

THE EFFECT OF STREET LIGHTS IN DELAYING LEAF-FALL IN CERTAIN TREES¹

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THE EXTENSIVE research on photoperiodism in recent years has demonstrated that the life cycle and activities of the plant are closely interwoven with the duration of the daily illumination. Most of the studies on this subject have been concerned especially with growth, flowering, and fruiting. There is a close interrelationship, however, between these phenomena and leaf-fall, in certain plants at least. A simple method of studying response to prolonged illumination is afforded by certain trees growing in proximity to street lights. Such trees often show retention of the leaves beyond the normal season. This is characteristic of a number of common genera and species.

In their pioneer work on the general subject of photoperiodism Garner and Allard (1920, 1921) early recognized that leaf-fall and ripening of the pods in Peking and Biloxi soy-beans (*Soja max*) were accelerated by exposure to short day lengths. Later the same authors (1922, 1923) demonstrated that in smooth sumac (*Rhus glabra*), dwarf sumac (*Rhus copallina*), and the tulip tree (*Liriodendron tulipifera*) the leaves were retained longer when the plants were given additional illumination. These results are also incorporated in the reviews by Kellerman (1926), Schick (1932), and Garner (1936). Mochkov (1929-1930), studying *Robinia pseudoacacia*, *Phellodendron amurense*, *Salix lanata*, and *Salix babylonica*, concluded that in longer days the periods of growth and vegetative activity increase, while in shorter days they decrease. Odén (1929) found that with seventeen hours of daily illumination in autumn the normally rather rapid fall of leaves continued all through the winter, in *Acer campestre*, *Lonicera periclymenum*, and *Viburnum opulus*. Similarly buds could be made to unfold in December by means of additional light. Kramer (1936) has demonstrated that *Fraxinus americana*, *Liriodendron tulipifera*, *Liquidambar styraciflua*, and *Quercus stellata* become dormant earlier if grown under short day-lengths. All of these, among others, excepting *Fraxinus americana*, grew later into the autumn when the days were artificially lengthened. The renewal of growth early in the year (beginning in January) could be hastened or retarded by lengthening or shortening the period of illumination.

This recent work supplements the somewhat generalized but nevertheless significant observations on leaf-fall reported in the older literature. It is well known that the falling of leaves, especially in autumn, is not the result of one simple cause, but may be due to the interaction of various factors, some internal, some external to the plant. Similarly, the retention of leaves on certain trees in winter is again not to be attributed to a single cause. The literature of this subject has been well reviewed by Pfeiffer (1928). The part played by relative illumination in the cyclic

development of woody plants has been stressed by a number of investigators, particularly by Klebs (1911, 1915, 1917) and Wiesner (1904, 1907). Klebs (1911) emphasized the differences in the responses of various genera to periods of darkness. As early as 1904 Wiesner astutely observed that, among the sundry types of leaf-fall, attributable primarily to various causes, there was one which he called "summer leaf-fall" that resulted from the shortening days of summer. He distinguished clearly between this kind of leaf-fall and that occurring in autumn; he was also careful to point out that it was not caused by summer drought and heat. Thus, soon after June 21, there was a dropping of the leaves, especially of those not so well illuminated, in certain species of *Acer* and of *Aesculus hippocastanum*. This continued fairly steadily until autumn leaf-fall set in. As would be expected, this "summer leaf-fall" did not apply to all genera of plants. *Laurus*, for instance, was little or not at all affected. Wiesner's deductions in this matter were well drawn, antedating by some sixteen years more modern work on photoperiodism.

POPULUS CANADENSIS Moench.—It was noticed on October 27, 1935, that trees of the Carolina poplar, *Populus canadensis*, growing in the streets on the outskirts of the City of New York had rather generally lost their leaves; however, those in fairly close proximity to street lights had retained some of the leaves in the portion of the tree that was artificially illuminated. Subsequently, 113 trees of this species were examined, with results as indicated in table 1. Of these 113 trees, 64 were not near street lights, and all of them lost their leaves as uniformly as would be expected. On the other hand, 49 Carolina poplars growing near street lights showed a partial retention of the leaves in each case. Figure 1 shows a row of three trees of *Populus canadensis*, one near a 76-watt 11-volt electric light, the other two farther away. The two more distant trees, though not far removed from the light, could not have been strongly influenced by it when they were all in leaf, since the first tree shaded the others. This photograph, taken November 6, shows that a considerable number of leaves still remained on the tree nearest the light. Figure 3 is a photograph of that same tree, taken November 13. It shows that the half of the tree toward the electric light is the one on which the leaves remained. The distal portion had been shaded by the proximal, and consequently the former no longer had leaves. It is also evident from figures 1 and 3 that the upper part of this tree, above the level of the lamp shade, is devoid of leaves. At the tip of the nearest branch of the illuminated tree of figures 1 and 3 the light from the bulb had an intensity of approximately 1.5 foot candles. A similar condition is shown in figure 4, in which a 76-watt

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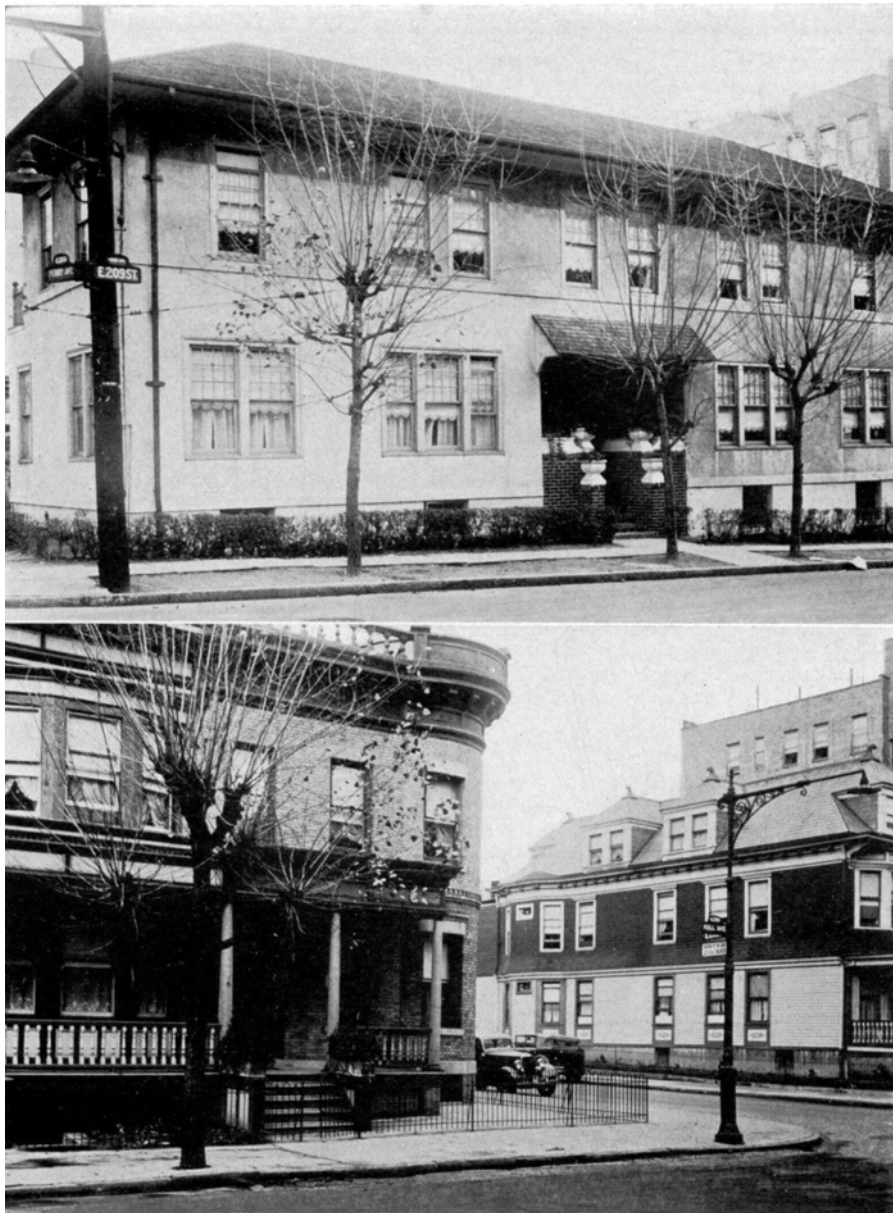


Fig. 1 (above). *Populus canadensis*, numerous leaves still present on the tree nearest the light, the other two trees entirely bare. Photographed November 6, 1935.—Fig. 2 (below). *Populus canadensis*, showing retention of leaves on the side of the tree nearest the light, the rest of the tree devoid of foliage. Light intensity at the tip of the branch nearest the light bulb (24 feet distant) a fraction over 1 foot candle. Photographed November 13, 1935.

TABLE 1. Retention of leaves due to electric lights.

	<i>Populus canadensis</i>	<i>Platanus acerifolia</i>	<i>Platanus occidentalis</i>	<i>Salix fragilis</i>
No. of trees near a light showing partial retention of leaves	49	32	2	10
No. of other trees observed, not near a light, and showing no such prolonged retention of leaves	64	62	2	21
Doubtful cases—trees near a light showing no marked retention of leaves	0	4	0	3
Totals	113	98	4	34

11-volt electric bulb, with a lamp shade to reflect the light down, is within the branches of a tree of *Populus canadensis*. Numerous leaves remained on the branches near the light; the entire upper portion was bare, as was the lower part on the side away from the light. This photograph was taken November 6, 1935. Figure 2, also of *Populus canadensis*, taken November 13, similarly shows numerous leaves on the side of the tree toward the source of artificial illumination, a 200-watt 120-volt bulb in this case. The light received at the tip of the nearest branch in figure 2 measured a fraction over 1 foot candle.

It is possible that the increased temperature resulting from the electric light may be a factor in a case like that in figure 4. However, the distance between the bulb and the tip of the nearest branch is 8 feet in the case represented in figures 1 and 3; it is 24 feet in that of figure 2; and in a third instance, almost as conclusive as that of figure 2, the distance was 45 feet. In this last case the light intensity at the tip of the nearest branch was less than 1 foot candle. It is incredible that increased temperature resulting from an electric light bulb of 200 watts and 120 volts can play any part in the open air at a distance of 45 feet. The effect in this case must apparently be attributed to the increased illumination. Since these lights burn from dusk to dawn, the affected parts of the tree are really continuously illuminated.

The defoliation of the Carolina poplar is strongly influenced by light. In every one of the trees near an electric light the result was clear-cut. Whether the light was north, east, south, or west of the tree was immaterial; in the instance represented in figure 1 the light is west of the tree; in that of figure 2 it is north. Similarly, the leaves retained were not necessarily toward the open side of the street.

The leaves of *Populus canadensis* receiving this additional illumination slowly dropped, so that by December 1 nearly all had fallen. Some of the leaves remained until after they had been killed by low temperature—being dry and turning dark. This was the exception, however. Eventually all of the leaves fell, so that the branches were quite bare. Since the leaves drop over a fairly long period, in both illuminated and non-illuminated trees, and since

the distance from the source of light may also be a factor, it is impossible to state accurately how long the leaves were held on the trees by the additional light. One month would be a conservative estimate, in many cases at least. In some cases it was definitely longer.

The leaves do not drop simultaneously under normal circumstances, the method and time of falling varying in different trees. And other factors, such as temperature and extent of exposure, undoubtedly play a part. However, the additional illumination is operative after these other factors have ceased to be of importance in the street trees here discussed. The condition portrayed in figure 1, for example, in which the two trees not illuminated are completely bare, while the tree near the light has numerous leaves, is the rule and not the exception. Retention due to light continues long after retention due to other factors has ceased to operate, in the poplars and in the other trees considered below.

PLATANUS ACERIFOLIA Willd. AND *PLATANUS OCCIDENTALIS* L.—Somewhat less sensitive than the Carolina poplar, but only slightly so, are the London plane, *Platanus acerifolia*, and our native sycamore, *P. occidentalis*. Of 98 trees of the former observed (table 1), 32 near a light showed retention of the leaves; four trees which would have been expected to show an effect, being near a light, gave only doubtful results, while they were being observed. Owing to the scattered distribution of this number of trees, it was impossible to get continuous data on all of them. Four trees of our native sycamore (*P. occidentalis*) were studied, two of them near lights, two not. The two former gave very conclusive evidence of the effect of the additional illumination. One of these, a very fine old sycamore growing on the campus of Columbia University, is illustrated in figure 5. This photograph, taken on November 19, 1935, shows that many leaves were still present near the electric lights, while the rest of the tree was bare. Each of the two globes shown in this photograph contains one light of 200 watts 110 volts. Branches three feet from the globes received light of approximately 12 foot candles in this case. The foliage of illuminated trees of *Platanus* and *Populus* was quite green. The leaves of the tree in figure 5 slowly turned brown



Fig. 3 (upper left). *Populus canadensis*, the corner tree of fig. 1, showing leaves on those branches nearest the light, and up to the level of the lamp shade, the remaining branches entirely without leaves. Light intensity at the tip of the branch nearest the light bulb (8 feet distant) 1.5 foot candles. Photographed November 13, 1935.—Fig. 4 (upper right). *Populus canadensis*, illustrating the effect of a light on leaves of the surrounding branches, which still have numerous leaves, while the rest of the tree is completely bare. Photographed November 6, 1935.—Fig. 5 (lower left). *Platanus occidentalis*, with abundant foliage on those branches near the electric lights, and with none on the other branches. Light intensity 3 feet from the globes approximately 12 foot candles. Photographed November 19, 1935.—Fig. 6 (lower right). *Platanus occidentalis*, the entire upper part of the tree devoid of leaves, the lower portion, especially near the light, with many leaves. A diagonal line drawn across this photograph would separate the illuminated from the non-illuminated portions, and the branches with foliage from those without foliage. Light intensity at the tip of the branch nearest the bulb 2 foot candles. Photographed November 15, 1935.

and dry toward the end of November, and many of them dropped. On December 24 a few of the old brown leaves were still present, and examination of the twigs of the illuminated portions of the tree showed that the bases of the petioles in many cases—but by no means in all of them—were still present. The blades and the upper parts of the leaf stalks in those instances had broken in the high winds, leaving the bases still attached to the twigs. This applies to both *Platanus acerifolia* and to *Platanus occidentalis*, but not to *Populus canadensis*; in the last named the whole petiole drops off in the late autumn.

Figure 6, also of *Platanus occidentalis*, was taken November 15. This tree, near a 200-watt 120-volt light, again demonstrates that the leaves that have received additional illumination have stayed on the branches, while some of the branches on the side away from the light, as well as the entire upper portions of the tree are quite devoid of foliage. The light intensity at the tip of the nearest branch in this case measured 2 foot candles.

OTHER GENERA.—The crack willow, *Salix fragilis* L., was also sensitive to light in its defoliation (table 1). Here too certain trees gave marked evidence, while several that would have been expected to show an effect, on the basis of their proximity to lights, gave no clear-cut results. The location of these "doubtful" trees, however, made continuous observation impossible. Eight examples of the Norway maple, *Acer platanoides*, appeared to give evidence of retention of leaves due to artificial illumination; and if they alone had been found, they could be considered in the same category with *Populus canadensis* and *Platanus*. But many examples of this species growing near electric lights were not affected; this species must therefore be studied further before it can be classified. It certainly is not so uniform in its response as the Carolina poplar and the two species of *Platanus*.

When the present observations were begun, toward the end of October, the process of defoliation was well along or completed in many of our trees. Consequently the observations on other genera and species were limited. From that time on, however, no such convincing evidence of the effect of illumination was obtainable in *Acer saccharinum*, *Ulmus americana*, *Tilia cordata*, and *Quercus rubra*. More thorough study, involving the whole period of autumn leaf-fall, might of course indicate light sensitivity in these. Considering Wiesner's (1904) data it might almost be expected in *Acer saccharinum*, though by the end of October trees of that species observed near lights were completely defoliated.

In view of the findings of Klebs (1914, 1917) for beech and oak, and of Odén (1929) on the effect of light in stimulating bud development, trees growing near street lights might perhaps have been expected to show earlier emergence of leaves from the buds in the spring. However, the same poplar, London plane, sycamore, and willow trees that were so decidedly affected in autumn showed no such response in spring

to the additional illumination, their leaves appearing simultaneously with those of non-illuminated trees.

DISCUSSION.—The foregoing observations admit of the general conclusion that light is an important factor in determining the time of autumn leaf-fall, in certain genera and species at least. This may be arrived at in two ways: light may affect the dropping of the leaves more or less directly, or it may be of rather indirect consequence, by influencing the time of emergence of the leaves from the bud. There can be little question that light directly causes a retention of leaves in *Liriodendron* and *Rhus* (Garner and Allard, 1923). It is true that *Liriodendron* was stimulated to send out new leaves by subjecting it to additional illumination in September. But this was not the case in *Rhus glabra* and *Rhus copallina*. And in all three of these the old leaves were retained or their fall was retarded by light. The data presented above may, and probably should, be interpreted similarly.

Under natural conditions the shortening days of autumn seem to play an important rôle in defoliation. It is altogether possible that the Carolina poplar, the London plane, and our native sycamore would retain their leaves considerably later into the autumn if it were not for the decrease in the daily period of illumination, even if all the other factors concerned, such as temperature and moisture, could be kept unchanged. On the other hand, it is also obvious that the Carolina poplar, for instance, does not retain its leaves indefinitely in continuous illumination, the other factors remaining as they now are. It responds eventually either to those other factors in the environment or to the gradual diminution in the total quantity of light. In view of what is known about defoliation, and in view of the marked sensitivity of the Carolina poplar to weak light, this response is more probably due to conditions other than light.

The London plane and the sycamore may be influenced less by these other factors and more by light, since many of the leaves in the illuminated parts of the tree do not fall even after they have become dry and brown. In strong winds the petioles of these leaves may be broken off above the base. On the other hand, these trees normally retain their leaves later in the fall than the Carolina poplar, and consequently proportionally less of an unusual stimulus (continuous illumination in this case) would be required to keep them on the trees until the time of more pronounced frost; and prolonged low temperatures may interfere with abscission. The varying day lengths at different latitudes must play an important part in determining the time of autumn defoliation, and in the deciduous habit in general.

Defoliation is normally accomplished through the abscission layer, and it is likely that light has an effect on the changes that occur in that layer. The effect of light on abscission may be direct, or it may be correlated with the changing metabolism of the leaf, or possibly of the branch as a whole. The

changing metabolism may in turn be concerned with the grosser processes of the leaf, or with the production of the minute amounts of the more enigmatical substances that affect the activity of the plant.

Since longer illumination—even from street lights—is important in causing the retention of leaves of certain trees in autumn, this same condition may possibly affect leaf- and flower-bud development late in the spring, and at other times of the year. Dingler (1905) demonstrated that leaves that are formed or emerge tardily in the spring or summer may persist on the trees till late in autumn. It is possible that the data presented above may be an indication of the effect of light on defoliation through later leaf development in the spring. Such later formed leaves might not fall till long after the others had gone. While this interpretation is possible, it very probably is not a complete explanation of the facts. Leaf-fall, in general, seems to depend on the genetic constitution of the plant, its protoplasmic make-up, and the numerous external and internal factors to which these are subjected.

Light intensities of 1 foot candle or even less, supplied by a bulb as much as 45 feet distant, may affect leaf-fall. Withrow and Benedict (1936) have reported that intensities of 0.3 foot candle, and in the China aster even of 0.1 foot candle, may induce photoperiodic responses.

When the leaves are emerging from the buds in April and May, in the vicinity of the City of New York, the days are much longer than they are in autumn when the leaves are falling. The unfolding of the leaf-buds in the early spring is apparently governed in this region by factors other than light—probably temperature. The results of Kramer (1936) lead to the same conclusion.

Changes in the length of day have been found, especially by Garner and Allard, to have far-reaching significance for the life cycle and maturity of a host of plants. Hardly less important are the results of Marcovitch (1924) on the effects, direct or indirect, of varying day lengths on the production of spring

and fall migrants and of males and oviparous females in the aphids; and the evidence, especially of Rowan (1926, 1930, 1931), that the shortening days of summer and autumn and the lengthening days of winter and spring may be controlling factors in the migrations of birds.

SUMMARY

Street lights in the City of New York cause a retention of the leaves of certain trees: Carolina poplar (*Populus canadensis*), London plane (*Platanus acerifolia*), sycamore (*Platanus occidentalis*), and crack willow (*Salix fragilis*).

Illuminated portions of a tree retain their leaves; shaded portions of the same tree do not. One side of a tree, or the lower part, may thus have numerous leaves, while the other side, and the upper part, may be entirely devoid of foliage.

A relatively weak light, at a distance of as much as 45 feet from the tip of the nearest branch, may cause retention of numerous leaves. Light intensity as low as 1 foot candle, or less, may be effective.

Some leaves may be retained at least a month, others more than that, beyond the normal season.

The orientation of the light with respect to the tree—i.e., north, east, south, and west—is not significant.

In *Populus canadensis* all of the leaves ultimately fall, abscission apparently taking place at the base of the petiole. In *Platanus acerifolia* and *Platanus occidentalis* some of the leaves are retained until killed by low temperature; then some of them break off above the base of the petiole.

Leaves of the *Populus* and *Platanus* species discussed remain green unusually long when receiving additional illumination.

Leaves of these same trees do not emerge from the buds earlier in the spring as a result of the additional illumination.

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