Light Penetration and Light-induced Seed Germination in Soil

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ABSTRACT

Light penetration through a Drummer silty clay loam and a Broomfield sand was measured spectrophotometrically and biologically. The spectrophotometric measurements showed that less than 1% of the incident light penetrated 2.2 mm at any wavelength between 350 and 780 nanometers for ped sizes up to 1 millimeter. Biological measurements with light-sensitive lettuce (Lactuca sativa) seeds in soil showed that an exposure to light equivalent to about 1 sunny day induced some germination of seeds which were 2 millimeters below the surface, but did not affect seeds 6 millimeters below the surface.

The known light sensitivity of many seeds (11) has led to the hypothesis that light may be important in inducing the germination of weed seeds in cultivated fields. Dormant seeds, brought close to the surface by cultivation, could receive light, either directly during cultivation or later through the soil, and could therefore germinate. Experiments have tended to confirm this hypothesis (3, 7, 10, 12). Still, there has been no attempt to measure light penetration into soil or to find out how near a seed must be to the surface to be affected. Nor has there been an attempt to consider the role of temperature in such germination, even though light sensitivity of seeds is known to be highly dependent on temperature (1-3, 6, 10, 11). We therefore measured light penetration through soil spectrophotometrically and also biologically, controlling temperature, and using light-sensitive lettuce seeds buried in the soil as our bioindicator. At temperatures below about 20 °C, Grand Rapids lettuce (Lactuca sativa L.) seeds do not require light treatment for germination, and will germinate when allowed to imbibe water. At higher imbibition temperatures, some of the seeds will germinate without light, but others need a light treatment for germination. At still higher imbibition temperatures none will germinate even if given a light treatment, but if the seeds are subsequently placed at an intermediate temperature, some will germinate without light and more will germinate with light. Prolonged incubation at the higher temperature may enhance the light requirement. Low germination temperatures will eliminate the light requirement completely, regardless of imbibition and incubation temperatures. The exact temperatures for these reactions differ with different batches of seeds, so we conducted preliminary experiments to determine the combination of imbibition and incubation time and temperature and germination temperature at which most of our seeds showed a light treatment requirement for germination.

MATERIALS AND METHODS

The two soils used were Drummer silty clay loam and Broomfield sand. The Drummer soil, when dry, is dark gray with a Munsell color notation of 5YR 4/1, and when moist is black (5YR 2.5/1). The two Drummer ped sizes, 0.42 to 0.50 mm and 0.84 to 1 mm, were separated by sifting. This soil maintains the integrity of its aggregates well through wetting and drying cycles. Dry Broomfield sand is yellowish brown (10YR 5/4), and the moist sand is dark yellowish brown (10YR 3/4). The sand grain size range was 0.3 to 0.5 mm.

To determine light transmittance spectrophotometrically, we used a Beckman DK-2A spectrophotometer, with soil samples in acrylic plastic cuvettes.

To determine light transmittance through soils biologically, we placed light-sensitive lettuce seeds at various depths in the soils, then exposed the soils to light. Subsequent germination of the seeds indicated light penetration into the soil.

In the preliminary experiments to determine the exact characteristics of our seeds and to establish the optimum temperature, time, and light regimes, we cultured seeds in Petri dishes, which were kept dark at the desired imbibition and incubation temperature for the desired time, then exposed to light and again placed in the dark at a desired temperature. Dark controls were exposed to the same temperature regimes, but were not exposed to light.

To allow extrapolation of our results to field conditions, we compared the effect of cool white fluorescent lamps (at 5.4 klx) to that of metal halide lamps (at 48 klx) and sunlight (at 105 klx) and also tested the relationship between illuminance and exposure time by exposing seeds at different distances from the fluorescent lamps for different lengths of time.

For biological evaluation of light penetration through soil, lettuce seeds were planted at the soil surface, 2 mm below the surface, or 6 mm below the surface in dry, 36 °C soil in each cup of dark brown 12-cup muffin tins. Each cup (70 mm in diameter at the top, 50 mm at the bottom, and 27 mm deep) had small holes in the bottom and was filled with soil to a depth of 22 mm. The dark controls were planted at the 2-mm depth, with the soil covered by four layers of Al foil sealed to the rim of the cup with black caulking compound. Each tin was placed in shallow 36 °C water until the soil was moist throughout, then removed, double wrapped in Al foil, and placed in the 36 °C chamber for 16 hr. The tin was then moved to a 27 °C chamber for 2 hr, after which it was unwrapped and placed in a 27 °C light chamber for 6, 60, or 600 min. The light source was a 1,000-w metal halide lamp in a reflecting fixture, with a heat filter consisting of 2 cm of flowing water in a 6-mm-thick acrylic plastic pan. The illuminance at the soil surface was 46 klx. During light exposure the soil temperature was monitored by small thermometers whose bulbs (2 mm thick, 5-mm diameter) were 2 mm below the soil surface at locations where there were no seeds. The relative humidity of the chamber was regulated to maintain the soil temperature at 27 ± 0.5 °C by controlling evaporation rate, and 27 °C water was added to the soil from below if needed.

After the light treatment, an empty muffin tin was placed upside down over each experimental tin (to provide space for seedling growth) and the pair of tins was double wrapped in foil and left at 27 °C for 70 hr, after which the germinated seedlings were counted.

1 Trade and company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the named product by the U.S. Department of Agriculture or the University of Illinois.

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RESULTS

Spectrophotometric measurements of transmittance of light through the two soils are shown in Figures 1 and 2. Very little light penetrated the soils. Less than 1% of the light was transmitted through layers 2.2 mm thick in either soil for the ped (sand grain) sizes and moisture conditions investigated. The soils differed somewhat in their transmittance characteristics. While both soils transmitted more of the long wavelength light than the short wavelength light, the Broomfield sand affected the quality of the transmitted light much more than did the Drummer soil. Broomfield sand permitted light penetration through the peds, the light penetrating several ped diameters. With the Drummer, however, essentially no light penetrated more than 2 ped diameters, because the peds were not translucent and light penetration was limited to the voids. Water in the soils affected light transmittance differently in the two soils. Moisture increased light transmission through Broomfield sand by decreasing the number and sharpness of the refractive index discontinuities. In contrast, moisture decreased transmission in Drummer soil by reducing the small amount of reflection between peds, which do not transmit light. When such dark soils are very wet the light transmission can be further reduced by the dark material dissolved or suspended in the water within the voids. Regardless of mode of transmission (peds and voids or voids only), almost no measurable light penetrated either soil deeper than 2 mm. The penetration of light into these soils did not follow Lambert's law of light absorption.

Figure 3 illustrates the dependence of light sensitivity upon the imbibition and incubation time and temperature. The seeds were placed in the dark at 36 °C for various imbibition-incubation times, then were transferred to a 27 °C temperature (dark), with and without a 1-min 27 °C light exposure at the time of transfer. With a 16-hr imbibition-incubation time, germination was about 85% for light-exposed seeds, 6% with no exposure. The temperature at which the light treatment was given was not critical; 22 to 32 °C gave the same result. The light effect could be completely reversed by a 1-min exposure to far red light. A 20 °C germination temperature (rather than 27 °C) eliminated the light requirement, giving 82% germination with and without the light treatment.

Table 1 shows the relative effectiveness of our three different light sources in inducing lettuce seed germination. This is compatible with what one might expect from the illuminances and spectral qualities of these light sources, combined with published phytochrome action spectra (1, 4, 5).

The time-illuminance equivalence for our seeds is shown in Table II. One hr of exposure to 4.6 lux was equivalent to 1 min at 310 lux or 3 sec at 5,400 lux, each giving about 50% germination. Thus, the time-illuminance equivalence holds over the range from 4.6 to 5,400 lux with cool white fluorescent lamps.

Tables III and IV show results of the experiments in which we measured light penetration into the soil biologically. In the Broomfield sand, germination at the 6-mm depth did not differ significantly from that of the 2-mm darkened control for any exposure time, indicating that light didn't penetrate 6 mm. At 2 mm, however, the germination percentage increased with exposure time and, with 10 hr of exposure, was about the same as that of the

FIG. 1. Light transmittance of Broomfield sand.

FIG. 2. Light transmittance of Drummer silty clay loam.

FIG. 3. Dependence of lettuce seed light sensitivity upon imbibition and incubation time and temperature.
Results with the Drummer soil (Table IV) resembled those found in the Broomfield sand. Germination at the 6-mm depth was about equal to that of the 2-mm dark controls for both ped sizes, indicating that not enough light penetrated 6 mm to induce germination. At the 2-mm depth, germination percentages increased as exposure times lengthened, but there was not enough light to give the maximum germination displayed by the surface-planted controls, even at the 10-hr exposure. In Drummer soil, the light which induced germination at 2 mm must have penetrated through voids, as there was significant germination only in the soil with the large peds.

### DISCUSSION

Light can penetrate soil so as to cause germination of light-sensitive seeds 2 mm below the surface. We estimate from our comparison of light sources (Table I) that induction of germination at a 2-mm depth would require about 1 sunny day for seeds comparable in sensitivity to our lettuce seeds. However, most weed seeds are deeper in the soil than 2 mm. We also estimate that several sunny days would not cause full germination at the 6-mm depth, except in very light colored soils, or in soils with peds greater than 1 mm in diameter. Extrapolation from Figure 1 indicates that enough light might penetrate 6 mm into moist Broomfield sand to affect termination, but any light reaching this depth would probably be so strongly biased toward far red as to inhibit, rather than promote germination. Seeds completely exposed to the atmosphere but within soil cracks would usually remain in shadow, but could receive enough light in 1 day to germinate. Seeds near a crack would have to be within 2 mm of the surface of the crack to be stimulated by 1 or 2 days of daylight. Seeds receiving 0.5 sec of direct sunlight during cultivation operations could probably be induced to germinate, as was indicated by Sauer and Struik (7), but only a very few of those less directly exposed for 0.5 sec would be affected.

Despite the possibility that light-sensitive seeds near the surface may be stimulated by daylight, the question remains whether the seeds will indeed show a light requirement under field temperature conditions. Diurnal temperature fluctuations of 20°C or more occur near soil surfaces. Almost all experiments purporting to show light sensitivity of seeds in soil (2, 3, 7, 9, 10, 12) seem to...
have had no seeds kept in darkness at field temperatures, and such experiments could not discriminate between light effects and temperature effects. The observed increases in germination (ascribed to light) might have resulted from temperature changes. Feltner (2) reported more weed emergence in light-cultivated field plots than in dark-cultivated plots. Here, temperature probably could not have caused the increased germination, but Feltner's results were so variable as to lack statistical significance. In laboratory experiments where the light sensitivity of seeds has been shown, very rigid temperature regimes have been required. The interactions between temperature and light sensitivity are many and variable (3, 6, 9–11), and extreme temperature fluctuations extend farther into the soil than does light (8). A seed, moved by cultivation, could be exposed to a different temperature regime, which might obviate the light requirement. Therefore the light requirement observed in seeds which have been moved to the laboratory may not exist near the soil surface in the field. In our research, we were unable to utilize sunshine for evaluating light penetration biologically, because we could not control the temperature well enough to insure that the germination was indeed light-controlled.

We conclude that enough light can penetrate most soils to induce germination of light-sensitive seeds at a 2-mm depth, but not much deeper. Evaluation of the importance of such induction must await demonstration of light sensitivity at actual field temperature regimes.

LITERATURE CITED

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