RESPONSE OF SEEDLINGS TO VARIOUS WAVEBANDS OF LOW INTENSITY IRRADIATION[1, 2]

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(WITH THREE FIGURES AND TWO PLATES)

The most extensive investigations concerning the influence of radiant energy within the visible spectrum on the growth of shoots of seedlings and storage organs have been conducted by COUPIN (**1**), MACDOUGAL (**2**), PRIESTLEY (**4**), and TRUMPF (**6**). These workers all agree that relatively low intensities of visible radiant energy in the range of 10 foot candles or less induce almost as complete morphological development of the stems and leaves of such shoots as high intensities of many thousands of foot candles. When low intensities are used, the leaves become green, expand into flat lamina, and the portions of the stem first laid down are greatly shortened as contrasted with plants grown in the complete absence of radiant energy where the leaves fail to develop chlorophyll, frequently do not expand, and the stem portions first laid down are relatively long. Many shoots, such as those of the red kidney bean, emerge from the germination medium with a well defined plumular hook, which does not completely disappear in the total absence of visible radiant energy. After the irradiation of the plants with low intensities of visible radiant energy, the plumular hook disappears.

TRUMPF came to the conclusion that chlorophyll synthesis was not directly connected with the mechanism involved in the disappearance of those characteristics associated with growth in the total absence of visible radiant energy. With short low intensity exposures he was able to secure leaf expansion, internodal shortening, and disappearance of the plumular hook without any apparent synthesis of chlorophyll. His results also indicated that it was the longer wavelengths of the visible spectrum that were primarily influential in causing leaf expansion, but stem elongation was not greatly affected by the red. The blue was more effective in inducing shortening of the stem. He used relatively wide bands of the red and blue regions which were balanced to equal readings with a selective radiometer.

This report concerns a preliminary investigation[3] on the influence of spectrally controlled radiant energy on the growth and development of red kidney bean seedlings and other physiologically young plants.

[1] Contributions from the Hull Botanical Laboratory 523.

[2] This work was aided in part by a grant from the Dr. Wallace C. and Clara A. Abbott Memorial Fund of the University of Chicago.

[3] A portion of the investigation was conducted at the Hull Botanical Laboratories, University of Chicago, during the winter of 1937–1938. The remainder of the investigation was conducted in the Department of Horticulture, Purdue University Agricultural Experiment Station, during the year of 1939–1940.

Procedure

The plants were grown in a series of six compartments 32 inches square by four feet high. The compartments were arranged in two units of three compartments per unit in a temperature controlled dark room having facilities for mounting the radiation equipment outside the room so that the lamps had a minimum influence on temperature. Above each compartment was built the radiation system which consisted of a tray of angle iron for the dyed gelatin secondary filters, over which was suspended a 25-inch square glass-bottomed filter cell, eight inches deep, containing distilled water. Where necessary to completely remove red radiant energy, an additional cell of glass, $1\frac{3}{16}$ inch deep by 24 inches square, containing a concentrated solution of copper sulphate, was immersed in the primary filter cell. This system eliminated the necessity of free surfaces of copper sulphate solutions above the plants. The lamp equipment was mounted above the filter cells, and consisted of 1500-watt vapor proof aluminum reflectors of the concentrating type. The details of the lamp equipment and filter systems on five of the six compartments are presented in table I.

TABLE I

DETAILS OF THE RADIATION SYSTEMS

WAVELENGTH LIMITS, Å	RADIATION SOURCE	PRIMARY AQUEOUS FILTER	SECONDARY FILTER DYED GELATIN FILM
BLUE 4047 and 4358 Hg lines	400-watt type H_1 high pressure Hg arc	10 cm. water and 3 cm. – 25 per cent. $CuSO_4 \cdot 5H_2O$	Victoria Pure Blue BO and Crystal Violet
YELLOW-GREEN 5461, 5770 and 5791 Hg lines	400-watt type H_1 high pressure Hg arc	10 cm. water and 3 cm. – 25 per cent. $CuSO_4 \cdot 5H_2O$	Pontamine Fast Yellow 5GL and Orange G
RED 6400 to approximately 9,000 continuous	300-watt gas-filled tungsten filament	10 cm. water	Chrysoidine Y and Crystal Violet—2 panes ⅛ inch Corning Aklo plate infrared absorbing glass
FAR RED 6800 to approximately 12,000 continuous	150-watt gas-filled tungsten filament	10 cm. water	Chrysoidine Y and Victoria Pure Blue BO
NEAR INFRARED 7200 to approximately 12,000 continuous	500-watt gas-filled tungsten filament	10 cm. water	Orange G, Pontamine Fast Red 8BL, and Acid Film Green 1854

The sixth compartment served as a dark plot. In some of the experiments, the near infrared treatment was eliminated and a second dark plot included. Figure 1 is a graph of the transmission spectra of the filter systems used.

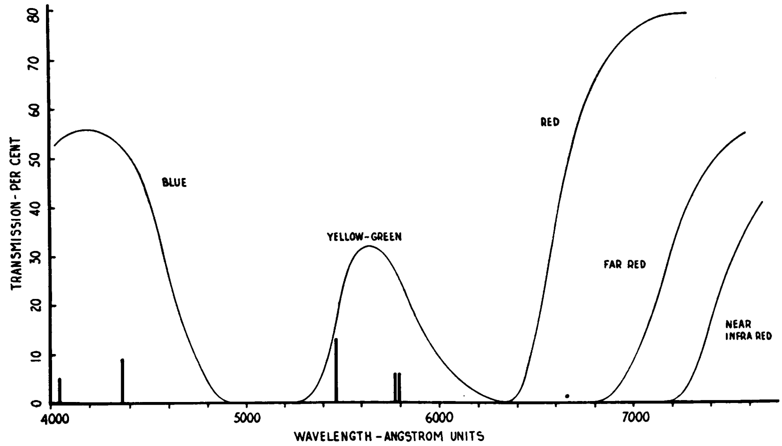


FIG. 1. Transmission spectra of the filter systems.

The energy was balanced with a thermopile which was mounted 20 cm. above the gravel surface and covered with a filter cell containing 18 mm. of ferrous ammonium sulphate saturated at 22° C., as described by PFUND (3). This filter efficiently absorbs radiant energy beyond about 8000 Å. with relatively little absorption within the range of the visible spectrum. The radiant energy for each plot was adjusted to the values presented in the tables of results. The final adjustments were obtained by placing narrow strips of black paper across the filter panes. It was assumed tentatively that the energy beyond 8000 Å. has little effect, this assumption being based upon a preliminary experiment in which no effects were obtained with radiant energy beyond this limit. For this preliminary experiment an irradiance of 1500 ergs per sq. cm. per second from an incandescent lamp source was filtered with 10 cm. of distilled water and a 3.5-mm. Corning no. 254 infrared transmitting glass with transmission from 8000 Å. to 12000 Å. The results secured indicated that no appreciable effects on red kidney bean occur when the plants were irradiated with these wavelengths.

The plant material was grown in subirrigation gravel culture beds, 6 inches deep by 28 inches square. Tap water was supplied to the beds automatically every four hours by means of a time switch and a centrifugal pump. A pair of small fans circulated air up over the beds at a sufficiently rapid rate to maintain the temperature of the compartments the same as that of the room. The irradiation was applied continuously with no dark periods, except for the experiments reported in table VI, where the irradiation was applied both continuously and for ten per cent. of the daily cycle, or 2.4 hours daily. Where high humidities were used, the air was kept supplied with water vapor from a small spray unit placed in front of a large fan. The temperature was maintained at 25° C.

Seeds of red kidney bean (*Phaseolus vulgaris*) were selected for uniform size. The variation in total seed weight per plot in any one experiment was not more than 0.5 per cent. There was considerable variation, however, in size of seed selected for the different experiments. The seeds were sown at a depth of one inch with a spacing of 2×2 inches. As soon as the plumular hook appeared above the gravel, the irradiation was applied. The plants were harvested 14 days from seeding.

Length measurements were made of the hypocotyl and first and second internodes. The internodes in this study were numbered from the cotyledon up the stem in the order of development. Fresh and dry weight were taken for the hypocotyl, first internode, cotyledons, first leaves and roots. Those portions of the plant above the first leaves were weighed as one fraction. The plant material was dried for 18 hours at 100° C. in a forced draft oven.

The leaf pigments were extracted with 100 ml. of acetone from 5 gm. of fresh leaf tissue. The relative chlorophyll concentration was then determined with a visual spectrophotometer from the specific transmissive index of the acetone solution using the 6630 Å. absorption band of chlorophyll.

Where transfers were made to the greenhouse from the radiation rooms, the greenhouse temperatures were maintained at approximately 19° C. during the day and 13° C. during the night. The short day condition was 9 hours long. Two long day conditions were used, one with 9 hours daylight supplemented with 15 hours of irradiation with 10 foot candles from an incandescent lamp or 9000 foot candle minutes nightly. The second long day treatment consisted of 9 hours daylight supplemented with equal energy of 9000 foot candle minutes supplied by intermittent irradiation with 200 foot candles on for 5 per cent. of the time or 1.5 minutes half-hourly. These greenhouse irradiation conditions were used because they were already in operation in connection with other experiments.

Seeds of pea (*Pisum sativum*), variety Little Marvel, were selected for uniform weight and sown with the same spacing and at the same depth as the red kidney bean, using the same wavebands and temperature. Length measurements were made of six internodes above the cotyledons and fresh and dry weights of leaves, stems, roots, and cotyledons were obtained. The plants were dried at 100° C. for 18 hours.

Pea, maize (*Zea mays*) and soybean (*Soya max*) seeds and small potato tubers (*Solanum tuberosum*) were selected for uniform size and these, together with tomato (*Lycopersicum esculentum*) and cocklebur (*Xanthium* *pennsylvanicum*) seed, were grown under far red treatment (6800 Å. to 12000 Å.), and in complete darkness, all other experimental conditions being similar to those outlined above.

Results and discussion

Of the five bands of radiant energy used, the yellow-green and red caused the most pronounced morphological effect as contrasted with plants grown in the total absence of radiant energy. The far red band produced almost as great an effect on the development of the plants as the yellow-green and red, but the blue and near infrared bands had much less effect. On the basis of the data in the tables, the near infrared appears to be almost as effective as the blue, but it should be noted that the energy of the near infrared was 15 times that of the other plots.

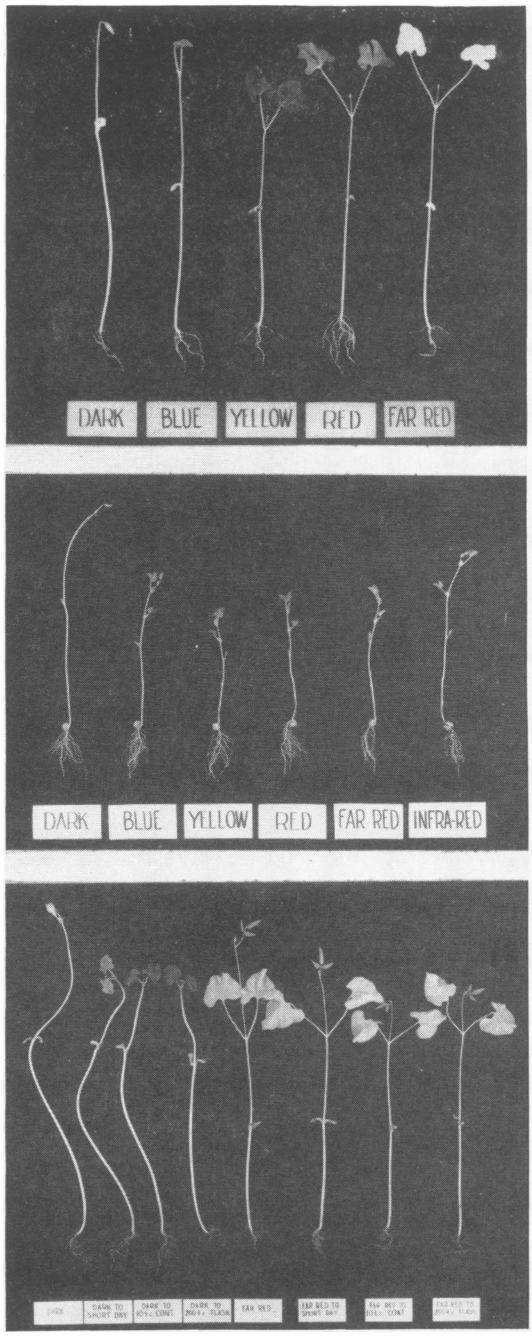
With the yellow-green and red bands of radiant energy, the hypocotyl and first internode lengths of red kidney bean were shortened (tables II, III, IV, and VI) and there was an increased development of the epicotyl above the first internode (plate I and fig. 2). Marked leaf expansion occurred under these wavelengths together with the rapid disappearance of the plumular hook.

Under the blue, there was some shortening of the hypocotyl and first internode. The apical hook originating as a plumular hook, moved toward the tip of the plant and at the time of harvest had become a petiolar hook of the first leaves. Little leaf expansion occurred. Under the near infrared, the plumular hook disappeared entirely and some leaf expansion took place.

The dry weights show that all of the spectral regions, especially the red, accelerated the movement of the food reserves from the cotyledons into the extremities of the plant, the accelerated movement taking place both up the stem into the terminal portions of the shoot, and down into the root system. The dry weights of these parts increased considerably over similar fractions of plants grown in complete darkness or in the other spectral regions (fig. 3). In plants grown in the complete absence of radiant energy, the hypocotyl and first internode, both adjacent to the cotyledonary node, received the major portion of the food reserves translocated from the cotyledons.

The percentage of dry matter was at a maximum in the longer wavelength treatments. The top-root ratio was at a minimum under the same conditions as a result of the accelerated tendency of the food reserves to move into the root system.

This whole series of reactions which was brought about most effectively by the longer wavelengths of the visible spectrum does not appear to be directly related to respiration since, as shown in table II, there does not appear to be any significant difference in loss of dry matter by the plants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FAR RED TO SHORT DAY

as calculated from the difference between the total dry weight at harvest and the dry seed weight minus the seed coat.

Neither do these responses appear to be related to the amount of chlorophyll present in the leaf. Table II presents the relative concentration of chlorophyll per unit of fresh weight of leaf tissue. The highest chlorophyll

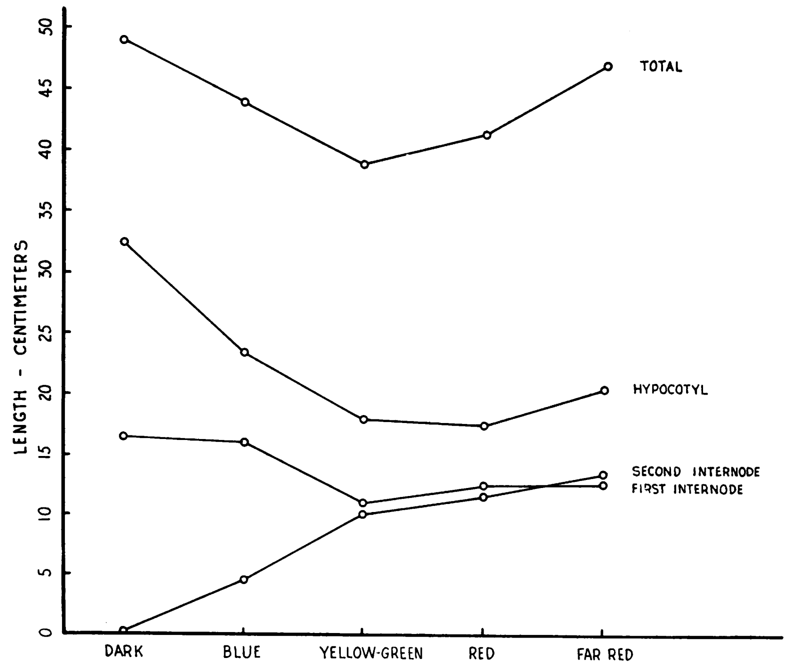


FIG. 2. Stem lengths of red kidney bean seedlings exposed to 500 ergs per sq. cm. per second of filtered radiant energy of the regions indicated.

PLATE III

EFFECT OF WAVELENGTH OF RADIATION ON THE GROWTH RESPONSE OF BEAN AND PEA

TOP.—Bean plants showed the maximum leaf expansion, development of the second internode, and the shortest hypocotyls in the yellow, red and far red. In the far red, only a trace of chlorophyll developed, whereas in the red, yellow and blue, the leaves were quite green. The development of the plants under the blue was similar to that of the plants grown in the dark with the exception of the presence of chlorophyll in those portions of the leaves exposed to the blue irradiation.

CENTER.—Pea, showing relationships similar to those exhibited by bean, although the differences occurring under the various spectral regions are not as marked.

BOTTOM.—Bean plants transferred from the dark and far red treatments to the greenhouse. The dark conditioned plants expanded their leaves and developed chlorophyll with a denser green color apparent in the long day treatment than in the short day condition. The plants conditioned by the far red failed to develop chlorophyll in the leaves previously exposed to the far red radiation. Those leaves in the bud at the time of transfer unfolded and developed chlorophyll.

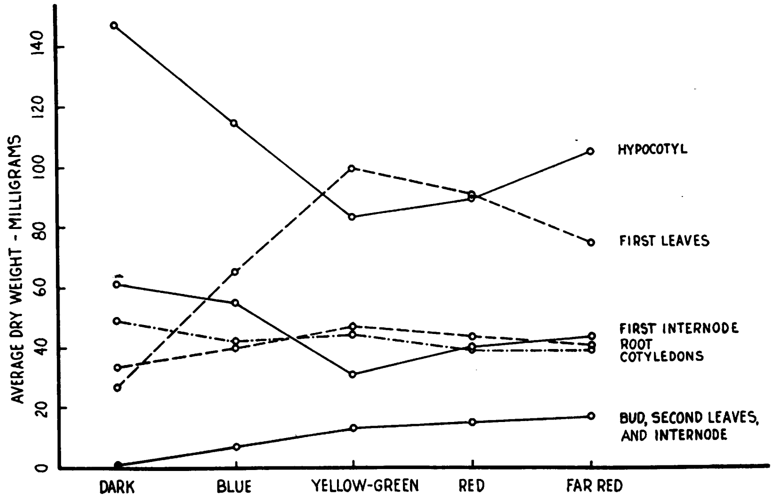


FIG. 3. Average dry weight per plant of various fractions of red kidney bean.

TABLE II

THE GROWTH RESPONSE OF RED KIDNEY BEAN SEEDLINGS* TO A CONTINUOUS IRRADIANCE OF 500 ERGS PER SQ. CM. PER SECOND AT 25° C.

PLANT FRACTION	DARK	BLUE	YELLOW-GREEN	RED	FAR RED
			LENGTH		
	cm.	*cm.*	*cm.*	*cm.*	*cm.*
Second internode	0.1	4.5	10.0	11.4	13.6
First internode	16.6	15.9	11.0	12.5	12.8
Hypocotyl	32.5	23.6	17.9	17.5	20.3
Total	49.2	44.0	38.9	41.4	46.7
			DRY WEIGHT		
	mg.	*mg.*	*mg.*	*mg.*	*mg.*
Bud, second leaves and internode	1	7	13	15	17
First leaves	27	65	99	90	74
First internode	61	55	31	40	43
Hypocotyl	147	114	83	89	104
Cotyledons	49	42	44	39	39
Root	34	40	46	43	40
Total	319	323	316	316	317
Percentage dry matter	4.9	5.6	6.0	6.0	5.9
Mg. respired	129	125	132	131	130
Top-root ratio	6.9	6.0	4.9	5.5	6.0
Relative chlorophyll concentration	0	14.5	27.0	16.5	0.9

* Plants per treatment: 100.

concentration appeared in the yellow-green. Since the leaves were not expanded in the blue, only a relatively small amount of surface was exposed to the radiant energy. In these exposed regions the green coloration appeared to be more intense than in any of the other plots, even though the extraction data, based on total leaf weight, does not show this.

The plants irradiated with the far red were consistently nearly as fully developed morphologically as those in the yellow-green and red plots, but the leaves contained only a trace of chlorophyll. SAYRE (5) has reported that chlorophyll is not formed to any appreciable extent by wavelengths longer than 6800 Å. The results of this experiment are in harmony with his conclusion. Chlorophyll synthesis therefore would not appear to be directly connected with the morphological responses obtained, since almost the maximum response occurred in the far red where almost no chlorophyll was present and a minimum response in the blue where a relatively high chlorophyll concentration obtained. These conclusions are in accord with those of TRUMPF who obtained similar morphological development without the synthesis of chlorophyll when the seedlings were treated with very short exposures to white irradiation.

TABLE III

THE GROWTH RESPONSE OF RED KIDNEY BEAN SEEDLINGS* TO A CONTINUOUS IRRADIANCE OF 100 ERGS PER SQ. CM. PER SECOND AT 25° C. AND 25 PER CENT. RELATIVE HUMIDITY

PLANT FRACTION	DARK	BLUE	YELLOW-GREEN	RED	FAR RED	INFRA-RED†
	LENGTH					
	cm.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
Second internode	0.4	4.1	9.3	9.5	8.9	5.8
First internode	21.5	15.3	15.2	14.4	15.6	18.3
Hypocotyl	23.6	20.6	15.4	15.0	16.1	21.6
Total	45.5	40.0	39.9	38.9	40.6	45.7
	DRY WEIGHT					
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Bud, second leaves and internode	1	6	11	13	11	9
First leaves	20	36	43	45	44	41
First internode	63	53	45	43	49	58
Hypocotyl	91	92	73	73	81	90
Cotyledons	70	54	62	56	60	54
Root	28	28	33	32	37	29
Total	273	269	267	262	282	281
Percentage dry matter	5.2	5.9	6.4	6.1	6.5	5.9
Top-root ratio	6.2	6.7	5.2	5.5	5.0	6.8

* Plants per treatment: 40.
† Adjusted to 1500 ergs per sq. cm. per second.

Several minor experiments were conducted on the plants irradiated with wavelengths longer than 6800 Å. as obtained in the far red treatment. Since the expanded leaves of these plants contained very little chlorophyll, and were yellowish in color, they were transferred to the greenhouse to full sunlight nine hours daily in order to determine whether chlorophyll would be synthesized normally in these plants. It was found that fully expanded leaves previously irradiated with the far red did not synthesize any chlorophyll in seven days time (plate I). At the end of a week the leaves were still alive but completely lacking in green coloration. The young leaves which unfolded after the transfer to the greenhouse developed chlorophyll quite normally. Plants taken from the dark to the greenhouse expanded their leaves which became green. In this case, the color was more intense in the long days than in the short days, as indicated in the photograph. Some of the plants from the far red were placed in tap water and some in a complete nutrient solution, but the effect was the same in both cases.

TRUMPF likewise obtained somewhat similar results with his plants which developed expanded leaves containing no chlorophyll under the influence of short exposures to white irradiation. His plants failed to develop chlorophyll in the older leaves on transfer to the greenhouse.

TABLE IV

THE GROWTH RESPONSE OF RED KIDNEY BEAN SEEDLINGS* TO A CONTINUOUS IRRADIANCE OF 100 ERGS PER SQ. CM. PER SECOND AT 25° C. AND 75 PER CENT. RELATIVE HUMIDITY

PLANT FRACTION	DARK	BLUE	YELLOW-GREEN	RED	FAR RED	INFRA-RED†
	LENGTH					
	cm.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
Second internode	2.3	5.5	11.4	11.7	9.9	5.5
First internode	23.8	16.5	16.4	14.6	15.5	18.2
Hypocotyl	21.6	18.5	14.6	15.4	16.2	20.7
Total	47.7	40.5	42.4	41.7	41.6	44.4
	DRY WEIGHT					
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Bud, second leaves and internode	2	7	16	15	12	7
First leaves	24	45	56	55	50	42
First internode	64	51	44	37	43	52
Hypocotyl	81	79	74	73	75	83
Cotyledons	46	44	40	42	45	46
Root	31	35	42	45	41	38
Total	248	261	272	267	266	268
Percentage dry matter	4.8	5.3	5.6	5.7	5.8	5.4
Top-root ratio	5.5	5.2	4.5	4.0	4.4	4.8

* Plants per treatment: 25.
† Adjusted to 1500 ergs per sq. cm. per second.

TABLE V

THE GROWTH RESPONSE OF PEA, VARITY LITTLE MARVEL, SEEDLINGS* TO A CONTINUOUS IRRADIANCE OF 100 ERGS PER SQ. CM. PER SECOND AT 25° C. AND 75 PER CENT. RELATIVE HUMIDITY

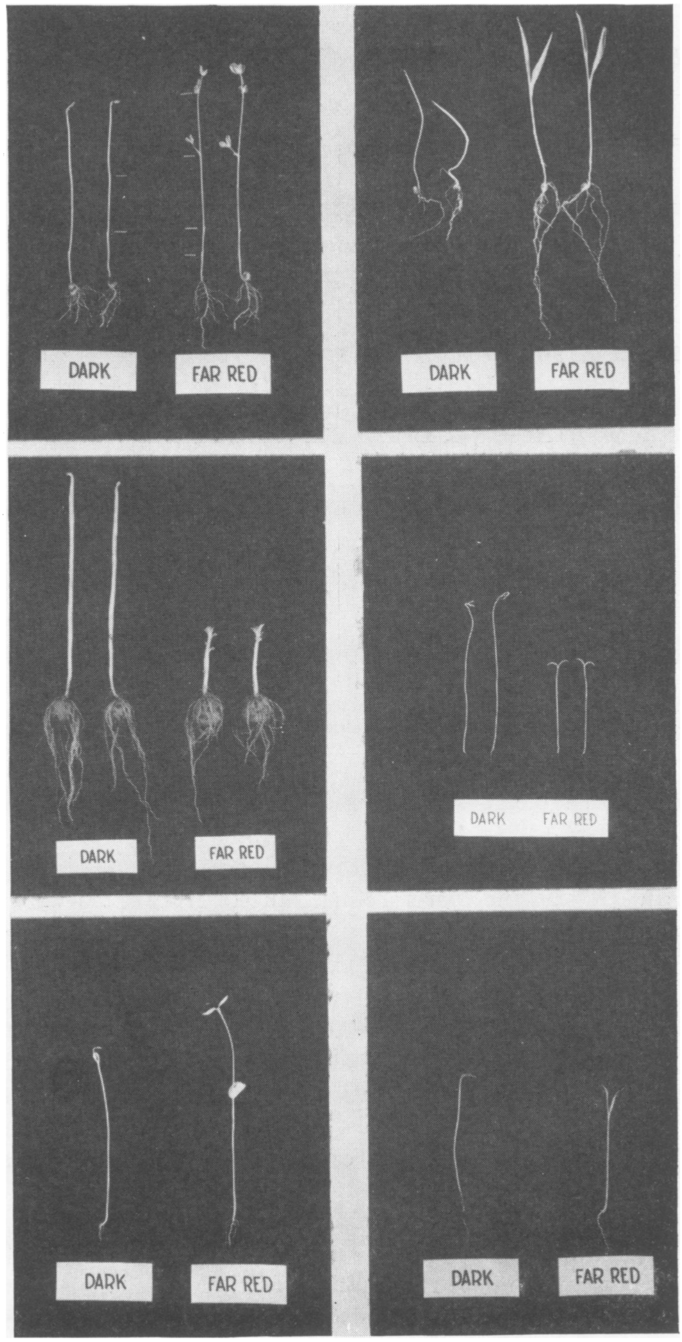
PLANT FRACTION	DARK	BLUE	YELLOW-GREEN	RED	FAR RED	INFRA-RED†
	LENGTH					
	cm.	*cm.*	*cm.*	*cm.*	*cm.*	*cm.*
Internode VI	0.4	0.8	0.9	0.6	1.1	1.1
Internode V	6.7	3.5	2.8	2.3	2.9	3.9
Internode IV	12.2	4.6	3.4	2.9	3.8	6.0
Internode III	9.9	6.0	3.2	3.6	4.1	6.1
Internode II	2.5	3.1	2.0	2.5	2.5	3.0
Internode I	3.9	3.8	3.1	3.5	3.7	3.7
Total	35.6	21.8	15.4	15.4	18.1	23.8
	DRY WEIGHT					
	mg.	*mg.*	*mg.*	*mg.*	*mg.*	*mg.*
Leaves	9	22	28	26	27	21
Stems	63	41	32	30	37	41
Cotyledons	46	44	44	37	43	41
Roots	24	24	27	25	27	24
Total	142	131	131	118	134	127
Percentage dry matter	5.1	5.4	6.0	5.7	5.7	5.1
Top-root ratio	3.0	2.6	2.3	2.3	2.4	2.6

* Plants per treatment: 30.
† Adjusted to 1500 ergs per sq. cm. per second.

Data given in table II were secured at 500 ergs per sq. cm. per second and in table III at 100 ergs per sq. cm. per second. These show the same general trend in all cases. It was not practical to reduce the intensity much further than 100 ergs and therefore intermittent irradiation was used with the lamps on for 2.4 hours daily so as to reduce the total daily radiant energy to 10 per cent. of the continuous irradiation. Height results for bean and pea under these conditions are given in table VI. It can be seen here that the differences were considerably less marked with intermittent irradiation, but there was still a great deal of influence on the development of the plants.

Tables III and IV give comparative data for results secured at 25 per cent. and 75 per cent. relative humidity. The same trend of morphological development was observed in both cases although a slightly higher percentage of dry matter occurred at the lower humidity, and the leaf expansion was not as great. The actual weight and height figures cannot be directly compared, however, since the initial seed weights were not the same.

Several experiments were run with the Little Marvel variety of pea and a set of typical results are given in table V. The weight results were similar to those obtained with bean. The leaves were somewhat more fully ex-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panded under the longer wavelengths and the total height was less. Internode lengths show that as the internodes become further removed from the cotyledons, they become shorter under all wavelengths of radiant energy, with the greatest shortening with the yellow-green, red, and far red (plate III). The leaves were heavier under the longer wavelengths, and the dry weights of the stems less.

Since bean plants develop with expanded leaves under radiant energy of wavelengths longer than 6800 Å. without appreciable development of chlorophyll, a number of other species of plants was grown without radiant energy and with this region of the spectrum applied continuously at 2000 ergs per sq. cm. per second. As can be seen from the photographs presented in plate II, the responses of all dicotyledonous plants were similar to those of the bean, with increased leaf expansion, shortened hypocotyl, and the disappearance of the plumular hook where either was present. In the case of maize, leaf expansion was greatly increased under the far red. Only a trace of green coloration could be observed in any of these plants.

Red kidney bean plants were grown in a preliminary experiment using a complete nutrient solution containing both nitrate and ammonium nitrogen. The same type of results was secured with a complete nutrient solution as with tap water.

Summary and conclusions

Seedlings of red kidney bean (*Phaseolus vulgaris*) and pea (*Pisum sativum*) were grown in gravel culture, subirrigated with tap water, in the complete absence of visible and near visible radiant energy, and irradiated with 500 and 100 ergs per sq. cm. per second of five bands of visible and near infrared radiation including: blue (4047, and 4358 Å. Hg lines); yellow-green (5461, 5770, and 5791 Å. Hg lines); red (6400 to approximately 9000 Å. incandescent); far red (6800 Å. to approximately 12000 Å incandescent); and 1500 ergs per sq. cm. per second of near infrared (7200 Å to approximately 12000 Å incandescent).

Seedlings of pea, maize, soybean, tomato, and cocklebur, and sprouts of

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PLATE IV

FAR RED RADIATION

Influence of low intensity far red radiation (6800–12000 Å.) on the morphological development of pea (top left), maize (top right), potato (center left), tomato (center right), soybean (bottom left), and cockle bur (bottom right). The far red caused the disappearance of the plumular hook in the dicotyledonous plants, a shortening of the hypocotyl where it was present, and increased the leaf expansion and development of the apical bud. Only a trace of chlorophyll occurred in the plants treated with the far red radiation.

TABLE VI

THE HEIGHT RESPONSE OF RED KIDNEY BEAN AND PEA, VARIETY LITTLE MARVEL, SEEDLINGS TO RADIANT ENERGY APPLIED CONTINUOUSLY AND FOR 10 PER CENT. OF THE DAILY CYCLE AT 25° C.

PLANT	IRRADIATION TREATMENT	PLANT FRACTION	DARK	BLUE	YELLOW-GREEN	RED	FAR RED	INFRA-RED*
Red kidney bean	Continuous	Second internode	2.3	5.5	11.4	11.7	9.9	5.5
		First internode	23.8	16.5	16.4	14.6	15.5	18.2
		Hypocotyl	21.6	18.5	14.6	15.4	16.2	20.7
		Total	47.7	40.5	42.4	41.7	41.6	44.4
	10 per cent. daily cycle†	Second internode	1.5	4.4	8.0	10.9	4.9	3.1
		First internode	23.2	21.7	21.2	17.4	21.0	22.5
		Hypocotyl	23.0	20.2	17.3	19.7	19.8	22.5
		Total	47.7	46.3	46.5	48.0	45.7	48.1
Pea	Continuous	Total	35.6	21.8	15.4	15.4	18.1	23.8
	10 per cent. daily cycle†	Total	35.6	27.3	24.0	23.4	28.2	33.2

* Adjusted to 1500 ergs per sq. cm. per second.

† All heights multiplied by factor 1.07 for bean, and 1.10 for pea, in order to adjust the total height of the dark plants to the same value for continuous irradiation and for irradiation applied for 10 per cent. of the daily cycle.

potato were grown in the absence of radiant energy and irradiated with 2000 ergs per sq. cm. per second of far red irradiation.

With red kidney bean, the yellow-green and red bands caused the most pronounced morphological differences as compared with plants grown in the complete absence of radiant energy. The far red produced almost as great an effect, but the blue and high intensity infrared were much less effective. The longer wavelengths of the visible spectrum caused a marked increase in leaf size and expansion and a shortening of the hypocotyl and first internode. The dry weights of the hypocotyl and first internode were greatly reduced, whereas the dry weights of the root, first leaves and the epicotyl above the first leaves were materially greater than those of the dark conditioned plants.

The data presented indicate that in the absence of radiant energy the major portion of the reserve material translocated from the cotyledons remained in those parts of the plant immediately adjacent to the cotyledonary node, *i.e.*, the hypocotyl and the first internode. The longer wavelengths of the visible spectrum increased the total amount of reserves translocated from the cotyledons, and also greatly increased the proportion translocated beyond the hypocotyl and first internode, that is, to the epicotyl above the first internode, and to the roots. The accelerated movement was considerably greater toward the apical portions of the stem than to the roots.

It is concluded that the process is not directly related to chlorophyll synthesis, since a minimum morphological response was produced by the blue region with a strong development of chlorophyll, and almost a maximum morphological response occurred in the far red where only a trace of chlorophyll appeared.

Pea gave much the same type of response as red kidney bean as to total stem length, leaf expansion and weight and translocation of material from the cotyledons.

The far red had essentially the same type of effect on maize, soybean, tomato, cocklebur, and potato as it had on red kidney bean. The far red region caused a disappearance of the plumular hook of the dicotyledonous plants, a shortening of the hypocotyl where present, an increased leaf expansion and an increased size of roots. Only a trace of green color was apparent in the leaves of any of these plants under the far red.

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