CROWN AND TILLER FORMATION IN WHEAT AND BARLEY

Thesis for the Degree of Ph. D.
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WILLIAM ELLIOTT HALL
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This is to certify that the

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IN WHEAT AND BARLEY

presented by

William Elliott Hall

has been accepted towards fulfillment
of the requirements for

PhD degree in Crop & Soil Sciences

C M Harrison
Major professor

Date Aug. 28, 1969

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ABSTRACT

CROWN AND TILLER FORMATION
IN WHEAT AND BARLEY

By

William Elliott Hall

Experiments were conducted to study the crown location and tiller formation in wheat and barley. The location of the crown was manipulated by altering light and seeding depth.

Light played an important role in determining the location of the crown. Seedlings grown in pots under tar paper lids developed crowns above the soil surface after the coleoptiles were threaded through holes in the lids into the light.

Environmental conditions promoting extreme elongation between the seed and crown caused wheat and barley seedlings to produce one or more subcrown nodes and internodes. Barley had shorter and more numerous subcrown internodes than wheat, but failed to emerge from excessive seeding depths.

Wheat and barley seedlings developed second crowns above the original crown when emerged seedlings were partially covered during the tillering stage. The second

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crown developed closer to the soil surface than crowns from shallow seeding.

Varying the light intensity by growing seedlings through colored beads disclosed the role of light in crown location.

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CROWN AND TILLER FORMATION IN WHEAT AND BARLEY

By

William Elliott Hall

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1969

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The moral support and sacrifice of the author's family during the course of this investigation is also recognized and deeply appreciated.

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INTRODUCTION

Early agriculturalists recognized the value of tillering and crown formation in small grain plants. Tiller production is variable, however, and a common practice is to use excessive seed to insure a sufficient number of heads per unit area for high yields. Such excess seeding may be detrimental to yields when limited rainfall results in plant competition for available moisture.

A better understanding is needed of the influence of environmental factors affecting the crown region. The crown contains the meristematic tissues of overwintering wheat and barley varieties from which comes the resumption of growth in the spring. It is also the origin of the secondary root system and the site of tiller bud formation. The recent development of the semi-dwarf wheat varieties whose coleoptile length is also reduced (Allen *et al.*, and Sunderman, 1964) has added to the problem of establishing a stand by restricting seeding depth.

With the advent of hybrid wheat production and the anticipated high cost of seed, the effect of seeding rates will be carefully analyzed and reduced to a minimum making tillering increasingly important.

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The purpose of this research is the study of factors affecting the location of the crown and its relationship to tillering. If it were possible to manipulate the location of the crown, better winter survival and more uniform tiller production might be achieved. Cultural practices to promote the greatest possible elongation of the subcrown internode might alleviate the depth of seeding problem of the semi-dwarf wheat varieties.

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REVIEW OF LITERATURE

Several references are available explaining the developmental anatomy and morphology of grasses. Percival (1921) has written a complete treatise on wheat and wheat production. Avery (1930) and McCall (1934) made anatomical studies comparing the development of embryos and seedlings of corn, wheat and oats. Bonnett (1961) has given a detailed description of the histology and development of the oat plant.

Some confusion has existed in the terminology and interpretation of the grass embryo and its development. McCall (1934) did much to clarify the terms and explain the homologies existing between three genera *Zea*, *Triticum*, and *Avena*. In all three, the scutellum diverges from the second node and the coleoptile from the third node. The difference between the three lies in the location of intercalary growth during germination and seedling development. Esau (1953) presents the modern view of anatomical differentiation in shoot and axes and cites 73 references on this complex growth process. Robbins (1931) compared the tillering of cereals to the branching of other herbaceous plants except that it occurred at the lower nodes. He stated that the average depth of the tillering node in cereals was about

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one to two centimeters, regardless of the depth the seed had been planted. Bonnett (1964) described tillering as "the normal process of branching in barley, other cereals, and grasses. It is the production of shoots with unexpanded internodes in the axils of the leaves which originate at the node of the stem just beneath the surface of the soil." Weaver (1926) stated that the secondary root system (crown roots) of wheat developed within an inch or two of the soil surface. The number of roots increased somewhat in proportion to the number of tillers. Locke and Clark (1924) described the normal situation of the wheat plant developing two sets of roots. The seminal, or seedling roots, were produced at the time of germination of the embryo. The second set, the coronal or permanent roots arose from the crown usually just below the surface of the ground. They reported, however, on two examples where the crown roots failed to develop and the seminal roots sustained the wheat crop.

Many early workers sought to determine the effects of various cultural practices on the number of tillers (Buffum, 1898 and Grantham, 1917). Researchers today usually include tiller counts as influenced by treatments and discuss its importance in relation to yield (Aamodt *et al.*, 1935; Rohde, 1963 and Woodward, 1966; Brown *et al.*, 1961; Kmoch *et al.*, 1957; McNeal and Davis, 1954).

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A few studies have been aimed at the control of tillering. Bonnett (1933) found that "when the reproductive stage began, the vegetative stage (tillering) was retarded. . . . When internode elongation began, axillary tiller buds were no longer formed." He concluded late varieties produced more tillers because of the extended vegetative period. Aspinall (1961) working with barley did not find tillering restricted to early phasic development but continuous even to heading when sufficient nutrients were supplied. He pointed out that perennation of grasses is attributed to the production of vegetative tillers after flowering of early tillers. In a later paper (1963) he concluded "that whatever system of apical dominance was operative within the barley plant, the distribution of mineral nutrients was vitally involved."

Leopold (1949) demonstrated the influence of auxin in tiller production of two grass species, one of which was barley, and that apical bud dominance reduced tillering. In his text, Leopold (1955) pointed out that in addition to the apical bud exerting inhibitory effects on lateral buds, young expanding leaves were also rich sources of auxin and known to inhibit the development of axillary buds.

Wardlaw (1952) reviews the biochemistry and morphogenesis of plant organs and states that indoleacetic acid applied to cut surfaces of roots and shoots stimulates root and shoot growth. Inge and Loomis (1937) studied the elongation c

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Friend (1965) found that the total number of leaves per plant obtained by increasing light intensities from 200 to 2500 footcandles was brought about by an increase in both the rate of leaf emergence on individual axes and an increase in the rate of tillering. As the rate of tillering increased to a greater extent than rate of leaf emergence, he concluded apical dominance was reduced by increasing light intensity. An increase in temperature from 10 to 25 C also increased the total number of leaves and tillers, but the rate of leaf emergence was stimulated more than tillering so that apical dominance appeared to be increased by higher temperatures.

Richards, Hagen, and McCalla (1952) have summarized work relating to influence of soil temperature on seedling morphology. There was general agreement that high temperatures, as they stimulated plant growth, produced greater elongation of the subcrown internode. Dickson (1923) observed that with temperatures above 20 C, the growing point of the culm broke through the coleoptile before emerging from the soil. At temperatures below 16 C, the coleoptile elongated faster than the growing culm until after emergence from the soil. He also studied the effect of temperature on tiller production in spring and winter wheat varieties. Optimum temperature for tiller production in Marquis spring wheat was found to be 20 to 24 C. Below 8 and above 3

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and above 32 C few tillers were formed. The cardinal temperatures for shoot development in Turkey winter wheat were in general about 4 C below those of spring wheat. Taylor and McCall (1936) noted that Turkey winter wheat had a tendency to produce tillers at the coleoptile node. Temperature had a definite effect on this characteristic. At 12 C more than 80 percent of the plants produced coleoptile tillers; at 16 C about 50 percent had tillers at the coleoptile node, and with temperatures above 20 C, coleoptile tillering seldom occurred. The spring wheat variety, Hard Federation, did not produce coleoptile tillers at any temperature.

Light plays a most important role in growth. Seliger and McElroy (1965) reviewed the biological effects of light in addition to explaining its physical characteristics and measurements. Gieger (1965) described light measurements as well as other environmental determinations at the soil surface. Hurd-Karrer (1933) reviewed the early work and presents the differences of photoperiodic response in rate of development and yields of winter and spring wheat varieties. The classical review of McKinney (1940) explained the action and interpretation of relationships between photoperiodism and vernalization. Hendricks (1958) discussed the initiation of the flowering stage of growth as a result of photoperiodism. Guitard (1960) observed that various photoperiods during different stages of growth resulted in differen

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different photoperiodic responses. Increased length of light period during the internode elongation (early vegetative) stage caused earlier initiation of tillering relative to the development of the first culm. The longer the duration of tillering, the greater the number of tillers produced. Increases in length of photoperiod following elongation of the first culm did not influence the number of tillers. Varietal differences in photoperiod response in relation to tillering has been reported by several workers (Downs et al., 1959; Aspinall, 1966; Wiggans and Frey, 1957; and Williams and Williams, 1968).

The list of workers showing increased tillering as a result of fertilizer is extensive. Included are: McNeal and Davis (1954), McNeal (1960), Brown et al. (1961), Rohde (1963), and Woodward (1966). Only Aspinall (1961, 1963) suggested that nutritional availability was responsible for prolonged tiller production or resumption of tiller growth after the floral stage had been initiated.

The other major cultural practice influencing tiller formation is rate of seeding. From the work of Buffum (1898) to the present, there are papers reporting the effect of seeding rate, or row spacing on tiller production, as it pertains to a component of yield (Sprague and Farris, 1931; Wilson and Swanson, 1962; Kindra et al., 1963; and Middleton et al., 1964). Bonnett (1933) defines tillering as "the

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normal process of adjustments of growth and is a method of utilizing the environment to a fuller extent."

There have been few studies on the depth of crown formation or location of crown roots. Pinthus (1969) indicated that coronal roots were affected by environmental factors only as tiller production was affected. McKinney (1923) found depth of tillering varied with environmental factors such as depth of seeding, amount of light and temperature. Webb and Stevens (1936) observed that hardy varieties of winter wheat have deeper crowns than do non-hardy varieties. This emphasizes the importance of the location of the crown. Friedberg (1932) found the tendency to produce tillers from the coleoptile a varietal characteristic, as did McCall and Taylor (1936). He pointed out the advantage such varieties had for recovery when the crown was damaged by frost. Janssen (1929) further emphasized the importance of the crown when he stated that in winter wheat all new roots in the spring developed from the crown of the plant and not from old roots. Other workers (Aamodt et al., 1935; Pauli, 1960; and Stickler and Pauli, 1964) related the importance of tiller survival and tiller density to yield. Shen (1964) in his studies with sudangrass reported the practice of ridging sugar cane in Taiwan. He found ridging sudangrass resulted in suppressed tillering but generally increased plant height, dry weight and yield of a single plant. He attributed this to the better developed crown and root system of ridged plants.

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PROCEDURES

This research was conducted in six separate experiments each designed to give specific information. These experiments were: (1) Seedbed preparation and depth of seeding; (2) The effect of daylight, depth of seeding, soil pressure and vernalization on crown formation and tiller production; (3) The effect of deep furrow seeding and crown covering on plant survival, crown location and tiller formation; (4) The effect of seeding rate and furrow treatment on tiller formation and crown location; (5) Determination of wave length affecting crown location, and (6) To determine if light quality at the soil surface influences crown location.

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EXPERIMENT I

SEEDBED PREPARATION AND DEPTH OF SEEDING

Methods

This experiment consisted of collecting and measuring winter barley plants of two varieties seeded in a 1965 winter barley varietal nursery. The seedbed for the nursery was prepared in two ways. Two replications were planted in the normal manner of plowing, two harrowing operations and cultipacking. The other two replications were planted where tillage consisted of only plowing and a single harrowing. The normally prepared seedbed was quite firm while the minimum tilled seedbed was very soft and permitted deeper sowing.

Plants were dug on October 27, 1964 in a 12-inch row section from each replication, and the distances from soil surface to crown node and from crown to seed remnant were determined. On June 23, 1965 additional plants were dug and the number of head-bearing tillers per plant were counted. Notations were made as to whether the tiller was formed at the crown node or arose from the coleoptile node.

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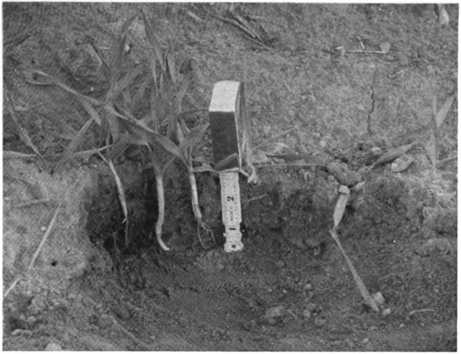
Data and Results

The minimum tilled seedbed, being soft, had the seed placed at the average depth of 6.3 centimeters while the normal tilled seedbed, being firm, had seed placed 1.9 centimeters. Figure 1 illustrates the differences of seeding depth. Table 1 shows the seeding depth and location of the crown node of the two winter barley varieties. When seeded at the lower depth, the crown formed 3.1 centimeters above the seed. At the shallow depth, only a few Hudson plants formed an internode raising the crown above the seed.

Table 1. Average depth of seeding and crown location of two barley varieties seeded in soft and firm seedbeds, September 1965

	Seedbed Preparation	
	Minimum (soft)	Normal (firm)
	centimeters	
Seeding depth		
Hudson	6.3	2.1
Wong	6.3	1.6
Average*	6.3a	1.9b
Crown depth		
Hudson	3.3	2.0
Wong	3.0	1.6
Average*	3.2a	1.8b
Average distance from seed to crown*	3.1a	0.1b

*Averages with different letters are significantly different at the 5% level.



Barley seeded in minimum tilled seedbed (soft) averaged 6.3 centimeters in depth. Crowns formed 3.1 centimeters (1.2 inches) above the seed.

Barley seeded in conventional tilled seedbed (firm) averaged 1.9 centimeters in depth. The crowns developed close to the seeding depth. Only a few Hudson plants had an elongated subcrown internode.

Figure 1. Comparison of seeding depth and crown formation in soft and firm seedbeds.

The remaining Hudson plants and all Wong plants formed the crown at the seeding depth.

Examination of seedlings showed tillers produced in groups progressively in the crown as described by Sarvella, Nilan and Konzak (1962). Tillers were formed successively from nodes of the germinating seedling. The first node of barley capable of producing a tiller is the coleoptile node. This and other tillers attached to the coleoptile tiller are described in Table 2 as group 1. Tiller groups 2, 3, and 4 are tillers arising from each successive node. The number of tillers produced per plant was less from the shallow seeding because fewer tillers formed in the fourth group.

Table 2. The average number of tillers per plant as of April 1965 on Hudson and Wong barley seeded at different depths

	Seedbed Preparation									
	Minimum (soft)					Normal (firm)				
	Tiller Location*					Tiller Location*				
	1	2	3	4	Total	1	2	3	4	Total
	Tillers per plant									
Hudson	0.7	2.4	2.2	1.9	7.5	0.3	2.5	2.1	1.5	6.4
Wong	1.1	2.5	2.4	1.7	7.6	1.0	2.5	2.3	1.5	7.3
Average	0.9	2.5	2.3	1.8	7.5	0.7	2.5	2.2	1.5	6.9

*Tiller location: 1 = tillers formed at coleoptile node, 2-3-4 = tiller groups formed at crown.

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A varietal difference in the number of plants producing tillers at the coleoptile node was observed. Wong produced more tillers at the coleoptile node than Hudson. Tables 2 and 3 show the average number of tillers per plant formed as tiller-groups at the different seeding depths and the percent of plants forming tillers in the different groups.

Wong produced an average of 1.1 tillers per plant at the coleoptile node with deep seeding and 1.0 tillers per plant at the coleoptile node with shallow seeding. Hudson produced an average of 0.7 with deep seeding and 0.3 tillers with shallow seeding. Only 31 percent of the Hudson plants formed tillers at the coleoptile node in the shallow seeding and 51 percent in the deeper seeding. Wong produced tillers at the coleoptile node on 92 and 85 percent of the plants in the deep and shallow seeding, respectively.

Table 3. Percent of plants forming tillers at various locations when seeded at two depths

	Seedbed Preparation							
	Minimum (soft)				Normal (firm)			
	Tiller Location*				Tiller Location*			
	1	2	3	4	1	2	3	4
Hudson	54	100	100	85	31	100	100	85
Wong	92	100	100	92	85	100	100	100

*Tiller location: 1 = tillers formed at coleoptile node, 2-3-4 = tiller groups formed at crown.

On June 23, 1965, after full-heading of the barley plants, the number of plants and head-bearing tillers were counted in three foot rows (Table 4). The deeper seeding had slightly more head-bearing tillers per plant. Although the nursery was supposedly seeded at a uniform rate for all varieties, Wong had a greater plant density in the samples than did Hudson. The tiller density per plant however was not significantly different.

Thirty-four plants of Hudson in the soft, minimum tilled seedbed produced 99 tillers, or an average of 2.9 heads per plant while the plants in the firm seedbed averaged 2.6 heads per plant. Wong plants produced 3.2 heads per plant in the soft seedbed, and 2.3 in the firm seedbed. With the shallow seeding, more plants produced only one tiller per plant. More Wong plants produced three heads per plant with the deeper seeding.

Table 4. Frequency table showing plants and head-bearing tillers per three foot row on June 23, 1965 in barley nurseries seeded on differently prepared seedbeds

	Seeding Depth			
	6.28 centimeters		1.86 centimeters	
Tillers per Plant	Plants	Tillers	Plants	Tillers
Hudson				
1	9	9	10	10
2	6	12	9	18
3	6	18	4	12
4	8	32	3	12
5	4	20	5	25
6	..	..	1	6
7	..	..	..	..
8	1	8	..	..
Total per 3-foot row	34	99	32	83
Average tillers/plant*		2.9		2.6
Wong				
1	7	7	20	20
2	11	22	10	20
3	12	36	12	36
4	2	8	4	16
5	5	25	1	5
6	5	30	2	12
7	2	14	..	..
8	..	..	1	8
Total per 3-foot row	44	142	50	117
Average tillers/plant*		3.2		2.3
Total for depth	78	241	82	202
Average*		3.1		2.5

*Statistical analysis failed to show significant differences between average at the 5% level.

EXPERIMENT II

THE EFFECT OF DAYLIGHT, DEPTH OF SEEDING, SOIL PRESSURE AND VERNALIZATION ON CROWN FORMATION AND TILLER PRODUCTION

The purpose of this experiment was to study the influence of certain environmental effects on the location of the crown, i.e., light, soil compaction, ridging (or addition of soil over emerged seedling), and length of prevernalization period. It was conducted in the greenhouse to facilitate precise seeding depths and controlled prevernalization period.

Methods

Fourteen treatments were designed for the following comparisons:

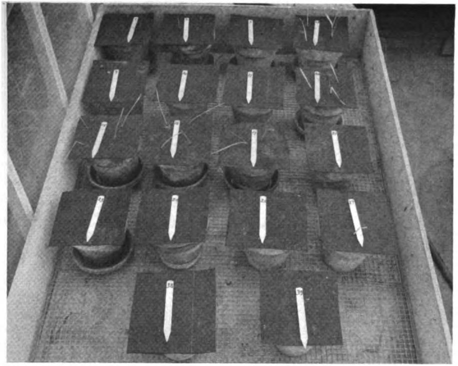
1. Dark versus light on the soil surface
2. Seeding depths of 2.5, 7.6 and 10.2 centimeters
3. Seeding depth of 7.6 centimeters versus seeding at 2.5 centimeters and later covering crowns to a depth of 7.6 centimeters
4. Loose versus packed soil over seed
5. Long versus short prevernalization period.

Two varieties of winter wheat, Gaines and Avon, and one variety of winter barley, Hudson, were used. Gaines is known for its prolific tillering when seeded early. Avon and Hudson are varieties commonly grown in Michigan.

Forty-two, six-inch clay plots were used. Accurate seeding depths were obtained by placing a rule along the inside of the pot and after placing the seed on one inch of soil, filling the pot to the required depth. Eight kernels were seeded and were thinned to five plants per pot. However, in some cultures less than five seedlings emerged.

Eighteen pots were covered individually with rigid tar paper to prevent light from reaching the soil surface and the remaining 24 pots received normal daylight (Figure 2). As seedlings in the covered pots reached the tar paper lid, small holes were punched in the lid and the coleoptile or first foliage leaf threaded through it. Thus the plants in covered pots received daylight after they reached the top of the six-inch pot. Watering was done by filling the saucers in which the pots were sitting to eliminate the necessity of removing the tar paper lids. Eighteen pots, nine covered and nine uncovered, had extra pressure exerted on the soil above the seed resulting in a packed seedbed condition. The remaining 24 cultures had a loose soil covering.

To determine the effect on the number of tillers from seedlings having a short growing period from planting until winter dormancy, three cultures (one of each variety)



Pots covered with tar paper to prevent daylight from reaching soil surface. As seedling leaves reached the tar paper lid a small hole was punched to permit emergence.

Uncovered pots. Note different seeding depths obtained by filling pots with various amounts of soil. Shallow seeding (2.5 cm) on the left, medium depth (7.6 cm) in the middle and deep seeding (10.2 cm) on the right.

Figure 2. Cultures to study effect of daylight, depth of seeding, soil pressure, and vernalization on crown formation and tiller production.

were placed in the cold room at 2 C three weeks after seeding. The remaining 39 cultures were placed in the cold room 60 days later where they and the original three remained for 60 days. The three cultures with a short vegetative period thus were subjected to the 2 C temperature a total of 120 days.

Data and Results

Too much pressure was used to compact the soil over the seed and only 18 of 90 seeds emerged. Most emergence was from the shallow (2.5 centimeters) seeding. Compaction reduced soil pore numbers and size creating a poor environment for germination and growth development. The coleoptiles of germinating seedlings were crinkled from growth elongation against the soil pressure. For this reason, comparisons do not include packed soil.

Tiller Production

Tiller counts were made on January 7, 1965 at the time the cultures were placed in the cold room and again on May 12 at harvest after having been out of the cold room for six weeks. At the time of the January 27 reading, the plants were 12 weeks old. Only a small amount of tillering had occurred as shown in Table 5. In covered pots the deep seeded cultures had slightly more tillers than the shallow seeded.

Table 5. The average number of tillers on five plants in cultures on January 27, 1965 (12 weeks old)

Treatment	Seeding Depth (cm)	Tillers per Plant			Average
		Gaines	Avon	Hudson	
Covered	2.5	1.3	1.0	1.0	1.1
	7.6	1.0	1.0	1.0	1.0
	10.2	1.1	1.2	1.5	1.3
	Average	1.1	1.1	1.2	1.1
Uncovered	2.5	1.0	1.0	1.0	1.0
	7.6	1.3	1.0	1.0	1.1
	10.2	1.0	1.0	1.0	1.0
	Average	1.1	1.0	1.0	1.0
Average for Variety		1.1	1.0	1.1	

The second tiller count was made when the plants were six months old, prior to heading. Only tillers exceeding 2.54 centimeters in length were counted. Much tillering had occurred since the previous count as shown in Table 6.

Gaines produced more tillers per plant than the other varieties. The deeper seeding of all varieties produced the most tillers. There was little if any difference in number of tillers due to light treatments.

Figure 3A shows the comparable growth of plants grown in covered pots with those uncovered prior to being placed in the cold room for vernalization at 12 weeks of age.

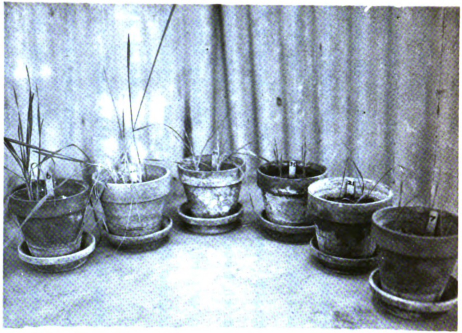
Table 6. The average number of tillers over 2.54 centimeters in length on five plants in cultures on May 12, 1965

Pot Treatment	Seeding Depth (cm)	Tillers per Plant			Average*
		Gaines	Avon	Hudson	
Covered	2.5	3.7	1.3	1.8	2.3a
	7.6	4.3	4.0	5.3	4.5b
	10.2	11.9	5.5	6.4	7.9c
	Average*	6.6a	3.6b	4.5b	4.9
Uncovered	2.5	3.8	1.0	1.7	2.2a
	7.6	7.8	5.0	4.0	5.6b
	10.2	7.9	7.0	5.0	6.6b
	Average*	6.5a	4.3b	3.6b	4.8
Average for Variety*		6.6a	4.0b	4.0b	

*L.S.D. (5% level) between:
seeding depths . . . . 1.9 tillers/plant
varieties . . . . 1.9 tillers/plant
seeding depths within variety 1.2 tillers/plant

Averages with different letters are significantly different at the 5% level.

A. Gaines wheat in covered (left) and uncovered (right) pots with seeding depths of 2.5 (pots 1 and 5) front; 7.6 (pots 2 and 6) middle; and 10.2 cm (pots 3 and 8) rear.



B. Growth of plants in 3 pots on right has been retarded by being in cold room for 60 days while the 3 pots on the left have had warmer temperatures. Varieties are Gaines (front 2 pots), Avon (middle), and Hudson (rear).

Figure 3. Comparison of plant growth made prior to placing cultures in the cold room for vernalization.

Plants in the covered pots (1, 2 and 3) were slightly taller than those in the uncovered pots (5, 6 and 8). Depth of seeding does not appear to have influenced the growth. The plants given the early cold treatment were suppressed in growth and tiller development at the time the other cultures were placed in the cold room. Figure 3B compares the growth of plants prior to being placed in the cold room (6, 20 and 34) with plants having been in the cold room for 60 days (7, 21 and 35). No tillering had occurred in the latter cultures at this time.

When tiller counts were made on May 12, six weeks after being removed from the cold room, plants in pots 7, 21 and 35 still had not formed tillers. Table 7 compares the tillers per plant in cultures receiving the early cold treatment and others seeded at the same depth. Plants receiving

Table 7. Average tillers per plant in cultures receiving early cold treatment and comparable cultures receiving later cold treatment

Length of Cold Treatment	Seeding Depth (cm)	Variety			Average
		Gaines	Avon	Hudson	
		number of tillers per plant			
60 days	7.6	7.8	5.0	4.0	5.6
120 days	7.6	1.0	1.0	1.0	1.0

60 days of cold treatment had an average of 5.6 tillers per plant while plants receiving 120 days of cold treatment produced only the main culm.

Figure 4 shows the crown and subcrown development of a plant of Gaines wheat receiving the early cold treatment and one having the later cold period. When plant No. 6 was placed in the cold chamber for vernalization it had only four tillers (Figure 3B). There was no apparent growth during the 60 day period when temperatures were held at 2 C. At the second tiller count six weeks after having been removed from the cold room and as shown in the photograph it had 18 tillers. Plants which were seeded at the 2.5 centimeter depth and after emergence covered with soil to 7.6 centimeters had not produced tillers prior to placing the pots in the cold room. On May 12, plants had tillered and tillers per plant are shown in Table 8. The tillering of covered plants was comparable to the shallow seeded cultures and less than the deep seeded ones.

Crown Formation

In cultures not given the early cold treatment, crown formation occurred prior to placing the pots in the cold room for vernalization. Figure 5A shows Hudson seeded at 2.5 centimeters in a covered pot prior to being placed in the cold chamber. The crown had formed above the soil surface. This phenomenon occurred in many of the covered pots.

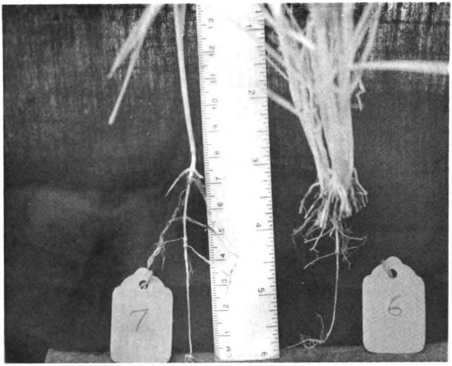


Figure 4. Plants of Gaines wheat both seeded at the 7.6 centimeter depth and dug six months after seeding. Plant No. 7 was placed in the cold room early, three weeks after seeding, where it remained for 120 days. Plant No. 6 was placed in the cold room at 60 days after seeding where it remained for 60 days.

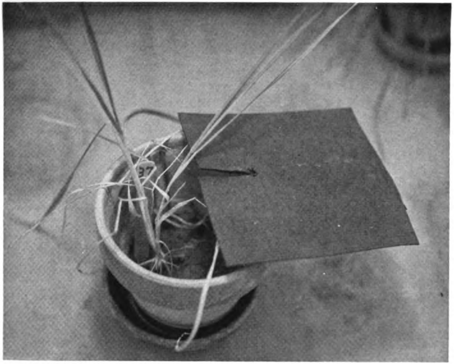
Table 8. Average tillers per plant on May 12, 1965 in cultures seeded at the 2.5 centimeters depth and having 5.1 centimeters of soil added after emergence compared to cultures seeded at 2.5 and 7.6 centimeters

Seeding Depth (centimeters)	Variety: Gaines	Avon	Hudson	Average*
	number of tillers per plant			
2.5 + 5.1	3.67	2.75	1.00	2.36b
2.5	3.75	1.00	1.67	2.70b
7.6	5.60	5.00	4.00	5.60

*L.S.D. (5% level) between treatments--1.54 tillers/ plant.

Table 9 shows the length of the subcrown internode as measured on May 27, 1965 when plants were harvested.

The increased length of this subcrown internode is most evident from the deep seeding. While not many deep seeded plants in covered pots produced crowns above the soil surface, Gaines had one such plant as shown in Figure 5B. The more common crown formation of deep seeded (10.2 centimeters) plants is shown in Figure 6, where Gaines formed the crown at seven centimeters above the seeding depth. Note that this is not a single subcrown internode as a node was also formed at 2.2 centimeters above the seeding depth. No roots or extension of the axillary bud occurred at this node, so there was no crown formation.



A. Hudson barley plant seeded 2.5 cm below the soil surface produced its crown 4.8 cm above seeding depth.

B. Gaines wheat seeded at 10.2 cm depth produced a crown above the soil surface.

Figure 5. Seedlings growing in pots covered by tar paper lids often produced the crown above the soil surface.

Figure 6. Plant of Gaines wheat seeded at depth of 10.2 centimeters produced a node at 2.2 centimeters and a crown at 7 centimeters above seeding depth.

Table 9. Average length of subcrown internode of five wheat and barley plants in covered and uncovered pots at various seeding depths as measured May 12, 1965

Light Treatment	Seeding Depth (cm)	Length of Subcrown Internodes: Gaines	Avon	Hudson	Average*
Covered pots	2.5	4.5**	5.2**	4.8**	4.2**a
	7.6	6.9	7.9**	7.1	7.3b
	10.2	7.1	9.0	6.0	7.4b
	Average	5.5	7.4	6.0	6.3
Uncovered pots	2.5	2.1	1.5	1.2	1.6a
	7.6	5.6	4.6	5.2	5.1b
	10.2	8.8	9.4	8.2	8.8c
	Average	5.5	5.2	4.7	5.2
Average for Variety		5.5	6.3	4.4	

*L.S.D. (5% level) between seeding depth 3.1 centimeters seeding depth within light treatment.

**Distance is greater than seeding depth, indicating that crown formed above soil surface.

The plants with an early cold treatment produced a slightly longer subcrown internode than did comparable seeded plants later vernalized. Table 10 compares the distance from the seeding depth to crown of plants treated to early cold with other untreated plants seeded at 7.6 centimeters.

The addition of 5.1 centimeters of soil after emergence to plants in pots seeded 2.5 centimeters deep, resulted in two crowns being formed. Figure 7 shows the two nodes formed by Gaines and Hudson. The original node was slightly below the soil surface of 2.5 centimeters and the second crown formed well above this level, but below the final soil surface of 7.6 centimeters. The barley plant formed only roots at the lower crown, but the wheat plant formed both roots and one tiller.

Table 10. Length of subcrown internode of early cold treated plants and other plants seeded at 7.6 centimeters as measured May 12, 1965

Pot Treatment	Seeding Depth	Length of Subcrown Internodes			Average
		Gaines	Avon	Hudson	
		centimeters			
Light, Early cold	7.6	6.5	5.1	5.6	5.7
Light	7.6	5.6	4.6	5.2	5.1

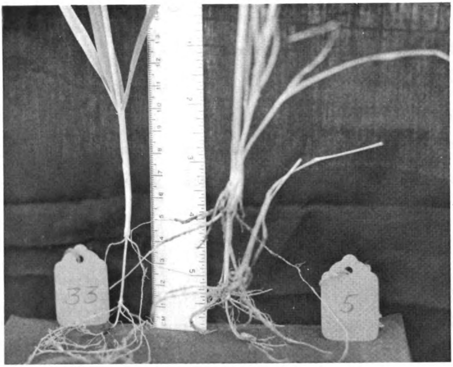


Figure 7. Two crowns were formed by Hudson (33) and Gaines (5) when 5.1 centimeters of soil was added to pots after plants emerged from a 2.5 centimeter seeding depth.

EXPERIMENT III

THE EFFECT OF DEEP FURROW SEEDING AND CROWN COVERING ON PLANT SURVIVAL, LOCATION OF THE CROWN AND TILLER FORMATION

As a result of the observed manipulation of the crown location in Experiment II, attempts were made to do the same in the field. The experiment would also permit a study of winter survival in relation to location of the crown and protection by snow cover in the bottom of deep furrow seedings.

Methods

Hudson and Wong were selected to represent two levels of winter-hardiness in barley and Avon as a common winter wheat variety.

Plot treatments were as follows:

1. (S) shallow seeding made in the normal manner, i.e., without cultivator shovels.
2. (D) deep seeding done by increasing the pressure tension on the seeding shoes.
3. (F) deep furrow seeding done by attaching six-inch cultivator shovels in front of the seeding

shoes and placing the seed in the bottom of the furrows.

4. (Cl) closed deep furrows which were seeded as in treatment 3 but the ridges leveled after emergence.

The cultivator shoes made a furrow eight centimeters deep in which the seed was placed and covered only 1.3 centimeters. The shallow seeding was also covered only 1.3 centimeters. Increasing the tension of the seeding shoes placed the seed 7.5 centimeters deep. On November 18, 1965 when the seedlings were six weeks old, half of the deep furrow plots were closed by leveling the ridges into the furrows. This caused the seed in the closed furrows to be covered 5.3 centimeters. Figure 8 shows the tillering and size of plants when the deep furrow plots were leveled.

Winter survival was determined by estimating the percent of stand in each plot on March 1, 1966. Tiller counts and crown measurements were made by digging plants on April 21, 1966. Only tillers exceeding 2.54 centimeters in length were counted. The location of tillers on the crown were identified by grouping them in order of origin, as described by Sarvella et al. (1962). Group one, primary tillers, are main culms and the first tillers attached to them. Group 2 tillers arise from a node just above the primary tillers. Those tillers coming from above the

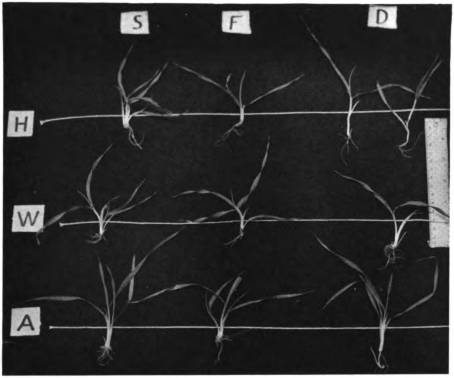


Figure 8. Size and tillering of seedlings of Hudson (H), Wong (W) and Avon (A) at time of closing half the deep furrow plots. Seeding treatments are (S) shallow seeded, (F) deep furrow and (D) deep seeded.

secondary tillers are group three. In this study, the latest tillers developed from a fourth group.

Data and Results

Differential winterkilling occurred between varieties. Avon survived 100 percent, Hudson averaged 55 percent and Wong had 50 percent survival. Winter survival data are shown in Table 11. No difference occurred between deep furrow and shallow seeded plots. The seed covering was the same in these two treatments and in the absence of a protective snow cover in the deep furrows there was no difference in plant survival. Plant density was less in closed deep furrow plots than in open deep furrows but higher than in deep seeded plots. The reduction in stand of the closed deep furrow plots may be due to the covering of the crown as

Table 11. Average plant survival of varieties in plot treatment on March 1, 1966

	Plot Treatment				
Variety	Deep Furrow	Shallow Seeded	Closed Deep Furrow	Deep Seeded	Varietal Average
Hudson	75.0	76.5	37.5	37.5	55.6
Wong	62.5	67.5	47.5	23.8	50.8
Avon	100.0	100.0	100.0	100.0	100.0
Treatment Average	79.2	80.0	61.7	53.8	

the survival is intermediate between deep seeded and open deep furrow plots.

Thermocouples were placed near the crowns of plants in three treatments; closed deep furrow, open deep furrows, and in the shallow seeded plots. Temperatures were automatically recorded on a Brown Honeywell Electronik(T) Strip Chart Recorder during the winter months. Figure 9 shows the plot treatments immediately after installing the thermocouples and closing the deep furrow plots.

Tiller counts are reported in Table 12. The deep furrow and the shallow seeded plots produced the greatest number of tillers per plant. These two treatments also had the best winter survival. Normally tiller production and plant density are expected to be negatively correlated. The positive association in this instance is explained by winter-killing of tillers and/or tiller buds. Greater tillering in the shallow seeded plots was due to more tillers at the group one level, the most protected group. In the deep seeded plots a lack of tillering is evident at the group four level, especially in barley. Group four are later tillers formed closer to the soil surface where they are more exposed to winter damage. A varietal difference in tillering is apparent by Wong having the least number of tillers. Wong is the least winterhardy variety. Winter-killing could account for the fewer number of tillers.

Figure 9. Plot treatments after closing the deep furrows lower left. The open deep furrows are shown directly above them. The deep seeded plot is at the lower right and the shallow seeded plot is adjacent to the open deep furrow plot.

Table. 12. Average number of tillers and their location on ten plants produced with different seeding methods, counted April 21, 1966

Variety	Seeding Treatment*	Tiller Group**				Total
		1	2	3	4	
Hudson	F	2.6	3.3	3.1	2.0	11.0
	S	2.3	1.7	2.0	1.1	7.1
	D	1.0	1.4	1.1	...	3.5
	Cl	1.4	1.4	2.1	...	4.9
Variety Average***						6.8a
Wong	F	1.6	1.4	0.9	0.1	4.0
	S	1.5	1.3	1.3	1.0	5.1
	D	1.1	0.8	0.6	0.3	2.8
	Cl	1.3	0.9	0.6	...	2.8
Variety Average***						3.6b
Avon	F	1.6	1.7	1.7	0.4	5.4
	S	2.6	2.7	2.0	1.3	8.6
	D	1.4	1.4	1.3	1.4	5.5
	Cl	1.6	1.6	2.0	0.4	5.6
Variety Average***						6.2a
Treatment Average***	F	1.9	2.1	1.9	0.7	6.6ab
	S	2.2	2.1	1.8	1.1	7.1a
	D	1.2	1.3	1.1	0.6	4.2b
	Cl	1.4	1.3	1.6	0.1	4.4b

*F = deep furrow; S = shallow seeded; D = deep seeded; Cl = closed deep furrow.

**Tiller groups according to node of origin (Sarvella et al., 1962).

***L.S.D. (5% level) between:
varieties 0.83 tillers per plant
treatments 2.47 tillers per plant.
Averages with different letters are significantly different at the 5% level.

The depth of crown formation from the soil surface is shown in Table 13. The crown formation in the deep furrow and shallow seeded plots was less than one centimeter from the soil surface. Seeding depth was 1.3 centimeters. Plants in the deep seeded plots (7.5 centimeters) produced crowns at 1.62 centimeters below the soil surface. The leveling of ridges and covering of seedlings in the closed deep furrow plots caused plants to produce a second crown. The first crown formed close to the depth of crowns in deep seeded plots and the second crown formed closer to the surface than crowns in shallow seeded plots.

Temperature readings as measured by thermocouples placed near the plant crown did not reveal a significant protective effect in the deep furrow plots. The lack of snow during the colder periods might explain the lack of insulative protection. Temperatures for two different periods are shown in Figures 10 and 11. Crowns in the closed deep furrows were consistently warmer than the other treatments during the cold weather period from January 24 to February 2, 1966 (Figure 10). The open deep furrow plots had slightly warmer temperatures than the shallow seeded plots in the early and very late portions of the period when temperatures were relatively moderate. In the middle of this period, air temperatures dropped to below -20 C and the open deep furrow temperatures became the lowest of the treatments. The differences in temperature did not affect plant

Table 13. Average depth of crown formation of wheat and barley grown with different seeding methods as measured April 21, 1966

Variety	Seeding Method					Varietal Average**
	Deep Furrow	Shallow Seeded	Deep Seeded	Closed Deep Furrow*		
				Upper	Bottom	
			centimeters			
Hudson	1.13	0.90	1.61	0.61	4.49	1.06
Wong	0.69	0.80	1.71	0.70	3.86	0.98
Avon	1.34	0.83	1.67	0.70	4.02	1.14
Treatment Average***	0.96b	0.85b	1.62a	0.67c	4.09	

*A second crown often formed after seedling was covered by closing the deep furrow--bottom is the depth of original crown and upper is the depth of the second crown.

**Does not include bottom node of closed deep furrow plots.

***L.S.D. (5% level) between: treatments .... 0.17 cm
treatment within a variety .... 0.30 cm.
Averages with different letters are significantly different at the 5% level.

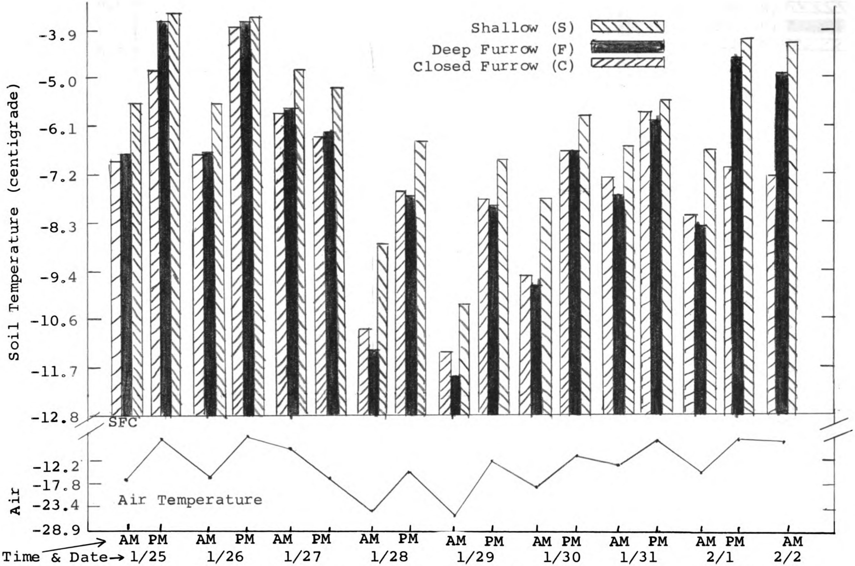


Figure 10. Air and soil temperatures of furrow plot experiment, January 25 to February 2, 1966.

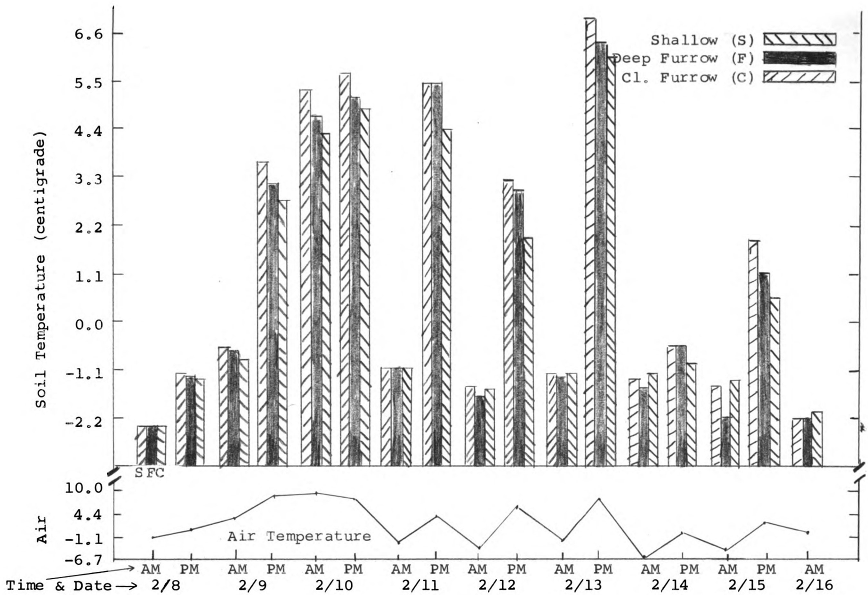


Figure 11. Air and soil temperatures of furrow plot experiment, February 8 to 16, 1966.

survival as stands in shallow and deep furrow plots survived equally well.

As air temperatures warmed during the second period, February 7 to 16, 1966 (Figure 11) a change in the relation of temperatures in the plots occurred. Temperatures at the crown level in shallow seeded plots reacted quicker to the change of the air temperature and were the highest. The temperatures in the closed deep furrow reacted slower and were recorded as the coldest. The relationship of temperature to growth would thus indicate those plots warming quickest would begin development earlier.

EXPERIMENT IV

THE EFFECT OF SEEDING RATE AND FURROW TREATMENT ON TILLER FORMATION AND CROWN LOCATION

Methods

A factorial experiment was designed involving four varieties, three seeding rates, and three furrow treatments to determine their effect on tiller formation, location of crown and grain yield. A drill was obtained that permitted accurate adjustments of seeding rate and the placement of seed in deep furrows or in a smooth surface.[1]

Seeding rates were 80, 120 and 160 pounds per acre. Avon, Gaines and Genesee winter wheat and Hudson winter barley were used. Seeding was done either in deep furrows or in a normal manner in a smooth surface. After plant emergence, half of the deep furrow plots were closed by leveling the ridges and covering the crowns of the emerged seedlings.

Figure 12 shows furrows approximately eight centimeters deep and the result of "closing" the furrows by

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[1]Grateful acknowledgment is made to the Department of Agricultural Engineering, Michigan State University and the Agricultural Engineering section, A.R.S., U.S.D.A., Washington, D.C. for providing a special research drill and tractor operator.

Open deep furrow plot with 8 cm ridges. Seed in bottom of furrow was covered 1.27 cm.

Closed deep furrow plot after leveling ridges. Seed is now covered approximately 5.27 cm.

Figure 12. Two furrow treatments applied to winter wheat and barley to determine the effect on crown location.

leveling the ridges and covering the crowns of the plants. Recovery and continued growth was as good in the closed deep furrow plots as in other treatments as shown in Figure 13.

Yield was determined on the center two rows of the four row plots. Harvest was accomplished with the nursery combine thresher. Just prior to harvest, three-foot portions of a guard row were dug to determine plant and tiller density.

Data and Results

Table 14 shows the plants per three-foot row for the varieties at the different seeding rates and furrow treatments. Plant density was influenced mainly by seeding rate. Covering of the emerged plants by closing, or leveling the deep furrows, did not reduce the plant density significantly.

Table 15 shows the tillers per three-foot row produced by the varieties at different seeding rates and furrow treatments. Again only the seeding rate made a significant difference in the number of tillers produced. Statistical analysis of the data showed significantly fewer tillers per square foot in the 80 pound per acre seeding rate. There was no difference in the tiller density in 120 and 160 pound seeding rates.

If there were more plants per three-foot row in the 160 pounds per acre rate than at 120 pounds and no significant difference in the number of tillers between the two rates, there must be more tillers per plant produced at the

Figure 13. Hudson barley in the foreground where ridges were leveled and crowns covered. The open deep furrow plots are in the rear. The ridges have sloughed down somewhat during the winter season. Stands in both plots were considered the same.

Table 14. Average number of plants per three foot row from different seeding rates and furrow treatments, July 21, 1966

		Average Number of Plants per Three Foot Row			
Seeding Rate	Variety	Shallow Seeded	Deep Furrow	Deep Furrow Leveled	Average for Seeding Rate*
80 lbs/A	Hudson	52	50	48	
	Avon	46	44	22	
	Gaines	61	56	38	
	Genesee	36	36	36	
Average for Rate x Treatment		48.8	46.5	36.0	43.8c
120 lbs/A	Hudson	74	95	73	
	Avon	83	67	78	
	Gaines	68	89	80	
	Genesee	101	82	73	
Average for Rate x Treatment		81.5	83.3	76.0	80.3b
160 lbs/A	Hudson	140	107	126	
	Avon	99	121	112	
	Gaines	101	89	93	
	Genesee	108	123	84	
Average for Rate x Treatment		112.0	110.0	103.8	108.6a
Average for Treatment		80.8	79.9	71.9	
Average for Variety x Treatment					Average for Variety
	Hudson	82	84	88	85.0
	Avon	70	77	76	74.6
	Gaines	70	78	76	75.0
	Genesee	64	80	81	75.4

*Averages with different letters are significantly different at the 5% level.

Table 15. Average number of tillers per three foot row produced by different seeding rates and furrow treatments, July 21, 1966

Seeding Rate	Variety	Average Tillers per Three Foot Row: Shallow Seeded	Deep Furrow	Deep Furrow Leveled	Average for Seeding Rate*
80 lbs/A	Hudson	92	82	69	
	Avon	83	82	44	
	Gaines	114	110	90	
	Genesee	75	93	103	
Average for Rate x Treatment		91.0	91.8	76.5	86.4b
120 lbs/A	Hudson	136	152	123	
	Avon	139	125	155	
	Gaines	131	174	128	
	Genesee	154	166	124	
Average for Rate x Treatment		140.0	154.3	132.5	142.3a
160 lbs/A	Hudson	183	140	199	
	Avon	124	160	151	
	Gaines	154	135	136	
	Genesee	162	170	120	
Average for Rate x Treatment		155.8	151.3	151.5	152.8a
Average for Treatment		128.9	132.4	120.2	
Average for Variety x Treatment					Average for Variety
	Hudson	137	124	130	130.7
	Avon	115	122	117	118.1
	Gaines	133	140	118	130.2
	Genesee	130	143	116	129.7

*Averages with different letters are significantly different at the 5% level.

lower seeding rate. This is confirmed by the data in Table 16. Each increase in the seeding rate significantly lowered the number of tillers per plant. The furrow treatments had no effect on the number of tillers per plant.

The yield of grain differed significantly between furrow treatments as shown in Table 17. A relationship between tillers and yield is shown by the high yielding treatment which had the most tillers per three-foot row. Varietal yields also differed significantly. Genesee which ranked first with Gaines for tillers per three-foot row and tillers per plant was the highest yielding.

Table 16. Average tillers per plant produced by varieties in different rate of seeding and furrow treatments, July 21, 1966

		Average Tillers per Plant			
Seeding Rate	Variety	Shallow Seeded	Deep Furrow	Deep Furrow Leveled	Average for Seeding Rate*
80 lbs/A	Hudson	1.8	1.6	1.4	
	Avon	1.8	1.9	2.0	
	Gaines	1.9	2.0	2.4	
	Genesee	2.0	2.6	2.9	
Average for Rate x Treatment		1.88	2.03	2.18	2.03a
120 lbs/A	Hudson	1.8	1.6	1.7	
	Avon	1.7	1.9	2.0	
	Gaines	1.9	2.0	1.6	
	Genesee	1.5	2.0	1.7	
Average for Rate x Treatment		1.73	1.88	1.75	1.78b
160 lbs/A	Hudson	1.3	1.3	1.6	
	Avon	1.3	1.3	1.3	
	Gaines	1.5	1.5	1.5	
	Genesee	1.5	1.4	1.4	
Average for Rate x Treatment		1.40	1.38	1.45	1.41c
Average for Treatment		1.67	1.76	1.79	
Average for Variety x Treatment					Average for Variety
	Hudson	1.6	1.5	1.6	1.57b
	Avon	1.6	1.7	1.8	1.69ab
	Gaines	1.8	1.8	1.8	1.81a
	Genesee	1.7	2.0	2.0	1.89a

*Averages with different letters are significantly different at the 5% level.

Table 17. Average yield of grain produced by different seeding rates and furrow treatments

Seeding Rate	Variety	Grain Yield Shallow Seeded	Deep Furrow	Closed Furrow	Average for Seeding Rate
		grams per plot			
80 lbs/A	Hudson	383.50	498.50	242.50	
	Avon	589.75	523.00	390.25	
	Gaines	553.00	550.50	329.50	
	Genesee	598.75	603.00	452.75	
Average for Rate x Treatment		531.25	543.75	353.75	476.25
120 lbs/A	Hudson	394.75	487.25	404.00	
	Avon	601.25	703.75	490.00	
	Gaines	495.50	519.75	334.25	
	Genesee	535.25	827.75	535.25	
Average for Rate x Treatment		506.69	634.63	445.38	528.90
160 lbs/A	Hudson	510.50	644.25	380.00	
	Avon	530.50	635.75	504.75	
	Gaines	430.50	522.00	383.75	
	Genesee	621.00	745.50	592.50	
Average for Rate x Treatment		523.13	636.88	465.25	541.75
Average for Treatment*		520.35b	605.08a	421.46c	
Average for Variety x Treatment					Average for Variety*
	Hudson	429.59	543.33	342.17	438.36c
	Avon	573.83	620.83	461.67	552.11b
	Gaines	493.00	530.75	349.17	457.64c
	Genesee	585.00	725.42	532.83	614.42a

*Averages with different letters are significantly different at the 5% level.

EXPERIMENT V

DETERMINATION OF WAVE LENGTH OF LIGHT AFFECTING CROWN LOCATION

Since Experiment III indicated that the absence of daylight caused an elevation of the plant crown, restricting the color of light received by the coleoptile might help to identify which wave length was concerned.

Methods

Colored beads were used to vary the light intensity and wave length striking the coleoptile of wheat as it emerged from the soil. If the light wave penetrating the beads was effective, the crown would be formed deeper in the soil as the coleoptile received the light at bottom of the beads. If the light wave was noneffective in triggering the plant to form a crown, the coleoptile would have to penetrate the surface of the beads before the crown would be formed, presumably at a shallow depth.

Six Avon seeds were accurately placed in soil five centimeters below the level of a layer of glass beads three centimeters deep, making the overall planting depth eight centimeters. Seedlings emerged in four days as shown in Figure 14. The seedlings were thinned to five per pot.

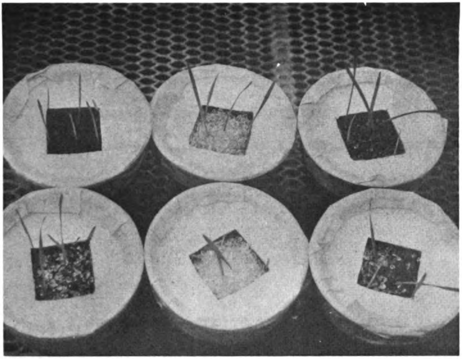

Figure 14. Wheat seedlings emerging through colored beads from seeding depths of eight centimeters. Bead colors (left to right: first row = blue, white, green; second row = black, yellow, red).

The percent of light transmission through the three centimeters of beads was determined by use of a Carl Zeizz Spectrophotometer PMO II prior to placing the beads in the pots. The percent transmission of different wave lengths through the 3-centimeter layer of beads is shown in Figure 15. Density of beads reduced transmission to less than 8 percent for all colors including the clear glass. Red and yellow colors attained 8 percent transmission at the longer wave lengths (yellow, 6500A and red, 7250A). The clear glass allowed 2.3 percent transmission at the 5250A length. Less than 1 percent transmission occurred in the blue and green beads at the shorter wave lengths of 4500A and 5200A, respectively.

Data and Results

All seedlings emerged four days after seeding. Heat and energy differences between bead colors thus appeared negligible. However, different plant heights were obtained with the different colored beads. Figure 16 represents graphically the average height of plants and the location of the crowns of plants grown through the colored beads. Figure 17 shows the difference in crown location between plants grown through red beads and black beads. The crown formed 3.5 centimeters under the red beads and at 1.0 centimeter under the black beads. Figure 18 compares the location of the crown in relation to the bead layer of all colored beads.

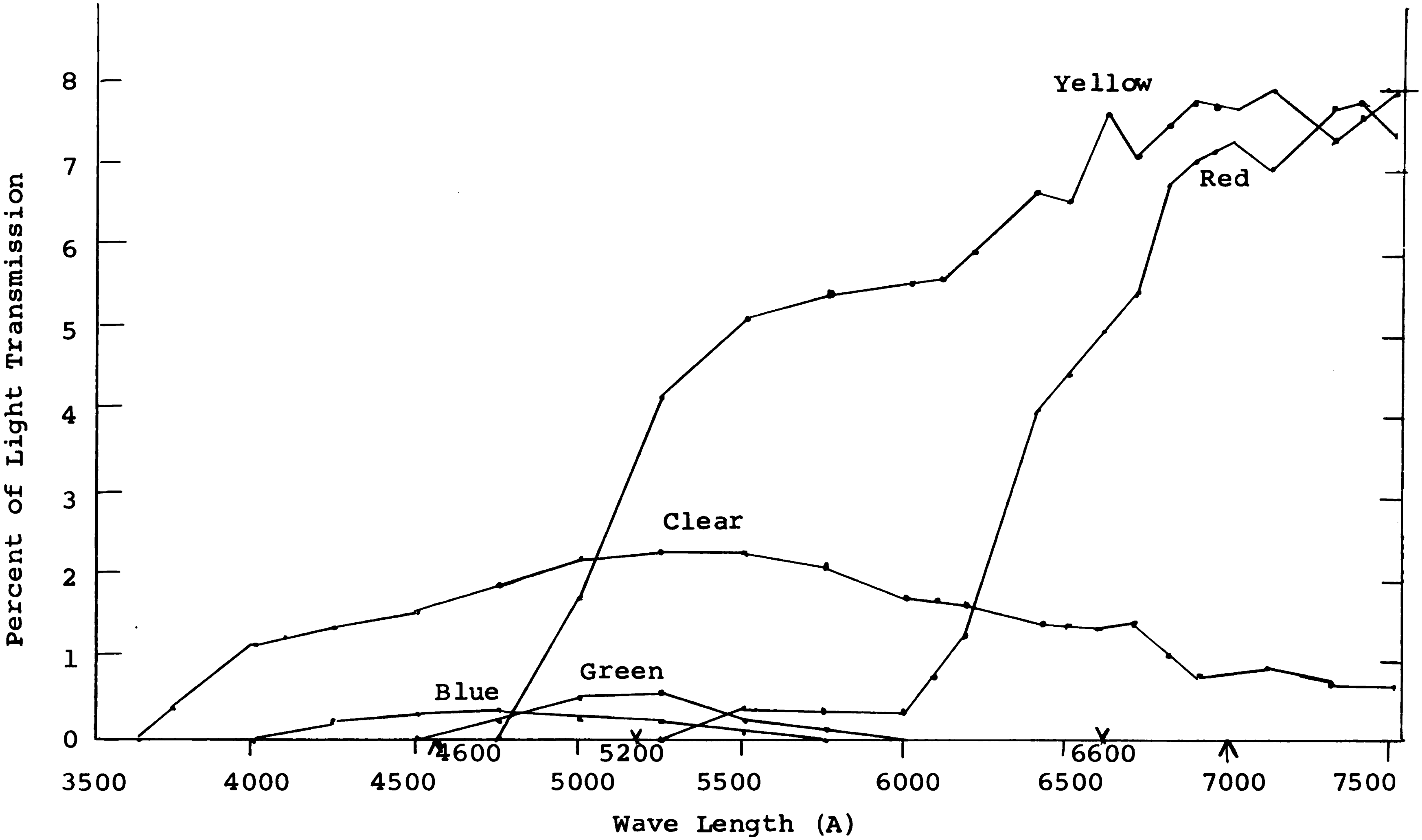

Figure 15. Percent of light transmission at different wave lengths through glass beads.

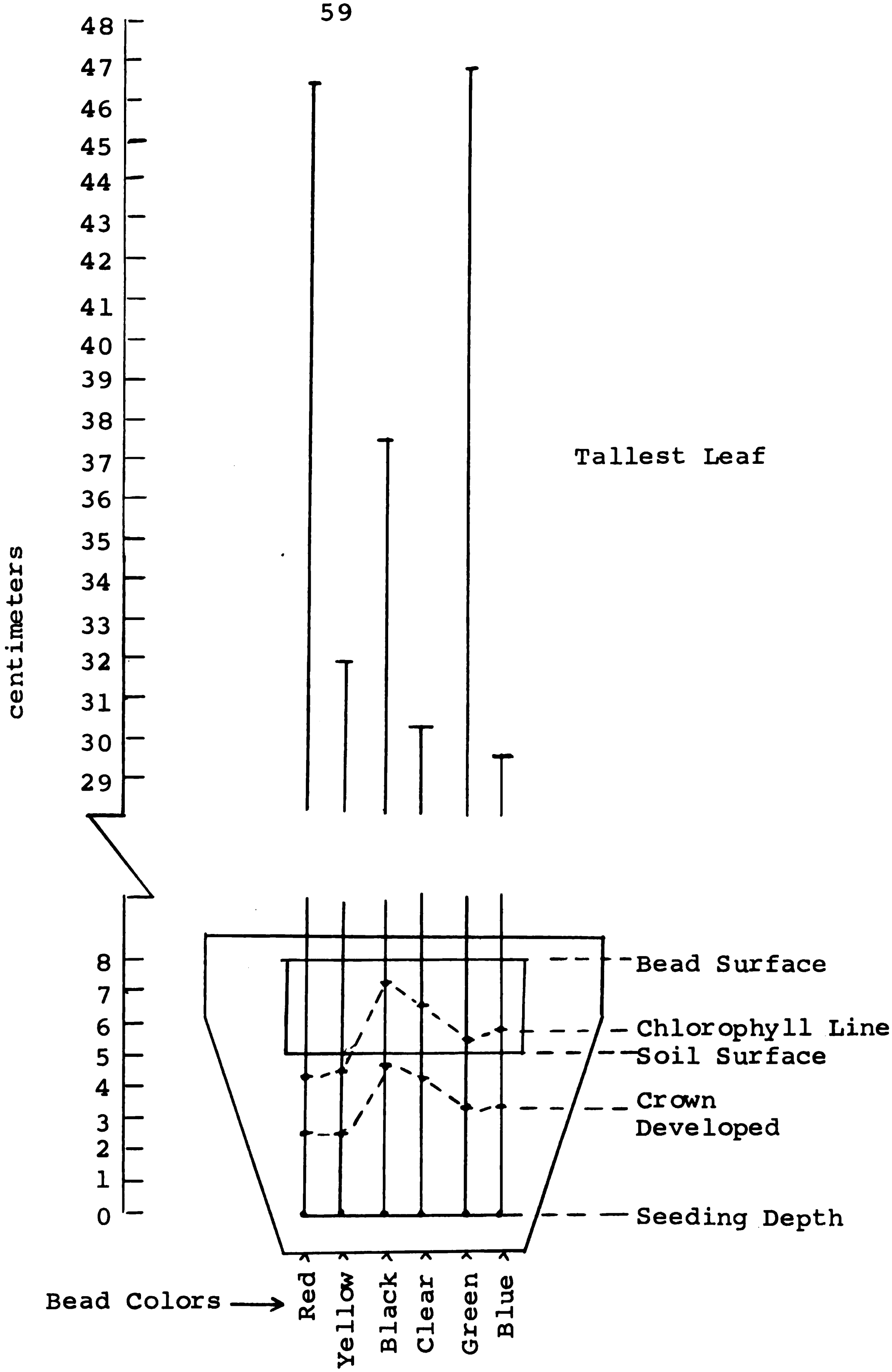

Figure 16. Average height, location of chlorophyll and crown development on wheat plants grown through colored beads.

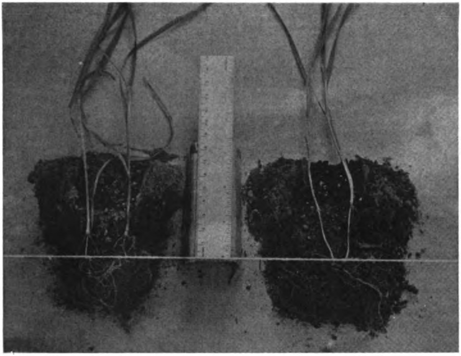

Figure 17. Location of crown development on wheat plants grown through red beads on the left and black beads on the right.

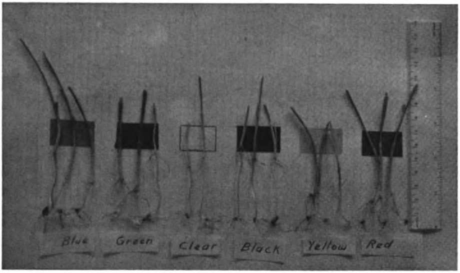

Figure 18. Comparison of location of crown development of Avon wheat plants in relation to layer of beads.

Table 18 records the average measurement on five plants of the subcrown internode, the distance from crown to chlorophyll development and the length of the tallest leaf of wheat seedlings grown through the colored beads. The longest subcrown internode was found on plants grown through the clear and black beads. Totaling the length of the subcrown internode and the distance from the crown to chlorophyll development shows light penetration was least through these two layers of beads.

Table 18. Average measurements of subcrown internode, crown to chlorophyll, and length of tallest leaf of wheat plants grown through colored beads, May, 1969

Bead Color	Peak Light Transmission	Measurement From: Seed Depth to Crown*	Crown to Chlorophyll	Tallest Leaf
	(A)	centimeters		
Red	7400	2.5b	1.8	46.5
Yellow	6600	2.5b	1.9	31.9
Clear	5500	4.2a	2.3	30.2
Green	5250	3.2b	2.1	46.8
Blue	4500	3.2b	2.6	29.6
Black	none	4.6a	2.5	37.5

*L.S.D. (5% level) between colors, 1.0 cm. Averages with different letters are significantly different at the 5% level.

The shortest subcrown internode was found on plants grown through the red and yellow beads. Totaling the length of the subcrown internode and the distance from the crown to chlorophyll development shows that chlorophyll developed 4.3 centimeters above the seeding depth, and that the light penetrated the bead layer to a depth of 2.7 centimeters. The green and blue light waves were intermediate in their effect.

Seedlings growing through the red and green beads produced the tallest plants, while those under the blue and clear beads produced the shortest plants.

EXPERIMENT VI

TO DETERMINE IF LIGHT QUALITY ON THE SOIL SURFACE INFLUENCES CROWN LOCATION

The objective of this experiment was to determine if the wave length responsible for crown formation could be identified by its penetration of the soil and the effect of light energy on crown location.

Methods

Avon wheat and Hudson barley were used. Seed was accurately placed in large 12-inch clay pots and covered with eight centimeters of coarse sandy soil. Soil particle analysis showed particle size distribution as:

54 percent larger than 1.00 mm

21 percent 0.53 to 1.00 mm

20 percent 0.25 to 0.53 mm

5 percent less than 0.25 mm

Various colored cellophane papers were used as filters over the tops of the pots to produce a range of wave lengths (Figure 19). The optical density and percent of light transmission of the cellophane was measured with a Hitachi-Perkin-Elmer UV-Vis Spectrophotometer. The percent

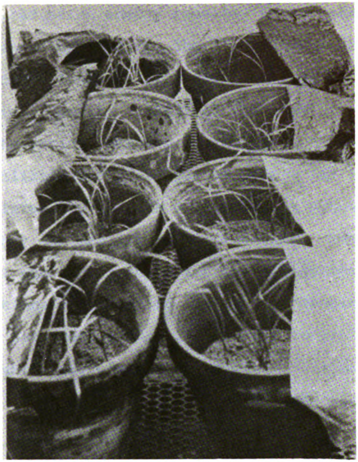

Figure 19. Colored cellophane paper used as filters to restrict wave length reaching soil surface in pots. Colors from left to right: (front row) clear and green, (second row) double layers of yellow, blue and red, (third row) single layers of yellow, blue and red.

of light transmission for the different colors at various wave lengths is shown in Figure 20.

The radiation energy received by the plants in each pot was balanced by altering the light intensity with multiple layers of cellophane. The green cellophane had the highest optical density (.2542) at its peak of transmission (5000A). The optical density of the other colors was adjusted utilizing the principle of Beer's law which states that light intensity through a material is proportional to the absorbency and density of the material. Table 19 gives the spectral photometric data for the cellophane filters and the calculations for equating the optical densities.

The pots were placed in a Sherer Controlled Environmental Laboratory where a constant 20 C temperature was maintained. Light was received from Ken-Rad T12 Extra white florescent bulbs. Light intensity at the top of the pots was measured as 2500 foot-candles with a Weston Illumination Meter Model No. 756. Watering was through the bottom of the pots.

Plants were pulled and location of the crown determined after four weeks of growth. Figure 21 shows the growth made by the plants under the cellophane filters prior to removal from the pots. The greatest morphological difference in plants occurred under the red, single layer filter where plants were more etiolated than plants under other filters. Comparable growth occurred between plants under

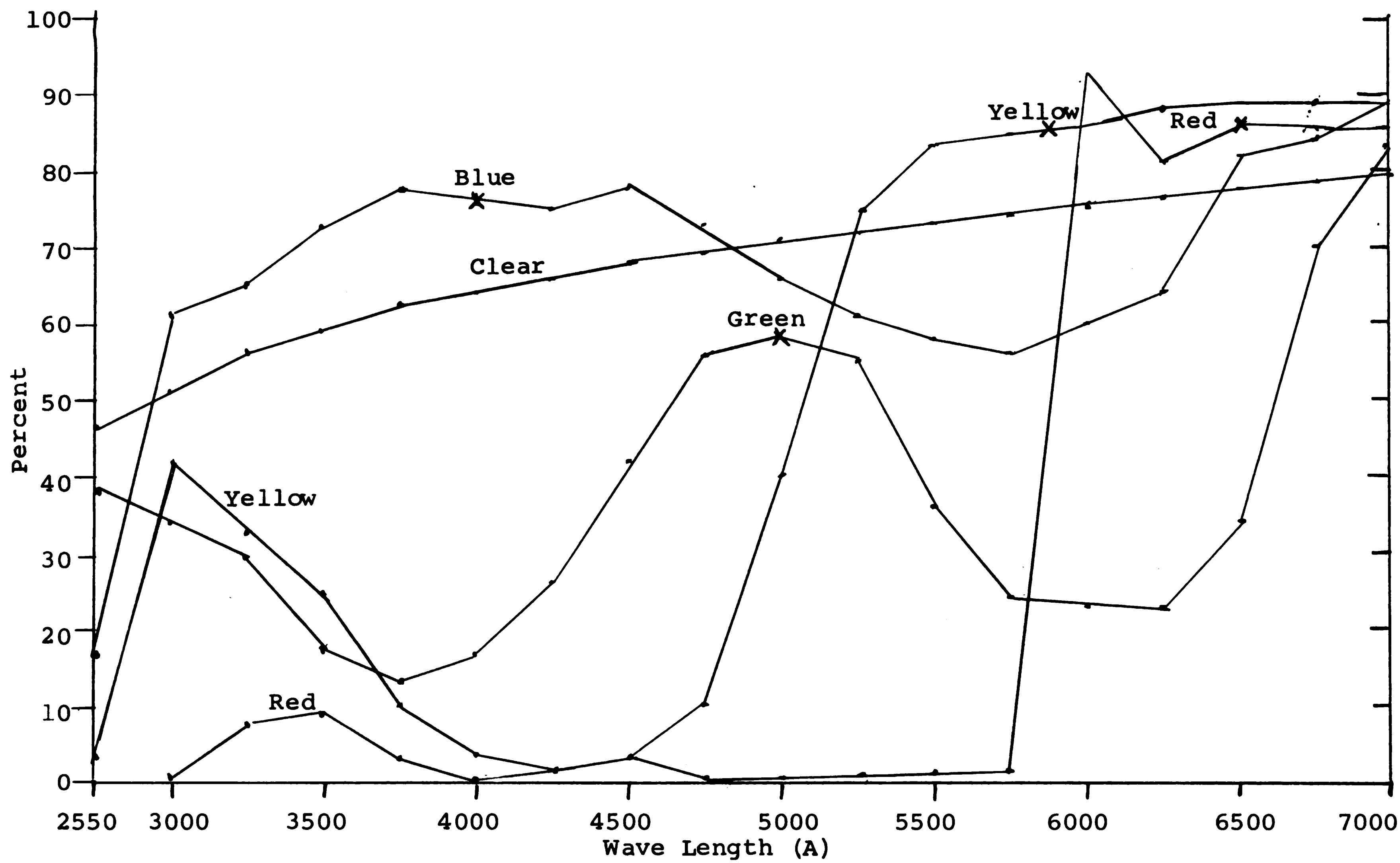

Figure 20. Percent transmission of different wave lengths through cellophane filters.

Table 19. Photometric data for colors of cellophane filters as determined by spectrophotometer and calculated at peak light transmission

Color	Wave Length (A)	Optical Density	Energy: Quanta/Sec.[a] (erg-cm)	Energy: Ratio to Green (%)	Equated Optical Density[b]	Cellophane Sheets[c]	Obtained Optical Density
Red	6500	.065	3.05	77	.194	2	.190
Yellow	5750	.060	3.45	87	.219	3	.210
Green	5000	.252	3.98	100	.252	1	.252
Blue	4000	.120	4.97	125	.315	3	.320

[a]One quantum/sec. = $hc/\lambda \times 10^{-18}$ erg-cm = $1987/\lambda \times 10^{-18}$ erg-cm where:

h = Planck's constant 6.624×10^{-27} erg sec.

c = speed of light 3.00×10^{10} cm/sec.

λ = wave length in Angstroms.

[b]Energy ratio x .252 (optical density of green).

[c]Equated optical density/optical density $\simeq$ number of sheets.

Figure 21. Growth of wheat and barley seedlings made under colored cellophane filters. Comparable growth was made between filters of the same color, but different energy values due to multiple layers of cellophane except for the red filters. Colors from front to rear are: green (front left), clear (front right), blue, yellow and red. Single layer filters (higher energy) covered the pots on the right.

filters of the same color but with different energy levels due to multiple cellophane layers, except for the red filters.

Data and Results

The attempt to balance the energy received through all filters was not entirely successful. However the range of energy between colors was much less than had no adjustment been made. Table 20 shows the percent of light transmitted and the energy values received from the 2500 foot-candle illumination as determined from the optical density of each filter.

The first five represent the filters adjusted for energy with additional layers of cellophane. The energy values range from 495 for red to 694 erg-centimeters for the clear filter. This is a 40 percent increase in energy value. If a single layer of cellophane had been used, the range would have been from 557 for green to 944 erg-centimeters for the blue filter, or nearly a 70 percent increase.

Figure 22 shows the percent emergence of seedlings in the different pots covered by filters. Emergence was poor in most pots, especially with barley seedlings where only 10 to 20 percent emerged. This appeared to be due to the extreme seeding depth and the tendency for barley to have shorter subcrown internodes so that the coleoptile failed to penetrate to the surface of the soil.

Table 20. Percent of light transmitted, foot-candles and energy values received from 2500 foot-candle light source as determined by measured optical density of each cellophane filter

Filter Color	Cellophane Layers	Optical Density	Percent Transmission[a]	Foot-candle Received[b]	Energy Values[c] (erg-cm)
Red	2	.190	65	1625	495
Yellow	3	.210	62	1550	535
Green	1	.252	56	1400	557
Blue	3	.320	48	1200	596
Clear	1	.244[d]	57[d]	1794[d]	694[d]
Red	1	.065	86	2150	656
Yellow	1	.060	87	2175	750
Blue	1	.120	76	1900	944

[a]Transmission = 1/Log O.D. x 100.

[b]2500 x percent of transmission.

[c]Foot-candles x quanta per second.

[d]Values for clear filter are averages of data obtained at four wave lengths: 4000, 5000, 5750 and 6500A.

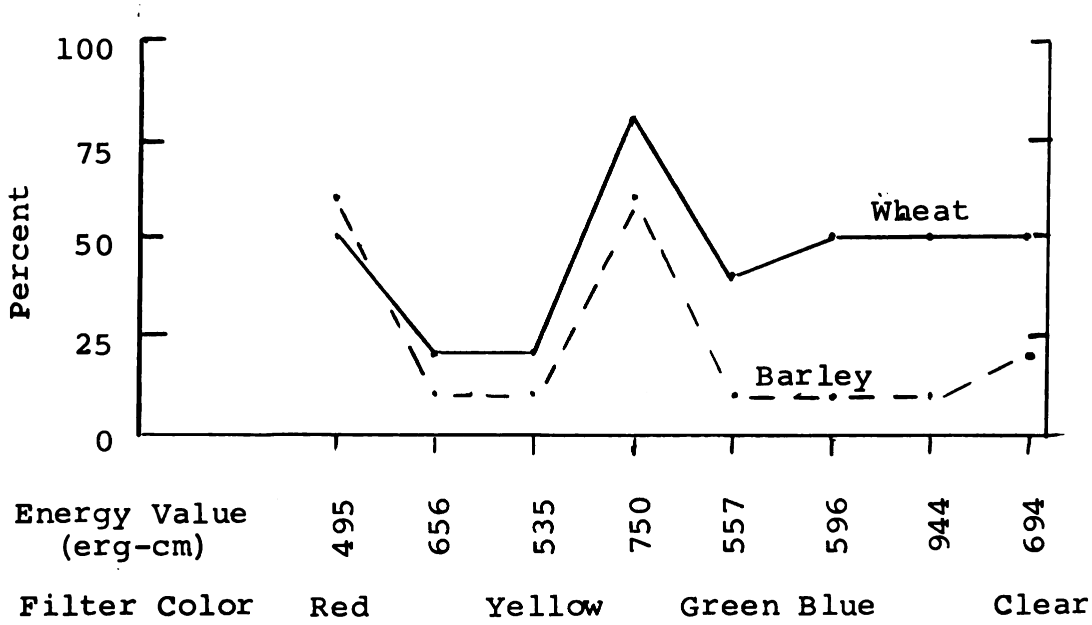

Figure 22. Percent of seedling emergence of wheat and barley sown under colored cellophane filters.

Most barley plants produced at least two subcrown internodes with root formation occurring at the lower node as well as at the crown. Figure 23 shows typical wheat and barley seedlings produced under the various colored filters. The lower node on the barley seedlings can be seen usually less than four centimeters from the seeding depth. The wheat seedlings on the other hand produced only the crown node between five and seven centimeters above the seed.

Table 21 shows the average distance from the seed to (1) the crown, (2) to the area of first chlorophyll development and (3) to the tip of the tallest leaf of the plants grown under the cellophane filters. Multiple layers of blue, yellow and red cellophane were used to balance the energy transmitted with the light. Thus the lower energy values of these colors represent multiple layers of cellophane and the higher energy values are from single layers. The crown location on seedlings tended to be higher in pots under filters with the lower energy values, particularly between plants in pots with filters of the same color. The uppermost crown node of barley followed this pattern, but it was not true for the lower node. Figure 24 shows graphically the locations of the crowns, area of chlorophyll formation and height of seedlings produced under colored filters. The area of chlorophyll development was also higher in the plants receiving lower energy. There is a parallel between

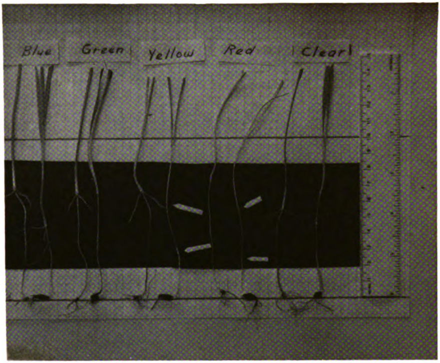

Figure 23. Wheat and barley seedlings grown under colored cellophane filters from seeding depth of eight centimeters. Barley (on the right of each pair) had at least two subcrown internodes, wheat (left plant of each pair) had only one.

Table 21. Average distance from seed to crown, area of chlorophyll development, and tip of tallest leaf of wheat and barley seedlings grown under cellophane filters, May 1969

			Wheat			Barley			
						Crown			
Color	Wave Length	Energy Value	Crown	Chlorophyll Development	Tallest Leaf	Lower	Upper	Chlorophyll Development	Tallest Leaf
	(A)	(erg-cm)	centimeters						
Blue	4000	944	5.7cd	7.4	40.5	5.5	5.7	8.5	38.0
Blue	4000	596	6.0bcd	8.4	50.3	4.4	5.4	8.0	33.0
Green	5000	557	6.8ab	8.5	42.4	4.2	7.0	8.5	35.0
Yellow	5750	750	6.3abc	7.1	38.2	3.8	6.1	7.6	25.0
Yellow	5750	575	5.9cd	9.3	42.0	4.0	6.5	9.0	21.5
Red	6500	656	5.3d	8.3	36.7	2.3	5.5	8.3	30.3
Red	6500	495	7.1a	9.2	41.9	5.0	7.4	9.9	34.6
Clear	5312**	694	5.5cd	7.3	33.6	3.8	5.3	8.5	23.5

*L.S.D. (5% level) between treatments, 0.8 cm. Averages with different letters are significantly different at the 5% level.

**Average of wave lengths 4000, 5000, 5750, and 6500A.

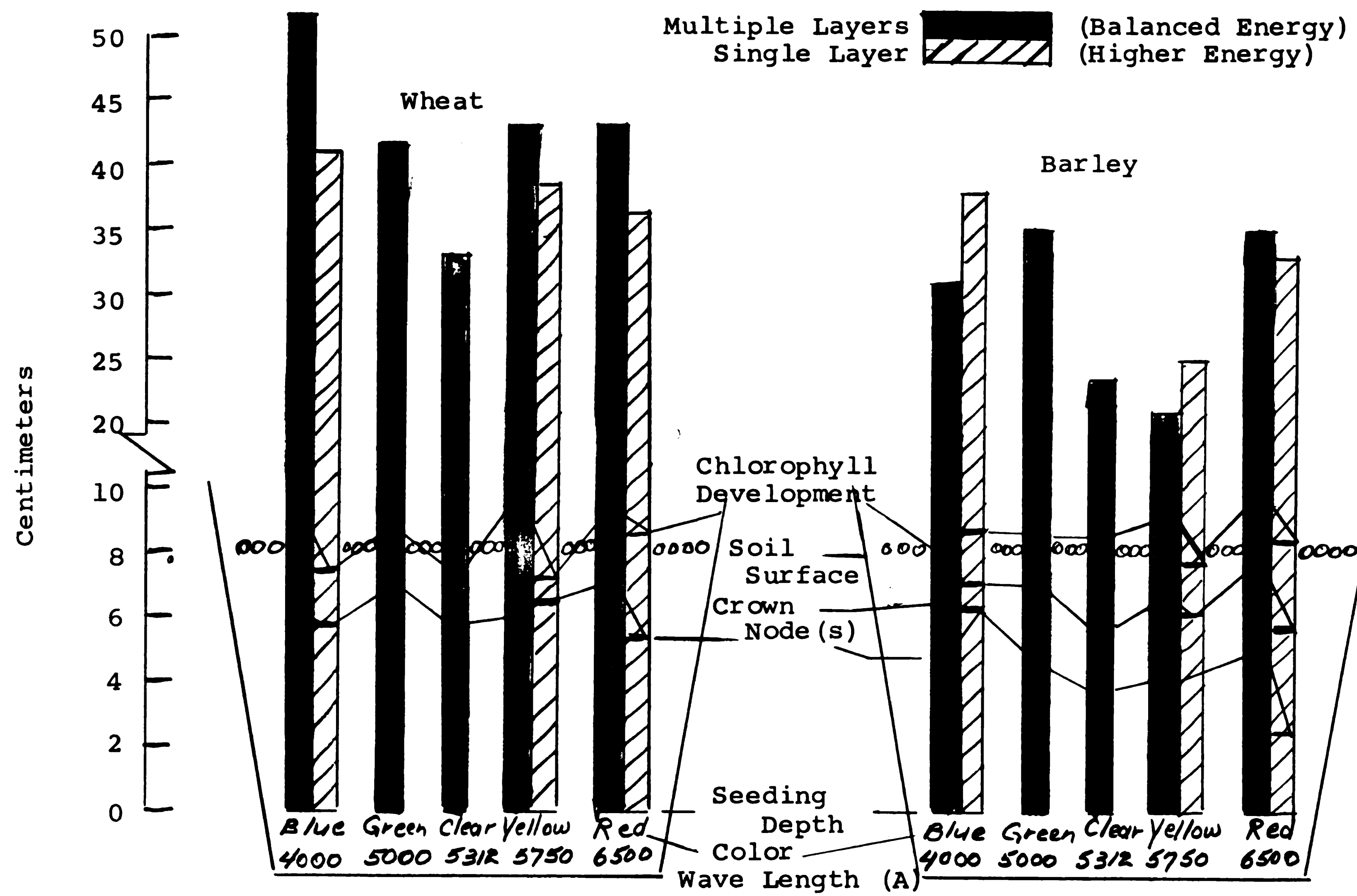

Figure 24. Locations of crown, chlorophyll development and height of tallest leaf of wheat and barley seedlings grown under colored cellophane filters.

the line of chlorophyll development and the location of the crown across the colors for wheat.

Variation in growth of the seedlings appeared to be associated with the energy level received at each wave length, as shown by comparisons of crown formation, chlorophyll development and height of tallest leaf. There are differences in location of these points between plants grown under single or multiple layers of cellophane. The single layer permitting higher energy radiation, resulted in decreased elongation of the plants and a compressing of the points measured.

The difference in response to energy levels is most evident within the same color wave length, especially in the red area where a difference in energy level from 500 to 650 erg-centimeters made a striking morphological change. In the blue area where the energy difference was from 600 to 950 erg-centimeters the response was less noticeable. As shown in Figure 25 there was a general lowering of the crown and chlorophyll line as energy radiation increased.

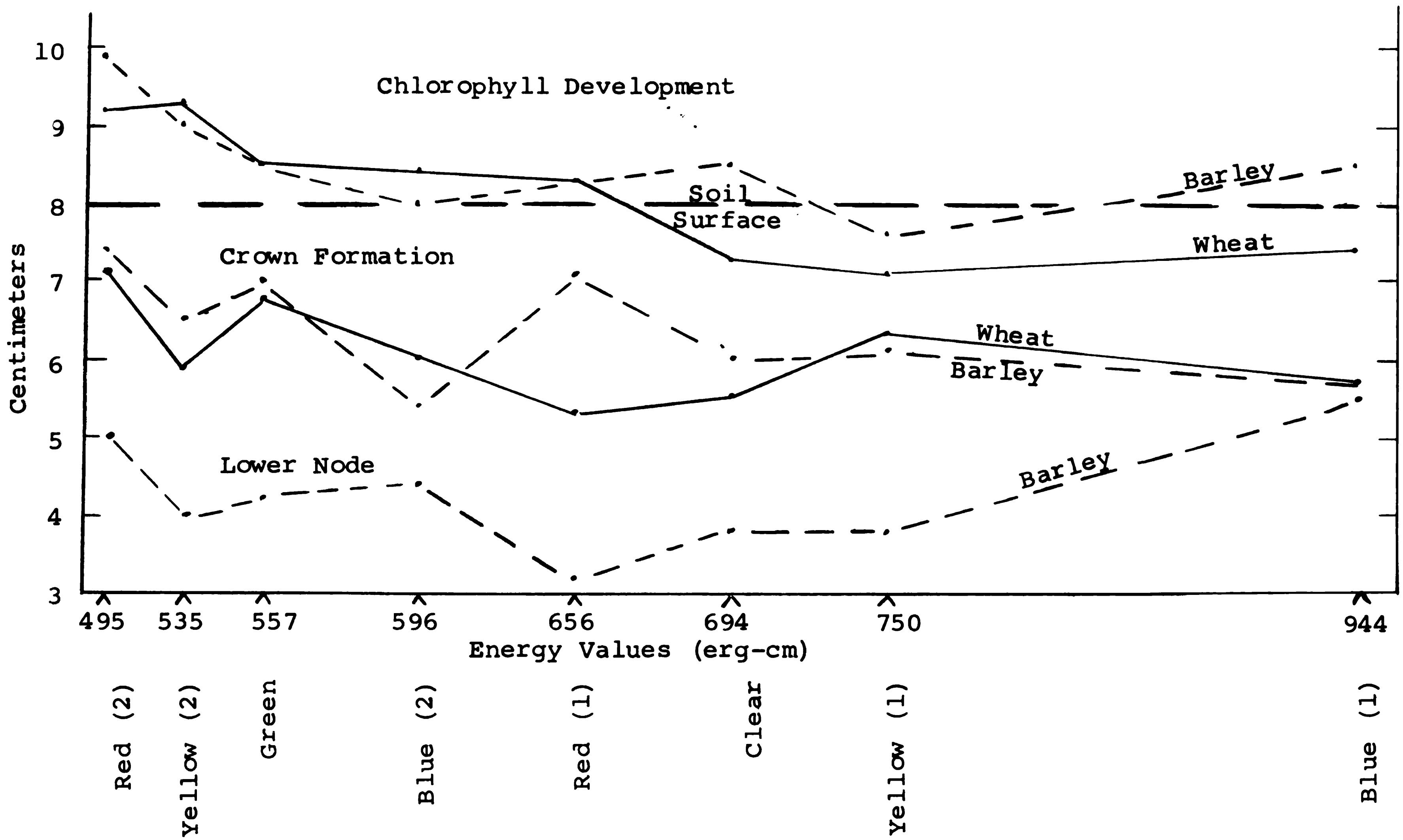

Figure 25. The crown location and area of chlorophyll development in wheat and barley seedlings as influenced by energy radiation through colored cellophane.

DISCUSSION

The crown of small grain plants is considered as that region of the plant where tillers and secondary roots originate. It is a succession of nodes and telescoped internodes, generally occurring near the soil surface. After germination, as growth of the seedling occurred, the apical meristem surrounded by the coleoptile was carried upward by elongation of the internode or internodes beneath the growing point. In some cases with deep seeding, more than one internode was formed below the crown. The internodes continued to elongate until emergence of the coleoptile or foliar leaf. Thus it may be more appropriate to refer to the growth as a subcrown "stem" with nodes and internodes similar to an above ground stem. The bud at each node could develop into a crown under proper environmental conditions. The name "crown" however should be reserved for the node where tiller buds are produced and elongate and the secondary root system develops. When the seedling received light, elongation of the internode halted and foliar leaves with axillary buds developed at the uppermost node.

Minimum tillage created a soft seedbed resulting in deeper seeding of barley. The normal seedbed preparation resulted in a firm seedbed and shallow seeding. No elongation of the subcrown internode occurred in the shallow seeding because the coleoptile emerged and received light before elongation of the apical meristem. With deeper seeding, the meristem became active and elongation of the internode occurred before the coleoptile emerged. As long as the coleoptile was kept in the dark, either by soil or by a tar paper lid, the one or more subcrown internodes elongated. Light seemed the principle factor in determining the location of the crown. Soil moisture and oxygen content were considered as factors in crown location. While they are undoubtedly important, the fact that the crown was formed above the level of the soil surface in darkness eliminates these as determinant factors in crown location.

The possibility of manipulating the location of the crown by covering the emerged seedlings of wheat and barley was investigated. A second crown was formed by seedlings of both species by covering them with soil after they had emerged and formed the first crown. The second crown formed at a node closer to the soil surface than the crown of shallow seeded plants. Apparently the covering of the crown allowed a temporary resumption of hormone production needed by the growing point for elongation purposes. Light was not completely removed from the seedlings as some leaf area always remained above the leveled soil surface. Very few tiller buds at the first crown elongated.

The influence of light intensity on crown formation has a practical application in explaining observations of Ferguson and Boatwright (1968) that wheat grown under stubble mulch produced crowns nearer the surface of the soil. The blanket of stubble litter would have reduced light intensity, as did the dark beads in the present experiments, elevating the location of the crown. Long wave lengths of red and yellow light (6600 and 7000A) permitted greater light transmission and effectively triggered the response for crown formation at a lower depth than the shorter wave lengths of blue and green (4600 and 5200A).

The finding of varietal differences in tillering confirms previous reports. Wong produced more tillers from the coleoptile node than did Hudson. However Hudson showed a depth of seeding-variety interaction to coleoptile tillering by producing more tillers at the coleoptile node when seeded deeper. Gaines also exhibited more tiller production capacity than other wheat varieties. Other factors were more important in tiller production than depth of crown formation. However there was a slight association between depth of crown formation and number of tillers produced per plant. Generally plants with deeper crowns produced more tillers than those with shallow crowns. The environment for tiller survival might be better at the lower depth. There would be less ground action from winter freezing and better protection from cold temperatures.

CONCLUSIONS

Light played a major role in determining the crown location of wheat and barley seedlings. During and after germination the apical meristem of wheat and barley seedlings elongated to form the subcrown stem until growth was halted by plant emergence into light, or food reserves of the seedling were exhausted. In normal conditions the subcrown stem consisted of a single internode, the axillary bud at the top node developing into the crown. With excessive seeding depth, the subcrown stem contained a series of nodes and internodes, the crown forming at the uppermost node. The subcrown stem of wheat and barley ceased elongation when the seedling received light.

When the coleoptile emerged and elongation of the subcrown stem ceased, foliar leaves with axillary (tiller) buds and the secondary root system developed to form the crown. The location of the crown was manipulated at least to a small degree by seeding depth. Seeding at lower depths permitted some elongation of the subcrown internodes and permitted the crown to be formed at a lower depth than with shallow seeding where no internode elongation occurred.

Barley had shorter subcrown internodes than wheat increasing the probability of it producing more than one subcrown internode. The shorter subcrown internodes also makes deeper seeding of barley more susceptible to failure of emergence.

Leveling of ridges between deep furrows to cover emerged seedlings can be used to manipulate the crown location. A second crown above the original crown was formed near the leveled soil surface. The possibility of rejuvenating the lower crown in case of winter damage to the upper crown was not explored but offers interesting speculation. The number of tillers and yield were not increased by this practice.

Varietal differences in tiller production and the point of tiller origin were observed. Wong produced more tillers from the coleoptile node than Hudson. Gaines produced more tillers than Avon or Genesee.

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