Summer 6-1-1950

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KALANCHOE TUBIFLORA AS INFLUENCED BY RADIATION

By Edna L. Johnson* and Dorothy B. Kingsbury

Kalanchoe tubiflora (Harvey) Hamet., a member of the Crassulaceae, which has proved to be well adapted to a study of responses to various environmental factors, is a native of Madagascar. It thrives in the greenhouses of this country, particularly during the long, hot days of late spring and summer; it blossoms, however, only during the short days of the winter months.

The original plants, from which those used in these experiments were propagated, were secured from the Fairchild Tropical Garden at Cocoanut Grove, Florida, through the kindness of Mr. A. C. Jordahn, the associate superintendent of the garden. From this strain, hundreds of plants have been grown in the University of Colorado greenhouse.

This species of Kalanchoe has a slender unbranched stem with spirally arranged cylindrical leaves which are typically mottled with purple streaks or blotches. The leaf, which is approximately 4–5 mm. in width and 6–7.5 mm. in length, has from 5 to 7 small teeth, between which small plantlets develop when the plant is reproducing vegetatively. Clamp (1934), who has described this plant, refers to the protuberances which extend outward from between the teeth as leaf-claws. It is at the tip of these claws that there develop the plantlets, each of which consists of a short disc-like stem bearing two pairs of leaves. While in this two-leaved condition, the plantlets fall to the ground and develop into new plants.

Experiments were set up to determine how growth, vegetative reproduction, and histological development of the stem tissues were affected by exposure to different intensities and qualities of light as supplied by fluorescent light tubes, and supplemental artificial light. A study of the development of roots and plantlets from detached leaves which were exposed to X-radiation is also included.

INFLUENCE OF DIFFERENT LIGHT INTENSITIES UPON VEGETATIVE GROWTH AND REPRODUCTION

Two groups of Kalanchoe plants were placed under each of five frames covered with cloth shades of different weaves which supplied the plants with light of different intensities. One group numbered 18 plants which averaged 6 leaves each; a second group of 14 plants averaged 12 leaves each. An equal number of controls were placed uncovered on the same greenhouse bench. Measurements being

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based on the intensity of light inside the greenhouse, which averaged 8100 foot-candles in direct noon sunlight, as 100 per cent, the approximate transmission of light under each of the five frames was 60, 49, 36, 25, and 6.8 per cent, respectively. All light measurements were made with a Weston Illumination Meter.

Bi-weekly measurements taken over a period of 14 weeks showed an increase in height with a decrease in intensity of light. Conclusions from a study of the measurements of the two groups of Kalanchoe are so similar that figures are given for the younger group only. Plate 1, A, which represents plants after 9 weeks under experimental conditions, and Figure 1, which graphically represents growth for 14 weeks, indicate that plants grown under the covered frames were taller than the controls. Those grown under the intensities of 60, 49, and 36 per cent, respectively, were very much alike in appearance, although there was a slight increase in height with the decrease in intensity. The average heights of the plants under the two lowest intensities were considerably greater than those of the control plants. Total height at the end of the 14 weeks showed that with a decrease of 40 per cent in intensity there was an average increase in height of 41 per cent; at the lowest intensity, which was 93.2 per cent lower than the controls, the plants were nearly two and one half times taller than the controls.

Kalanchoe plants of this age are characterized by short internodes, the leaves often appearing in a rosette arrangement. A decrease of light intensity to 49 per cent of maximum greenhouse light did not greatly affect the lengthening of internodes. Those grown at lower intensities, however, demonstrated marked internodal elongation. One may note from Plate 1, A, that plants grown under the lowest intensity showed definite signs of etiolation.

The dry-weights of both experimental groups, with the exception of the smaller plants grown under 49 per cent transmission, decreased with decreasing intensities. Plants grown under the lowest intensity had a very low dry-weight, although they attained the greatest height; the plants of the younger group weighed only one eighth of that of the controls while those of the older group averaged one third of the controls.

With decreasing intensities of light the plants assumed a paler color with a virtual disappearance of the pronounced mottled appearance typical of normal leaves. Under conditions of diminished light, the leaves became longer and more flattened, with the exception of those under the lowest intensity, which were shorter, flattened, and spatulate in outline.

These results with Kalanchoe are in general agreement with the results of Popp (1926) and Shirley (1929), who grew plants under various intensities of sunlight. They found that, in general, those plants receiving the greatest amount of light were the most vigorous, whereas the shade plants were taller with longer internodes.

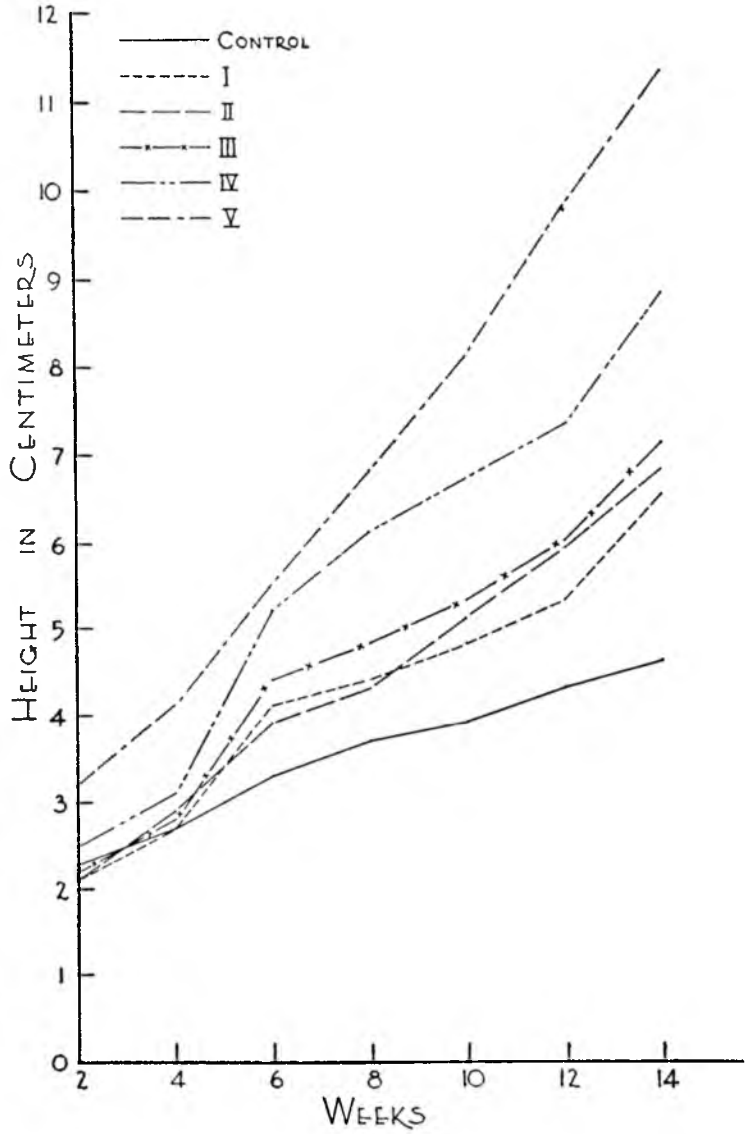

FIGURE 1. Growth curves showing the height of Kalanchoe plants grown under different intensities of light. Control, 100% transmission; I, 60%; II, 49%; III, 36%; IV, 25%; and V, 6.8%. In general, there is a regular increase in total height with decreasing intensity of light.

Bi-weekly counts made of the little plantlets which develop at the leaf tips indicated that plantlet production at intensities of 49 per cent transmission and above varied but little from that of the controls. Few developed under 36 per cent

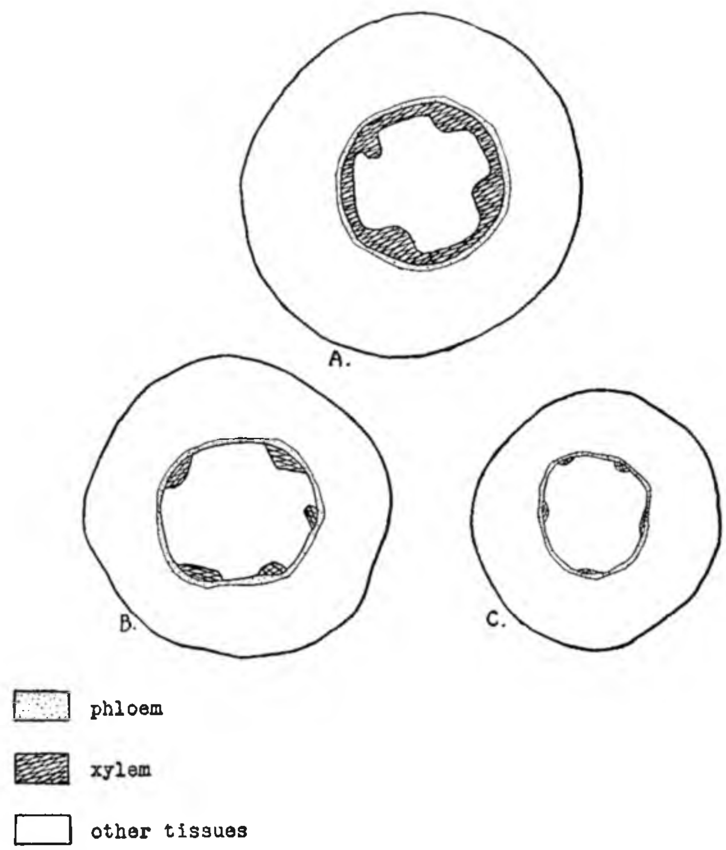

FIGURE 2. Diagrams of stem cross sections at the seventh internode of Kalanchoe grown under different light intensities, ×20. A, control under 100% transmission; B, 60%; C, 6.8%. Note the greater development of xylem in the control plant as compared with that of plants grown under reduced intensity of light.

transmission; none on the smaller-sized plants under either 25 per cent or 6.8 per cent transmission.

Decreased intensity of light favored rooting of small plantlets which were shaken from stock plants, placed on moist filter paper, and exposed to light of different intensities. Under the lowest intensity, 100 per cent rooting occurred after 4 days, as contrasted with but 5 per cent for the controls. Later, rooting occurred in all plantlets.

Examination of stem cross sections of Kalanchoe indicated that under the higher intensities there was a greater development of xylem than in those under the lower intensities. In the experimental plants, as compared with the controls, xylem tissue was reduced in regions above the fourth internode, with only vessels of the protoxylem being lignified; those under the lowest intensity had a very small amount of lignified protoxylem throughout the length of the stem (Fig. 2). Histological examination of sections of stems of the control and of plants grown under the four higher intensities showed a reddish-brown-colored sap, present in some of the cells throughout the pith and cortex, which was absent in plants grown under the lowest intensity of light.

TABLE I

Approximate range of wave lengths in which maximum energy was transmitted by the various fluorescent lamps

Lamp	Approximate range of wave lengths in which maximum energy was transmitted (Angstroms)
White	5000–7000
Blue	4000–5600
Gold	5400–7000
Green	4800–6000
Red	6000–7000

EFFECT OF DIFFERENT QUALITIES OF LIGHT

Studies of the effect of different regions of the spectrum upon plant growth have included the use of colored glass, with the sun as the source of illumination, and of various types of colored filters illuminated with artificial light. Colored fluorescent lamps, which Naylor (1941) has reported as being advantageous for the study of the relation of light-color to the growth of plants, were used to determine how different qualities of light affected growth. Plants were placed under each of five wooden frames covered on the sides with heavy window-shade material, green on the outside and white on the inside. Each frame was fitted with a solid wooden top, on the inside of which was fastened a fixture for a 22-inch, 20-watt Mazda fluorescent lamp. One frame each was used for the blue, green, gold, red, and white lamps.

Table I gives the approximate continuous range of wave lengths in which maximum energy was transmitted under each lamp as estimated from spectral distribution curves by Weitz and Cissell (1939). Two groups of Kalanchoe plants were used under each frame; one group of 15 smaller plants averaged 6 leaves each while a second group of 12 averaged 12 leaves each. Controls were left uncovered on the same greenhouse bench with the experimental plants. Beginning with September, the experimental plants were exposed for 14 weeks to continuous light of the different qualities except for a daily 2-hour period of exposure to normal daylight. Exposure of the plants to a short period of normal daylight was a precautionary measure to prevent death of any of the groups, particularly those under the red light.

Bi-weekly height measurements made for a period of 14 weeks indicated that the light from the red, green, and gold lamps caused excessive elongation of the stem. In both the 6- and 12-leaved groups, those exposed to the red light had a total height nearly five times as great as that of the controls and were taller than those under the green or the gold lights. The height and leaf size of plants grown under the blue and the white lamps were more nearly like that of the controls (Plate 1, B); they were shorter than any of the other experimental plants and were similar in appearance. Figure 3 shows the growth curves for the younger group of plants; curves made for the older group are very similar.

After exposure of the plants to lights of different qualities for a period of 14 weeks, the dry weights of both the younger and older groups were taken. The weights were greatest for the controls and for those under the white light, lower and about the same for those under the blue and the gold, much lower for those exposed to red light and for those grown under the green. Bar diagrams (Fig. 4) which were constructed to show the comparison between the average weight in milligrams per centimeter in height for the younger plants under the different qualities of light indicate that a greater amount of dry weight per centimeter of height was attained in the full sunlight and under the blue light, while a very low value was shown for the red. Thus the plants under the red lamps which grew the tallest also had the lowest value when milligrams of dry weight per centimeter of height were considered.

Internodal elongation was greatest under the red light. The plants having the next longest internodes were those under the green and the gold, the greatest average internode length being about three fourths that of the longest ones under the red lamp. The plants under the blue and white lights had the shortest internodes of all the experimental plants, but even these were much longer than those of the controls.

The occurrence of flattened leaves with pale, indistinct mottling was most pronounced in plants grown under the red and green lights. Figure 5 represents relative length and thickness of leaves grown under the different lights. Longer leaves were produced under the white and blue. While the leaves of the controls were typically tubular in shape, those under the gold, green, and red were small, irregular, and

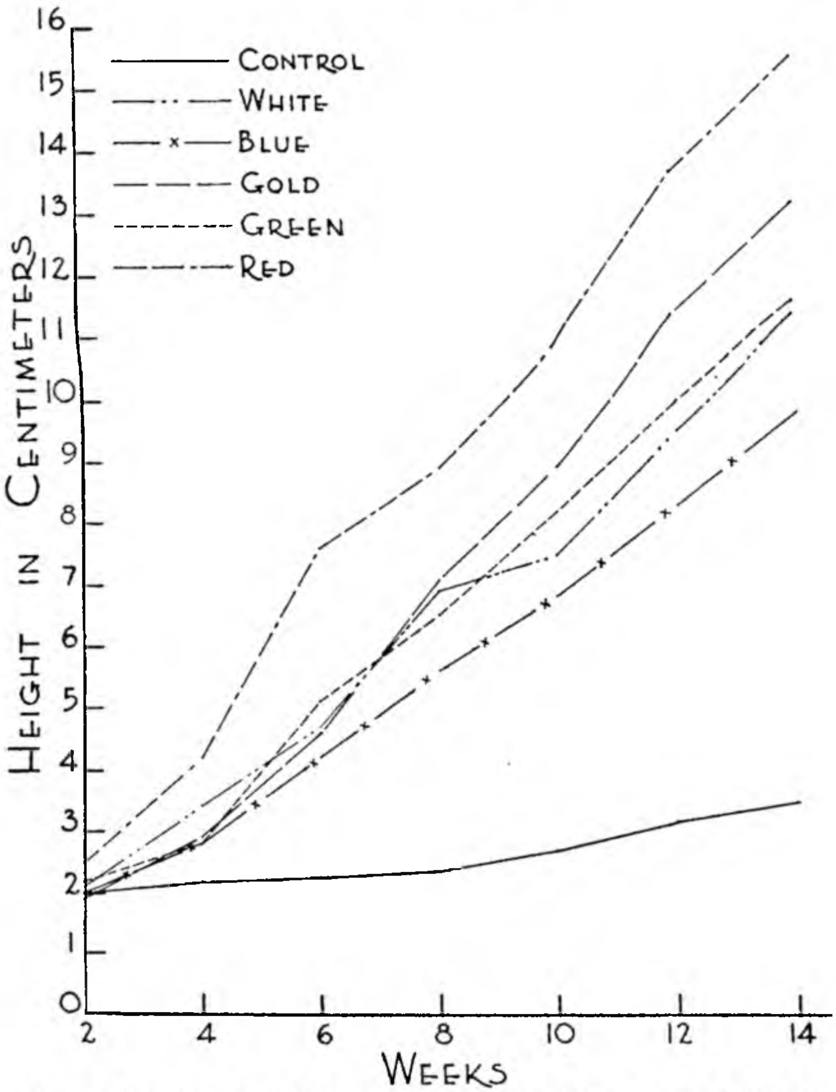

FIGURE 3. Growth curves of Kalanchoe plants grown under different qualities of light. Note the increased height of plants under the lamps which emitted only the longer wave lengths.

unevenly thickened, and a few had bifurcated tips. Rohrbaugh (1942), who grew red kidney beans under different fluorescent lamps with filters to narrow the re-

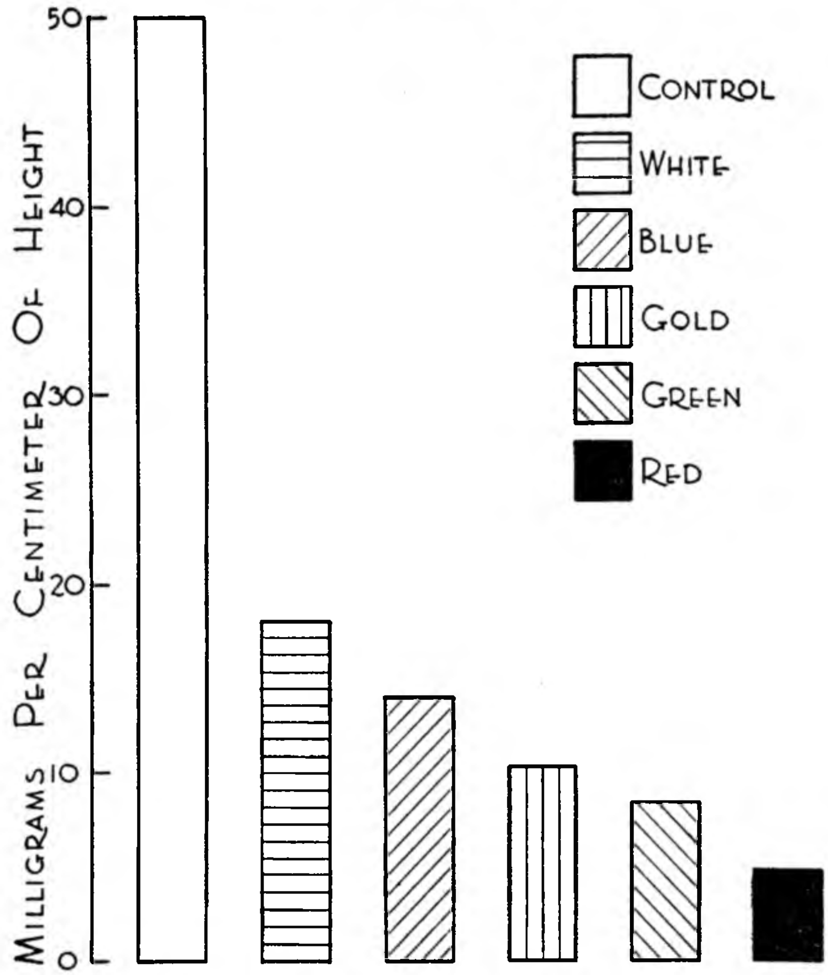

FIGURE 4. Bar diagrams which represent the average weight in milligrams per centimeter of height of plants grown under different qualities of light. The shortest plants grown under the blue and the white lamps have the highest value on this chart while the tallest plants, which were those grown under the red, have the lowest value.

gions of the spectrum, reported that average leaf area was least in the green. Kingsbury (1945) found that when zinnias were grown under green, blue, and white fluorescent lights of the same intensity the leaves of those under the green lights were smaller. Leaf claws which produce the tiny plantlets failed to develop on many of the leaves of plants grown under these lamps. Leaves of experimental plants tended to display a permanent epinastic curvature which was very pronounced in the plants under the red, green, and gold lamps (Plate 1, B). Those

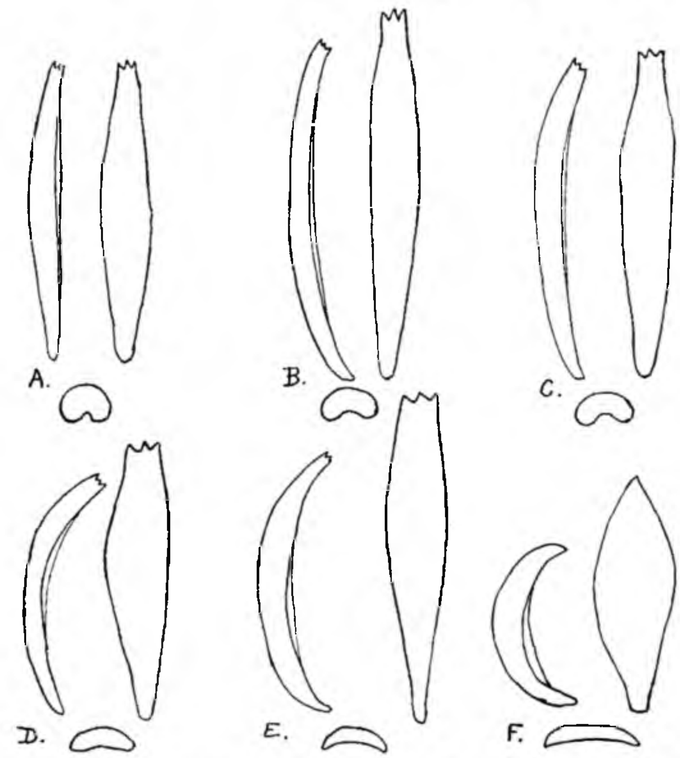

FIGURE 5. Drawings showing relative curvature, lengths, and thickness of leaves from the seventh node of Kalanchoe plants grown for 14 weeks under light of different qualities. A, control; B, white; C, blue; D, gold; E, green; F, red. Each leaf was drawn from the side to show curvature; from the top (flattened out) to show length; and in cross-section to show thickness. Note the greatest leaf length under the white and decreased thickness and pronounced curvature in leaves under the gold, green, and red.

under the blue and white lamps showed less of this downward curvature, especially in the leaves toward the top.

None of the plants grown under normal daylight nor those under the red lamps produced plantlets during the 14 weeks of observation, which extended from the latter half of September through December. The greatest number of plantlets was developed under the blue light, followed in order by the white and the gold; a few were formed on the plants of the older group under the green light, but none on those of the younger group. That long duration of light is an influencing factor in plantlet formation, is confirmed by figures given in Table II in the third section of this paper, which deals with the response of this species to continuous light. Observations made by Johnson (1948) over a period of three and one half years also clearly indicate the fact that vegetative reproduction is much more abundant during the long days of spring and summer. Green light allowed development of very few plantlets, and these only on the older plants. This would indicate that the quality of light as well as intensity and duration is an influencing factor in the formation of plantlets.

Examination of stem sections indicated that the greatest amount of lignified tissue occurred in plants grown in normal daylight. Xylem tissue was somewhat reduced in all experimental plants, especially in the upper internodes, with only the vessels of the protoxylem lignified; plants under the red and green lamps developed little xylem. The experimental plants under the blue and white lamps had a greater lignification of xylem than plants grown under the green and gold lamps. This fact is in agreement with the work of Pfeifer (1928), who reported that vascular development is always best in the full spectrum and poorer in the absence of the blue and violet.

A reddish-brown sap which normally occurs in the pith and cortex of the controls was less abundant in the tissues of the experimental plants, especially in those grown under the gold, green, and red lamps.

RESPONSE TO CONTINUOUS LIGHT

Ten groups, each containing ten Kalanchoe plants which had been transplanted four months previously when in the 6-leaved stage, were selected for this experiment. About the middle of January, half of each of the ten groups were placed under conditions where they were exposed to continuous light. Normal daylight was supplemented with that from a 200-watt bulb which was turned on at 6:30 every night and turned off at 6:30 in the morning. Equal numbers of controls were grown under the same environmental conditions except that they received only light of the normally short days of winter.

After two weeks' exposure to continuous light, plantlets were evident on many of the leaves; none developed on the control plants until 15 weeks after the experiment was started. The young plantlets on the experimental plants were noticeably pinker than those of the controls. After the plants had received continuous light for three months, a count of the plantlet-bearing leaves indicated a greatly increased number on the experimental plants as compared with those on the controls. As may be seen from Table II, there were at least five times as many leaves reproducing vegetatively on the experimental plants as there were on the corresponding control group; in one group, there were eight times as many. The number of plantlets recorded in the table represents those which were on the plants the day the records were taken; no attempt was made to estimate the total number of plantlets formed, as they were constantly developing and soon dropping to the ground. The total number on single plants was greatly increased in the case of those given supplemental light. In one group, 39 times as many plantlets occurred

TABLE II

Vegetative reproduction of Kalanchoe ubiflora *when exposed to continuous light*

Group Number	Leaves per plant at beginning of experiment		Average number of plantlet-bearing leaves after 3 months' exposure to continuous light			Average number of plantlets per plant		
	Control	Continuous light	Number		Increase of experimental over control	Number		Increase of experimental over control
			Control	Cont. light		Control	Cont. light	
					%			%
1	16	15.2	2.6	10.2	295.8	4.6	24.8	439.1
2	9.6	10.8	2.6	7.4	184.6	4.6	18.6	304.3
3	14.0	13.4	2.4	11.2	408.3	5.0	29.8	496.0
4	14.8	11.6	1.8	12.0	566.7	4.0	36.0	800.0
5	11.4	10.0	1.8	13.7	661.1	3.4	36.2	964.7
6	13.2	12.4	.4	9.6	230.0	.6	24.2	3933.3
7	9.8	9.4	0.0	8.8	—	0.0	21.6	—
8	11.2	15.0	2.0	10.0	500.0	4.6	34.7	654.3
9	13.8	14.4	2.0	12.5	520.0	5.6	32.8	485.7
10	11.4	10.4	1.6	8.4	425.0	3.8	21.2	557.9

in the experimental group as in the control, and in no group were there fewer than three times as many as in the corresponding control group.

Six weeks after the experimental groups had begun to receive additional light, typical plants appeared as shown in Plate 1, C. It may be noted that the short internodes of the controls caused the plants to appear in rosette form; no plantlets had yet formed on the controls when this photograph was taken, and none appeared until the longer days of April. The experimental plants, however, were characterized by lengthened internodes, which increased the plant height, and by the development of many plantlets. During the latter part of May, another count was made of the plantlet-bearing leaves and also of the total number of plantlets. At this time, when there was a considerable increase in the length of normal daylight, only three of the experimental groups exceeded the controls in average number of plantlet-bearing leaves, and only four of the experimental lots exceeded the controls in the average number of plantlets per plant.

This species is a short-day plant which flowers only during the short days of the winter months. It would be expected that vegetative formation of the plantlets would be greatly increased during the longer light periods, either those occurring naturally or those artificially induced.

DEVELOPMENT OF DETACHED LEAVES AFTER EXPOSURE TO X RADIATION

The tips of detached Kalanchoe leaves were irradiated with a dose of 2000 r-units, and each leaf was suspended in tap water by means of a fine wire. Untreated leaves similarly attached were used as controls. Records of plantlet development were taken at intervals during a period of 47 days. Data are given only for the 8 irradiated and 8 control leaves which lived throughout the entire experimental period. Results which are summarized in Table III show that by the twenty-third

TABLE III

Formation of plantlets on detached leaves with apices immersed in water

Time in days	Control			Irradiated		
	Leaves with plantlets	Total no. of plantlets	Plantlets at apices developing roots	Leaves with plantlets	Total no. of plantlets	Plantlets at apices developing roots
	%		%	%		%
9	25	2	0	0	0	0
11	37	3	0	25	2	0
16	62	5	0	75	6	0
23	100	11(+2)*	27	100	17	11
29	100	13(+7)	61	100	17	100
36	100	14(+9)	100	100	18	100
47	100	15(+10)	100	100	35	100

* Number in parentheses indicates plantlets developing at leaf base in the air.

day all of the leaves had regenerated plantlets; roots also had developed on some plantlets. At the end of five weeks, all plantlets which had formed at leaf apices had rooted. On the irradiated leaves, plantlet formation occurred only at the leaf apices while on the controls two thirds of the total plantlet number developed from the basal end of the leaves which extended into the air. In Plate 2, which pictures representative control and irradiated leaves, there may be noted plantlets regenerating from the basal end of the control leaves which were not immersed in the water. It is evident that there is better root development from the plantlets on the apices of the irradiated leaves than on the controls.

X-radiation of leaf apices did not hasten the beginning of plantlet formation nor did it hasten the development of roots on the plantlets. The total plantlet production, however, was increased. Considering those formed on apices only, the irradiated leaves showed 133 per cent increase over the controls at the end of 47 days; when, however, those on the bases as well as those on the apices were counted, it was found that the number on the irradiated apices increased but 40 per cent.

SUMMARY

The effect of different intensities and qualities of light and that of supplemental artificial light on the growth, vegetative reproduction, and vascular development of stem tissues of *Kalanchoe tubiflora* were considered in this study. X-radiation effects on the root and plantlet development of detached leaves are also considered.

With decreased intensity of light, *Kalanchoe tubiflora* increased in height but decreased in dry weight. The leaves became lengthened, flattened rather than tubular, pale green with indistinct markings; at low intensities the leaves of very young plants were short and spatulate. The production of plantlets at the leaf tips and the time for their root initiation were decreased with a decrease in intensity of light. Xylem development was greatest in the stem under the higher light intensities. With but 6 per cent of normal greenhouse light, only a very small amount of lignified protoxylem developed throughout the length of the stem.

When young Kalanchoe plants were grown under colored fluorescent lamps, it was found that those under the blue and the white lamps more nearly resembled the controls in height and in dry weight. The leaves also were similar in appearance except for the somewhat paler color, flattened rather than tubular shape, and greater length of those under the lamps. Small, pale leaves, some with anomalies and permanent epinastic curvatures, developed in stems and leaves under the green, gold, and red lamps. Plantlet production was stimulated by the blue and white lights, and to some extent by the gold. The greatest amount of xylem was formed in the stems of plants grown under the blue and white lights.

When plants in the 6-leaved stage were exposed to normal daylight supplemented with artificial light to make a 24-hour day, leaves began bearing leaflets within two weeks. After three months' exposure to continuous light, the experimental plants had from 6–8 times as many leaves reproducing vegetatively and from 3–39 times as many leaflets present as had the controls. Leaflets of the experimental plants appeared much pinker in color than did those on the controls. The experimental plants were also characterized by lengthened internodes, which increased the plant heights.

Irradiated leaf tips suspended in water developed many more plantlets at the end of one and one half months than did the control leaves; however, plantlet initiation with subsequent root formation was not hastened by the treatment.

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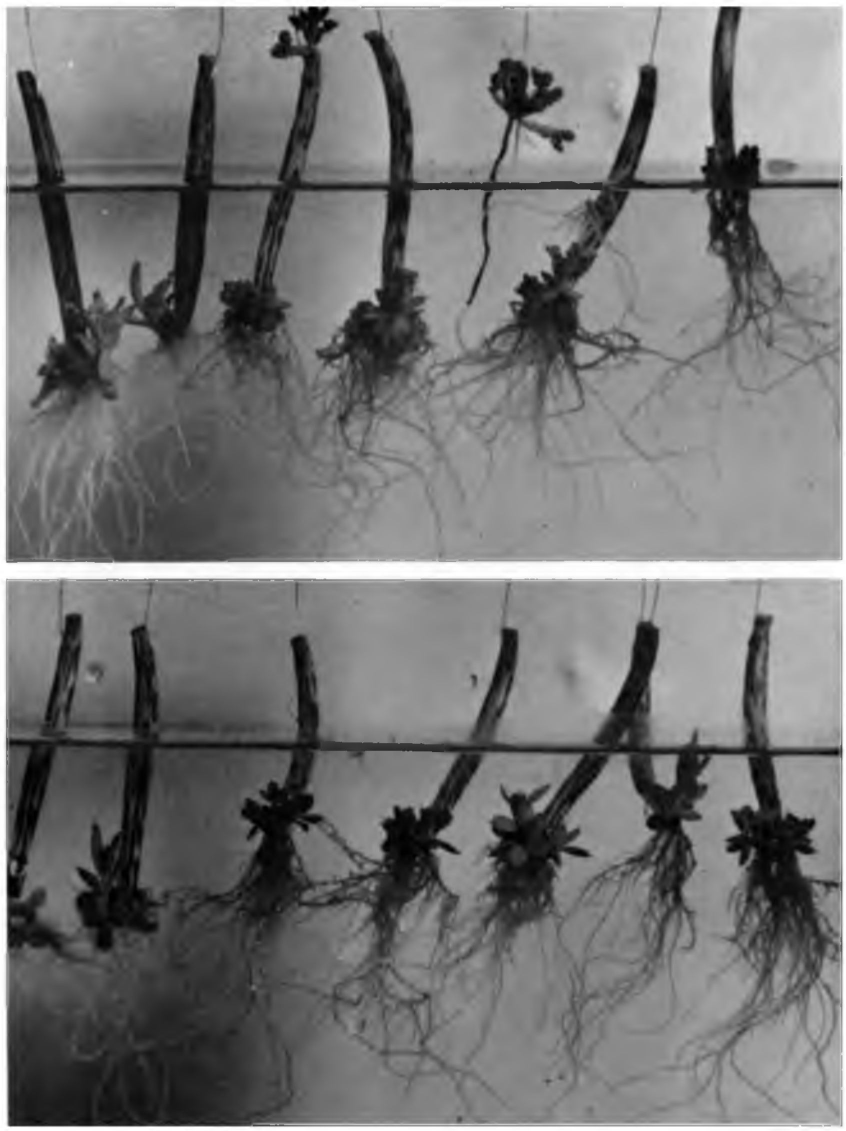
PLATE 1

A. Appearance of Kalanchoe plants (6-leaved group) after 9 weeks' growth under different intensities of light. From left to right, intensities of light are 100, 60, 49, 36, 25, and 6.8 per cent transmission. Note the longer, flattened leaves of plants grown under 36 per cent and 25 per cent transmission; also the slender stems and short, flat, rounded leaves without plantlets under 6.8 per cent transmission.

B. Kalanchoe plants grown for 14 weeks under different colored fluorescent lamps. Left to right: plants grown under full sunlight (control), green, gold, white, blue, and red lamps. Note the epinastic curvature of leaves and the weakened stems of plants under the green, gold, and red; also the similarity in appearance of those under the blue and white lamps.

C. Young plants of *Kalanchoe tubiflora*. Typical controls in two pots at the left. At the right, typical experimental plants which were exposed to continuous light for six weeks. Note the elongated internodes and plantlet development induced by supplemental light.



Plantlet development on detached leaves of *Kalanchoe tubiflora* suspended in water. Below, irradiated leaves with plantlet number and root development increased over the controls (above). Note that some control leaves have developed plantlets at the proximal or basal ends which extended into the air.