INFLUENCE OF DIFFERENT LIGHT REGIMES OF BROAD BAND AND MONOCHROMATIC RADIATION ON THE INDUCTION OF DIAPAUSE IN THE CABBAGE MAGGOT *HYLEMYIA BRASSICAE* (BOUCHE) (DIPTERA:ANTHOMYIIDAE)

by

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Short title

EFFECT OF LIGHT ON *HYLEMYIA BRASSICAE* (BOUCHE)

Sosnowska

ABSTRACT

M.Sc. BOZENA MAGDALENA SOSNOWSKA Entomology

INFLUENCE OF DIFFERENT LIGHT REGIMES OF BROAD BAND AND MONOCHROMATIC RADIATION ON THE INDUCTION OF DIAPAUSE IN THE CABBAGE MAGGOT, HYLEMYIA BRASSICAE (BOUCHE) (DIPTERA:ANTHOMYIIDAE)

Diapause in the cabbage maggot, Hylemyia brassicae (Bouché), is induced under photophases of 6 hours and 12 hours in a 24-hour photoperiod.

The whole larval stage is sensitive to photoperiod and the process of diapause induction is accumulative.

Light breaks occurring during the scotophase of a 24-hour photoperiod may significantly suppress diapause induction. The larvae are sensitive to different wavelengths with energy levels as low as 0.14 mw/cm^2.

Violet (395 mμ), blue-green (495 mμ) and short-wave infrared (1750 mμ) regions of the light spectrum strongly avert diapause in the cabbage maggot.

H. brassicae is sensitive to white light (400-750 mμ), ultraviolet (330 mμ), and blue (460 mμ) also. There is a partial response of the maggots to green (525 mμ), yellow (570 mμ), orange (600 mμ), and near infrared (800 mμ). Red (675 mμ) light is inactive.

Longer wavelengths of monochromatic radiation in the infrared (900 mμ, 1000 mμ), are also effective in preventing diapause.

RESUME

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La diapause dans l'asticot du choux, Hylemyia brassicae (Bouché), est le résultat de photophases de 6 heures et de 12 heures dans une photopériode de 24 heures.

Toutes les phases larvaires sont sensibles à la photopériode et le procéssus qui l'induit est cumulatif. L'occurrence de la diapause peut être réduite de façon significative si on jette de la lumière pendant la scotophase d'une photopériode de 24 heures.

Les larves sont sensibles de différentes longueurs d'onde contenant un niveau d'énergie aussi réduit que 0.14 mw/cm^2. Les régions du spectre qui empêchent le plus la diapause chez l'asticot du choux sont les longueurs d'onde suivantes: le violet (395 mμ), le bleu-vert (495 mμ), et les infra-rouges à ondes courtes (1750 mμ).

H. brassicae est sensible en plus à la lumière blanche (400-750 mμ), l'ultra-violet (330 mμ) et la lumière bleue (460 mμ). Les asticots réagissent en partie à la lumière verte (525 mμ), jaune (570 mμ), orange (600 mμ) et presqu'infra-rouge (800 mμ). Il n'y a aucune réaction à la lumière rouge (675 mμ).

Les longueurs d'onde plus longues de rayons monochromes dans l'infra-rouge (900 mμ, 1000 mμ), peuvent empêcher la diapause d'une manière efficace.

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I. INTRODUCTION

Life on earth has evolved in the presence of a daily cycle of daylight and darkness.

This environmental rhythm of recurring alternation of illumination and darkness is the earth's natural photoperiod. The geographical distribution, seasonal biology, growth form, metabolism and behaviour of the animals are all influenced by the diel rhythm of photoperiod.

The seasonal biology of many temperate zone insect species is timed so as to allow the yearly production of two or more generations under favourable climatic conditions, but only one generation in areas where the climate is rigorous. In either case, the species overwinter in a state of hibernation known as diapause (Beck, 1968).

The term "diapause" was first used by Wheeler (1893) to specify a stage in the embryonic development of Conacephalus.

Henneguy (1904) extended the term by applying it to the state of arrested development occurring in the eggs of Bombyx and in the larvae of Liparis.

It has since been further extended to cover similar phenomena occurring at any stage of the life cycle of an organism.

Danilevskii (1965) points out that the major function of diapause is to synchronize the life cycle of the animal with the seasons of the year. It helps temperate zone arthropods to withstand harsh winter conditions. Correlated with this, the diapause stage is frequently cold hardy, resistant to desiccation, and is often a non-feeding stage.

Diapause in insects is induced by photoperiod, temperature, diet, relative humidity and the age of the parent insect, although the photoperiod plays the most important role.

The object of this study was to detect which region of the light spectrum is photoperiodically active in the induction of diapause in Hylemyia brassicae, Bouché. The maggots were subjected to different wavelengths of broad band radiation and to monochromatic light in the far-red and infrared regions.

The regions of broad band radiation which proved to be the most effective in suppression of diapause were further investigated using monochromatic light.

This thesis is in part a repetition of work on the Effect of Light on Hylemyia brassicae, Bouché reported by Owusu-Manu (1969) and in part a continuation of this work.

II. REVIEW OF LITERATURE

A. Biology of *Hylemyia brassicae*, Bouché

Hylemyia brassicae attacks cabbage and related crops throughout the temperate zones of the world, and its life history and habits have been outlined by many authors (Slingerland, 1894; Hewitt, 1911; Gibson and Treherne, 1916; Schoene, 1916; Eyer, 1921; Caesar, 1922; Brittain, 1927; Smith, 1927; Vasina, 1928; Vodinskaya, 1928; Nikitina, 1938; Fulton, 1942; de Wilde, 1947; Miles, 1951, 1952, 1953, 1954, 1956a, 1956b; Foott, 1954; Sherwood and Pond, 1954; Read, 1956, 1958, 1960, 1965a, 1969; Swailes, 1957, 1961, 1963, 1967, 1971; Auclair *et al.*, 1958; Hughes, 1959; Read and Welch, 1960; Zabirov, 1961; Forbes, 1962; Doane and Chapman, 1964a, 1964b; Berte *et al.*, 1965; Allen, 1965; Traynier, 1965, 1967a, 1967b; Harris and Svec, 1966; Priore, 1967; Varis, 1967; Ritchot, 1968, 1969, 1970; Zohren, 1968; Mukerji, 1970, 1971; Vereecke and Hertveldt, 1971).

The eggs of the cabbage root fly are laid singly in the soil within two inches of the stem of the host plant. Oviposition preferences are correlated with the presence

of mustard oil glucosides in hosts. The chemostimuli provided by plants might be more potent than the physical characteristics of hosts in eliciting oviposition (Traynier, 1965).

Egg-laying occurs in warm, sunny weather and long periods of sunshine with temperature at least 60°F (Vodinskaya, 1928; Miles, 1952; Harris and Svec, 1966). In cool, wet and windy weather fewer eggs are laid (Miles, 1953).

The number of eggs laid by a female fly is variable. Miles (1952) reported 122 eggs from a female fly; Harris and Svec (1966) found that an average egg production per female was 371 eggs over a period of 66 days. They also have shown that number of eggs laid is markedly increased by the addition of yeast hydrolysate to the diet. The eggs and first instar larvae are very susceptible to desiccation at low relative humidities (Swailes, 1957; Read, 1965a; Harris and Svec, 1966; Vereecke and Hertveldt, 1971).

The eggs hatch three to five days after oviposition and the young larvae enter the roots and develop through three instars before re-emerging to form their puparia in the soil about the base of the plant (Smith, 1927; Sherwood and Pond, 1954; Mukerji, 1971).

The duration of the larval stage varies between 19 and 25 days with an average of 23 days (Smith, 1927; Read, 1965a; Harris and Svec, 1966). The average period of pupation is 15 days (Smith, 1927; Zabirov, 1961).

According to Vodinskaya (1928) the pupae are killed at temperatures over 25°C and at 6°C they enter diapause. Six to 20 days after pupation, they emerge as adults under 16-hour photophase and a temperature of 20°C. More recent investigations indicated that under short day conditions the pupae are induced to diapause and the diapausing pupa is the overwintering stage. Temperatures of 70-80°F applied to the flies and the larvae prevented either diapause induction or adult development from the pupae; the insects stay in a state of aestivation (Zabirov, 1961; Missonier, 1963; Read, 1965a, 1969; Harris and Svec, 1966; Owusu-Manu, 1969).

Males reach sexual maturity soon after emergence and will mate during their whole life span. Most males mate for the first time within five days of emergence (Swailes, 1971). The females have been found to mate only once. Mating and oviposition activity in the laboratory and in the field are greatest in the morning (Swailes, 1961, 1971).

Longevity of the adults is about 29 days for the females and 19 days for the males at a temperature of 21.1-23.9°C (Foott, 1954).

B. Environmental Influence on Diapause Induction

1. Photoperiod

Two publications in 1933 announced the discovery of an effect of photoperiod on insect diapause.

Sabrosky et al. (1933) reported that adult and nymphal diapause of the pigmy grasshopper, Acrydium arenosum, could be prevented by maintaining the insects under continuous illumination.

Kogure (1933) published a detailed study of the role of daylength on the incidence of embryonic diapause in the silkworm, Bombyx mori. Since the time of these two pioneer studies, more papers have been published on photoperiodic influence of diapause. The ability to react to changes in daylength has been found in representatives of all the principal orders of insects: Lepidoptera, Diptera, Hymenoptera, Neuroptera, Coleoptera, Orthoptera and Odonata (Danilevskii, 1965).

Photoperiodic adaptations have been observed in species with extremely varied modes of life. Many of the

forms lead exposed lives, but daylength adaptations are also found among forms that live in concealment with marked negative phototropism. Thus many insect larvae, including maggots of the cabbage root fly, H. brassicae, which live in the soil on the roots of plants, react to daylength. Thus photoperiodic reactions may occur even in species living in places with very slight illumination. The reaction, however, is not obligatory. The connection between photoperiodic adaptations and the type of seasonal cycle is very clearly marked. Close dependence of development on the light conditions is particularly typical of polycyclic species with facultative diapause; that is, a diapause that may or may not be manifested in a given individual or population, depending on the environmental conditions prevailing during certain critical stages of the insect's development (Beck, 1968).

Owusu-Manu (1969) gives an extensive literature review on photoperiod and diapause in the cabbage maggot.

2. Light intensity

Photoperiodic induction of diapause necessarily involves the reception of light by the insect, either as an input of light energy over a span of time or as the reception of light-on and light-off stimuli. A receptor system and an effector system must be involved in

photoperiodism, the amount of energy required to elicit a response should vary according to the characteristics of the receptor complex. Action spectra are therefore needed, in which the amount of energy required to effect a standard response has been determined for different wavelengths of impinging light (Beck, 1968).

Observations on the light intensities required for the photoperiodic induction of diapause have indicated that very low energy levels are effective. The larva of Metriocnemus knabi Coquillott is sensitive to light intensities as low as 0.025 lux and below (Paris and Jenner, 1959). Kogure (1933) found the threshold of sensitivity in an egg of the silkworm as low as 0.01 foot candles and the young larvae were sensitive to 0.08 foot candles.

Light energy levels as low as 0.05-0.5 $\mu w/cm^2$ are adequate to break diapause of codling moth larvae and 0.01-0.2 $\mu w/cm^2$ is adequate for the oak silkworm pupae (Norris et al., 1969).

Monochromatic radiation at an energy level as low as 0.05 $\mu w/cm^2/nm$ in the violet, blue, green, yellow and orange portions of the visible spectrum is effective in suppressing diapause in the boll weevil, Anthonomus grandis Boheman (Harris et al., 1969).

Photoperiodic induction in insects is independent of light intensity provided that a certain threshold is surpassed. This threshold of perception for white light shows a considerable variation among species. In the adult Colorado potato beetle, the threshold is below 0.1 lux. Above this value the effect increases with intensity until at five lux it remains constant (Wilde and Bonga, 1958).

The onset of diapause in oriental fruit moth larvae, Grapholitha molesta, Busck is controlled by the illumination of light intensity of 3 f.c., but that of 1.1 f.c. is not effective (Dickson, 1949).

Lees (1953) found that the threshold of light perception for the fruit tree red spider mite, Metatetranychus ulmi, is in the region of 1-2 f.c. If the illumination is greater than this at the threshold of the sensitivity the mites are not induced to diapause and the incidence of diapause is affected only by the duration of the photoperiod and is independent of intensity and total light energy. Mites were reared either with an 8-hr photoperiod and a light intensity of 90 f.c. or with a 16-hr photoperiod and a light intensity of 45 f.c.; although the total light energy was constant, the mites were induced to diapause just like under the first conditions.

Owusu-Manu (1969) reported that short-wave infrared radiation averted diapause in the cabbage maggot when an energy level of 28 $\mu w/cm^2$ was given. He indicated that there is a threshold of sensitivity above which any increase has no effect on the determination of diapause.

3. Spectral response

Insect diapause is controlled by different wavelengths of the light spectrum. The most effective wavelengths have been found to lie between about 400 and 550 mμ.

Kogure (1933), who made the first investigation in spectral response in insects, reported that violet light (350-510 mμ) exerted the greatest photoperiodic activity in the silkworm, orange-yellow (above 550 mμ) was only slightly active, and red (675 mμ) completely inactive.

Diapause in Metatetranychus ulmi is inhibited by high intensity radiation in red, orange and IR regions of the spectrum (Lees, 1953).

De Wilde and Bonga (1958), in experiments with interference filters of narrow spectral transmission bands, have demonstrated that in the adult Colorado potato beetle a wavelength of 675 mμ is still active in inducing diapause, while 700 mμ and above are without effect.

The oak silkworm, Antheraea pernyi, is sensitive to violet, blue, blue-green light spectra. The cocoon integrates the light especially in the blue region (440-510 mμ) and then the light penetrates the pupal cuticle to act on the brain where it is absorbed by a pink brain pigment. Yellow (580 mμ) and red (640 mμ) light spectra do not prevent diapause (Williams et al., 1965).

The action spectra for breaking diapause in codling moth, Laspeyresia pomonella (L.), are similar to those acting in the same manner in the oak silkworm and show maximum sensitivity in the short visible wavelength region (400-500 nm) (Norris et al., 1969).

The spectral region that is most effective for suppression of diapause in the boll weevil, Anthonomus grandis, Boheman, lies between 400-665 nm; the 359-390 nm and 670-1000 nm spectral regions are less effective (Harris et al., 1967). These insects were exposed to narrow bands of monochromatic light also. The results confirmed previous experiments. Boll weevils seem to be intermediately sensitive to a band of radiation from red through far red and into the near IR region of the spectrum (Harris et al., 1969).

The addition of UV radiation to the visible light caused significant reduction in the incidence of diapause of the horn fly, Haematibia irritans (L.) (Depner, 1962).

With respect to prevention of diapause in H. brassicae, wavelengths in the violet, blue, blue-green, and the shortwave infrared regions of the spectrum are photoperiodically active, while wavelengths between 500 mμ and 600 mμ, that is, green, yellow and orange, and those below 395 mμ (ultraviolet) and near infrared are less efficient. Red light is totally inactive (Owusu-Manu, 1969).

Many insects that live in soil or thick plant stems are nevertheless sensitive to photoperiod. Callahan (1965) has suggested that irradiation in the infrared range may play an important role in the photoperiodism of these insects.

4. Infrared radiation

Radiation beyond the visible region and its influence on insect life has intrigued workers for some considerable time. The nighttime environment is primarily an infrared environment and plants and animals emit highly in this region. Several authors claimed that night flying insects can emit special waves of rays for communication with and location of the individuals of the opposite sex (Fabre, 1913).

Callahan (1965a, 1965b) observed far infrared radiation emitted in the 9 μ region by the nocturnal moths. Vibrating their wings, the moths send their mating signal across the space and can locate each other in total darkness.

Duane and Tyler (1950) suggest that there is a correlation between moth attraction and the infrared portion of the spectrum. Some insects fly to an incandescent light source through fog and even through cloud. Infrared radiation has a greater ability to penetrate clouds than visible and ultraviolet light which are scattered or absorbed by water content in the air.

Because the infrared band falls between the bands of light and radar (0.75μ to 10^3μ) it has many of the characteristics of both visible and radar waves. It may be focused by lenses and yet can be transmitted like radar or radio through materials that block visible light such as wood, leaves (Jagger, 1967; Hackforth, 1960; Callahan, 1965a).

Callahan (1965a, 1965b) believes that infrared frequencies might be involved in diapause phenomena. In his theory he points out that diapause control by infrared radiation is strongly suggested by the corn earworm's habitat relations: the earworm egg is laid at night on the corn silk, the larva immediately after hatching tunnels

down the silk beneath many layers of corn husk, then drops off at night and pupates underground. Very little visible light penetrates a dense stand of corn and one corn leaf is a band pass filter for NIR which effectively blocks most visible light (Yocum et al., 1962).

Harris et al. (1969) tested the response to infrared radiation by the boll weevil, Anthonomus grandis, Boheman. Boll weevil shows an intermediate response (between suppression and induction) to infrared radiation in the 0.8μ to 4.5μ region.

Diapause in H. brassicae, Bouché was prevented when larvae were subjected to shortwave infrared (1750 mμ) and there was a partial effect in near infrared (800 mμ) (Owusu-Manu, 1969).

Considering the sensitivity of insects to infrared radiation, Callahan (1965) suggests that maybe the control line of diapause should not be drawn between light and dark but further along the spectrum between near infrared energy and intermediate infrared or far infrared energy.

C. Effects of Light Breaks on Diapause Incidence in H. brassicae Pupae During the Scotophase of a Photoperiod Regime Applied to the Larvae

An early hypothesis to explain photoperiodic induction of diapause was that some essential factor, such as a hormone, was synthesized during one phase of the photoperiod, and degraded or neutralized during the opposite phase (Beck, 1968).

Because diapause induction results from the exposure of the sensitive growth stages of an insect to a succession of daily cycles of an effective photoperiod, de Wilde (1962a) postulated that some unidentified diapause-inducing factor was produced and accumulated until the amount present in the insect was sufficient to evoke the state of diapause. Diapause-inducing factors are not active in light only or dark only, but diapause is induced only in response to certain durations and sequences of illumination and darkness.

The duration of the scotophase has frequently been found to be more critical than photophase duration in the induction of diapause. For this reason, several workers have concluded that if the photoperiodic induction of diapause involves the measurement of time, it must be primarily the duration of the scotophase that determines whether or not diapause will occur. The scotophase has,

therefore, been subjected to critical analysis in regard to its importance in diapause and its possible role in time relationship.

Pupal diapause in the cabbage worm, Pieris brassicae (L.) was shown to be induced by short daylengths. If the scotophase was interrupted by a short period of light, the incidence of diapause was reduced, but the amount of reduction depended upon the time at which the light break occurred (a two-hour light break most effectively prevented diapause when it occurred each day at 16 hours after the beginning of the photophase) (Bunning and Joerrens, 1960). Barker (1963), Barker et al. (1963, 1964) found that even very short light pulses (about 0.001 second) would effectively reduce the incidence of diapause in Pieris brassicae (L.) if they occurred each day at about 14 hours after the onset of the photophase.

A light break of one hour which occurred 17 hours after the beginning of the photophase was shown to prevent the induction of diapause in the European corn borer, Ostrinia nubilalis (Beck, 1962a).

The most effective light breaks in diapause reduction of the pink bollworm, Pectinophora gossypiella, occurred at either 15 or 20 hours after the onset of the photophase (Adkisson, 1963, 1964, 1965, 1966).

Benschoter (1968) showed that light periods of five minutes or more in the dark phase strongly inhibited diapause of bollworm, Heliothis zea (Boddie), and tobacco budworm, H. virescens (F.). A light period near either end of the dark phase was much more effective in preventing diapause of tobacco budworms than one in the middle of the dark phase.

The light is most inhibitory to diapause of codling moth, Carpocapsa pomonella, after the onset of the main photoperiod. Thereafter the level of diapause rises until at 24 hours there is no effect from the two-hour light interruption. After 24 hours the light interruption again begins to inhibit diapause and another maximum of diapause inhibition is obtained at the 40-hour point (Peterson and Hammer, 1968). Photocycles of 72 hours with eight-hour photophases and interrupted nights, produce significant depression of the diapause curve eight hours after dusk and eight hours before dawn in the same species (Hammer, 1969).

D. Light Penetration into Soil

Light is the major factor which induces diapause in the cabbage root maggot. The sensitive stage to photoperiod, the larva, lives inside the roots of cruciferous plants in the top 10 cm of the soil. Larvae must be able to detect

irradiation of very low intensities because a large part of light is absorbed, reflected and scattered by the soil particles and plant tissues; consequently no light or very little light may reach the maggots.

A certain amount of solar radiation incident on the earth's surface may not be immediately reflected and absorbed but may penetrate to considerable depths depending on the nature of the surface (Sellers, 1967). The depth of penetration of light into the soil varies depending on type of the soil, its structure, distribution, density and colour of the soil particles, and water content (Sauberer, 1951; Geiger, 1965). Soil types which reflect most light from their surface are also those which allow the deepest penetration of light (Baumgartner, 1951).

The soil particles themselves are in general opaque and the light penetrates into the soil through the pores. The larger the grains and the pores, the further the light can travel into the soil. Baumgartner (1951) showed that in coarse sand with the grain size of 4 to 6 mm, 1/1000 of the outside light penetrates to a depth of 20 mm; where one-half of the penetrating light is absorbed in the first millimeters, in fine sand with a grain size of 0.1 to 0.5 mm. The light permeability of pure mineral soils grows with the water absorption, whereas that of humic and swelling soils diminishes with increase in water content (Baumgartner, 1951).

The depth of light penetration also depends on the wavelength of the incident light (Sellers, 1965).

For the sun, the maximum emission is near 500 mμ which is in the visible region of the electromagnetic spectrum (Johnson, 1963; Sellers, 1967), and almost 99 per cent of the sun's radiation is contained in the wavelengths ranging from 150 to 4000 mμ. Of this, nine per cent is in the ultraviolet (less than 400 mμ), 45 per cent is in the visible range (400-740 mμ) and 46 per cent in the infrared (above 740 mμ) (Sellers, 1967).

The attenuation of solar radiation is caused by scattering and absorption by the atmosphere. The ultraviolet portion is absorbed mainly by ozone, which produces an abrupt termination of the solar energy reaching the earth's surface at a wavelength near 2900 Å (Gates, 1966). The largest proportion of absorption of infrared radiation is due to the presence of water vapour. The basic constituents making up the atmosphere, oxygen and nitrogen, do not absorb infrared radiation and neither do the rare gases contained in the atmosphere. The absorption depends on the wavelengths and it has been found that the atmosphere does not transmit practically any infrared radiation of wavelengths exceeding 15 μ (Vasko, 1968).

Most soils and vegetation readily absorb energy in the ultraviolet portion of the electromagnetic spectrum

and scatter and reflect it at longer wavelengths (Sellers, 1965). Therefore, with increasing depth in the soil, proportionally less of the radiation is in the short wavelengths. Sauberer (1951) found that blue light (0.47 μ) is reduced to 0.01 of its surface intensity at a depth of 18 mm in wet sand; at the same depth, orange light is reduced to 0.1 of its surface intensity. He also estimated the shift of the spectral parts of the light in relation to the number of reflections. According to him the proportion of light of a wavelength of 0.8 μ increases after four reflections 15-fold. The light in the soil is therefore preponderately red. Some measurements on spectral distribution of light in the soil showed relatively high transmission in the green. This could be explained by a high content of chlorophyll owing to algae. The soil samples were stored in the dark for four years and then tested again. At that time the high transmission in the green had disappeared (Sauberer, 1951).

E. Light Penetration and Absorption in Plants

A relatively small amount of research has been done on the spectral properties of plants and most of that work has concerned itself with the visible and very near infrared portions of the spectrum. Plants absorb very effectively throughout the ultraviolet and the visible regions of the

spectrum where the energy is required for photosynthesis (Gates et al., 1965). However, Gates and Benedict (1963) showed that of the total energy absorbed by plants, approximately 75 per cent is reradiated and 25 per cent is dissipated by convection and transpiration. Plants absorb poorly the near infrared which prevents them from becoming overheated, and absorb the far infrared which causes them to be efficient radiators.

Some research has been done on the spectral composition of the solar radiation changes when passing through the canopy of deciduous and coniferous trees. According to Orth (1938) these changes are due to the selective absorption of pigments in the leaves, reflection from the leaf epidermis and transmission through the leaves.

Vezina and Boulter (1966) found that under the pure stands of maple canopy and red pine canopy the far-red predominated with decreasing amounts of green, blue, red and ultraviolet. The high proportion of the far-red light in both stands has been attributed to the high transmission by the leaves, since chlorophyll transmits freely in this region.

Gates (1965) states that there are two regions of the spectrum where relatively little absorption will occur in plants, a region from 500 mμ to 600 mμ and a region

from 700 mμ to 1200 mμ. The presence of pigments other than chlorophyll tends to broaden the domain of absorption throughout the visible region. This is supported by Smith and French (1963) who claim that most land plants and algae have very little detectable light absorption beyond 700 mμ.

The absorption of a plant will be different for sunlight, cloudlight, incandescent light, fluorescent light or any other source. Cumming (1963), who was using both incandescent and fluorescent light sources in his experiments on the dependence of germination on photo-period and light quality, showed that a greater percentage of far red than other parts of the light spectrum is transmitted through green plants.

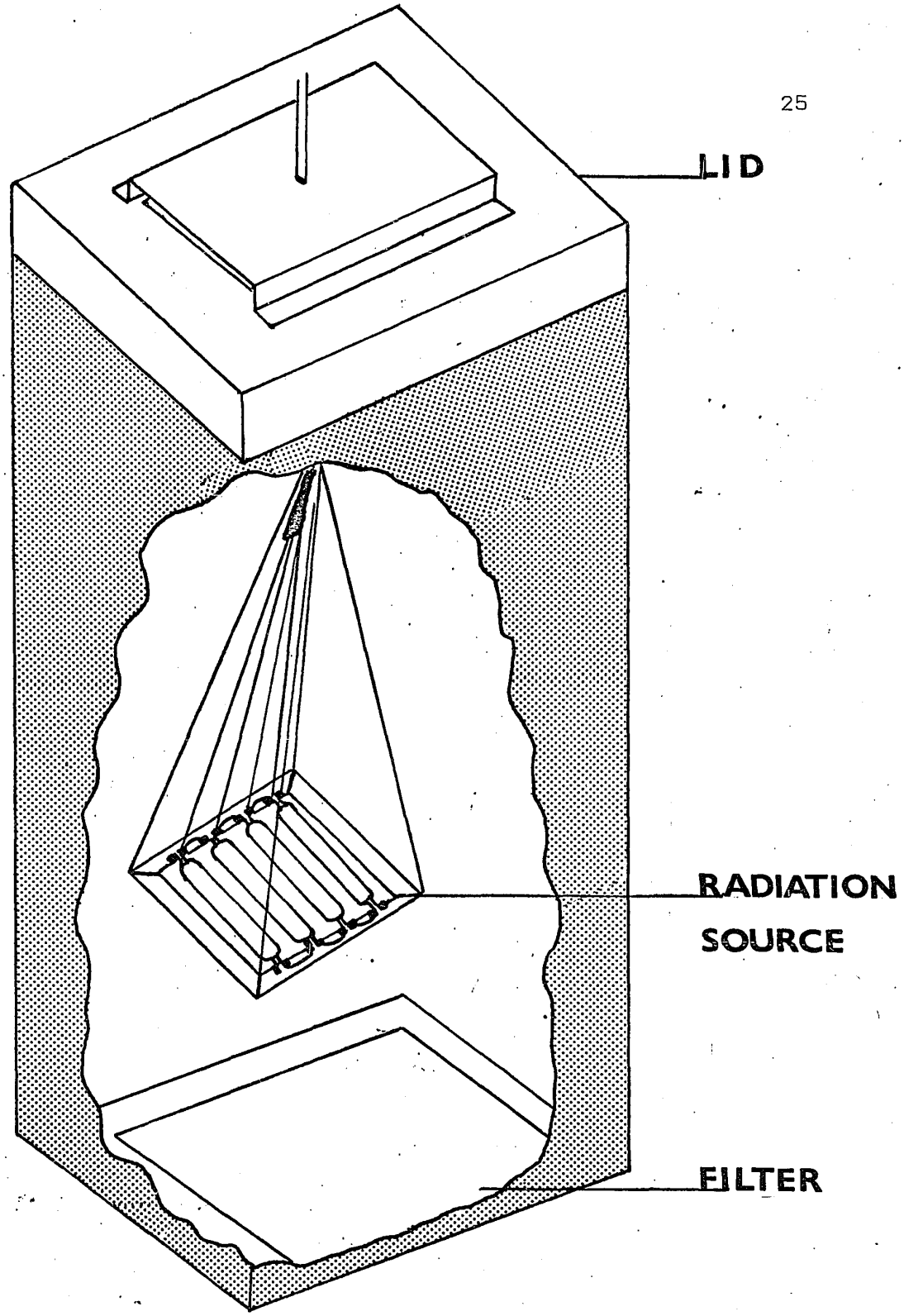
III. MATERIALS AND METHODS

A. Control of Light Regime of Broad Band Radiation

The radiation spectrum investigated was divided into 10 ranges and each range of wavelength was taken as a treatment. Each treatment was divided into three replicates. White light, 16-hour photophase and 12-hour photophase treatments also were included.

A black aluminium box was used for filtering the light. The body of the box was rectangular and measured 27 cm long x 18 cm wide x 18 cm deep. Inside the box was mounted a wooden frame 8 cm long x 6.5 cm wide with four F_4T_5D fluorescent lamps attached to it (Figure 1).

Fluorescent lamps produce much less radiated heat per lumen of light than incandescent lamps. Because of this property they were chosen for the experiments on diapause in the ultraviolet and visible ranges. This means that fluorescent lamps give a small amount of infra-red radiation which can be almost completely eliminated when passed through the filters. The fuses and ballasts for the lamps when warmed up could be infrared radiators.



BLACK ALUMINIUM BOX USED TO FILTER VISIBLE LIGHT. FIG.1

To avoid this radiation, they were attached to a wooden board and kept outside the environment chambers.

For the experiments with infrared radiation, 60-watt and 250-watt incandescent lamps were employed as the light sources.

The energy level of radiation intensity was kept constant for all the treatments. Unfiltered white light obtained from a F_{14}/T_{12} C.W. Sylvania fluorescent tube outside the filter box, was applied for 12 hours with an incident energy level of 0.25 mw/cm^2. At the end of this period filtered light only was applied for the final four hours of the daily photophase of 16 hours with an incident energy level of 0.14 mw/cm^2 on the top of the turnip.

The light energy was measured using a Yellow Spring Instrument (YSI) Kettering Model 65 Radiometer[1] with the probe at the top of the rearing medium.

Light intensity was controlled by lifting up or lowering the light box according to the inverse square law. (It states: "the intensity of radiation emitted from a point source varies as the inverse square of the distance between the source and the receiver.")

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[1]YSI Kettering Model 65 Radiometer Inc. Yellow Springs, Ohio.

Into the bottom of the light box Corning Glass Filters 16.5 cm x 16.5 cm were inserted.[1] The ranges of wavelengths with the peaks of transmission and the filters employed are shown in Table 1.

When testing the response of the maggots to different intensities of infrared radiation, neutral density filters were also employed (neutral density filters no. 12.5H, 15P, 15S, 15T).[2]

The experiments on spectral response were carried out in Sherer Model R 16 B growth chambers. The chambers were lined inside with black paper to avoid light reflection. Each growth chamber was divided into two halves so the experiments with two different treatments could be carried out at the same time (Figure 2, Plate 1).

Photoperiodic control was affected through the use of a timer connected to the source of light energy.

---

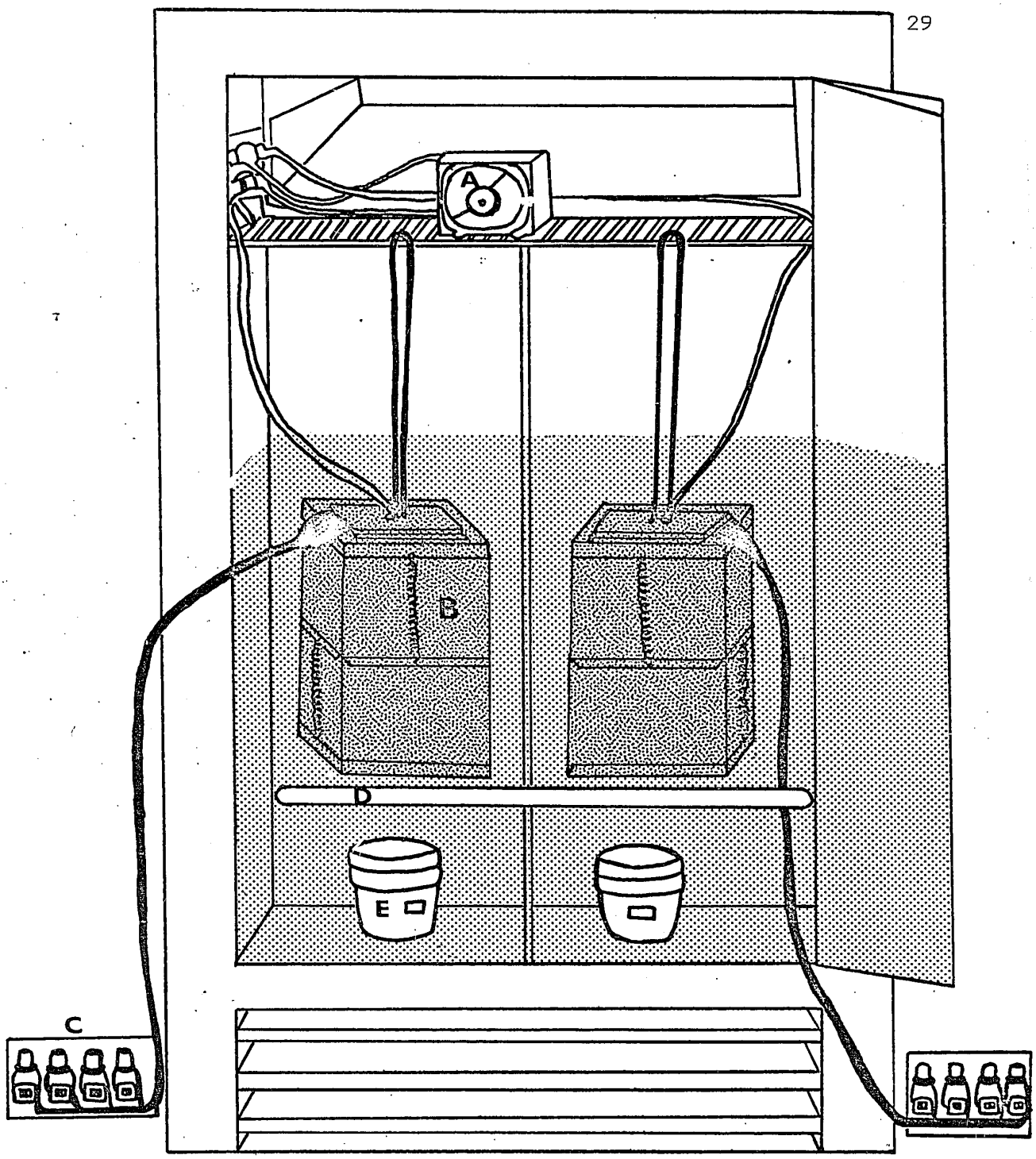
[1]Corning Glass Works, Corning, N.Y.

[2]Perforated Products, Inc., Brookline, Mass.

TABLE 1. Ranges of wavelengths, peaks of transmission, and filters employed

Transmission range (mμ)	Transmission peak (mμ)	Glass filter used	Colour obtained
400-750	-	CS 3-75+1-69	Filtered white light
230-420	330	CS 7-54+1-69	Ultraviolet
370-425	400	CS 3-75+7-51+1-69	Violet
430-500	460	CS 3-72+5-60+1-69	Blue
460-580	500	CS 3-71+5-56+1-69	Blue-green
480-570	525	CS 4-64+1-69	Green
555-610	570	CS 3-66+4-96+1-69	Yellow
590-630	600	CS 4-94+2-62+1-69	Orange
620-750	675	CS 2-59+1-69	Red
710-1125*	800	CS 7-69	Near infrared
730-4500*	1750	CS 7-57	Short-wave infrared

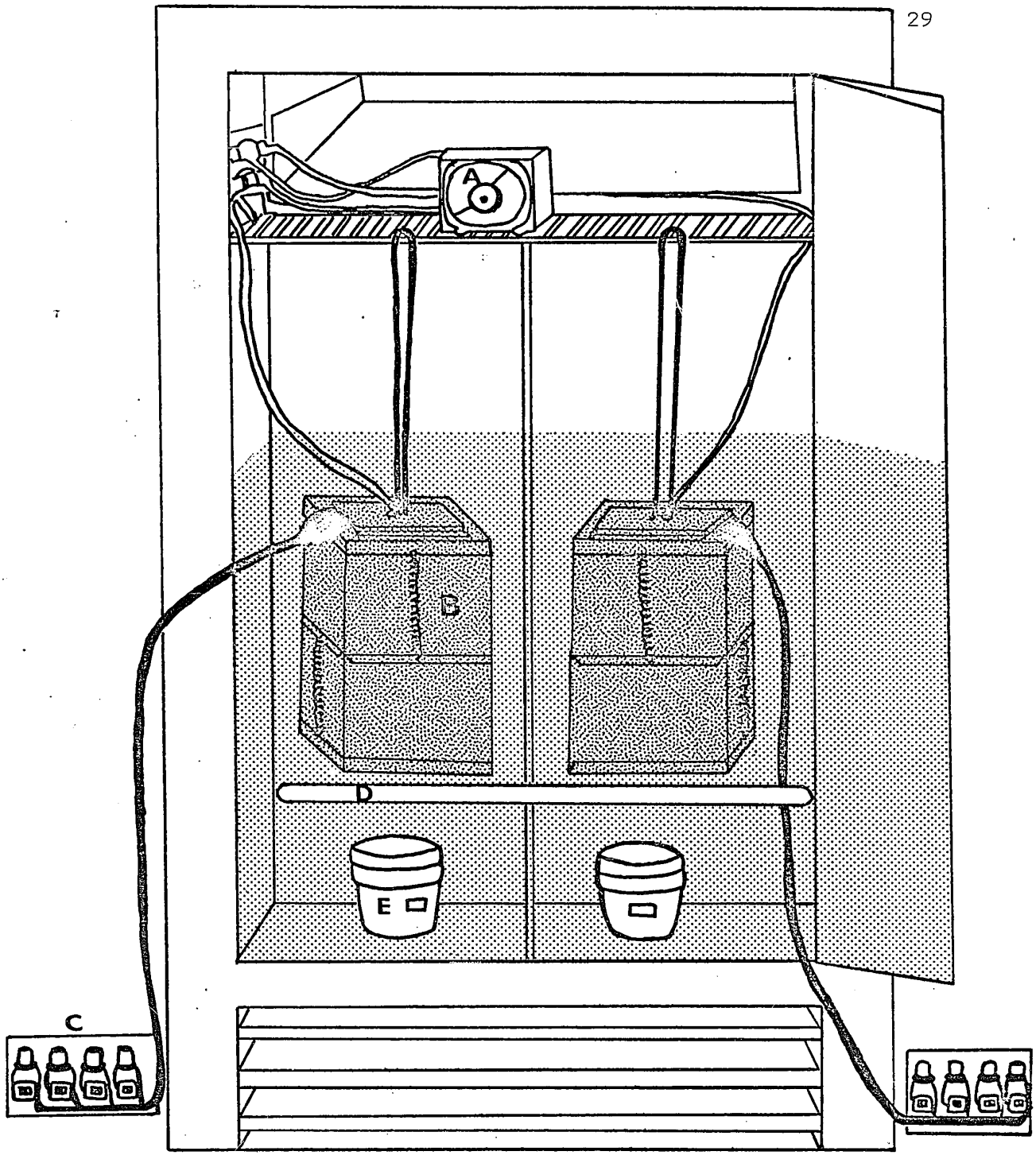
*Radiation obtained from 60-watt Sylvania incandescent lamps.



ENVIRONMENTAL CHAMBER WHERE THE EXPERIMENTS ON SPECTRAL RESPONSE WERE CARRIED OUT

A-TIMER. B-LIGHT. C-BOARD WITH BALASTS. D-FLUORESCENT LAMP. E-CULTURE POT.

FIG. 2



ENVIRONMENTAL CHAMBER WHERE THE EXPERIMENTS ON SPECTRAL RESPONSE WERE CARRIED OUT

A-TIMER. B=LIGHT. C-BOARD WITH BALASTS. D-FLUORESCENT LAMP. E-CULTURE POT.

FIG. 2

B. Control of Monochromatic Light

The response of Hylemyia brassicae, Bouché to the narrow bands of radiation was tested using a Hilger and Watts D 330[1] Single Monochromator and a Sherer Model Cel R 16 B controlled environment chamber (Figure 3).

The specification of the monochromator is:

Focal length :	300 mm nominal
Diffraction gratings:	
Blank size	80 mm diameter
Ruled area	52 mm x 52 mm
Grating ruling	1200 L/mm
Blaze wavelength	0.5 μ
Preferred wavelength range	0.33 μ to 1.0 μ
Approximate reciprocal dispersion	26 A/mm

A hole was drilled in the side-wall of the controlled environment chamber into which a metal pipe was inserted. The exit slit of the monochromator and pipe were connected with a black cardboard sleeve so that the beam of the light could travel into the chamber and irradiate the sample.

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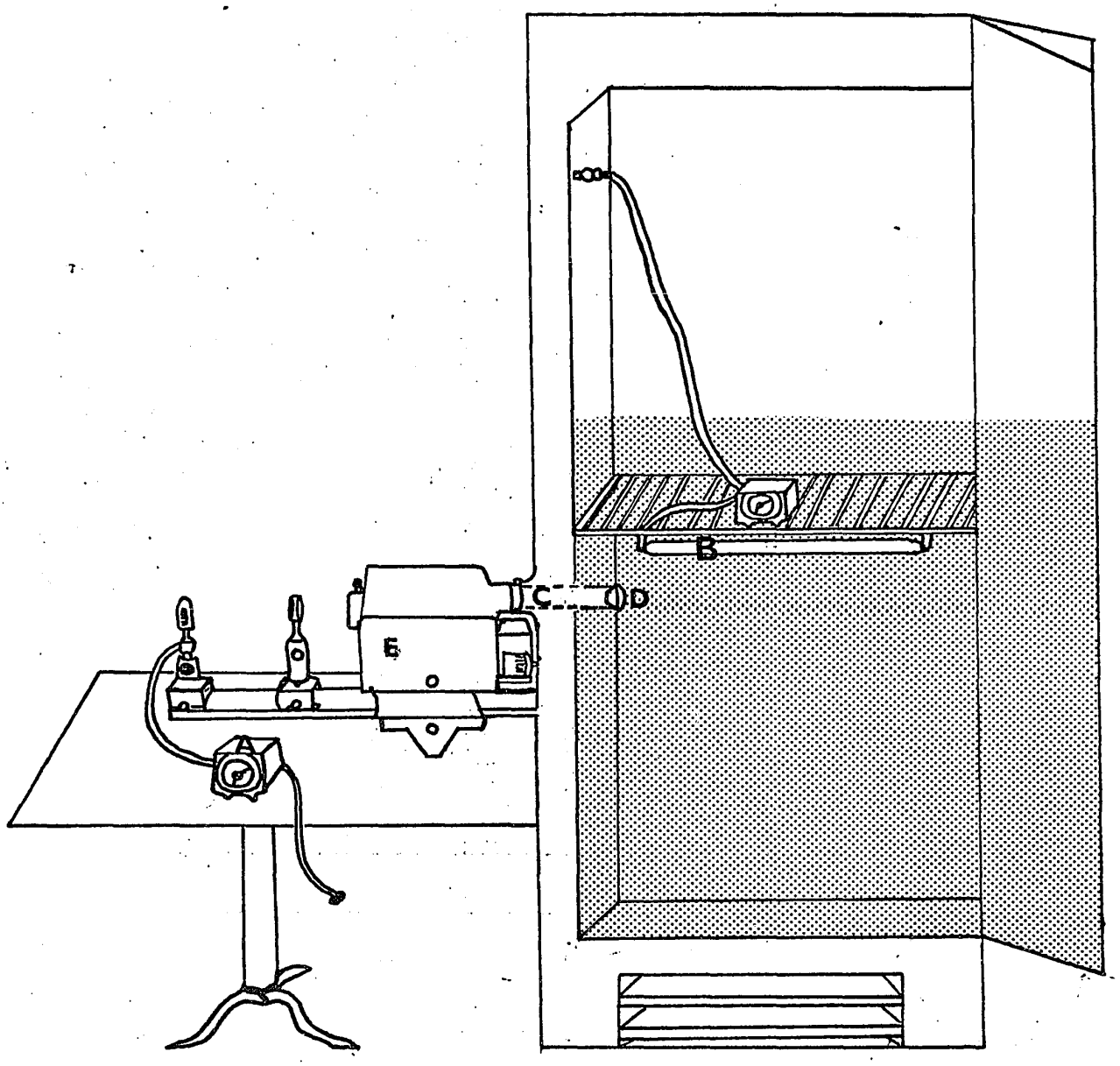
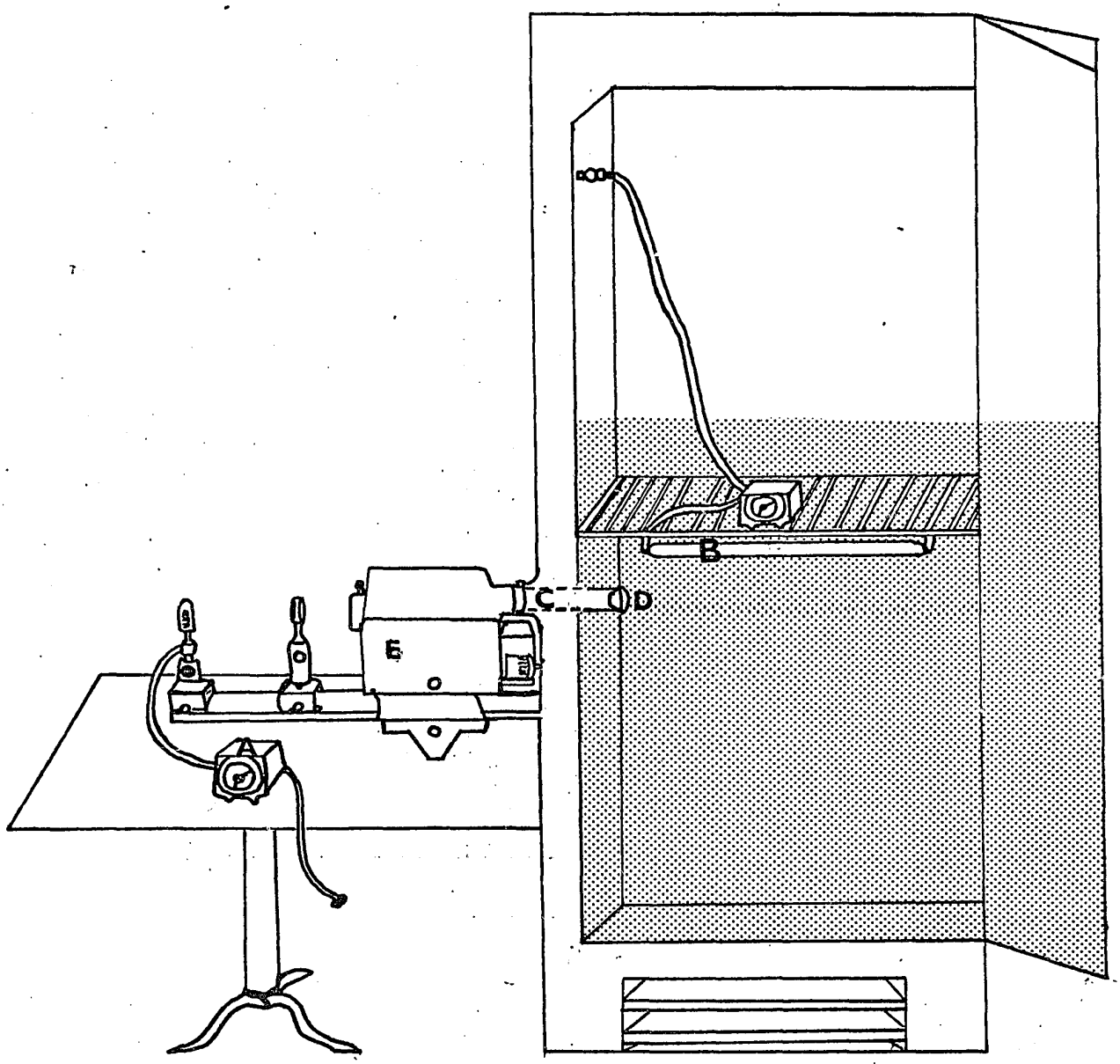
[1]Rank Precision Industries (Canada) Ltd., Analytical and Industrial Divisions, 3218 Wharton Way, Mississauga, Ontario.



ENVIRONMENT CHAMBER SET UP WITH MONOCHROMATOR

A-TIME-CLOCK. B-FLUORESCENT LAMP. C-METAL PIPE. D-SAMPLE.
E-MONOCHROMATOR

FIG. 3



ENVIRONMENT CHAMBER SET UP WITH MONOCHROMATOR

A-TIME-CLOCK. B-FLUORESCENT LAMP. C-METAL PIPE. D-SAMPLE.
E-MONOCHROMATOR

FIG. 3

The sample consisted of a 60 mm x 20 mm petri dish containing a turnip slice (26.5 g) infested with cabbage maggot eggs. It was fitted at the end of the metal pipe so it could be irradiated for a 12-hour period by white light obtained from F_{14}/T_{12} C.W. fluorescent lamp mounted inside the environment chamber and for an additional 4-hour period by monochromatic light from the monochromator. The light source for monochromatic light was a 250-watt Sylvania Quartz Idione lamp. The wavelength of the emergent radiation was changed by rotation of the micrometer drum of the monochromator. Anti-clockwise rotation produced changes to longer wavelengths and vice versa.

The light energy obtained from the F_{14}/T_{12} C.W. fluorescent tube was equal to 0.25 mw/cm^2, and the incident energy level of monochromatic light was equal to 0.078 mw/cm^2.

The response of the insects to monochromatic light was tested in the far-red and infrared ranges (800 mμ, 1000 mμ). The insects were also subjected to the visible wavelengths which were found to be most effective in the broad band wavelength (violet, 400 mμ; blue, 460 mμ; blue-green, 500 mμ) experiments.

C. Effects of Light Breaks on Diapause Incidence in *H. brassicae* Pupae (during the scotophase of a photoperiod regime applied to the larvae)

Experiments on the photoperiodic response of cabbage root maggots and experiments on the effect of light breaks during the scotophase on diapause induction were carried out in a Sherer Model Cel 255-6 environment chamber. Illumination was obtained from one $F_{20}T_{12}$ C.W. fluorescent tube with a light intensity of 0.52 mw/cm^2 at the surface of the larval medium.

The light timer of the environment chamber was programmed to give an additional period of 1.5 hour of light at different times of the dark period. Light interruptions occurred within a 24-hour lighting cycle with a photophase of 6 hours and a scotophase of 18 hours (6L:18D).

The light breaks occurred 8 hours, 10 hours, 12 hours, 14 hours, 16 hours and 20 hours after the onset of photophase in each experiment, respectively.

D. Temperature and Humidity

The temperature and the relative humidity were verified by a recording thermohygrograph. A tray with saturated sodium chloride solution was kept in each environment chamber to maintain the desired level of humidity at 75 per cent R.H.

The temperature was also checked twice a day using a mercury thermometer.

E. Culture Methods

1. Culture methods in flower pots with soil

H. brassicae used for this study were obtained from the Canada Department of Agriculture Research Station, Charlottetown, P.E.I., as diapausing pupae in August, 1970, and maintained at Macdonald College from that time on.

The adult flies were kept in cages with a wooden framework 22.5 cm^2, a 6 mm plywood base, and the other sides covered by 36 mesh (0.96 type) polyvynyl gauze (Plate 2). A 20.0 cm x 12.5 cm sliding clear plastic plate was used at one side to provide an access into the cage (Owusu-Manu, 1969).

The culture method used was a modified form of that described by Read (1960, 1965a).

The cages with flies were kept in Sherer Model Cel 255-6 environment chambers at a day temperature of 21°C (16 hours) and a night temperature of 19°C (8 hours) with a relative humidity of 60 ± 5%. The light intensity on top of the cage was 0.52 mw/cm^2 obtained from $F_{20}T_{12}$ C.W. Sylvania fluorescent tubes. About 250-300 flies per cage were fed on sugar solution (50% H_2O + 50% sugar) and a specially prepared diet. A 25 ml vial was filled with sugar solution inverted over a 5.5 cm diameter bottom of a petri dish lined with cotton wool. The following diet was placed in a 60 mm x 20 mm plastic petri dish:

whole wheat flour	8 parts by volume
granulated sugar	8 parts by volume
powdered brewer's yeast	4 parts by volume
granulated honey	3 parts by volume
water	1 part by volume

All the ingredients were thoroughly mixed together to form an even paste. About 1 to 2 kg of this diet was prepared at one time and kept refrigerated. Water was supplied in a 60 mm x 20 mm plastic petri dish.

Dead flies were removed each day. When working with flies an incandescent lamp was held at the opposite side of the cage from the door. The adults are positively photoactive and this decreased the number of escapes.

When the flies were six days old, the oviposition dish was placed in each cage. The oviposition dish consisted of 5.5 cm diameter petri dish filled with washed damp sand in which a slice of turnip was partially inserted.

The eggs were collected every 48 hours. The sand and turnip were washed in a beaker and the floating eggs were decanted onto a piece of dark cloth resting on a sieve. Using a camel brush, 600 eggs were counted and spread over the bottom surface of a whole turnip (about 10 cm diameter). A soil mixture was prepared of three parts of sterilized black soil to one part of sand. A five-inch diameter plastic flower pot, four inches in height, with three dental wicks inserted into the drainage holes, was filled with soil mixture covering the turnip and eggs. This pot was then placed inside a similar pot 4.75 inches in height filled with 129 ml of water to keep the dental wicks moist. The pots with the eggs were kept under the same conditions as the adults for 48 hours and then subjected to the desired treatment. Thus the treatment started with the first instar larvae and lasted 25 days until pupation. The larvae, pre-pupae and the early pupae were subjected to 12 hours of unfiltered fluorescent daylight with a 4-hour extention of filtered light and 8 hours of darkness (L12:F4:D8).

On the 26th day after eclosion from the egg, the pupae were removed from the soil, counted, divided into three random groups and each group was put into an emergence cup. Emergence cups were made of 11 cm diameter x 12 cm deep paper cups filled with damp sand and covered with white muslin. Each of these three groups was then taken to be one replicate.

Pupae were kept at 16-hour photophase (L16:D8) and temperature of 21°C, 75 ± 5% R.H. For 25 days the emerging adult flies were counted every 24 hours and placed in the cages. After the 25th day, the remaining pupae were examined. All dead pupae were rejected, others were considered as "diapausing pupae." Dead pupae were either flattened, soft and black, or dried and shiny in appearance (Owusu-Manu, 1969).

2. Culture methods in sterile conditions

Attempts were made to rear the larvae on an artificial diet to eliminate the soil barrier and to detect the direct influence of infrared and monochromatic radiation on the larvae. Preliminary experiments on rearing the larvae on agar media and turnip slices indicated that strong growth of bacteria and fungi suppressed egg hatching and development of first instar larvae. To prevent this, a culture method was developed using sterile techniques.

All glass-ware, the cloth for egg collecting, were sterilized in an autoclave for 15 minutes under 15 psi pressure. Using a knife and no.14 cork borer small turnip slices were prepared, 12 mm thick. The eggs and turnip slices were surface sterilized using a modified method of sterilization described by Riker and Riker (1936). The eggs and turnip slices were immersed for 20 minutes in 0.05% sodium hypochlorite, rinsed in 70% ethyl alcohol and washed three times in sterilized, distilled water. The eggs had to be less than 24 hours old, otherwise the sterilization could prevent the eggs hatching (Friend and Patton, 1956). Plastic disposable petri dishes, 150 mm x 25 mm, were filled with a white cotton batting layer moistened with sterilized distilled water. Ten turnip slices were placed on the surface of the cotton with sterile forceps. Various numbers of eggs per each turnip slice were placed using a flame sterilized needle.

The petri dishes with larvae were examined every day. After 18 days almost all the larvae had left the turnip and bored into the cotton to pupate. On the 25th day the pupae were collected. Three generations of the flies were reared this way in conditions of 16-hour photo-period, temperature of 21^{o}C and 75 $\pm$ 5% R.H.

F. Light Penetration Into Soil and Turnip

Filtered light was transmitted through the soil layers and turnip slices. The light sources mounted inside the filter box were: four F_4T_5D 14-watt fluorescent tubes for white light and the visible portion of the spectrum and 150-watt incandescent lamps for short-wave infrared and near infrared.

Analysis of soil type and size of soil particles was made by the Soil Science Department at Macdonald College. The soil used was sandy loam consisting of 75% sand, 12.5% silt, 12.5% clay, and 10.7% organic matter. The size of the soil particles was estimated as follows:

2 mm	0%
2.0-1.0 mm	1%
1.0-0.5 mm	32%
0.5-0.105 mm	61%
0.105 mm	6%

Petri dishes, 150 mm x 25 mm, were filled with this soil to obtain 1/2 mm, 1 mm, 3 mm, 4 mm and 6 mm thick soil layers. The side walls of the petri dishes were painted black to avoid reflection from the glass. Three direct readings of irradiation energy levels were recorded and averaged at each range using an International Light Model IL 600 Photometer. Readings were taken at the surface of

the soil and turnip slices and then beneath, 1/2 mm, 1 mm, 3 mm, 4 mm and 6 mm layers of soil and turnip slices (Plates 5 and 6).

The amount of light penetrating the soil was expressed in per cent of incident radiation on the soil or turnip surface.

G. Analysis of Results

Each treatment was divided into three replicates. The percentage of diapause incidence was calculated in each replicate using the formula given by Missonier (1963):

$$\% \text{ Diapause} = \frac{\text{Pupae not developed} \times 100}{\text{Pupae not developed} + \text{dead pupae} + \text{emerged pupae}}$$

The percentage of diapause for each treatment was then averaged giving the mean diapause incidence.

All the experiments could not be carried out simultaneously in the laboratory and diapause tendency of the population may change, therefore it was necessary to employ control groups for each experiment, so as to allow comparison of the effect of different filtered light regimes. The control groups were placed in 12-hour and 16-hour photophases. The diapause incidence in the 12-hour photophase was taken as the basic unit of 1.00 and all the other treatments were compared with this control.

Index of Effectiveness =

$$\frac{\text{\% diapause under 12-hour photoperiod}}{\text{\% diapause under filtered light treatment}}$$

An Index of Effectiveness greater than one indicates sensitivity of the insects to that filtered light or photophase. When significant differences were indicated between the treatment means, using the analysis of variance, the means were compared by Duncan's new multiple range test (Steel and Torrie, 1960).

Analyses of variance were performed on the data obtained from the investigation on the larva as the sensitive stage. Regression analysis was performed on the data for the experiments on the age of the larvae on photoperiodic response.

Student's t test was performed on the data obtained in the experiment on the effect of light breaks during the scotophase on diapause induction.

IV. PRELIMINARY EXPERIMENTS AND OBSERVATIONS

A. Biology and Behaviour of H. brassicae

Rearing techniques were developed and observations on the biology of the cabbage root fly were carried out as a basic study for the experiments on spectral response.

The emergence of the flies from the pupae obtained from the Canada Department of Agriculture Research Station, Charlottetown, P.E.I., occurred within seven days of placing them at 16-hour photophase, 21°C, 60 ± 5% R.H. conditions. The flies emerged during a period of two months. The vermiculite[1] with the pupae was kept moistened because in dry conditions the flies had difficulty in expanding their wings. First mating was observed 3-4 days after emergence. If gravid females were not supplied with an oviposition medium they died without ovipositing. The longevity of the adults was about 15-20 days and fertility was reduced with age. On the 10th day after first oviposition only a few eggs were collected.

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[1] F. Hyde and Company Ltd., Montreal.

Eighteen to twenty days after eclosion the larvae entered the prepupal stage. It was very important to keep the culture in drier conditions (about 30% R.H.) to allow the larvae to pupate. Excess water during late larval stage caused death of the maggots. The growth of fungi and bacteria in sterilized soil was slow and did not affect development of the maggots. Under 12-hour photophase the larval development took 3-4 days longer than under 16-hour photophase.

1. Preliminary methods of rearing larvae on the artificial media

Several methods of rearing the maggots were attempted. None of the methods described by Riker and Riker (1936), Hamid (1966), Allen and Askew (1970) was successful in rearing the cabbage maggots.

The eggs of cabbage root fly placed on sterilized washed turnip hatched but the maggots did not grow and none subsequently pupated. Possibly food materials essential to larval development were not present in heat-sterilized rutabaga tissue (in agreement with Doane and Chapman, 1964).

B. Preliminary Experiments on Spectral Response and Sensitivity of *H. brassicae* to Low Light Intensities

Preliminary experiments were carried out on spectral response of the maggots to unfiltered white light, filtered white light, green, orange, short-wave infrared, near infrared. Incandescent lamps were mounted inside the light boxes. This study was undertaken to learn how to adjust the light boxes to the desired level of light intensity and how to use the photoelectrical equipment.

The larvae were subjected to light intensities of 1 mw/cm^2, 0.5 mw/cm^2 and 0.1 mw/cm^2 under 16-hour photophase conditions. H. brassicae maggots were found to respond to light intensity as low as 0.1 mw/cm^2.

V. RESULTS

SECTION I

A. Culture Procedures

1. Rearing maggots to adults in sterile conditions

Three generations of H. brassicae flies were reared in sterile conditions on turnip slices and simultaneously three generations of the insects were obtained by rearing on rutabagas kept in the soil. Each turnip slice was infested with five eggs, making 50 eggs per petri dish and each turnip, about 6 cm diameter was infested with 50 eggs and covered with soil in a flower pot.

The pupae were measured, weighed, the percentage and ratio of emerged adults were estimated and compared with those reared in the same time in non-sterile conditions in the soil. The pupae were examined just after pupation because the weight of the pupae decreased rapidly with time.

The efficiency of the rearing method in sterile conditions was compared with that in non-sterile conditions in Table 2.

TABLE 2. Comparative development of three successive generations of H. brassicae, Bouché, in sterile conditions and in non-sterile conditions in the soil

	Puparial weight (mg)		Puparial length (mm)		Adult emergence (%)	Ratio ♀ : ♂
	Range	$\bar{X} \pm$ S.E.	Range	$\bar{X} \pm$ S.E.		
Sterile rutabaga slices						
Gen. I	10.5-16.3	13.47 ± 0.52	6.5-7.8	7.18 ± 0.09	30	1:1.14
Gen. II	11.2-16.7	13.92 ± 0.34	6.6-7.5	6.87 ± 0.04	48	1:1
Gen.III	9.7-16.9	13.87 ± 0.39	6.0-7.2	6.58 ± 0.05	70	1:1.18
In the soil						
Gen. I	9.7-16.5	12.90 ± 0.55	6.0-7.9	7.13 ± 0.11	40	1:1.22
Gen. II	9.5-16.1	13.07 ± 0.55	6.0-7.7	6.93 ± 0.10	48	1:1
Gen.III	9.2-16.6	13.15 ± 0.47	5.6-7.5	5.86 ± 0.14	50	1:1.08

For the criteria studied, differences between the two groups of insects were minor. The puparia reared in sterile conditions were as heavy and as long as those reared on turnip in the soil. The percentage of adults emerging increased with each successive generation to a level similar to that obtained on turnip in the soil. The sex ratio of the adults reared in sterile conditions was almost the same as those reared in non-sterile conditions.

2. The effect of crowding of the larvae of H. brassicae on the size of pupae and the incidence of diapause

The experiments of Owusu-Manu (1969) on the effect of crowding of the larvae on the size of the pupae and incidence of diapause were extended. He found no correlation between the number of eggs per turnip and the percentage emergence or the incidence of diapause.

Surface sterilized turnip slices fitted into the petri dishes (20 mm x 60 mm) were infested with different numbers of sterilized cabbage root fly eggs. The larvae were reared under 12-hour photophase. This culture method was used to find out if crowding has any effect on diapause incidence of the cabbage maggots. Results are shown in Table 3.

TABLE 3. The effect of crowding of the larvae of H. brassicae on the size of pupae and the incidence of diapause

No. of eggs per turnip slice (26.56g)	No. of pupae per turnip slice	Per cent pupation %	Puparial weight (mg)		Puparial length (mm)		Diapause %	Ratio ♀ : ♂
			Range	$\bar{X} \pm$ S.E.	Range	$\bar{X} \pm$ S.E.		
20	15	75.00	10.1-16.3	14.91±0.41	5.0-7.9	6.68±0.22	66.67	1:0.66
40	29	72.50	12.9-16.5	15.07±0.17	6.0-8.0	6.95±0.10	62.07	1:1.20
60	47	78.30	10.5-16.1	13.51±0.29	5.6-7.5	6.51±0.09	63.83	1:1.42
80	53	66.25	12.3-16.4	12.03±0.33	6.2-7.7	5.87±0.16	66.04	1:0.66
100	81	81.00	12.1-16.5	15.59±0.11	6.0-7.5	7.09±0.04	74.08	1:0.90
120	97	80.83	11.8-16.1	13.70±0.13	6.1-7.5	7.06±0.03	68.04	1:0.90
140	111	79.28	11.7-16.2	14.27±0.14	5.9-7.0	6.42±0.03	68.46	1:1.05
160	115	71.87	11.5-16.3	14.62±0.14	5.7-7.2	6.66±0.04	64.34	1:0.90
180	124	68.88	11.5-16.0	14.93±0.09	5.5-7.0	6.32±0.04	63.70	1:1.04
200	152	76.00	11.5-16.0	13.82±0.11	5.0-7.9	6.22±0.05	65.78	1:1.0
220	154	70.00	10.4-12.1	10.25±0.08	5.0-7.5	5.48±0.07	66.88	10:1.2
240	179	74.58	9.7-13.5	11.44±0.09	5.0-6.1	5.68±0.02	65.92	0.8:1.0
260	186	71.53	9.0-10.2	9.59±0.02	5.0-5.5	5.12±0.01	68.27	1:1.1

Crowding did not influence the percentage of pupation and diapause. The weight and length of the pupae reduced as the number of eggs per slice of turnip (26.5 g) increased over 200. Based on the results of these tests the infestation of a turnip slice with 200 eggs was chosen for the experiments on monochromatic and infrared radiation.

B. An Investigation of the Larva as the Stage Sensitive to Photoperiod

1. The effect of transferring the larvae of H. brassicae from 12-hour to 16-hour photophase on incidence of diapause at 21°C

To investigate if the larval age has any influence on light perception, the following experiment was conducted. Five flower pots filled with soil and turnip infested with cabbage root fly eggs were prepared. One of them was placed under 12-hour photoperiod for 25 days until pupation. Four other pots were kept under 12-hour photoperiod conditions for different durations and then transferred to 16-hour photoperiod. The pupae were counted, and put into the emergence cups. The adults were collected every 24 hours.

Appendix Table 4a, b, c, and Figure 4 show that the process of diapause induction in H. brassicae is accumulative. The percentage of pupae increases with duration the larvae are kept at 12-hour photophase.

2. The effect of transferring the larvae of H. brassicae from 16-hour to 12-hour photophase on incidence of diapause at 21°C

Another group of larvae was first exposed to long-day photoperiod and then moved to short-day conditions. The data in Appendix Table 5a, b, c, and Figure 5 suggest that diapause may be induced in a large number of individuals in the early instars but much of this induction may be reversed by exposure of the last larval instars to long days.

Both groups of experiments show that the whole larval stage is sensitive to photoperiod.

SECTION II

A. Effects of Light Breaks on Diapause Incidence in *H. brassicae* Pupae (during the scotophase of a photoperiod regime applied to the larvae)

The response of cabbage maggots to photoperiod with light interruptions within 18-hour scotophase was tested.

Light breaks of 1.5 hours began 8 hours, 10 hours, 12 hours, 14 hours, 16 hours and 20 hours after the onset of photophase, respectively.

Appendix Table 6 and Figure 6 show that the light breaks after 8 hours and 14 hours from the beginning of photophase are the most effective in suppressing diapause induction in the cabbage maggots. An intermediate effect between diapause suppression and induction was caused by the light breaks occurring after 10 hours and 20 hours from the onset of photophase, respectively.

Summarizing, light was most inhibitory to diapause in the cabbage maggot 8 hours after the onset of the light period. Thereafter the level of diapause rose until at 12 hours there was no significant effect by a 1.5 hour light interruption. Then again, the light break inhibited diapause and another minimum of diapause induction occurred at the 14-hour point. Thereafter the percentage of diapause increased again.

Figure 6. The effect of 1.5 hour light interruptions on diapause incidence in H. brassicae, during 24-hour lighting cycles with a photophase of 6 hours and a scotophase of 18 hours (6L:18D) at 21°C.

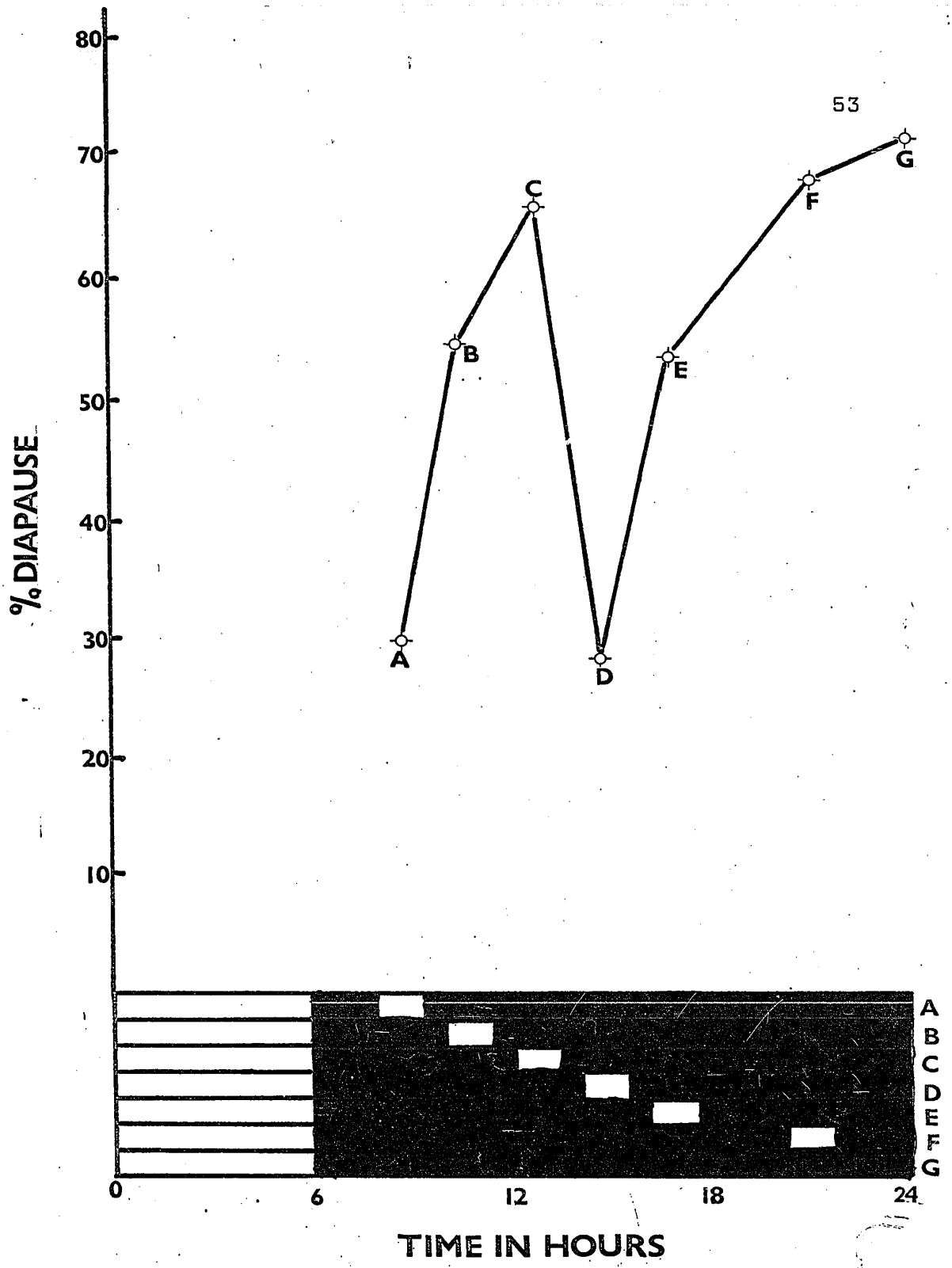

80
70
60
50
40
30
20
10
% DIAPAUSE
A
B
C
D
E
F
G
0
6
12
18
24
TIME IN HOURS

FIG.6

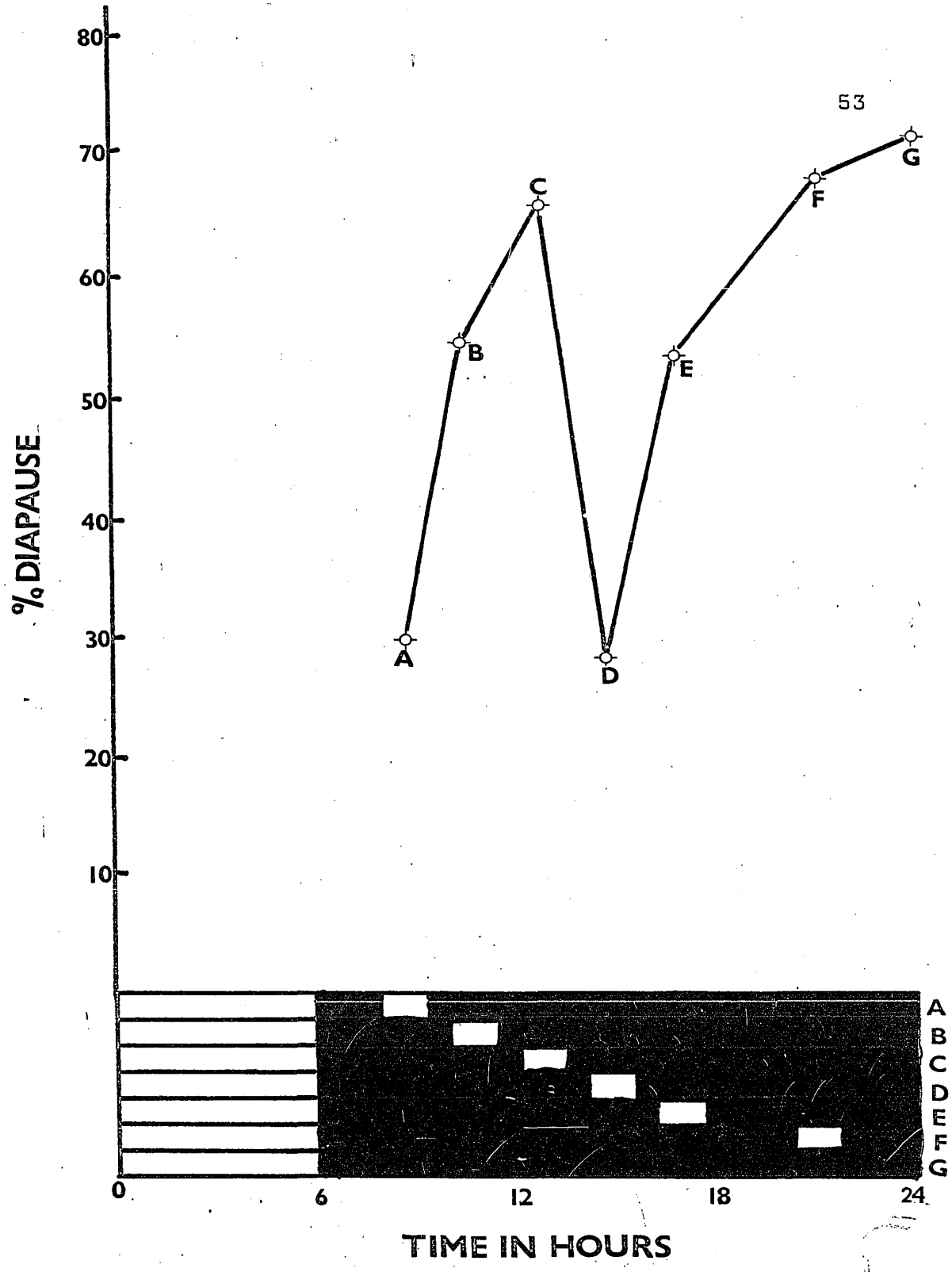

80
70
60
50
40
30
20
10
% DIAPAUSE
A
B
C
D
E
F
G
0
6
12
18
24
TIME IN HOURS

FIG.6

SECTION III

A. Spectral Response to Broad Band Radiation

The effect of filtered light on diapause in H. brassicae was evaluated by comparing the response of the insects exposed to short day and long day regimes. Suppression of diapause comparable to that caused by the long day implied sensitivity to the 4-hour extended exposure; induction of diapause comparable to that caused by the short day implied insensitivity.

The results in Appendix Table 7a and b and Figure 7 show that diapause in cabbage root fly is strongly inhibited by violet (395 mμ), blue-green (495 mμ), short-wave infrared (1750 mμ).

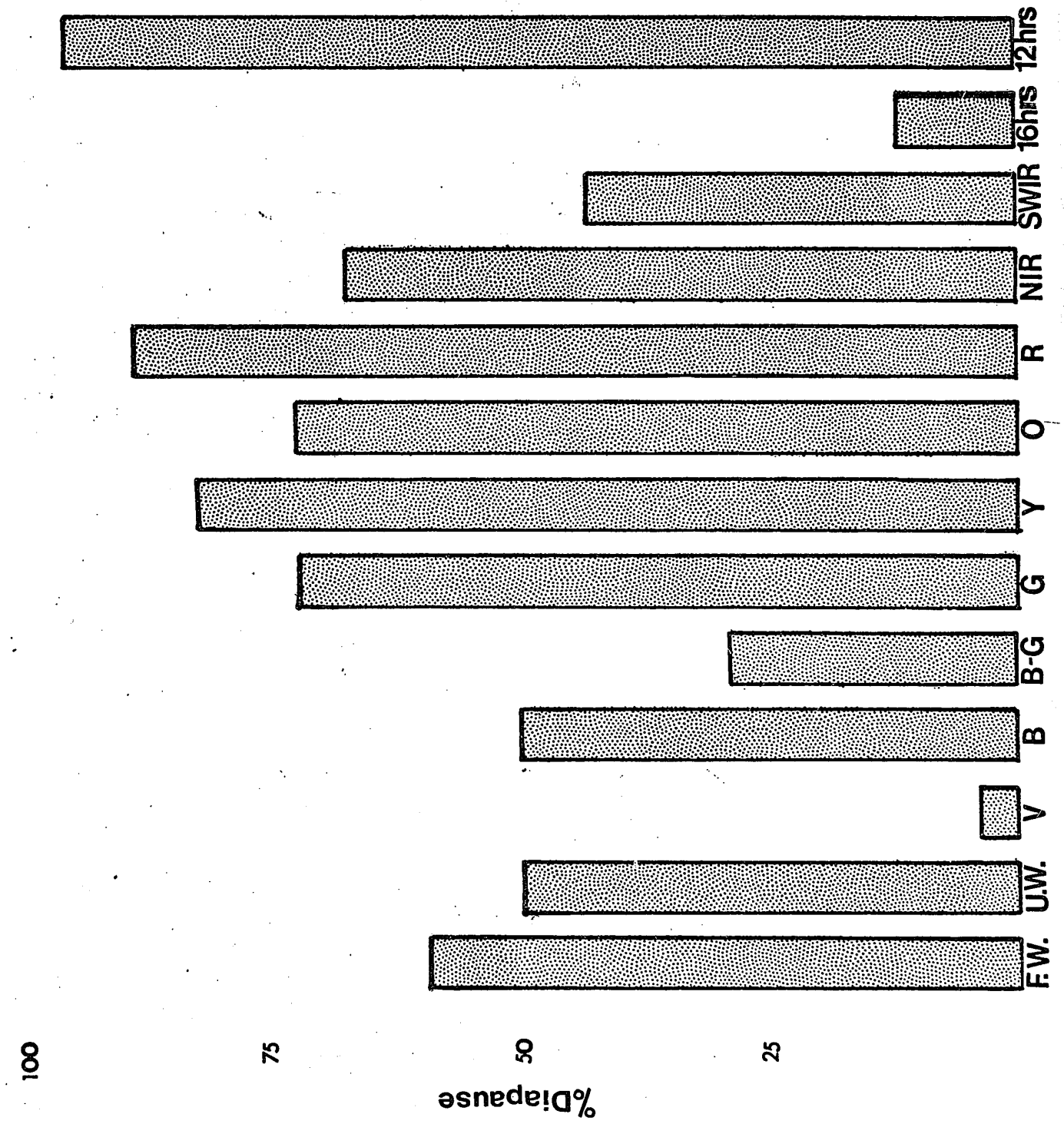
Response of the maggots to red (675 mμ) and yellow (570 mμ) did not significantly differ from those exposed to 12-hour photophase.

There was a partial effect in the ultraviolet (330 mμ), blue (460 mμ) and filtered white light (400-750 mμ).

Statistically, no significant difference was found between the response to violet (395 mμ) and 16-hour photophase treatments. With increasing wavelengths, diapause incidence increased and was minimally prevented at the red (630-750 mμ) region.

Figure 7. The effect of different wavelengths of light filtered by Corning Glass Filters on the induction of diapause in H. brassicae, Bouché at 21°C.

F.W.	Filtered white light (400-750 mμ)
U.V.	Ultraviolet (330 mμ)
V	Violet (400 mμ)
B	Blue (460 mμ)
B-G	Blue-green (500 mμ)
G	Green (525 mμ)
Y	Yellow (570 mμ)
O	Orange (600 mμ)
R	Red (675 mμ)
NIR	Near infrared (800 mμ)
SWIR	Short wave infrared (1750 mμ)
16 hrs	16-hour photoperiod
12 hrs	12-hour photoperiod


%Diapause
100
75
50
25
F.W.
U.W.
V
B
B-G
G
Y
O
R
NIR
SWIR
16hrs
12hrs

There was no significant difference between red (675 mμ) and yellow (570 mμ) and between red (675 mμ) and 12-hour photophase; however, there was a difference between yellow (570 mμ) and 12-hour photophase. Above the red (630-750 mμ) region, diapause incidence decreased, in the near infrared region (800 mμ) a response similar to that of green (525 mμ) and orange (600 mμ) was obtained.

The insects were sensitive to the shortwave infrared (1750 mμ) region also.

At the short wavelength region of the spectrum, sensitivity decreased from the violet (395 mμ) into the ultraviolet (330 mμ) and blue (460 mμ) regions.

B. Response of H. brassicae to Monochromatic Radiation

Experiments on the effect of broad bands of visible and infrared radiation indicated that radiation at 750 mμ and 1750 mμ and radiation at 400 mμ and 500 mμ were more effective than radiation at 675 mμ and 750 mμ and between 330 mμ and 400 mμ in suppressing diapause in the cabbage maggot.

The results showed the need for additional work with narrow bands of far-red and infrared radiation and for some emphasis on the effect of narrow bands of the wavelengths in the visible spectrum which were found to be the most effective in suppressing diapause.

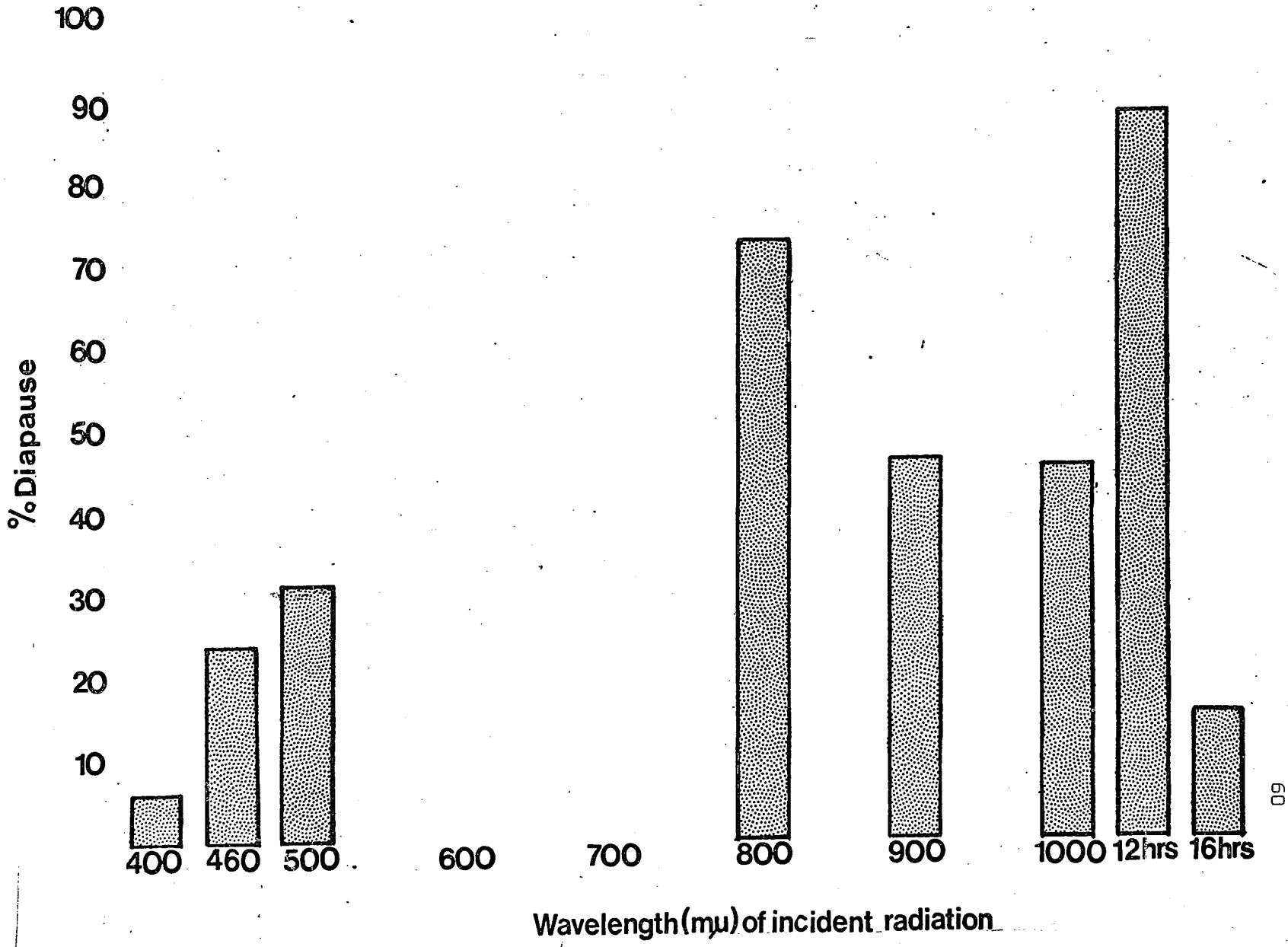
The results (Table 8a, b and Figure 8) confirmed a response in the visible region when violet (400 mμ) and blue (460 mμ) were examined.

These spectra are photoperiodically active in both broad band and narrow band radiation.

Blue-green (500 mμ) monochromatic light was less effective in suppressing diapause.

The larvae were also sensitive to longer wavelengths of monochromatic radiation in the infrared (900 mμ and 1000 mμ).

Figure 8. The effect of different wavelengths of monochromatic light on the induction of diapause in H. brassicae, Bouché at 21°C.


100
90
80
70
60
50
40
30
20
10
% Diapause
400
460
500
600
700
800
900
1000
12hrs
16hrs
Wavelength (mμ) of incident radiation

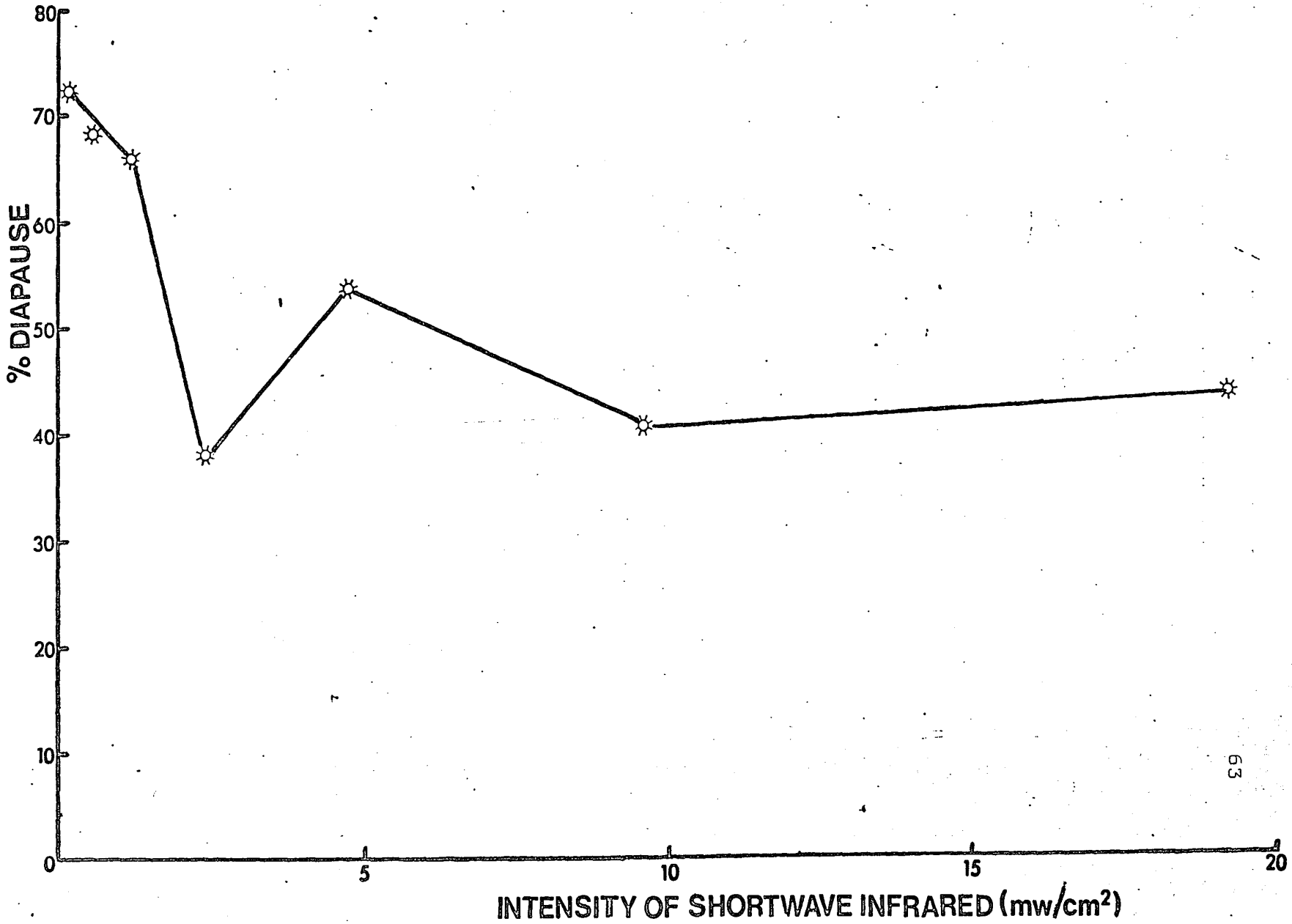
C. Sensitivity of *H. brassicae* to short-wave Infrared Radiation

Groups of larvae were subjected for 12 hours to unfiltered fluorescent light and for 4 hours to the short-wave infrared radiation of 0.2 mw/cm^2, 0.6 mw/cm^2, 1.2 mw/cm^2, 2.4 mw/cm^2, 4.8 mw/cm^2, 9.6 mw/cm^2 and 19.2 mw/cm^2, respectively. Infrared radiation was obtained by filtering the light from an incandescent lamp through a CS7-57 Corning Glass Filter.

The larvae were reared on turnip slices, the soil barrier was eliminated and the maggots were irradiated almost directly.

Analysis of results (Appendix Table 9 and Figure 9) shows that there is no significant difference between the treatments of 0.2 mw/cm^2, 0.6 mw/cm^2 and 1.2 mw/cm^2; and between 2.4 mw/cm^2, 4.8 mw/cm^2, 9.6 mw/cm^2 and 19.2 mw/cm^2. However, there is a significant difference between two groups. The larvae do not respond strongly to the intensities below 2.4 mw/cm^2. At 2.4 mw/cm^2 they do respond by demonstrating reduced diapause. Increasing the intensity to 19.2 mw/cm^2 does not further reduce the incidence of diapause.

Figure 9. The effect of intensity of shortwave infrared radiation on the incidence of diapause in H. brassicae kept at 21°C.


% DIAPAUSE
80
70
60
50
40
30
20
10
0
5
10
15
20
INTENSITY OF SHORTWAVE INFRARED (mw/cm²)

SECTION IV

A. Light Penetration Into Soil

An investigation was conducted on the penetration ability of light of different wavelengths into the soil mixture used for rearing the cabbage root maggots.

The same wavelengths as those used for the experiments on diapause were employed, except for ultraviolet (350 mμ). Transmission of the ultraviolet portion of the electromagnetic spectrum through the soil was not tested because the wavelengths shorter than 400 mμ were immediately absorbed by glass and soil. Transmitted energy in this wavelength range (230-420 mμ) was so low that it was not detectable by the photometer.

Results shown in Appendix Table 10 and Figures 10 and 11 indicate that with increasing depth in the soil proportionately less of the radiation in the short wavelengths (violet, 400 mμ) (blue, 460 mμ), and more in the longer wavelengths (red, 675 mμ) and infrared range (near infrared, 800 mμ, short-wave infrared, 1750 mμ) is passed.

Figure 10. Penetration of filtered white light and unfiltered white light into soil.

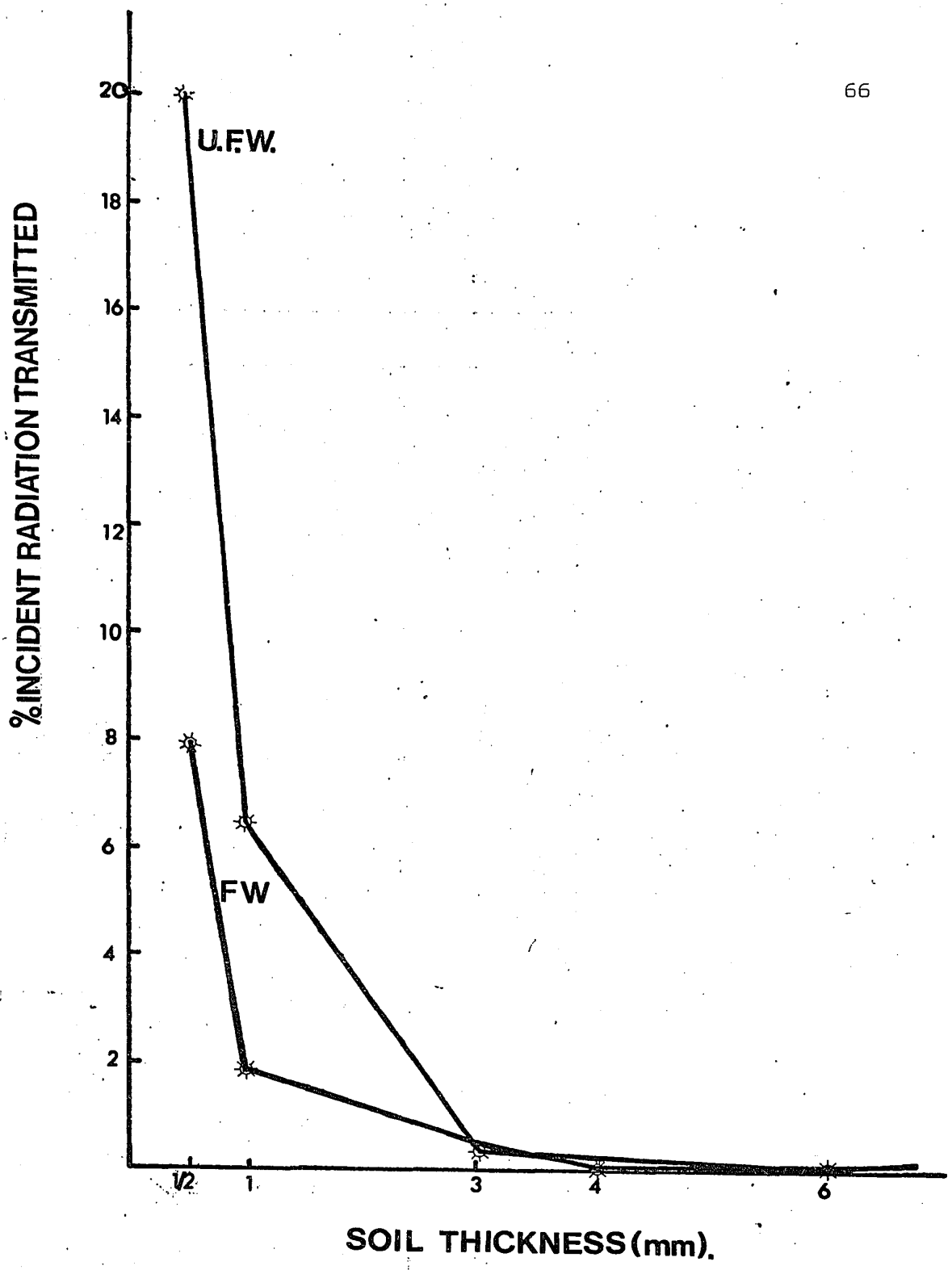

% INCIDENT RADIATION TRANSMITTED
20
18
16
14
12
10
8
6
4
2
U.F.W.
FW
1/2
1
3
4
6
SOIL THICKNESS (mm).

FIG. 10

Figure 11. Penetration of light of different wavelengths into soil barriers of 1/2 m, 1 mm, 3 mm, 4 mm, 6 mm thick.

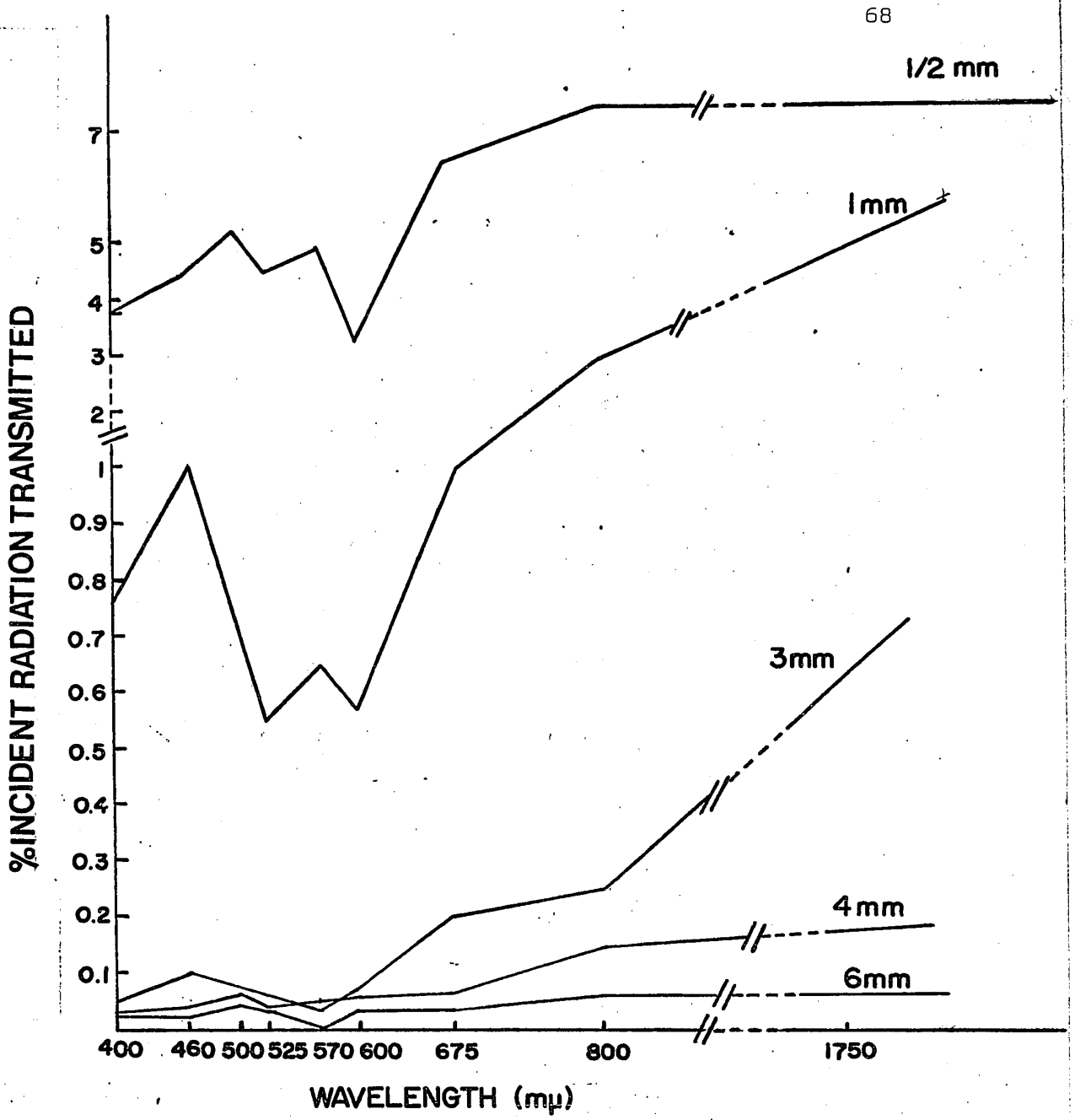

1/2 mm
1mm
3mm
4mm
6mm
%INCIDENT RADIATION TRANSMITTED
7
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
400
460
500
525
570
600
675
800
1750
WAVELENGTH (mμ)

FIG. 11

B. Light Transmission Through the Turnip

This study was undertaken to show the transmission of the light through turnip which is the medium for the *H. brassicae* larvae. The object was to find a relationship between the wavelengths responsible for diapause control and light transmission through the turnip.

The results shown in Appendix Table 11 and Figures 12 and 13 indicate that with increasing thickness of the plant tissues there is less penetration in the short wavelengths (ultraviolet, 330 mμ; blue, 460 mμ); and more in the longer wavelengths (orange, 600 mμ; red, 675 mμ), and especially in the infrared range of the light spectrum (near infrared, 800 mμ; short-wave infrared, 1750 mμ). Relatively little absorption, higher transmission occurs in the 500 mμ to 600 mμ and the 700 mμ to 1100 mμ regions.

Figure 12. Transmission of filtered white light and unfiltered white light through the turnip.

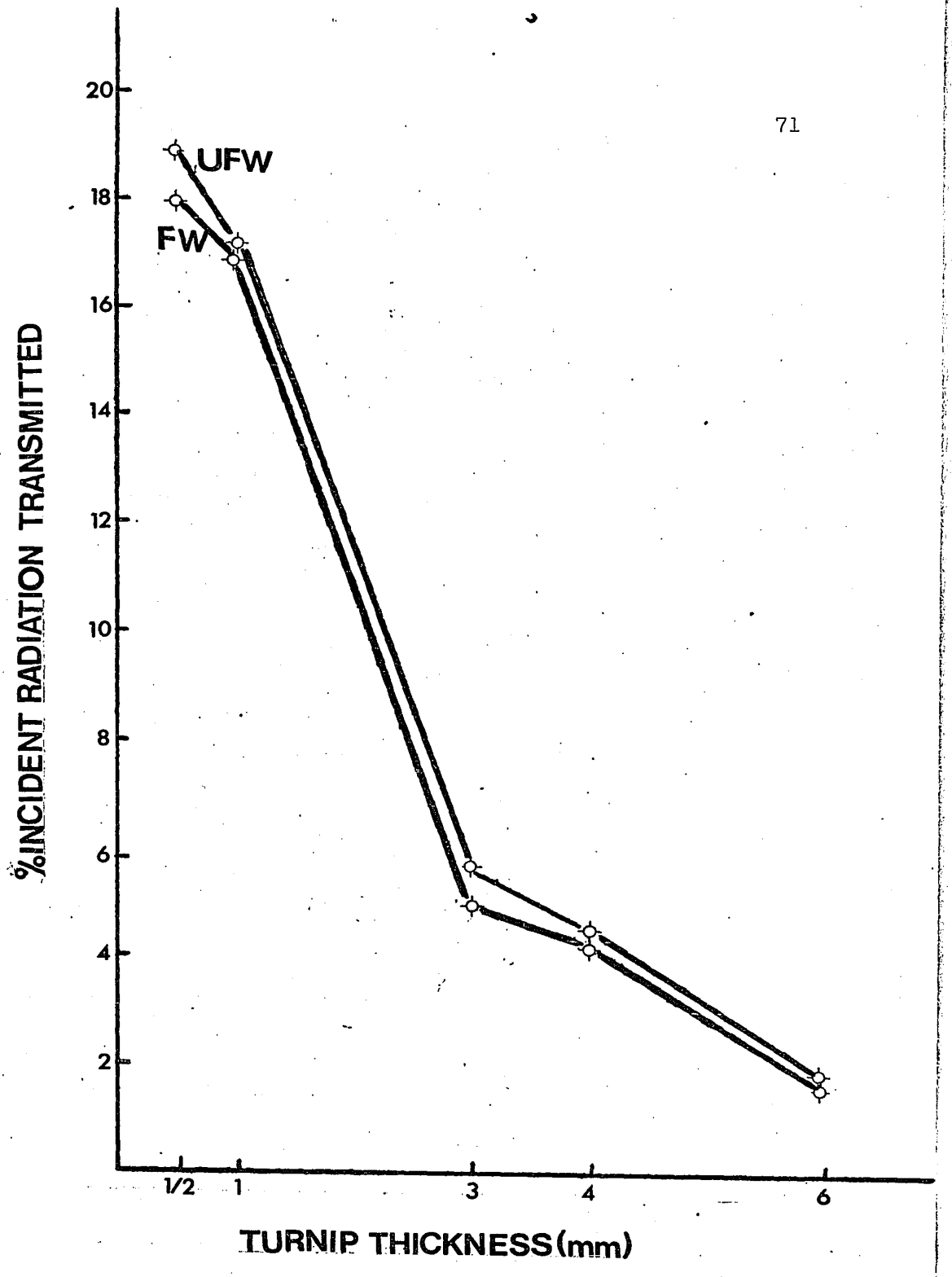

20
18
16
14
12
10
8
6
4
2
UFW
FW
%INCIDENT RADIATION TRANSMITTED
1/2
1
3
4
6
TURNIP THICKNESS(mm)

FIG.12

Figure 13. Transmission of light of different wavelengths through the turnip slices, 1/2 mm, 1 mm, 3 mm, 4 mm, 6 mm thick.

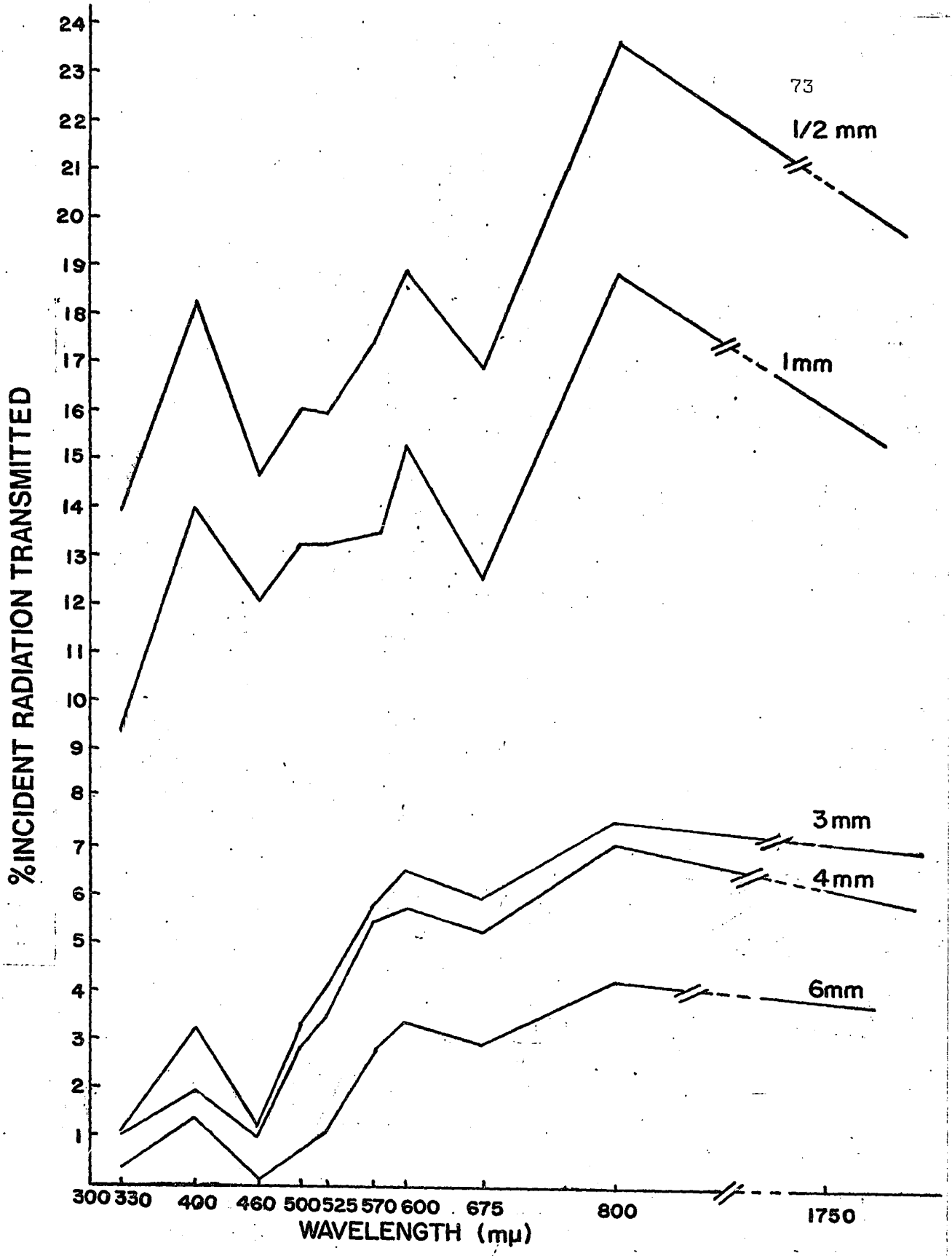

%INCIDENT RADIATION TRANSMITTED
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1/2 mm
1mm
3mm
4mm
6mm
300 330 400 460 500 525 570 600 675 800 1750
WAVELENGTH (mμ)

FIG.13

VI. DISCUSSION

The larva is the sensitive stage to photoperiod in the cabbage root fly (Hughes, 1960; Zabirov, 1961; Missonier, 1963; Read, 1965; Owusu-Manu, 1969).

In any consideration of the theoretical and practical implications of photoperiod on diapause incidence in H. brassicae, it is important to determine the relationship between the growth stage of the larvae and the influence of photoperiod. Series of experiments were conducted in which larvae were reared at 21°C and under either 16-hour photophase (non-diapause) or 12-hour photophase (diapause inducing). Transfers of the larvae were made from one photoperiod to another, after various durations of time. No sharply critical stage was found, the whole larval stage is sensitive to the photoperiod. The process of diapause induction in the cabbage maggot is accumulative. The longer the larvae are subjected to short-day conditions, the higher the percentage of the maggots which go into diapause.

Possibly the substances inhibiting insect development are produced throughout the whole larval life or larvae initially exposed to short-day and then moved to

long-day conditions may still be capable of producing growth-promoting substances. The diapause inducing effect of a 12-hour photophase appeared to be partly reversible, even as late in the life cycle as 15 days after eclosion. The 16-hour photoperiod promoted uninterrupted development and this effect was slightly reversible. However, the maggots kept as long as 15 days in long-day conditions, when transferred to the short-day could still be induced to diapause. These results are in general agreement with previous observations made on the cabbage maggot (Missonier, 1963).

Pupal diapause is determined as a developmental commitment response to photoperiods experienced during earlier growth stages. In many insects, diapause determination occurs during the larval stages. Sensitivity to light during the larval instars may vary with age. The nature of such variations has been studied by a number of authors. Dickson (1949), by transferring larvae of Laspeyresia molesta from short to long days, and in parallel experiments from long to short days, discovered that abrupt age-changes in sensitivity do not occur in larvae of that species.

For Polia oleracea (Way and Hopkins, 1950) and Pyrausta nubilalis (Mutchmor and Beckel, 1959) it has been shown that diapause is determined by the light conditions

operating from the moult in the final instar. Short-day conditions have no effect on younger instars. Increased sensitivity in the older instars is observed also in Antheraea pernyi (Tanaka, 1950a, 1950b; Belov, 1951). In Barathra brassicae sensitivity remains uniform throughout larval development, and the percentage of diapausing larvae increases in proportion to the duration of action of the short-day (Masaki, 1957b). On the other hand, pupal diapause in the Chinese oak silkworm is determined by the photoperiods to which the last two larval instars are exposed. Claret (1966a, 1966b) reported that pupal diapause in the cabbage butterfly, Pieris brassicae, is determined in the last two instars (fourth and fifth), but the two stages differ in their sensitivity to photoperiod. When reared under long daylengths, the larvae could not be committed to diapause by transfer to short-day photoperiods if the transfer was accomplished after the beginning of the fourth stadium. By that stage, the larvae had been irreversibly committed to the non-diapause pattern. On the other hand, larvae that were reared under the short day photoperiod would be diapause-determined unless transferred to long daylengths sometime during larval growth.

Diapause determination could be reversed by long-day exposure at any stage up to the beginning of the fifth stadium, but not after that point.

The experiments reported here demonstrated that pupal diapause in the cabbage maggot was induced by short daylengths. If the scotophase was interrupted by a 1.5 hour period of light, the incidence of diapause was reduced, but the amount of reduction depended upon the time at which the light break occurred.

Light breaks at 8 hours and 14 hours after the onset of photophase were the most effective in suppressing diapause induction. The percentage of the maggots which went into diapause when the dark period was interrupted after 12 hours and 20 hours did not significantly differ from that of the 6-hour photophase without a light break in the scotophase. The light breaks which occurred 10 hours and 16 hours after the onset of photophase showed an intermediate effect between the two groups mentioned above.

Beck (1968) discussed the conclusion of Adkisson (1964) that the pink bollworm, Pectinophora gossypiella, had periods of light sensitivity with the circadian rhythm and that both the "light-on" and "light-off" signals were involved in determining diapause incidence. He disagreed with Adkisson's hypothesis because when the bollworms were exposed to a photoperiod of 6L:18D they were not induced to diapause but according to Adkisson's theory they should have diapaused due to the light sensitive periods being in the scotophase of that regime.

Beck (1968) advanced a different explanation of the effects of light breaks on diapause induction. He suggested that "light-on" and "light-off" stimuli might be merely phase setting signals for endogenous rhythms and the light breaks could be the phase setters.

The results obtained with H. brassicae do not exclude the possibility of Adkisson's theory being correct because with the 6L:18D photoperiod there was indeed the predicted high diapause incidence. On the other hand, the light break data show a diapause response picture which suggests a 6-hour periodicity, i.e., Figure 6 shows minimum diapause incidence when light breaks occurred 8 hours and 14 hours after the onset of the photophase (schedules A and D), similar response is obtained with the light breaks of 10 hours and 16 hours after the onset of the photophase (schedules B and E), and maximum diapause incidence when light breaks occurred 12 hours and 20 hours after the beginning of the photophase (schedules C and F). This can be interpreted to support Beck's suggestion that light breaks act as a phase-setting mechanism.

The experiments with light breaks occurring 8 hours and 16 hours after the onset of photophase, respectively, demonstrated that the length of the scotophase alone does

not control diapause induction, which is in agreement with Adkisson's (1964) results for the pink bollworm.

Response of the cabbage maggots to different wavelengths of radiation was tested utilizing daylight fluorescent lamps; results were compared with those of Owusu-Manu* who used incandescent lamps as the sources of energy. Both groups of experiments indicated that radiation in the violet (395 mμ), blue-green (495 mμ) and short-wave infrared (1750 mμ) regions of the spectrum strongly averted diapause in the cabbage maggot. There was a partial response in the ultraviolet (330 mμ), filtered white light (400-750 mμ), green (525 mμ), orange (600 mμ), yellow (570 mμ) and near infrared (800 mμ) regions. Red light (675 mμ) did not prevent diapause.

Using the index of effectiveness, two groups of experiments were compared (Table 7a). It is concluded that diapause in the cabbage maggot is suppressed more by filtered white light (400-750 mμ) and violet (395 mμ) obtained from fluorescent light sources, than by filtered white light (400-750 mμ) and violet (395 mμ) obtained from incandescent light sources. However, the response to blue (460 mμ) and yellow (570 mμ) is higher when using incandescent lamps.

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*Owusu-Manu (1969).

With incandescent light filtered for passing blue and yellow, there is a large amount of infrared passed by the Corning Glass Filters because of secondary band pass characteristics.

Kogure (1933) found that violet-blue-green (350-510 mμ) exerted the greatest photoperiodic effect in the silkworm, while Dickson (1949) found that in the oriental fruit moth, the most sensitive region was the blue-yellow (400-580 mμ).

De Wilde and Bonga (1958) found that the Colorado beetle was sensitive to filtered light from 423-675 mμ, while Lees (1953) observed that the range from the near ultraviolet-blue-green (395-500 mμ) had a photoperiodic effect inhibiting diapause incidence in Metatetranychus ulmi. The most effective region for suppressing diapause in the boll weevil was between 400 and 665 mμ (Harris et al., 1967).

It seems that in all these observations, the range from 400-500 mμ is involved in the photoperiodic response of the arthropods concerned. It is apparent that so far as the present observations are concerned, the violet-blue-green region is photoperiodically active.

The experiments with the infrared radiation confirmed the observations made by Owusu-Manu (1969). Short-

wave infrared region (1750 mμ) was shown to be photoperiodically active. Near infrared (800 mμ) was less effective in suppressing diapause in the cabbage maggot.

Narrow bands of 84 Å obtained from a Hilger and Watts Model D 330 Single Monochromator were evaluated. The spectral region between 400 and 460 mμ is more effective in suppressing diapause than either 500 mμ or the region between 900 mμ and 1000 mμ. These results are much like those which were obtained earlier when working with the broad bands of radiation. High response of the cabbage maggots in violet (400 mμ) and blue (460 mμ) of broad band radiation was confirmed by the experiments with the same wavelengths of monochromatic light.

The region above 800 mμ was shown to be photoperiodically active; with longer wavelengths there is higher response of the maggots.

In conclusion, it may be stated that the violet-blue-blue-green (395-500 mμ) region of the light spectrum is responsible for the photoperiodic reaction in diapause induction in the cabbage maggot, H. brassicae; response of the maggots to the broad (800 mμ, 1759 mμ) and narrow bands (800 mμ, 900 mμ, 1000 mμ) of far red and infrared radiation tends to support the Callahan's theory of diapause control and infrared radiation.

The cabbage maggots respond to different light spectra regardless of light intensity as long as the intensity is above a minimum threshold. When subjected to filtered light of an intensity at the soil surface, of 0.14 mw/cm^2, H. brassicae larvae reacted similarly to those exposed to 28.0 mw/cm^2.*

These levels of radiation are much lower than those possible under field conditions; for example, solar radiation measured through a window at Macdonald College on November 14, 1971, at 1:00 p.m. gave a reading on the Y.S.1 Radiometer of 120 mw/cm^2.

Experiments with monochromatic light showed that the cabbage maggots can respond to intensity as low as 0.078 mw/cm^2 on the surface of the medium. The limit of sensitivity of the larvae must be even lower if transmission of the tissues of a turnip is considered.

On the other hand, there were differences in diapause incidence when maggots were exposed to the various intensities in short-wave infrared region. After a certain threshold is passed, the light intensity does not significantly change diapause suppression.

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*OWusu-Manu, 1969.

The effectiveness of weak light has also been noted for other species studied. Way and Hopkins (1950), in experiments with Polia (Diataraxia) oleracea, found that a change in the light intensity during the light part of the day from 220-foot candles to 1-foot candles did not affect the photoperiodic reaction. Consequently the limit for this species lies considerably below 10 lux.

According to Dickson (1949) external light of 3-foot candles (32 lux) proved to be adequate for photoperiodic reaction in larvae of the fruit moth Laspeyresia molesta, which lives inside fruit. If one considers the low translucency of the tissues of an apple, the limit of sensitivity of the larvae must actually be close to 1 lux, i.e., close to the limit found in free-living species.

Very high sensitivity has been discovered in the Colorado beetle (De Wilde and Bonga, 1958). The first signs of photoperiodic reaction are observed in it with light of even 0.1 lux. The reaction increases with increase in light intensity up to 5 lux, at which point it reaches its full value, and further increases in light intensity do not affect it.

Very high sensitivity has been found in the boll weevils which in experimental conditions reacted to light intensity as low as 0.05 mw/cm^2 (Harris et al., 1969).

The level of illumination accepted by organisms as "daylight" must be higher than the intensity of moonlight, as only in that case could the photoperiodic reaction retain its biological significance as a seasonal regulator of vital phenomena. It is known that the maximum light during the period of the full moon does not exceed 0.25 lux, and dispersed moonlight is even weaker (Sharonov, 1945). When one considers the sensitivity to light and the living conditions of the majority of insects, it is evident that moonlight cannot substantially affect their photoperiodic reactions.

Danilevskii (1965), however, pointed out that diapause is induced by both the temperature and the light conditions. The night temperatures are lower and this could eliminate the effect of the moonlight and therefore the action of temperature and light cannot be considered in isolation.

The transmission of different regimes of light through the soil indicated that with increasing depth in the soil proportionately less of the radiation is in the short wavelengths (violet, 395 mμ; blue, 460 mμ) and more is in the longer wavelengths (red, 675 mμ) and infrared range (NIR, 800 mμ; shortwave infrared, 1750 mμ). This is in agreement with the other investigators (Baumgartner, 1951; Sauberer, 1951; Sellers, 1965). The transmission of

the ultraviolet portion of the electromagnetic spectrum was not tested because the wavelengths shorter than 400 mμ are absorbed by soil and glass and the transmitted light intensity was so low that it could not be detected by the photometer. This has been shown to be of advantage for soil inhabitants as they are very susceptible to ultraviolet light and are injured by it (Baumgartner, 1951).

This investigation again supports the probability of H. brassicae sensitivity to very low intensities of light. The percentage of incident radiation decreases rapidly with the increasing depth of soil. However, the larvae feeding inside the roots of cruciferous plants, under 10 cm thick soil layer, still are capable of responding to the transmitted radiation.

An investigation on the light transmittance through the turnip tissues showed that the light in 500 mμ to 600 mμ and 700 mμ to 1100 mμ regions penetrates the plant better than the wavelengths of ultraviolet (330 mμ), blue (460 mμ), red (675 mμ). This is in agreement with Gates (1965), Robertson (1966), Vezina and Boulter (1966).

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APPENDIX

TABLE 4a. The effect of transferring the larvae of H. brassicae from 12-hour to 16-hour photoperiod on incidence of diapause at 21°C R.H. 60 ± 5%

Age of the larvae (days)	Number of pupae	Number of adults	Number of undeveloped pupae	Per cent diapause	Mean per cent of diapause
2	33	27	1	3.03	4.90
	22	21	1	4.54	
	28	26	2	7.14	
7	24	21	2	8.33	8.89
	23	21	2	8.69	
	31	28	3	9.67	
11	21	7	11	52.38	48.01
	24	11	10	41.66	
	28	14	14	50.00	
15	28	9	19	67.85	63.75
	23	8	15	63.40	
	30	12	18	60.00	
19	34	1	33	97.05	95.43
	29	2	27	93.10	
	26	1	25	96.15	

TABLE 4b. Analysis of variance on the percentage of diapause in *H. brassicae* subjected to different durations of 12-hour photophase and then transferred to 16-hour photophase at 21°C

Source	d.f.	Sum of squares	Mean square	F_{calc}	F_{tab}
Total	14	17549.0075			
Treatment	4	17436.4553	4359.1138	387.2938**	5.99
Sampling error	10	112.5522	11.2552		

**Significant at .01 level

TABLE 4c. The regression analysis of percentage of diapause in *H. brassicae* on time the larvae were kept at 12-hour photoperiod before being transferred to 16-hour photoperiod at 21°C

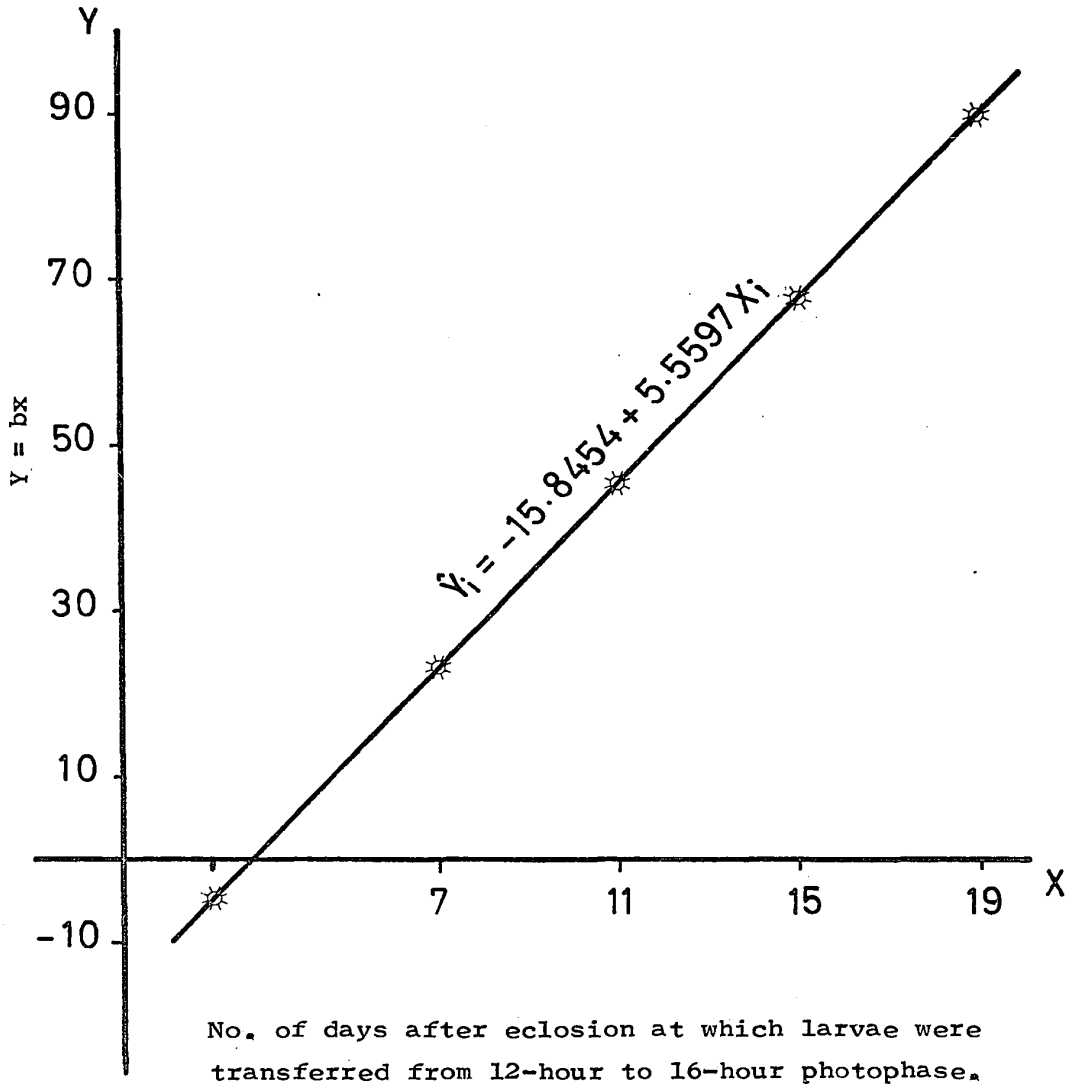
Age of the larvae (days) X	% diapause Y	Squares X^2	Squares Y^2	Products XY
2	3.03	4	9.18	6.06
2	4.54	4	20.61	9.08
2	7.14	4	50.98	14.28
7	8.33	49	69.39	58.31
7	8.69	49	75.52	60.83
7	9.67	49	93.51	67.69
11	52.38	121	2743.66	576.18
11	41.66	121	1735.56	458.26
11	50.00	121	2500.00	550.00
15	67.85	225	4603.62	1017.75
15	63.40	225	4019.56	951.00
15	60.00	225	3600.00	900.00
19	97.05	361	9418.70	1843.95
19	93.10	361	8667.61	1768.90
19	96.15	361	9244.82	1826.85
Sum 162	662.99	2280	46852.72	10109.14
Mean 10.8	44.20			

$$b = \frac{\Sigma XY - \Sigma X\ Y/n}{\Sigma X^2 - (\Sigma x)^2/n} = 5.5597$$

$$a = \bar{Y} - b\bar{X} = -15.8454$$

Regression Equation $= \hat{Y}_i = -15.8454 + 5.5597X_i$

Figure 4. The regression line of percentage of diapause in H. brassicae on time the larvae were kept at 12-hour photophase before being transferred to 16-hour photophase at 21°C.



No. of days after eclosion at which larvae were transferred from 12-hour to 16-hour photophase.

FIG. 4

TABLE 5a. The effect of transferring the larvae of *H. brassicae* from 16-hour to 12-hour photoperiod on incidence of diapause at 21°C R.H. 60 ± 5%

Age of the larvae (days)	Number of pupae	Number of adults	Number of undeveloped pupae	Per cent diapause	Mean per cent of diapause
2	36	29	6	16.66	16.56
	39	33	6	15.38	
	34	28	6	17.64	
7	29	23	6	20.68	20.63
	55	44	11	20.00	
	33	26	7	21.21	
11	40	37	4	10.00	11.96
	40	37	4	10.00	
	44	37	7	15.90	
15	34	30	4	11.76	13.67
	46	40	6	13.04	
	37	32	6	16.21	
19	28	23	2	7.14	5.95
	33	22	1	3.03	
	26	24	2	7.69	

TABLE 5b. Analysis of variance on the percentage of diapause in *H. brassicae* subjected to different durations of 16-hour photophase and then transferred to 12-hour photophase at 21°C

Source	d.f.	Sum of squares	Mean square	F_{calc}	F_{tab}
Total	14	407.5930			
Treatment	4	357.6150	89.4038	17.8886**	5.99
Sampling error	10	49.9780	4.9978		

**Significant at .01 level

TABLE 5c. The regression analysis of percentage of diapause in *H. brassicae* on time the larvae were kept at 16-hour photoperiod before being transferred to 12-hour photoperiod at 21°C

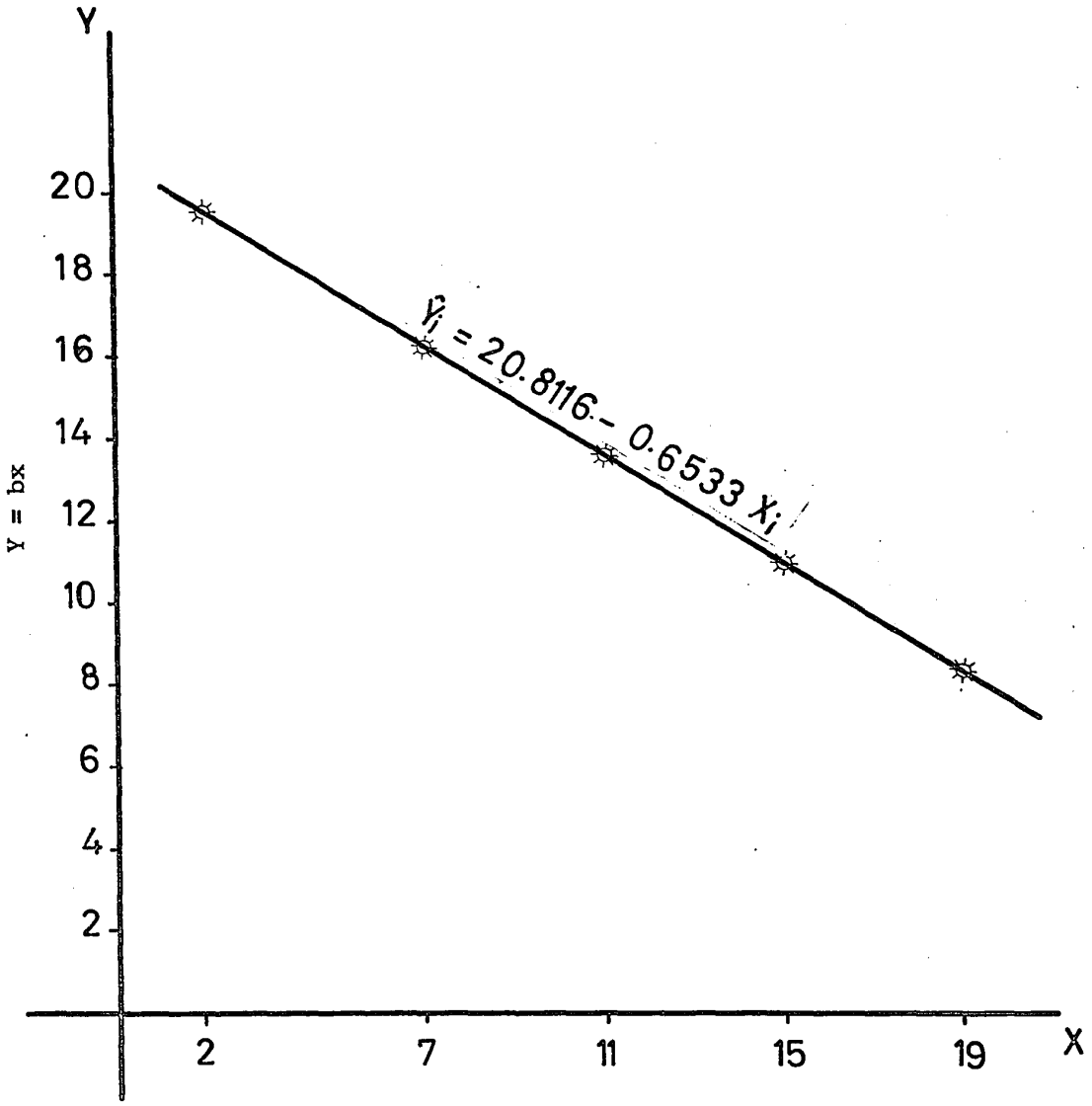
	Age of the larvae (days) X	% diapause Y	Squares X^2	Squares Y^2	Products XY
	2	16.66	4	277.56	33.32
	2	15.38	4	236.54	30.76
	2	17.64	4	311.17	35.28
	7	20.68	49	427.66	144.76
	7	20.00	49	400.00	140.00
	7	21.21	49	449.86	148.47
	11	10.00	121	100.00	110.00
	11	10.00	121	100.00	110.00
	11	15.90	121	252.81	174.90
	15	11.76	225	138.30	176.40
	15	13.04	225	170.04	195.60
	15	16.21	225	262.76	243.15
	19	7.14	361	50.98	135.66
	19	3.03	361	9.18	57.57
	19	7.69	361	59.14	146.11
Sum	162	206.34	2280	3246.00	1881.98
Mean	10.8	13.76			

$$b = \frac{\Sigma XY - \Sigma X\ Y/n}{\Sigma X^2 - (\Sigma x)^2/n} = -0.6533$$

$$a = \bar{Y} - b\bar{X} = 20.8116$$

Regression Equation $\hat{Y}_i = 20.8116 - 0.6533X_i$

Figure 5. The regression line of percentage of diapause in H. brassicae on time the larvae were kept at 16-hour photophase before being transferred to 12-hour photophase.



No. of days after eclosion at which larvae were transferred from 16-hour to 12-hour photophase.

FIG. 5

TABLE 6. The effect of 1.5 hour light interruptions on diapause induction in H. brassicae, during 24-hour lighting cycles with photophase of 6 hours and scotophase of 18 hours (6L:18D) at 21°C 60 ± 5% R.H.

No.of hours of photophase after the light break occurred	Per cent diapause			
	Rep.I	Rep.II	Rep.III	Mean
8	24.13	35.55	25.55	28.41**
10	56.00	62.50	45.83	54.77*
12	52.17	69.56	68.18	63.30
14	40.62	13.30	30.00	27.97**
16	61.29	48.38	51.61	53.76*
20	73.33	60.00	64.28	65.87
6-hour photophase (6L:18D)	65.38	62.74	70.58	66.23
	69.44	71.42	80.00	73.62
	72.41	72.41	63.33	70.72
	76.66	80.00	73.33	78.00
	66.66	70.37	69.23	68.75
	79.16	75.00	73.91	77.35

*Significant at .01 level

TABLE 7a. The effect of different wavelengths of broad band radiation on the induction of diapause in H. brassicae (Bouché) at 21°C

Treatment range (mμ)	Peak (mμ)	Per cent diapause	Mean per cent of diapause*	Index of effectiveness	Index of effectiveness for the experiments with an incandescent light source**
400-750	-	62.06 57.89 57.16	53.03 d	1.57	1.02
230-420	330	49.57 50.62 48.15	49.44 d	1.88	1.88
370-425	395	3.16 3.65 2.84	3.21 a	28.92	5.42
430-500	460	50.79 47.33 51.67	49.93 d	1.86	6.27
460-580	495	28.11 29.33 27.55	28.33 b	3.28	3.40
480-570	525	62.69 72.09 79.06	71.31 e	1.30	1.54

*
**See footnotes at end of table

(table continued on p.113)

TABLE 7a (continued)

Treatment range (mμ)	Peak (mμ)	Per cent diapause	Mean per cent of diapause*	Index of effectiveness	Index of effectiveness for the experiments with an incandescent light source**
555-610	570	83.33 82.85 78.57	81.58 f	1.14	1.71
590-630	600	67.61 71.91 73.07	70.86 e	1.31	1.39
620-750	675	85.57 90.00 86.66	87,41 fg	1.06	0.98
710-1125	800	66.66 72.72 63.01	67.46 e	1.38	1.76
730-4500	1750	41.81 38.46 44.64	41.63 c	2.23	2.88
12-hour photophase	-	92.54 90.76 95.21	92.83 g	1.00	
16-hour photophase	-	9.16 12.08 10.11	10.45 a	8.88	

*Values followed by the same letter(s) not significantly different at .01 level (Duncan's new multiple range test)
**The experiments carried out by Owusu-Manu (1969)

TABLE 7b. Analysis of variance on the percentage of diapause in *H. brassicae* at 21°C under different wavelengths of light

Source	d.f.	Sum of squares	Mean square	F_{calc}	F_{tab}
Total	38	28757.1509			
Treatment	12	28471.6600	2372.6383	216.0794**	2.96
Sampling error	26	285.4909	10.9804		

**Significant at .01 level

TABLE 8a. The effect of different wavelengths of monochromatic light on induction of diapause in H. brassicae (Bouché) at 21°C, 60 ± 5% R.H.

Treatment wavelength (mμ)	Per cent diapause	Mean per cent diapause	Index of effectiveness
1000	45.45 58.33 36.36	46.71 d	1.91
900	51.72 46.66 41.37	47.15 d	1.89
800	70.00 82.35 65.78	72.71 e	1.23
400	3.22 9.37 3.12	5.23 a	17.04
460	26.92 20.00 28.00	24.97 bc	3.57
500	25.00 35.00 35.00	31.67 c	2.81
12-hour photophase	97.67 87.50 83.33 94.28 88.09 83.78	89.11 f	1.00
16-hour photophase	14.70 16.66 12.00 20.00 13.79 14.28	15.23 ab	5.85

Values followed by the same letter(s) not significantly different at .01 level (Duncan's new multiple range test).

TABLE 8b. Analysis of variance on the percentage of diapause in *H. brassicae* at 21°C under different wavelengths of monochromatic light

Source	d.f.	Sum of squares	Mean square	F_{calc}	F_{tab}
Total	29	26513.0439			
Treatments	7	25733.5184	3676.2169	103.7512**	3.59
Experimental error	22	779.5255	35.4330		

**Significant at .01 level

TABLE 9. Effect of light intensity of the short-wave infrared radiation in induction of diapause in H.brassicae (Bouché) at 21°C, 60 ± 5% R.H.

Energy level mw/cm^2	Per cent diapause			
	Rep.I	Rep.II	Rep.III	Mean
0.2	75.00	72.22	69.44	72.22
0.6	66.66	80.00	60.00	68.88
1.2	75.00	59.18	61.21	65.13
2.4	36.00	38.00	41.81	38.60
4.8	50.00	55.00	58.09	53.69
9.6	40.00	44.00	37.50	40.50
19.2	48.00	40.00	40.00	42.67

TABLE 10. Penetration of light at different wavelengths into the soil (Percentage of the incident radiation)

Soil layer mm	UFW	F.W. 400-750 mμ	Violet 400 mμ	Blue 460 mμ	Bl-Gr. 500 mμ	Green 525 mμ	Yellow 570 mμ	Orange 600 mμ	Red 675 mμ	NIR 800 mμ	SIR 1750 mμ
1/2	20.0	8.0	3.8	4.5	5.2	4.5	4.9	3.3	6.5	7.5	7.54
1	6.5	1.9	0.76	1.0	0.7	0.55	0.65	0.57	1.0	1.2	1.40
3	0.38	0.5	0.05	0.1	0.08	0.06	0.32	0.07	0.12	0.25	0.63
4	0.2	0.07	0.03	0.043	0.07	0.04	0.05	0.052	0.062	0.15	0.18
6	0.13	0.05	0.02	0.02	0.04	0.03	0.002	0.03	0.037	0.059	0.065

TABLE 11. Penetration of radiation at different wavelengths through turnip (Percentage of the incident radiation)

Thickness of turnip mm	UFW	F.W. 400-750 mμ	UV 330 mμ	V 400 mμ	B 460 mμ	B-G 500 mμ	G 525 mμ	Y 570 mμ	O 600 mμ	R 675 mμ	NIR 800 mμ	SIR 1750 mμ
1/2	19.0	18.0	13.9	18.3	14.76	16.1	16.0	17.5	19.0	17.0	23.8	20.90
1	17.4	17.0	9.39	14.0	12.1	13.3	13.3	13.5	15.36	12.6	19.0	16.30
3	5.7	5.1	1.17	3.24	1.21	3.3	4.1	5.83	6.58	6.0	7.61	7.27
4	4.6	4.3	1.03	1.97	1.0	2.85	3.6	5.5	5.85	5.3	7.14	6.36
6	1.9	1.7	0.39	1.40	0.13	0.76	1.17	2.83	3.41	3.0	4.3	3.90

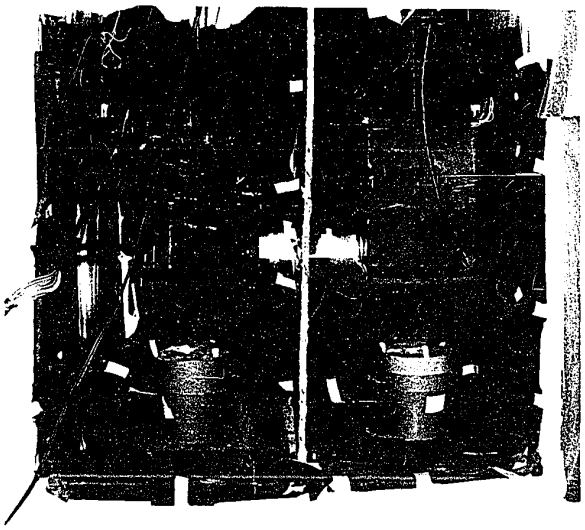


Plate 1

H. brassicae larvae subjected to two different treatments of broad band radiation

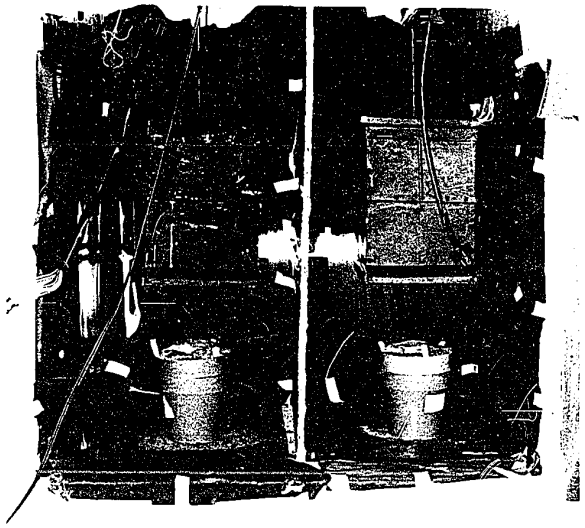


Plate 1

H. brassicae larvae subjected to two different treatments of broad band radiation

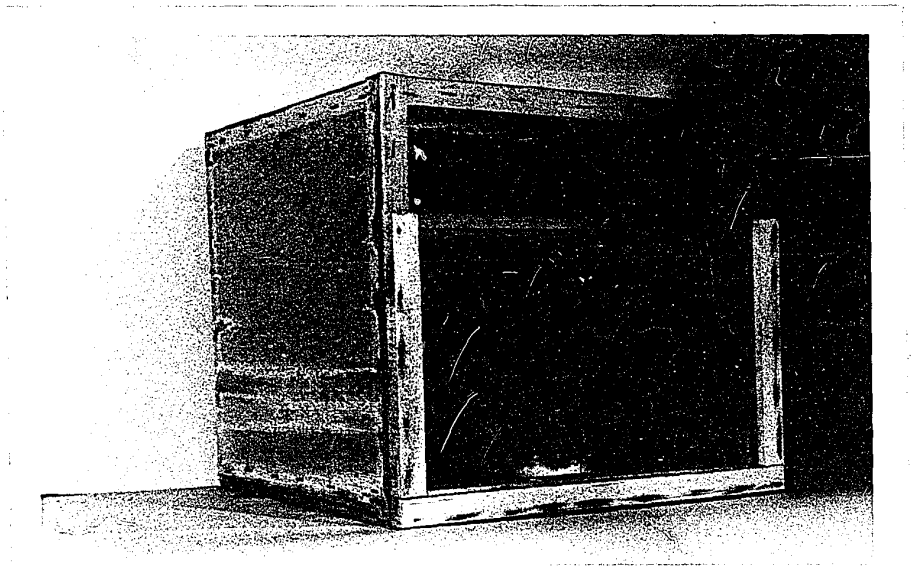


Plate 2

A cage with the adult flies

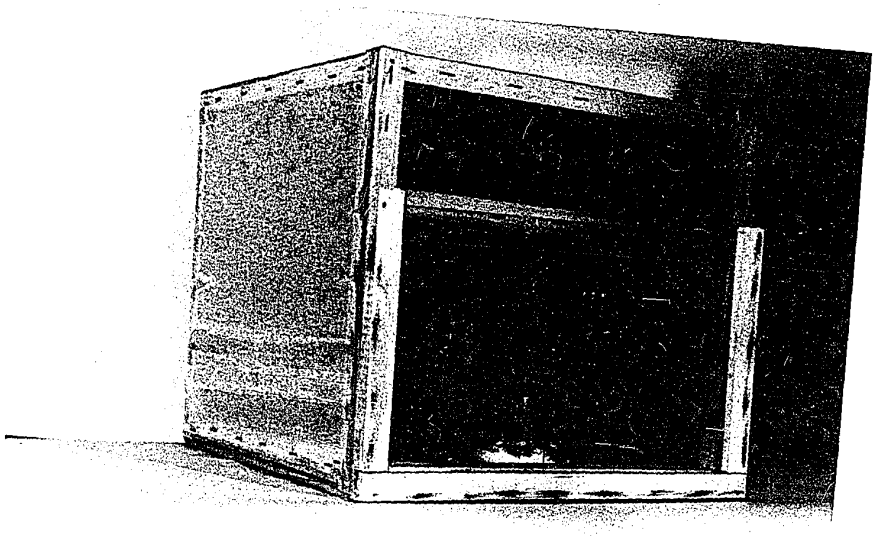


Plate 2

A cage with the adult flies

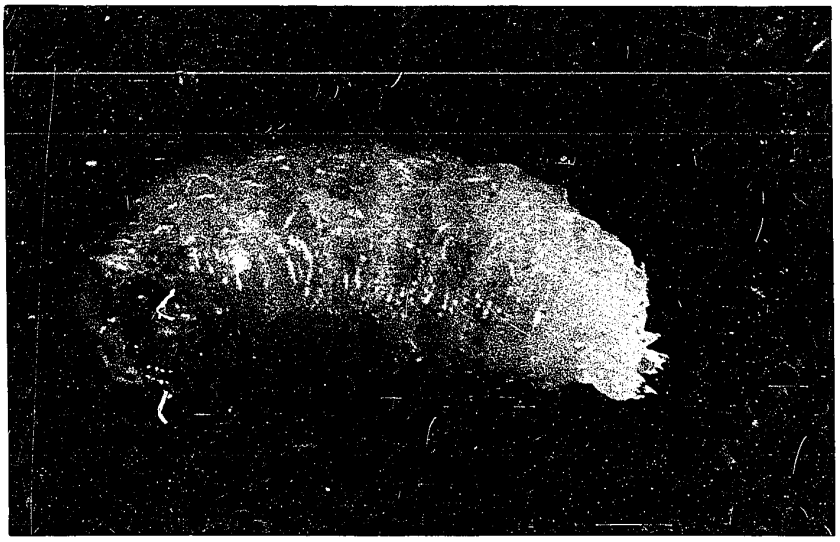


Plate 3

Sensitive stage to photoperiod - larva

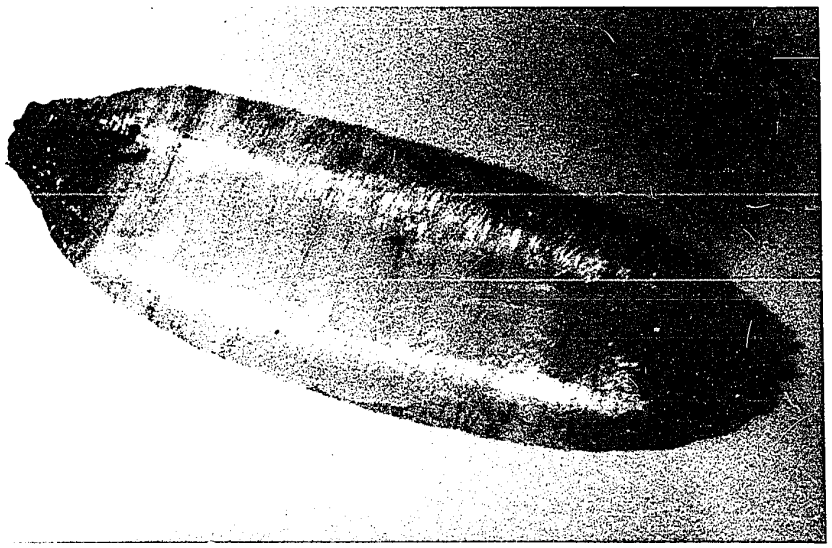


Plate 4

Responsive stage to photoperiod - pupa

Plate 3

Sensitive stage to photoperiod - larva

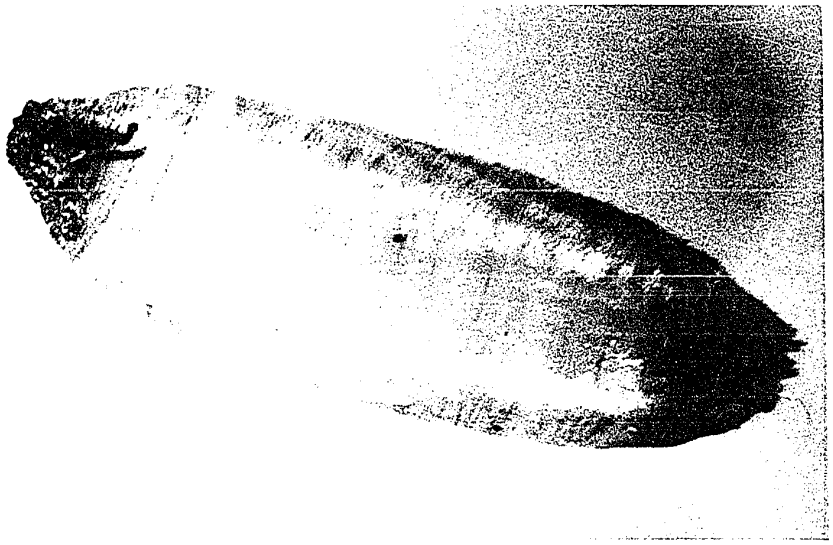


Plate 4

Responsive stage to photoperiod - pupa

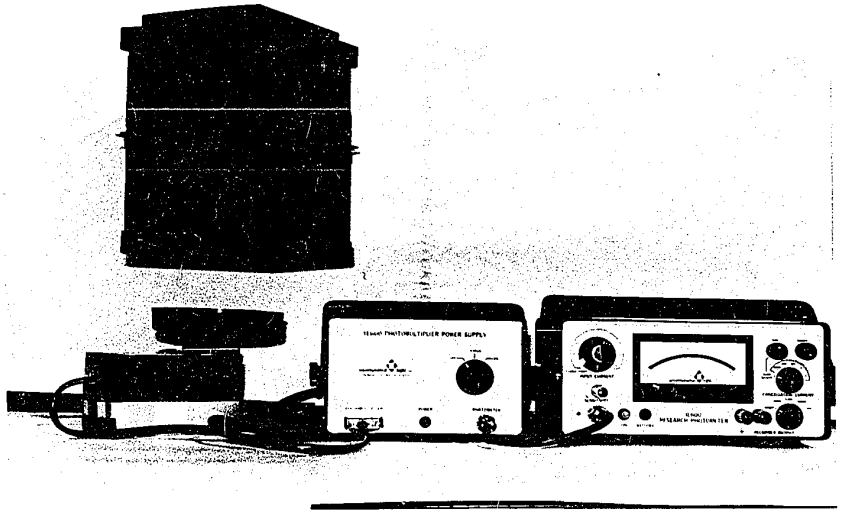


Plate 5
Experimental set-up for light penetration into the soil

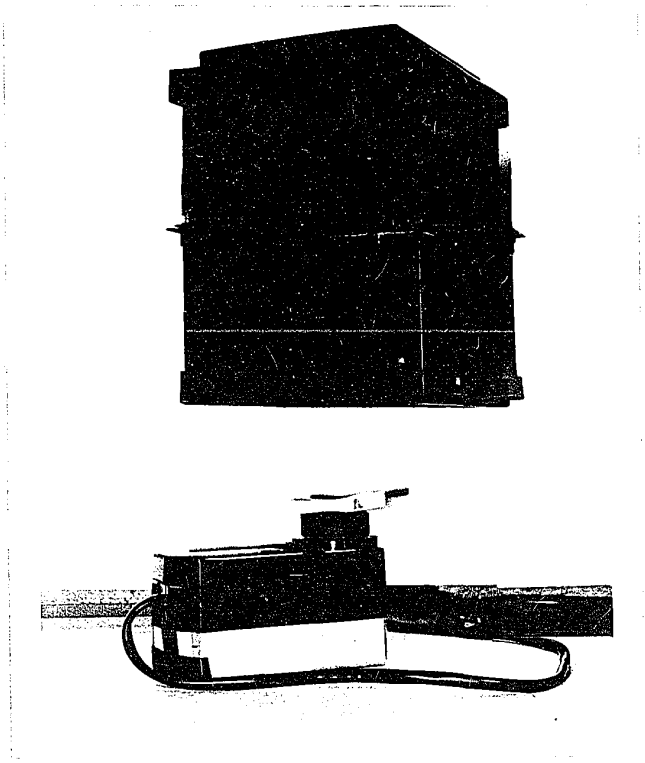


Plate 6
Experimental set-up for the light penetration through the turnip

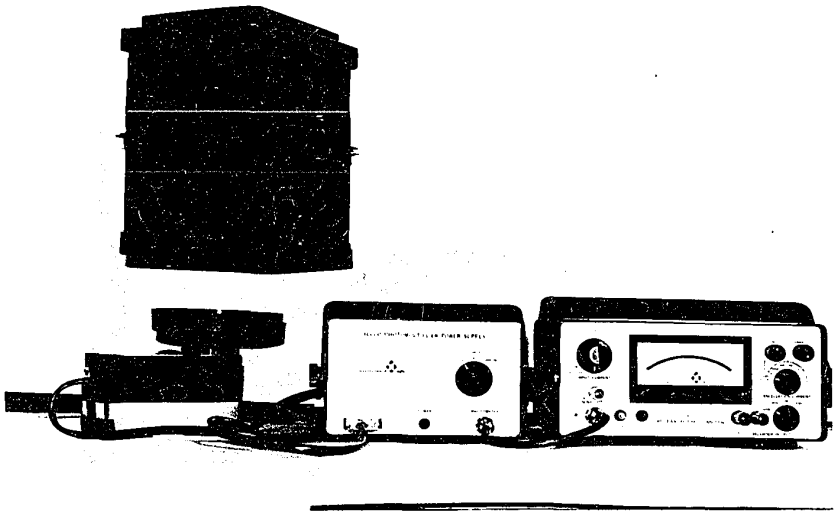


Plate 5
Experimental set-up for light penetration into the soil

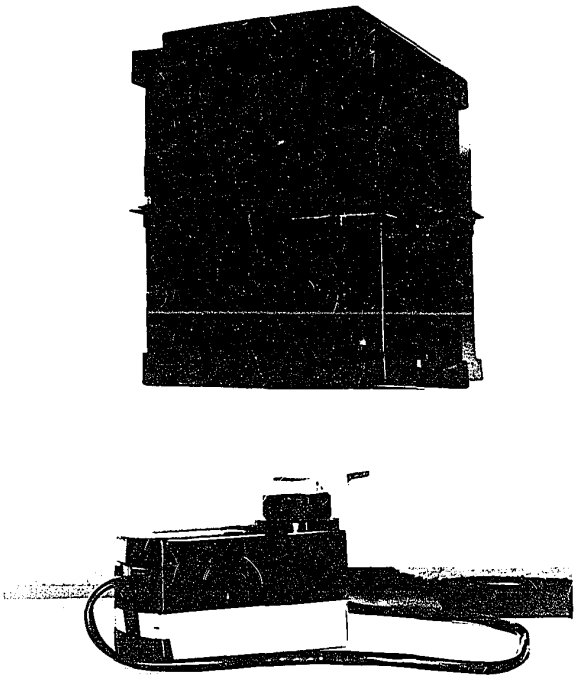


Plate 6
Experimental set-up for the light penetration through the turnip

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