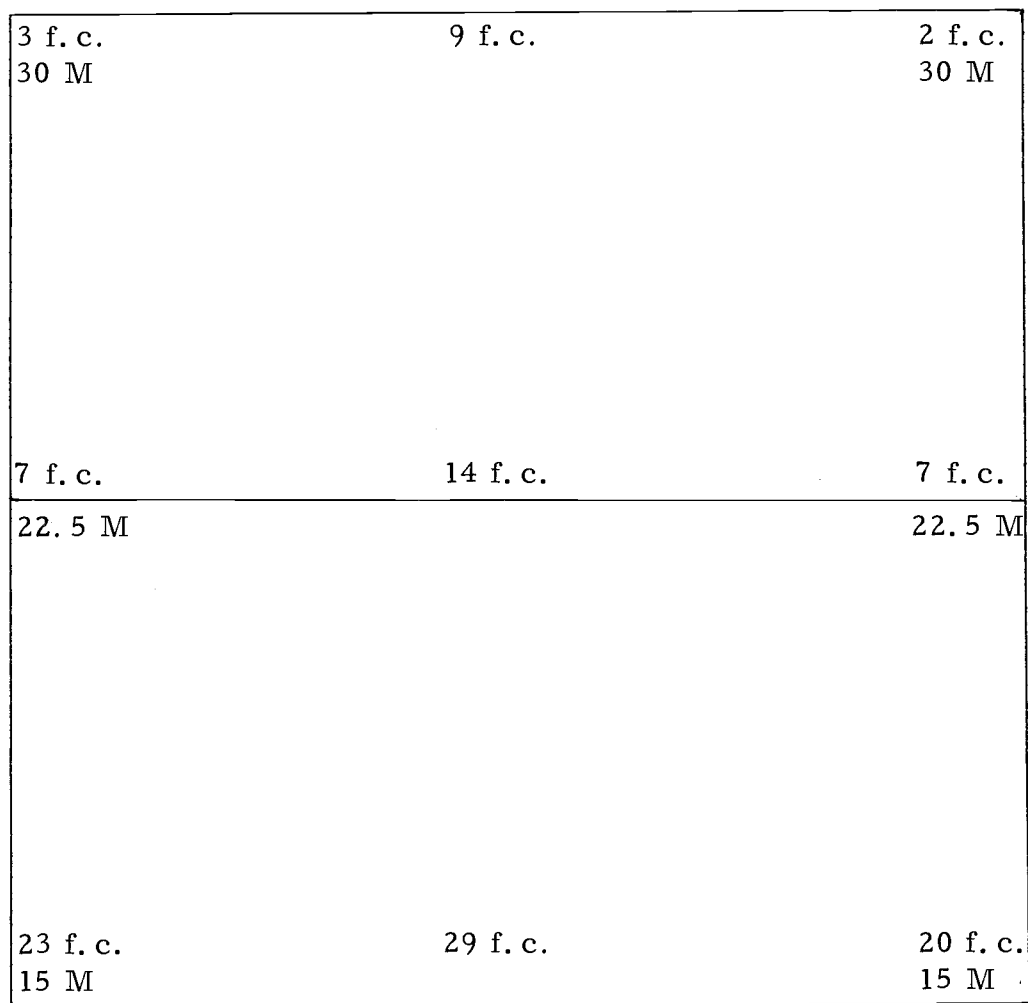


Figure 2. 1972-73 light intensity map.

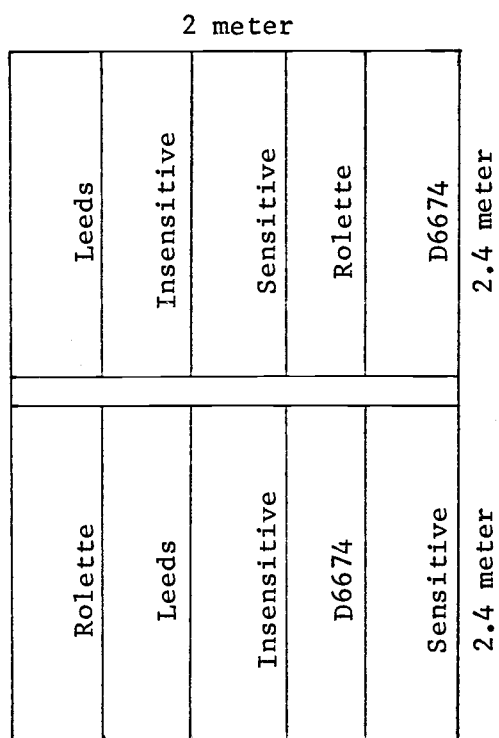


Figure 3. Planting scheme for Santa Ana study.

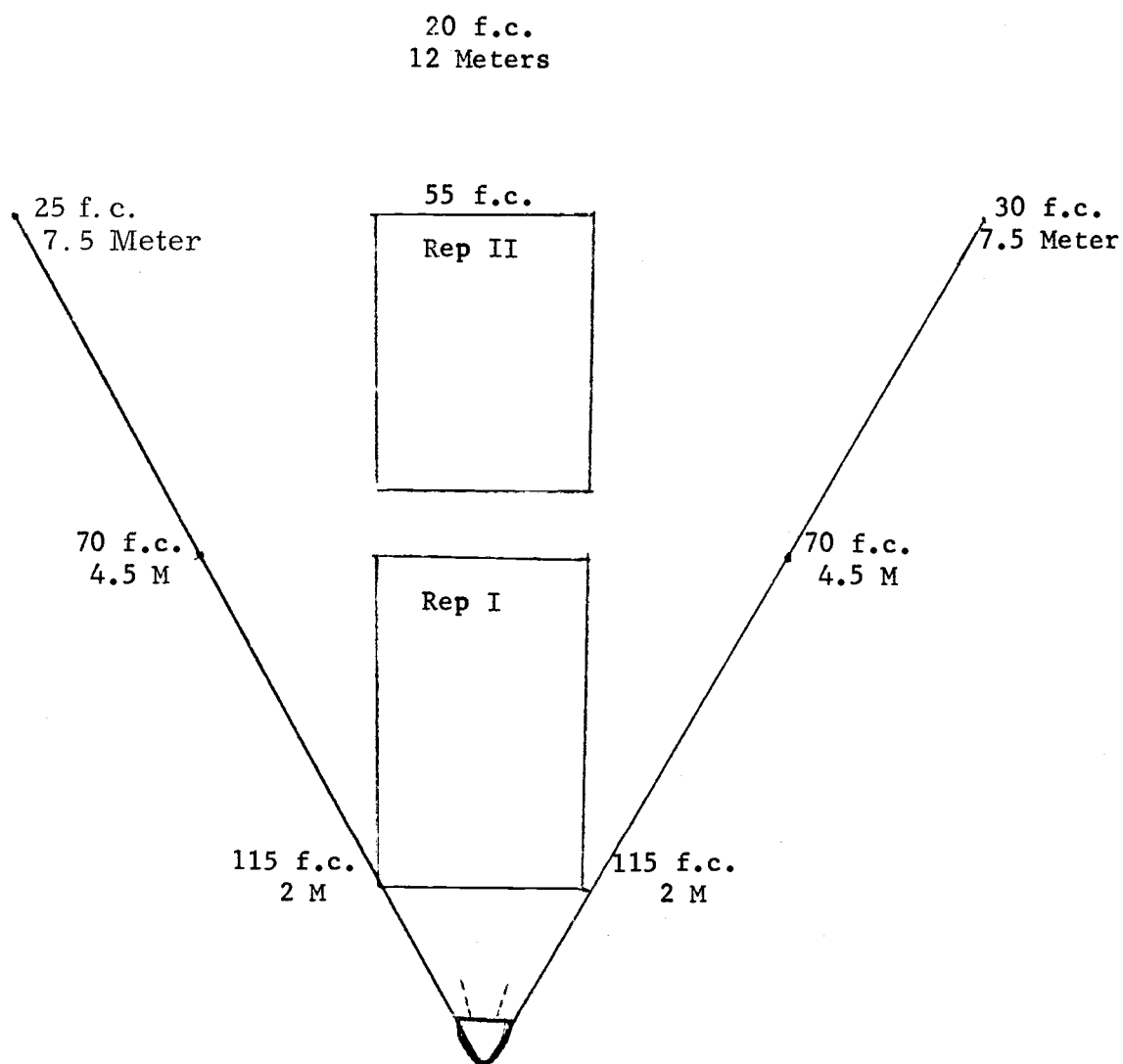


Figure 4. Light intensity map of Santa Ana plot.

Observations from both growth chamber and field studies included:

- a. Comparative date of heading
- b. Duration of night interruption
- c. Intensity of light

To observe the plants' response, other than heading, to night interruption the following data were gathered:

- a. Plant height and internode length
- b. Number of tillers
- c. Length of head
- d. Number of kernels per head
- e. Weight of kernels per head
- f. Protein content of kernels
- g. Seedling vigor in relation to protein content of the seed

The first 5 characters were determined in the usual manner of measuring, weighing and counting. The protein content of the seed was determined by the staff of the Cereal Technology Department on an "as is" basis using the Kjeldahl nitrogen test. The seed had been stored in paper packets at room temperature for more than 1 year.

To observe seedling response to protein content of the seed, 50 kernels each of Ward durum, Rolette durum, and the experimental oat grown under night interruption and normal conditions were germinated according to official procedure in State Seed Department germinators.

After 7 days the length and weight of the oat shoot and primary root of each germinated seed, was taken. After 10 days the length and weight of the durum shoot and primary root of each germinated seed was taken.

Per acre cost of night interruption was calculated on basis of

- a. Lighting equipment required
- b. Depreciation of equipment
- c. Cost of power

ANALYSIS OF DATA

Data were analyzed using standard statistical procedures. All experiments were analyzed as completely random design.

RESULTS AND DISCUSSION

Growth Chamber Results

The Effect of Night Interruption

In all the growth chamber experiments, adjusted to represent either the Santa Ana, or the Yuma environments, night interruption accelerated heading. As far as this writer is aware no studies have previously attempted to duplicate the effective day and night temperatures and the daylength of a given area in growth chambers.

The initial studies were simply concerned with the effect of night interruption on the heading of durum wheat. The 1300 f. c. intensity of light provided in the growth chamber for the daylight period also was used for the night interruption. Night interruption commenced 40 days after planting. The illumination, for night interruption, was imposed for 1 hour each night, 11-12 o'clock, until head emergence took place. The Santa Ana (Aug. 1-Nov. 15) growth regime was utilized (Table 2). Date of heading is shown in Table 5. The sensitive line headed at the same time as the insensitive line where night interruption was imposed (Figure 5). In the control chamber (no night interruption) the sensitive line did not head (Figure 6).

The night interruption schedule of 1300 f. c. for 1 hour was imposed on the near-isogenic durum lines in a growth chamber duplicating the Yuma, Arizona regime (Table 3). Plantings were made

Table 5. Effect of night interruption with 1300 f. c. of light for one hour on daylength-sensitive and daylength-insensitive near-isogenic durum lines under the Santa Ana regime.

Daylength response	Date of planting	Start of night interruption	Date of heading	
			Treated	Control
Sensitive	8-7-71	9-17-71	10-11-71	No head
Insensitive	8-7-71	9-17-71	10-11-71	10-11-71



Sensitive - Insensitive

Figure 5. Influence of night interruption on heading of the sensitive durum line.



Insensitive - Sensitive

Figure 6. Plant response under the normal Santa Ana (Aug. 1-Nov. 12) regime.

Oct. 28, 1971. By January 25, 1972 the insensitive line had headed in the control chamber but no heading of the insensitive lines had occurred in the chamber where night interruption had been imposed.

Investigation revealed that the incandescent lamps in the night interruption chamber were not functioning; hence as found by Lane et al. (40) and others (13, 25, 23, 47, 49, 50) the growth of these durum lines remained vegetative under fluorescent illumination alone.

Salisbury and Ross (60) quoted the results of several researchers which stated that red light prompted flowering in long-day plants. In this case where the fluorescent light illumination, consisting primarily of wavelengths in the 600-700 millimicron band (red), caused the durum to remain vegetative. Lane et al. (40) attributed such reaction to greater optical density of green leaves to red than far-red light. Thus under low-intensity light little red light may reach the tissues on the lower side of the leaves. Lane et al. (40) speculated that incandescent lamps which emit more far-red energy than fluorescent possibly maintain a higher Pfr level in the lower tissue than the fluorescent lamps, which in turn suggests that optimal induction in long-day plants occurs at intermediate phytochrome-Pfr levels with higher levels inhibiting induction. Incandescent light was provided and both the sensitive and insensitive lines headed by February 14.

To properly check the response of the sensitive and insensitive durums to 1 hour of night interruption under the Yuma regime the experiment was repeated in growth chamber supplying 1800 f. c. The sensitive and insensitive lines and Leeds headed in 80, 81 and 82 days, respectively, as shown in Table 6. There was a significant difference in the heading date of the insensitive and Leeds. Leeds, a newly released durum variety, was included in this test and responded as the other lines to night interruption but in the control chamber remained

Table 6. Plant response to night interruption of 1800 f. c. for 1 hr.

Durum lines	Daylength response	Regime	Sown	Date of heading	Days to head
Sel 190-5	Sensitive	Yuma	2-18-72	5-9-72	81
Sel 191-6	Insensitive	"	"	5-8-72	80
Leeds	Unknown	"	"	5-10-72	82
L. S. D. - .05					1.51

vegetative as did the sensitive line. Reaction of the sensitive line is shown in Figure 7.



Figure 7. Responses of sensitive and insensitive durum lines to a simulated normal Yuma winter environment.

Effect of Light Intensity and Time on Heading

The interaction of time and the light intensity of night interruption was observed under a simulated Santa Ana regime in the growth chamber with 1300 f. c. illumination for the night break. The duration imposed each night was for one hour in one experiment and 2 hours in the other. The longer exposure accelerated heading (Table 7). There

Table 7. The effect of heading of durum by imposing a night interruption of 1300 f. c. for one and two hours under a simulated Santa Ana regime.

Daylength response	Time of interruption	Length of interruption	Sown	Days to heading
Sensitive	11-12 pm	1 hr	8-7-71	65 a*
Sensitive	10-12	2 hr	11-15-71	60 b
Insensitive	11-12	1 hr	8-7-71	65 a
Insensitive	10-12	2 hr	11-15-71	55 b
Leeds (sensitive)	10-12	2 hr	11-15-71	60 b

* Means followed by different letters are significantly different at the 5% level.

was no significant difference in the heading of sensitive and insensitive within each lighting regime, but there was a significant difference in the heading dates of each line between lighting regimes. The acceleration of heading reflects the interaction of time and intensity. Such a response should be expected according to Salisbury and Ross (60).

The insensitive line in the control chamber headed in 65 days while the sensitive line remained vegetative as reported and shown previously.

Essential reaction was considered attained when plants headed in the growth chambers where night interruption had been imposed. Years of seed increase and experimentation in Yuma and Santa Ana has revealed that it requires about 135-155 days to mature durum at Yuma and about 115 days to mature sensitive durums at Santa Ana. The days to heading under night interruption was of chief concern. Lebsack et al. (42) notes that at Obregon, Mexico in some near-isogenic durum lines, similar to those used in this study, that the sensitive line required 130 days to head and the insensitive line required 130 days to head and the insensitive line required 63 days to head. These data are quite similar to results obtained at Santa Ana.

For the Yuma regime heading response was compared for night interruptions of 100 f.c. for 1 hour, 10 f.c. for 5 hours and 10 f.c. for 2.5 hours (Table 8). Heading is accelerated by higher light intensity according to Aspinall (2) and Aspinall and Paleg (3, 4). Though the plants headed under all treatments the least number of days to head for the sensitive lines was with the 100 f.c. for 1 hour treatment. There was a significant difference between the different environments. This effect of higher light intensity was as found by Friend et al. (20) also. Figures 8 and 9 show heading response.

Rapid acceleration of head emergence by higher intensity causes the plant to elongate earlier but also to cease earlier. Paleg and

Table 8. Heading response to two light intensities with varying durations of night interruption under the Yuma regime in the growth chamber.

Lines	Response	Days to heading		
		100 f.c. for 1 hour	10 f.c. for 5 hrs	10 f.c. for 2.5 hrs
Sel 190-5	Sensitive	81	84	89
Sel 191-6	Insensitive	81	79	81
Leeds	Sensitive	81	84	84
Mean of sensitive lines		81	82.5	84.7
L. S. D. - .05				1.24



Figure 8. Reproductive response to night interruption of 100 f.c. for 1 hour.



Figure 9. Reproductive response to night interruption of 10 f. c. for 5 hours.

Aspinall (48) reported this also. This was evident in the height of the plants (Figure 10).

The plant response for reproduction under the 10 f. c. --5 hour regime was good. Plant height was greater than at the higher intensity of night interruption. Under the light regime of 10 f. c. for 2.5 hours heading occurred for the two daylength-sensitive durum lines as well as for the daylength insensitive line. However, the sensitive lines were later. The plants under this regime more nearly approached normal height.



Figure 10. Comparative plant height response to light intensity X duration.

The comparative effect of different light intensities over an equal given period of time is shown in Table 9. The decrease to 5 f. c. in

Table 9. Reproductive response of daylength-sensitive durum lines to two night interruption treatments in a simulated Arizona environment in the growth chamber.

Daylength response	Days to heading	
	10 f. c. for 5 hours	5 f. c. for 5 hours
Insensitive	80	84
Sensitive	84	100
Leeds (Sensitive)	83	97
Mean	82 a*	94 b*

* Means followed by different letters are significantly different at the 5% level.

intensity delayed heading 14 to 16 days on daylength-sensitive durums. The insensitive line was slightly delayed. This test indicates that intensity is an important factor when using night interruption to hasten heading.

Interaction of Night Interruption and Number of Days Treatment Was Imposed

The simulated Yuma environment was used with a night interruption regime of 10 f. c. --5 hours. The data in Table 10 indicate that increasing the number of hours of exposure to a night interruption of 10 f. c. for 5 hours per night shortens the number of days to heading.

Table 10. Plant response (days to heading) to total number of hours of night interruption with 10 f. c. --5 hours per night.

Entry	Days to heading					Control
	245 hrs	185 hrs	150 hrs	70 hrs	35 hrs	
Sensitive	89	90		125		153
Insensitive	81	82				89
Rolette	80	84				115
Ward	83	80	90		117	131
Oats	81					122
Means	82.8	83.8	90	125	117	122
Observations	20	16	4	4	4	20
Error variance = 2.088*						

* Treatment mean square was highly significant. d.f. = 51

Effect of Temperature and Light Intensity on Heading

Higher temperature in conjunction with night interruption accelerates heading (Table 11). The higher effective temperatures of Santa

Table 11. Heading response of experimental plants to a night interruption regime of 5 f. c. for 5 hours under simulated Yuma and Santa Ana environments.

Entries	Daylength response	Simulated environment	Effective temperatures		Days to heading	Obs*
			Day	Night		
			C	C		
Leeds	Sensitive	California	23.9	15.0	59	5
Sensitive	Sensitive	California	"	"	63	5
Insensitive	Insensitive	California	"	"	52	5
Insensitive	Insensitive	Arizona	21.1	10.0	84	4
Sensitive	Sensitive	Arizona	"	"	100	5
Leeds	Sensitive	Arizona	"	"	97	4
Rolette	Unknown	Arizona	"	"	88	4
D6674 (Ward)	Unknown	Arizona	"	"	97	5

Error variance = 3.9304**

* Obs = observations.

** Treatment mean square was highly significant. d. f. = 28.

Ana, with the same light intensity as applied to the Yuma regime, hastened flowering 37-42 days. An interaction of light intensity and temperature similar to that found in this experiment was reported by

Friend et al. (20) and was confirmed in a personal communication from Aspinall of Australia. Two new durum entries were included in the growth chamber representing the Yuma regime.

Field Studies

Effect of Night Interruption and Temperature on Heading

Santa Ana, 1972-73, Field Experiments

The experiment in California was begun Aug. 2, 1972. Night interruption, 5 hours each night, was initiated Sept. 12. Excessive light was available. All lines except the sensitive had started heading by Oct. 4, in the plot with night interruption treatment. By Oct. 19 all lines were well headed. In the control plot Rolette and the insensitive line had started heading on Oct. 4. On November 13, when the experiment had to be discontinued Leeds, D6674 (Ward) and the sensitive had not headed. Figures 11 and 12 compare stages of growth control and treated plots. This response is good evidence that heading is controlled by photoperiod.

Plant samples were pulled and shipped to North Dakota. Control vs. treated plants are contrasted in photographs taken of material which had been shipped back to Fargo (Figures 13 and 14).

Leeds and D6674 (Ward) responded as daylength-sensitive and Rolette responded very much as daylength insensitive in the Santa Ana



Figure 11. Control plot at Santa Ana, California two months after sowing.



Figure 12. Night interruption plot of Santa Ana, California two months after sowing.



Figure 13. Effect of night interruption on sensitive and insensitive lines at Santa Ana, California.



Figure 14. Plant response to normal daylength during August-November at Santa Ana, California.

environment. Thus the response to daylength of the new durum varieties Rolette and Ward was established in the field.

Yuma, Arizona, 1972-73, Field Experiments

The fields planted November 17 had night interruption initiated on January 12 on a very limited area. The area of earlier heading and greater height is shown in Figure 15. Heading commenced on Feb. 18.

Figure 16 shows the area of durum induced to early heading and early maturity. This area was that which showed a light meter reading of 6 f. c. or more. Barley in a nearby field showed ripening response at 1.5 f. c. Distance from light source is shown in meters.

Night interruption was imposed until April 6 when the crop was at proper stage for swathing. The unlighted area of the field started heading March 20 and was not ready to swath until May 5. Four weeks were gained by use of night interruption. Paleg and Aspinall (48) in Australia hastened the maturity of barley by 3-4 weeks.

Every year there is damage from sparrows and wild doves. The treated (night interruption) area was devastated in a short time because of availability of choice food in an otherwise immature grain field.

By May 5th that part of the field growing under normal Arizona conditions completed growth at a greater height than the night interrupted segment (Figure 17).

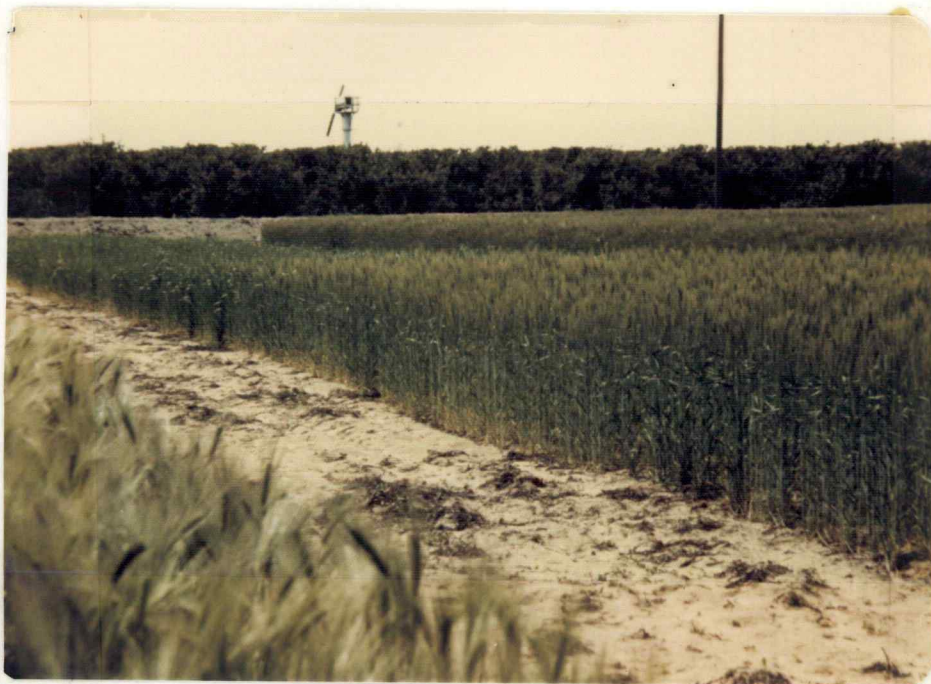


Figure 15. Effect of night interruption on daylength sensitive *Ward durum*.

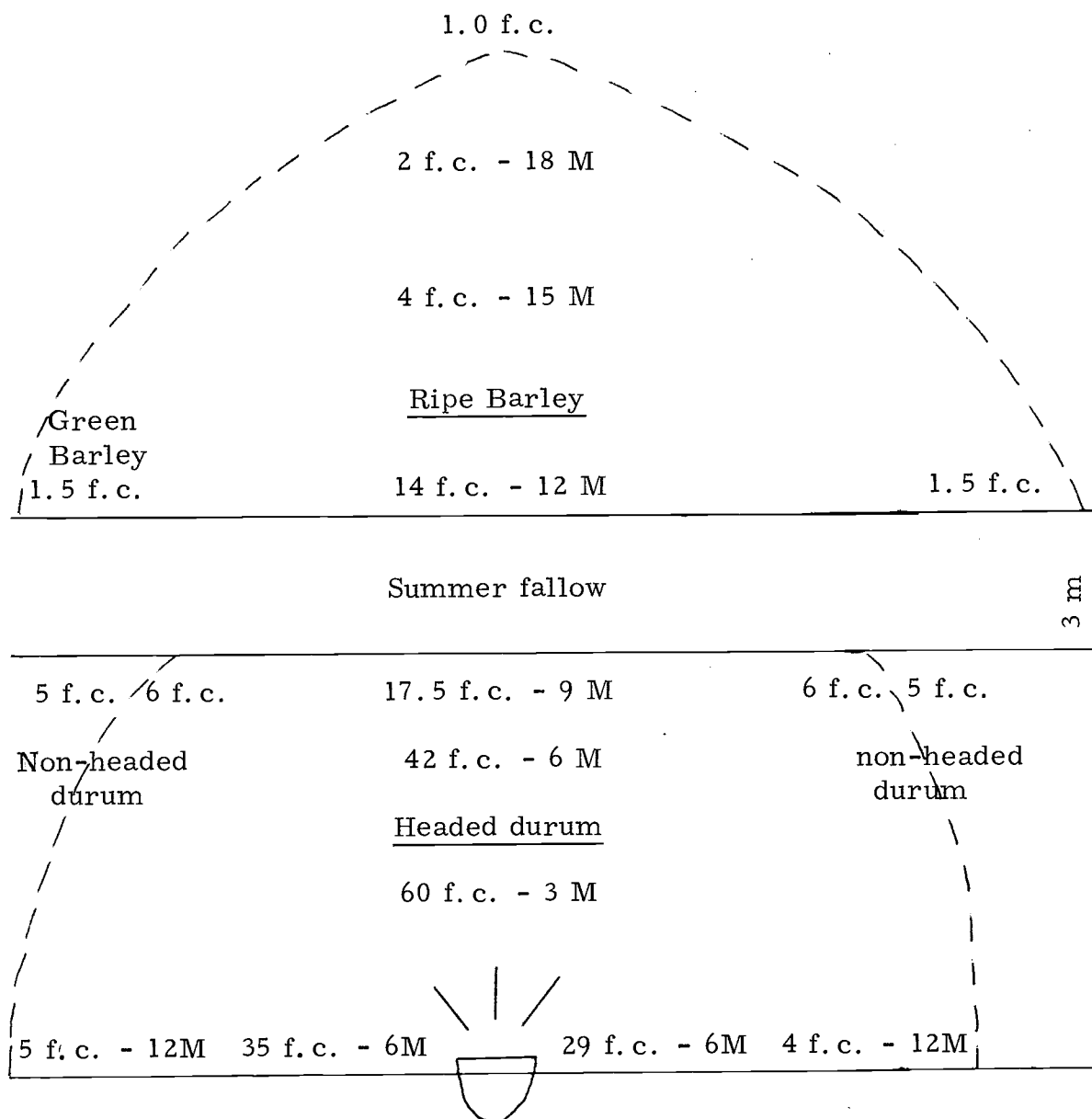


Figure 16. Light intensity in field area.



Figure 17. Growth under normal conditions vs growth under night interrupted regime in the Arizona regime.

Although early heading of the durum occurred only in the measured light area of 10 f. c. or more, the barley growing nearby was considerably advanced where 4 f. c. of light struck it. There was some response in the barley where 1.5 f. c. of light was present (Figure 18).

Aspinall (48) of Australia working with barley reported that with a light intensity of less than 1 f. c. the plants were significantly more advanced than the control plants. In a personal communication Aspinall agreed that the higher temperatures in his experiments were an aid as reported by this writer earlier.

In another field trial (1973-74), which was planted November 26, the night interruption was initiated January 14, but was terminated



Figure 18. Effect of night interruption on barley.

March 14. This experiment was to determine if continued treatment was required for early ripening. Heading occurred February 28 in the lighted area and March 20 in the unlighted area. The termination of night interruption on March 14, however, resulted in a cessation of the ripening process and by April 9 the treated area and the control area appeared the same. The entire field was ready to harvest May 5 (Figures 19 and 20). This date was no earlier than normal. Hence, night interruption must be continued at least 85 days (Figure 21).

Borthwick (personal communications) found that continued application of short photoperiods on soybeans from time of floral initiation had a measureable accelerative effect on maturity. He was of the



Figure 19. 60 days of night interruption.



Figure 20. Normal regime.



Figure 21. 85 days night interruption vs. 60 days of night interruption.

opinion that continued application of night interruption would have a similar effect on the maturing of long-day plants.

Responses Other Than Heading of Spring Wheat to Night Interruption with Incandescent Light

Floral Initiation

Dissection of durum plants grown in growth chambers with the Yuma environmental regime showed that floral initiation had not commenced 37 days after planting. Dissection was made on material from two growth chamber studies. In both growth chamber studies floral initiation was underway 8 days after night interruption was initiated. Paleg and Aspinall (48) noted that night interruption accelerated floral initiation.

Plant Development

Seed set (Tables 12, 13, 14, 15, 16) was significantly affected in 3 tests out of 5. Though 2 were not significantly affected the trend was toward reduction of kernel numbers by night interruption. This is to be expected according to Heslop-Harrison (34). Plant height appeared to be reduced by night interruption. This was not statistically analyzed. Other studies (2, 12, 19, 22, 47) have shown similar results. Head length was also affected (Table 14). Tiller numbers (Table 14) and 1000 kernel wt. (Table 15, 16) were not affected--similar results were obtained by Paleg and Aspinall (48) and Ryle (58).

Table 12. Effect of night interruption in the growth chamber on seed set in near-isogenic lines.

Treatment		Kernels per head
Sensitive	10 f.c.--5 hours	29.9
Insensitive	10 f.c.--5 hours	34.1
L.S.D. .05		6.9

Table 13. Plant response to varied hours of night interruption in growth chambers. Yuma environment was simulated.

Entry	Obs*	Hours of night interruption	Plant ht-cm	Response	Days to heading
				No. of kernels per spike	
Sensitive	4	245	76.2	25	91
"	4	185	88.9	32.7	92
Insensitive	6	245	81.3	25.7	84
"	5	185	83.8	37.6	83
"	2	0	114.3	52.5	91
Ward	4	245	86.4	33.0	82
"	3	150	88.9	45.0	92
"	1	0	106.7	49.0	133
Rolette	7	245	63.7	12.9	82
"	6	0	78.7	18.2	112

Error variance = 88.9537**

* Obs = observation.

** The d.f. were 33 and the treatment mean square was highly significant.

Table 14. Field response of Ward durum to night interruption in 1972-73, at Yuma, Arizona.

Treatment	Length of internode	Number of tillers	Plant height	Length of head	Number of kernels per head
Normal	9.33 cm	2.77	102.5 cm	7.27 cm	30.74
Night interruption	9.90 cm	2.85	99.5 cm	5.96 cm	22.3
L. S. D. - .05		.546		.73	5.67

Table 15. Field response of Rugby durum to night interruption in 1973-74, at Yuma, Arizona.

Treatment	Plant height cm	Kernels per head	1000 kernel weight
Normal	127.5	39.9	36.61
Night interruption	110.0	35.8	36.4
L. S. D. - .05		5.4	3.2

Table 16. Effect of light intensity on oats.

Intensity	Height cm	Kernels/panicle	1000 kernel weight in gms
25 f. c.	91.4	52.7	29.98
7 f. c.	121.9	62.5	29.75
L. S. D. - .05		8.8	3.1

Data of Table 17 show the increase in height in the early phase of night interruption but that eventually plants grown under normal conditions grew taller in this experiment.

Table 17. Comparative plant heights at beginning and end of treatments with different light intensities.

Light intensity f. c.	Meters from light source	Height in cms at two dates	
		3-12-74	5-3-74
12	1.5 Headed	72.4	96.5
54	3.1 "	69.9	96.5
38	4.6 "	68.6	96.5
28	6.1 "	78.7	99.1
26	7.6 "	86.4	101.6
20	9.1 "	86.4	106.7
12	10.7 "	78.7	106.7
12	12.2 "	78.7	106.7
10	13.7 "	76.2	111.8
6	15.2 (heads emerging)	73.7	119.4
5	16.8 (awns)	68.6	124.5
4	18.3 No awns	71.1	129.5
2	24.4 "	58.4	129.5
2	54.9 "	40.6	129.5

Plants were shortest under highest light intensity. Heading had occurred 45 feet from light source where the intensity was 10 f. c. Heads were emerging in the area receiving 6 f. c.

Protein

The effect of night interruption on protein content of durum and oats was studied. Table 18 shows that grain samples from areas in the field where night interruption had been imposed contained a higher protein content than those produced under normal Arizona winter conditions.

Table 18. Effect of night interruption on protein content of durum and oats.

Variety	Treatment	Intensity	Percent protein	Year
Ward	Night interruption	10 f. c.	11.7	1972-73
Ward	Control		7.9	1972-73
Oats		25 f. c.	15.6	1972-73
Oats		3 f. c.	13.6	1972-73
Sensitive	Night interruption	10 f. c.	17.5	1972-73
Sensitive	Control		13.8	1972-73
Rugby	Night interruption	10 f. c.	11.2	1973-74
Rugby	Control		8.5	1973-74

Although samples were drawn from four entries involving two types of cereals and from two seasons of production, the data indicate that night interruption of 60 days or 85 days hastened reproduction and

increased protein content. The starchiness of the control and the vitreousness (high protein) of the grain produced under night interruption are shown in Figure 22. Fertilizer was applied in the irrigation water during the growing season; therefore, plants in the control and night interrupted plots should have received comparable amounts of nitrogen.



Figure 22. Effect of night interruption on kernel quality.

Protein Content of Seed and Its Effect on Seedling Vigor

Since night interruption appeared to produce the same effect as a long day, apparently the same plant hormonal activities were initiated for protein synthesis, which is known to be stimulated by light

according to Salisbury and Ross (60). More research is needed on the effects of night interruption on protein content. If the protein content of seed produced on the earlier maturing plants under night interruption is increased, night interruption could have an additional advantage according to Lopez and Grabe (45) and others (55, 63), who reported that seed with higher protein content promotes seedling vigor and higher yields.

The seedling vigor of the Ward and Rugby durums was investigated by germinating 50 seeds each of both the controls and the seed produced under night interruption. The seedling vigor of oats grown under inadequate and adequate light intensities for successful night interruption was also investigated.

The durum seedlings were measured and weighed after being in the germinator 10 days. The oat seedlings were measured and weighed after 7 days in the germinator. Data are presented in Table 19. The shoot weight of the durum showed significant effect of high protein. All of the oat growth parameters measured responded significantly to the higher protein.

Table 19. Seedling response as related to protein content of the seed.

Entry	Treatment	Shoot		Roots	
		Length cm	Weight gms	Length cm	Weight gms
		*	*	*	*
Ward	Night interrupted	10.596 a	.1156 a	16.676 a	.07966 a
Ward	Control	10.342 a	.0893 b	16.368 a	.08614 a
Rugby	Night interrupted	10.28	.09674 a	16.512 a	.05712 a
Rugby	Control	9.974 a	.08152 b	16.01 a	.055 a
Oats	25 f.c.	8.082 a	.07138 a	11.44 a	.03744 a
Oats	3 f.c.	7.744 b	.0438 b	8.83 b	.0286 b

* Means followed by different letters are significantly different at 5% level.

Night Interruption - Per Acre Cost and Estimated Benefit

To ascertain the economic feasibility of using night interruption for early increases, a comparison was made of the three increase schemes possible for North Dakota. These schemes are as follows:

- A. A normal North Dakota increase without a winter increase in the south.
- B. A normal Arizona winter increase preceding a North Dakota summer increase.
- C. An Arizona winter increase with the aid of night interruption.

Table 20 compares the estimated production over a 3 year period.

Table 20. Three increase schemes and comparative production.

A/ Normal increase in North Dakota.

Ha	Estimated Kg/Ha		Potential tons	
.4	X 2688	=	1.09*	1st year
16**	X 2016***	=	32.3	2nd year
480	X 2016	=	967.7	3rd year

* Increase under normal conditions and 20" rainfall.

** On basis of seeding rate of 1 bu per acre.

*** State average under normal planting dates.

B/ Normal winter increase in Arizona + a North Dakota increase.

Ha	Estimated Kg/Ha		Potential tons	
.4 in Arizona	X 3696*	=	1.5	winter
22	X 1344**N. Dak.	=	29.6	1st year
440	X 2016	=	887.0	2nd year
13,200	X 2016	=	26,611.2	3rd year

* Based on average normal production at Yuma.

** Based on North Dakota yields from later planting.

C/ Arizona winter increase using night interruption and North Dakota summer increase.

Ha	Estimated Kg/Ha		Potential tons	
.4 in Arizona	X 3360*	=	1.3*	winter
20	X 2016 in N. Dak.	=	40.3	1st year
600	X 2016	=	1,209.6	2nd year
18,000	X 2016	=	36,288.0	3rd year

* Based on reduced yield because of night interruption.

The use of night interruption possibly could increase the production of valuable seed 33% over normal Arizona increase by the third year of increase, and could be nearly 30 times greater than a normal North Dakota increase during the same period. The possible yield advantage of a new variety is not considered in these calculations.

The yields of Arizona seed increases are based on the last 3 years of Arizona field increases. The yields under night interruption treatments were calculated from relating 40 kernels per head (Table 15) to average yield of 55 bu/A and 36 kernels per head, resulting from the effect of night interruption to unknown yield. Yield was calculated at 50 bu/A.

To promote an earlier increase, the following portable lighting equipment, producing a minimum of 6 ft-c of light, would be required for one acre (Table 21).

The metal equipment would be depreciated over a 10 year period, and the cables depreciated over a 5 year period. Thus, the annual cost of equipment would be \$285.50 per acre.

The annual power costs for night interruption of the 200' X 200' field would be as follows:

$$\begin{aligned} &24 \text{ lamps} \times 1500 \text{ watts} \times 5 \text{ hours nightly} \\ &\quad \times 90 \text{ days} \div 1000 \text{ hours} \times .014\text{¢ per KWH} = \\ &\quad \underline{\$226.80 \text{ per acre.}} \end{aligned}$$

The annual additional cost per acre for producing 55 bushels of durum would be \$226.80 power costs plus \$285.50 annual equipment

cost. Thus, the additional cost for a 30 day acceleration in harvest date would be \$9.31 per bu.

Location of poles and horizontal and vertical projection are shown in Figure 23. An isofoot candle in Figure 24 shows the light intensities.

Table 21. Equipment required to produce a minimum of 6 f. c. on one acre of land.

6	24' metal poles (20' mounting height) in 8' sections @ <u>3.09 per foot</u>	<u>772.50</u>
6	bars (for mounting 4 quartz lamps) @ <u>38.25</u>	<u>229.50</u>
24	Quartz flood lamps (Af. 1500 watt-240V) @ <u>40.00</u>	<u>960.00</u>
1	time clock @ <u>20.00</u>	<u>20.00</u>
625'	electric cable @ <u>\$.20/ft</u>	<u>125.00</u>
300'	electric cable @ <u>\$.08/ft</u>	<u>24.00</u>
10	waterproof connectors @ <u>10.00</u>	<u>100.00</u>
1	waterproof contactor @ <u>475.00</u>	<u>475.00</u>
	Total	<u>2706.00</u>

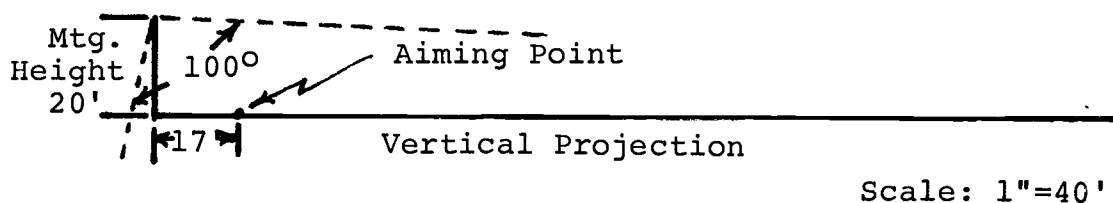
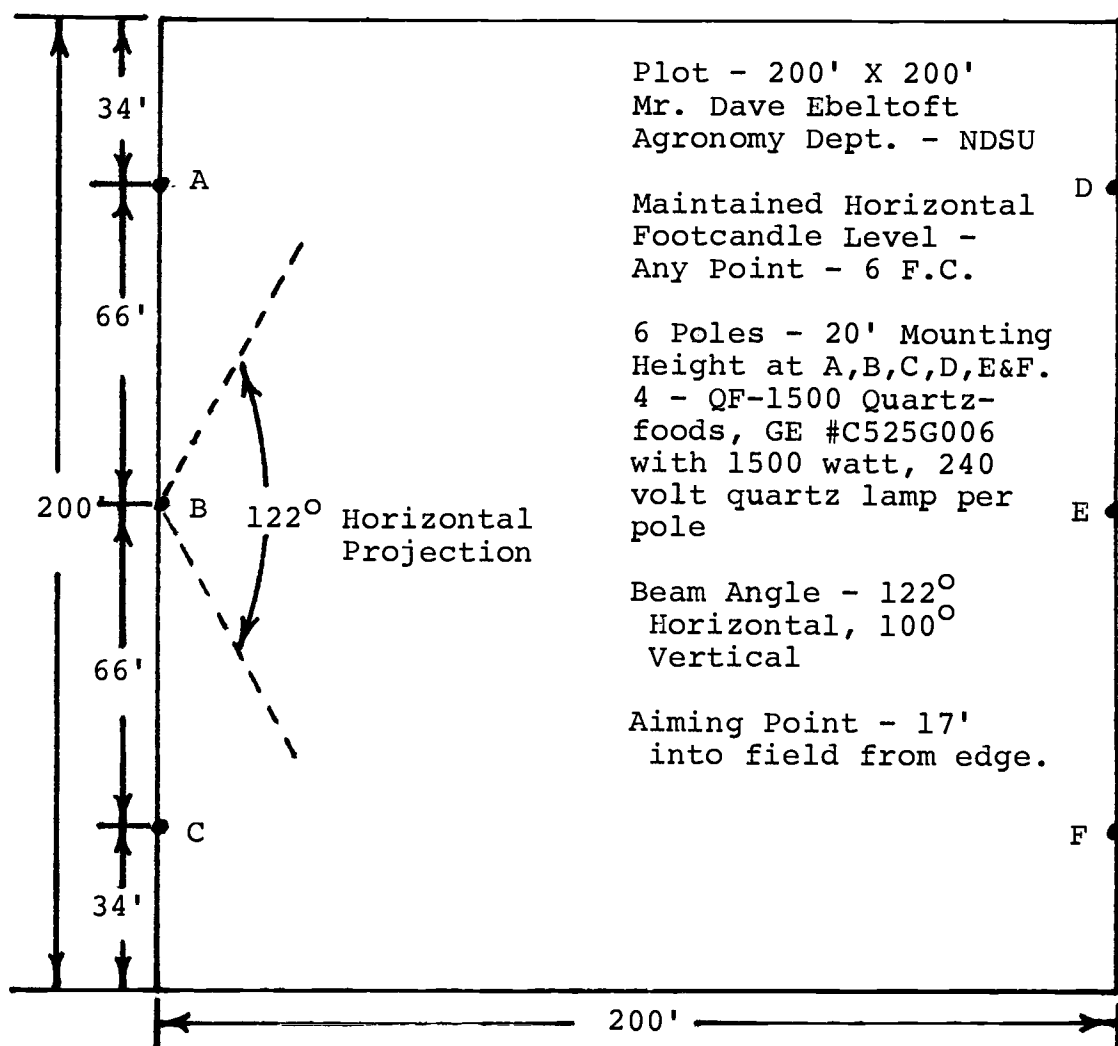
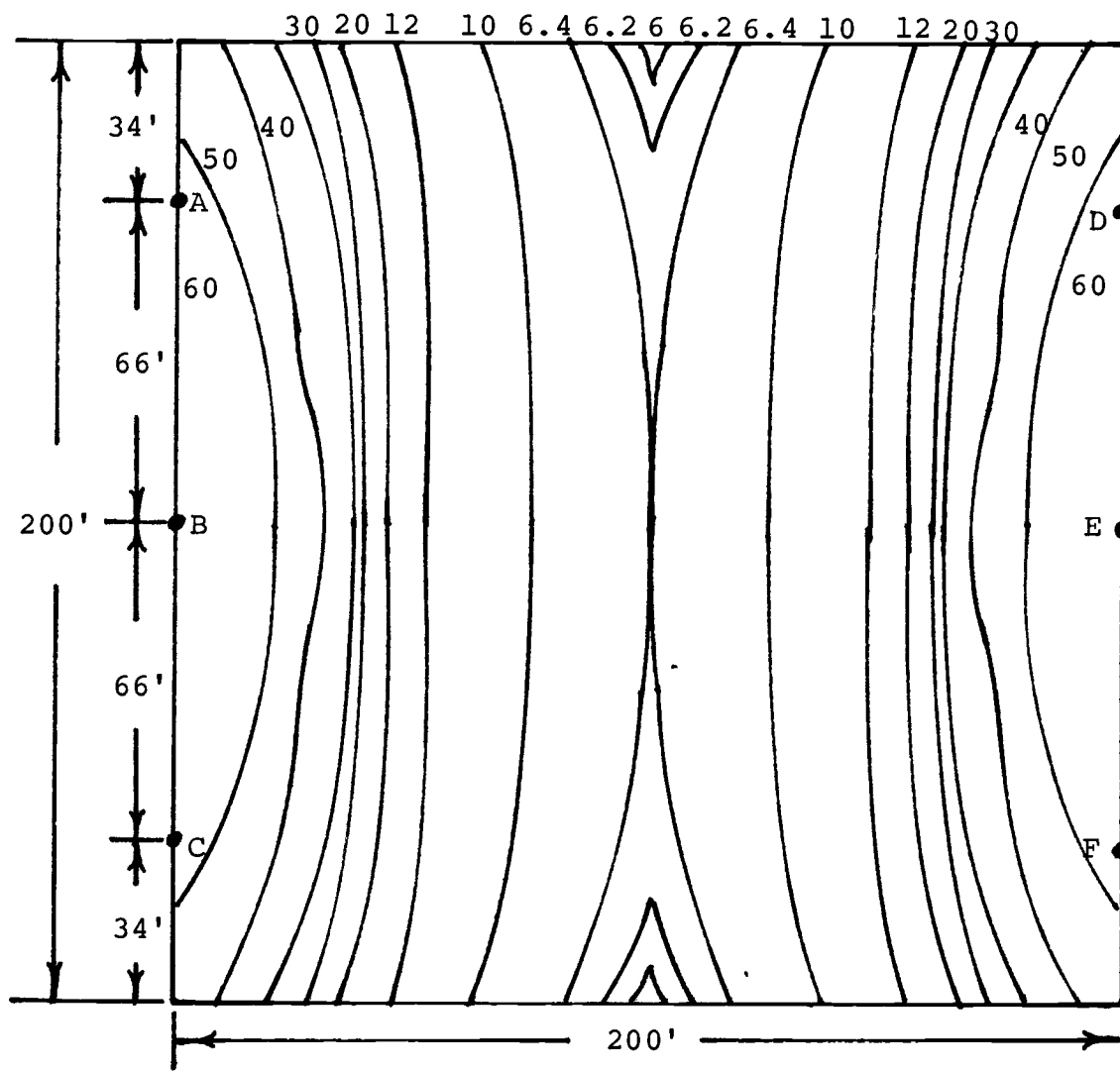


Figure 23. Field Lighting Scheme.



Approx. Insofootcandle Diagram

6 Poles - A,B,C,D,E&F - 20' Mounting Height
 4 - QF-1500 Quartzfloods per pole, 1500 watt, 240 Volts
 Aiming Point - 17' into field from edge
 Beam Angle - 122° Horizontal X 100° Vertical

Scale: 1"=40'

Figure 24. Light intensity in footcandles achieved on the field from proposed system.

GENERAL DISCUSSION

The major objective of this investigation was to determine if the harvest of daylength-sensitive long-day cereals grown during the winter in Arizona could be hastened 30 days by the use of night interruption. A secondary objective was to ascertain the number of night interruptions required, and the light intensity and duration needed for each night interruption.

Data collected in these experiments supported results of several previous investigations, and new fields of research were suggested.

The investigations revealed that the heading of long-day cereals growing in a short-day regime can be initiated and accelerated by the proper quality and quantity of light used for night interruption. Night interruption was used to create short nights. The phenomenon that the dark period must be shorter than the "critical night" to induce flowering is stated by Salisbury and Ross (60).

Investigations in the growth chamber and in the field indicated that at least 85 days of night interruption in the Arizona environment were required to achieve a 30 day gain in harvest date. Sixty days of night interruption hastened heading but did not hasten ripening. Thus, it was shown that continued exposure to night interruption had an accelerative effect on maturity and night interruption must consist of 5 hours/night of 6 f.c. light intensity to stimulate maturity in the desired time.

The studies revealed that a warmer environment with night interruption causes heading and maturity to take place earlier, as shown in Table 11 where the California environment was compared to the Arizona environment. It was shown that a higher intensity of light during night interruption required less exposure time (Table 8).

Although only a low intensity of light (10 f. c.) was required for night interruption, proper proportion of the light must be in the far-red wave length to induce heading. The far-red wavelength was provided by incandescent lamps. Fluorescent lights (red) of much higher intensity, when the only light source, did not induce heading in the growth chamber. Friend et al. (25) speculated that the earlier heading under far-red (incandescent) lights is due to higher energy of the far-red wave length.

The use of night interruption to hasten heading and ripening results in shorter plants, shorter heads and fewer kernels (Tables 14, 15, 16, 17). This has been attributed to the fact that when heading is initiated changes in the ontogeny of the plant takes place (Friend et al. , 22).

Fewer kernels per head, resulting from the effect of night interruption, suggests lower yields in the California and Arizona increases but the possible gain of 30 days in planting time in North Dakota could mean an increase of 13-40% according to Jensen and Weiser (37).

Over a two-year period involving two durum varieties and one oat line the night interruption, which induced heading, also caused the seed to have a higher protein content. This phenomenon should be studied further.

The effect of higher protein on seedling vigor was investigated. The shoots of the durum seedlings produced from the high protein seed were significantly heavier than those produced from the lower protein seed. The other growth parameters studied were not significantly affected. The higher protein content of oat seeds did produce heavier and larger seedlings.

At an additional cost of about \$9.31 per bushel it is possible to return important germplasm to North Dakota for planting 30 days earlier. This cost is minimal when related to the possible gain in number of bushels produced in the third year.

SUMMARY

Four years of night interruption studies in the field, on long-day cereals, were conducted during the fall and winter season in California and Arizona respectively. Similar experiments were carried on, during the same period, in growth chambers which were adjusted to simulate the Santa Ana, California and the Yuma, Arizona environments. Incandescent lamps were used for night interruption.

The studies revealed that:

1. The spectral composition of light is important to the photo-periodic process. Lack of incandescent lights (high in far-red) delayed considerably or prevented the reproductive phase in the long-day durum.
2. Night interruption imposed one month after seeding induces floral initiation in the long-day plant in 8 days.
3. Kernels per head are reduced by use of night interruption but kernel weight appears to be unaffected.
4. Plant height is reduced but tiller numbers appears unaffected by the night break.
5. Night interruption, in the field appears to produce kernels having a higher protein content.
6. Oat seedlings produced from the high protein seeds were larger and heavier than those produced from the lower protein seeds.
7. The shoots of durum seedlings produced from the seeds having

a higher protein content. The weight of the roots and the length of the root and shoot were not significantly affected.

8. The continuing of night interruption after heading took place was found to have an accelerative effect on the ripening of the long-day cereals.

9. A plant breeder can easily determine the response of his early generation material to daylength by growing a few seeds of a given line in each of two growth chambers which are adjusted to simulate the Santa Ana, California environment. One chamber would serve as a control. The other would have night interruption imposed in it.

10. During the 3 month period of approximately August 10 to November 10 near Santa Ana, California night interruption of 5 f. c. / 5 hours is sufficient to induce the heading of daylength-sensitive durums. Night interruption to be imposed one month after planting and continued until ripeness. The effective day and night temperature means for the period are 23.6 C and 15.1 C respectively.

11. During the period of November 15 to May 15 near Yuma, Arizona a night interruption scheme of 6 f. c. / 5 hours is sufficient to induce the heading of daylength-sensitive cereals. Night interruption to be imposed about one month after planting and continued until ripeness. The effective day and night temperature means for the period are 21.2 C and 10.3 C respectively.

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