

## Photo-biological Control of Weed Germination

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### Abstract

Photocontrol of weed germination via phytochromes is suited to reduce weediness of agricultural fields by means of the method of lightless tillage. Basing on 25 years of experience and research on this topic in Franconia the present state of possibilities and problems of this method is presented.

**Keywords:** Weed control; Lightless tillage; Phytochrome; Moonlight; Photosensitivity change

### Introduction

Brightness of light in the open is variable and its spectral distribution is modified over the day. Moreover self-shading within the canopy changes both brightness and spectral distribution of light. Spherical illuminances in the open switch between 140 klx at clear noon and 1 mlx at cloudy midnight, this is a factor of 100 millions or 8 orders of magnitude and over.

At noon the spectral photon flux is >90% between blue at 450 nm and deep-red at 765 nm. At 7 p.m. relative spectral photon flux drops to ≈30% at 450 nm, and it is >90% between 745 and 820 nm. This is the red shift at sunset [1,2].

Vegetation strongly modifies light spectrum, by selective filtering through plant pigments. Two leaves reduce to  $10^{-4}$  at 450 nm, to 2% at 550 nm; to  $5 \times 10^{-4}$  at 680 nm, but ≈30% remain from 750 to 800 nm. Thus plant canopy greatly modifies spectral irradiance in the open, due to selective filtering by assimilatory organs. It is visually perceived as green or vegetation shade. Plants own a visual system too, occurring in all cells, to adapt the whole organism to its light biotope. One intracellular eye system of plants is known as phytochromes [3,4].

### Photocontrol by phytochromes

Phytochromes have overlapping absorption spectra and are photochromic; this means they are photoconverted back and forth. Phytochromes role is to sense both light quality and quantity, to convert these magnitudes into two molecular signals: photostationary fraction and formation rate of the effector state  $P_{fr}$  [5]. Typical of phytochromes is the repeatable red/far-red reversibility, as detected for germination of *Lactuca sativa* (Lettuce), by Borthwick et al. [6]. Phytochromes are cytoplasmic chromoproteins, dimeric and with open-chained tetra pyrrole chromophores. Five phytochromes are known, phyA to phyE. They control numerous photomorphogenic responses in the plant kingdom, including germination [7].

Meaning of phytochromes for nature and farming can be demonstrated by alternatively irradiating imbibed achenes of *L. sativa* with white light or vegetation shade below 2 leaves. Exposure to 650 nm red yields ≈80%  $P_{fr}/P_{tot}$ , 740 nm far-red ≈3%  $P_{fr}/P_{tot}$ , whereas WL yields ≈50%  $P_{fr}/P_{tot}$ , and strong green shade ≈4%  $P_{fr}/P_{tot}$ . This perfectly explains why germination hardly occurs in strong canopy shade [4].

Most seeds of wild growing plants, including small seeded weeds, respond positively photoblastic. Photocontrol is phytochrome mediated and typified as very low fluence response (VLFR) or low fluence response (LFR). Therefore, daylight flashes during tillage might induce germination of weeds, whereas most crop plants have been selected to

germinate in darkness. This differing reaction to light was the reason to start trials with lightless tillage [8]. Photocontrol of weeds in an agricultural field was first tested in Franconia by bio-farmer Karl W. Seydel in the year 1981/82 [9], published in 1989, lightless tillage has been tested worldwide for 25 years. Numerous single trials failed but multiple night-time cultivation might be helpful to sufficiently reduce the weed-cover in agricultural fields [2].

Important factors of influence are annual pattern of temperature and rainfall, type of soil, method of farming, application of fertilizer and the dormancy and quiescence state of weed seeds. This means we deal with a complicated multifactorial interaction of variable external factors with a complex biological system. Main problem is the seasonal variation of dormancy, differing between weed species [10-12]. Therefore, great variability for lightless tillage in single field trials has to be expected [3,13-16].

### Pioneer field trial

First field trial was performed in Franconia on two parallel and neighbouring field strips, threefold cultivated in succession at noon or after 10 p.m.: Ploughed 26-09-1981; hoed 27-03-1982; harrowed 04/07-04-1982. On 10<sup>th</sup> June 1982 a weed cover of 80% was documented for the daylight treated strip, but only 2% for the nightlight treated. Weed inventory was typical of the association *Aphano-Matricarietum* and 30 recorded species showed differing response. But species with potential for adventitious rooting increased. In this pioneer field night-time tillage achieved sufficient weed reduction for 7 years without using herbicides [8]. Such surprising result encouraged to run further field trials in cooperation with other farmers.

### Further field trials

Cooperating with Agricultural High School Weihenstephan-Triesdorf seed-bed combination "Garomat," equipped with lightproof cover, was used to run field trials close to Triesdorf. A detailed block diagram of emerged weeds was elaborated on 10-07-1991, 33 d after strip trials [17]. Result was questionable, because of field history: Ploughed in day light late fall 1990 and harrowed two and one week

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before running strip trials to smooth the winter-raw surface, was a bad error! Four more successful field trials were performed in Franconia:

1. In an intensely cultivated field near Weiden weed emergence was recorded after false seed-bed preparation night/day on 17/18-04-1991. Weed density for the night treated strip stood around 50% until 3 months after treatment [17].

2. In an ecologically farmed field near Hüttenbach, sown with oat and other seeds on 13-04-1992, co-emergence of weeds was observed from sowing. Weed density of night-treated strips was 20 to 60% of day-treated ones until harvest on 07-08-1992, giving 15% heavier grains of oat [17].

3. In a carrot culture near Langenzenn co-emergence of weeds was studied for three variants of sowing on 23/24-06-1992: daylight, nightlight, and nightlight and rolled. From 15 to 38 d after sowing the number of weeds/0.1 m<sup>2</sup> was 80 to 90, ≈25 and ≈20, respectively. Moreover, mean leave lengths of carrots until 4 months after sowing were 30 and 25 cm for night and daylight sown cultures, respectively. And most important: Carrot yield night versus day sown was 252 versus 133 g/m [17].

4. An ecologically farmed field near Kalchreuth was sown with winter rye on 11/12-10-1991. Co-emergence of weeds was documented 5 to 7 months after sowing. Weed density increased from 60 to 120 weeds/0.1 m<sup>2</sup> for the daylight sown area and from merely 20 to 30 for the nightlight sown area. Weed emergence was stable until harvest on 27-07-1992 and dry weight of the rye grains harvested from the nightlight sown area was 8% heavier [17].

## Conclusions

1. Single night-time cultivation has the potential to reduce weediness of arable land to 70 to 20% of the daylight control, supported by numerous trials [13].

2. Threefold repeated night-time tillage reduced the weed cover down to <5% versus 80% for daylight tillage but repetition of such trials is still lacking.

3. Effect of lightless tillage requires that photostimulation by preceding cultivations is vanished: in warm humid conditions it fades within 3 weeks; during the cold of winter it may last up to 9 months; in dry soil it exists until the next rainfall, this may be years in the desert [18,19].

4. This indicates variable memory for photostimulation of the seed-bank, dependent on the climatic situation, and needs further investigation.

5. Soil cultivation in bright daylight produces faster weed emergence than lightless tillage. This may be used to get weed emergence timely in advance of lightless seedbed preparation, to reduce competition between crop plants and weeds [8,13,20].

6. Rolling disturbed soil after lightless tillage reduces light penetration and weed emergence [8,17].

7. Performing lightless tillage without knowledge of field history, pattern of rain fall, and offer of fertilizer, is a pointless working strategy [17].

## Co-emergence of crop and weed

Emerging crop plants and weeds channel light into soil and photostimulate co-emergence of photosensitive weed seeds [21,22].

Mainly far-red light is penetrating into soil via etiolated hypocotyls and roots, because of elevated internal brightness up to fivefold of outside [23].

## Variable memory of seed-bank

Our field trials have shown there is a memory within the seed-bank. In spring and summer differences between day- and night-time tillage disappear in 3 to 6 weeks. However, after a late autumn cultivation emergence differences continue for 9 months [17]. We ask: Is this memory effect under control of phytochromes?

Therefore, seeds of *Chenopodium album* (Fat-Hen) and *Stellaria media* (Common Chick-Weed) were sown in pots with mineralised wet peat on 08-12-2000, either in day-light or after sunset, according to Grundy et al. [24]. Latter seeds were irradiated with far-red light for one day before being covered and buried in the open. Weed emergence was weekly observed over 2½ years to clarify whether a reserve of far-red absorbing seed phytochrome B<sub>fr</sub> controls emergence of weeds over several months or even years. A recovery program was started on 06-05-2003. Far-red irradiated seeds produced significantly reduced emergence for almost 2½ years. This indicates that germination and emergence of weeds in the field is dependent on far-red absorbing seed phytochrome B<sub>fr</sub>, as formed during ripening of seeds [25]. Further investigation of this finding is recommended.

## Influence of nitrate

Numerous agricultural weeds poorly respond to modified light exposure during tillage. Many imbibed seeds show varying germination after short-term light exposure [26]. Therefore, germination control by light, nitrate, and temperature has been studied in the laboratory for the common weeds *Thlaspi arvense* (Field Penny Cress) and *Matricaria inodora* (Scentless Mayweed). Description of material, germination tests, light exposure and measurement, and phytochrome equilibrium determinations, are given in Hartmann et al. [19,27].

**Germination of THAR** has been studied, using seeds from differing locations. It was shown that dormancy is determined by soil, brightness and temperature during ripening. Relieve from thermodormancy is obtained by *thermo and photo periodic* treatment if imbibed in nitrate containing medium, also if nitrate is applied after light exposure [27].

**Germination of MATIN** was analyzed, using a batch of achenes collected from a crop field near Erlangen, giving following results [19].

1. Sown in 0.01 molar KNO<sub>3</sub> or NaNO<sub>3</sub> and exposed to 10 h photoperiod of white light for >7 days gives up to 75% germination.

2. In H<sub>2</sub>O, NaCl or KCl ≈40% germination results.

3. Germination in darkness was 1 to 2%.

4. Around 75% germination is also obtained in 0.01 molar KNO<sub>3</sub> at 20°C if 5 min red pulses are given for 7 days in an interval of 24 h or ≈12 h.

5. Five daily repeated red- or white-light pulses of 5 min saturate germination and completely substitute for white light photoperiod.

6. Germination is also stimulated by light if nitrate is applied after light exposure. This is typical of many nitrophilous agricultural weeds and an important point for lightless tillage.

7. Using 10 pulse exposures of 5 min with ≈12 h interval perfect red/far-red reversibility could be demonstrated, indicating that photocontrol of germination is phytochrome mediated.

8. This determines *MATIN* to be a shallow germinating weed, poorly responding to lightless tillage.

### Photocontrol by moon and night-light

An interesting question was: Is moon or nightlight bright enough to induce germination of photosensitized weed seeds during night-time tillage? [8,28]. Therefore, the photostimulation by natural moon- and night-light has been tested with differently sensitized achenes of *L. sativa*. Method: Sensitized achenes (= S) were sown in 0.01 molar KNO<sub>3</sub> and chilled at 4°C for 7 days. Partially sensitized achenes were sown in water and chilled for 7 days. Unsensitized achenes (=U) were sown in 0.01 molar KNO<sub>3</sub> or water stored at 22.5°C for 7 days. For these differently sensitized achenes fluence-response curves have been elaborated for a) clear full moon, b) full moon at 95% cloud cover, c) no moon with light reflecting rain clouds, and d) starlit heaven without moon.

**Results:** For sensitized achenes and the exposure conditions a), b), c), and d) the exposure periods for 50% germination were 1, 3, 30 and 40 s, respectively. To get saturating germination the corresponding periods were 5, 30, 200 and 500 s, respectively. For partially sensitized achenes in a clear full moon exposure period for 50% germination increased to 120 s, and 2 h exposure did not saturate. For unsensitized achenes in nitrate or water 2 h exposure in full moon merely produced ≈ 20% germination or below 2%, respectively [29,30].

**Conclusion:** Seconds of full moonlight, or even minutes below the starlit heaven, are bright enough to photostimulate emergence of photosensitized seeds. Thus, repeated night-time cultivations may well cause increasing emergence of weeds in a phase of high photosensitivity [19,20].

### Variation of photosensitivity

The question is what range is covered by maximal and minimal photosensitivity of germination, and is there a reversible sensitivity shift? For clarification differently sensitized achenes of *L. sativa* have been used to elaborate fluence-response curves for red or white light. Method: Sensitized achenes (=S) as before. Desensitized achenes (=D) stored in darkness at 35°C for 14 days, followed by light exposure and darkness for 3 days. Resensitized achenes (= R) were desensitized and afterwards chilled at 3.5°C for 6 to 7 days, followed by light exposure and darkness for 3 days. Unsensitized achenes (=U) were as before. With these achenes fluence-response curves were elaborated as follows: U for red in water or nitrate; S for red in nitrate; D for red in nitrate and water; D for white light in water; R for red in nitrate [31].

**Results:** Half-response fluences and relative photosensitivities were taken from these curves and given in Table 1. It is evident that photosensitivity of achenes of *L. sativa* may fluctuate by chilling and warming over nine orders of magnitude within one week. For highest sensitivity half-response fluence corresponds to ≈1 μs of full sun or ≈1 s of full moon. For lowest sensitivity half-response fluence corresponds to >2 h of full sun.

Pretreatment	Half-Response Fluences	Relative Sensitivity
Untreated	red 240 μmol m <sup>-2</sup>	1
Sensitized in nitrate	red 3 nmol m <sup>-2</sup>	80 × 10 <sup>3</sup>
Desensitized in nitrate	red 1 mmol m <sup>-2</sup>	0.24
Desensitized in water	white 15 mol m <sup>-2</sup> (red 15 mol m <sup>-2</sup> )	20 × 10 <sup>-6</sup>
Resensitized in nitrate	red 13 nmol m <sup>-2</sup>	18 × 10 <sup>3</sup>

**Table 1:** Relative photosensitivity of differently sensitized achenes of Lettuce, as derived from fluence-response curves for red and white light [31].

**Conclusions:** It is long standing knowledge that emergence of weeds shows seasonal periodicity between high photosensitivity and dormancy [10-12]. Stratification may reversibly change photosensitivity of germination over 9 orders of magnitude within 1 week, dependent on temperature patterns and nitrate offer during imbibition [12,31,32].

**Need for daily repeated exposure:** The situation for thermodynamically dormant seeds to germinate in the field is imbibition below some mm soil, where daily repeated exposure to weak light occurs. Such response is typical of many small-seeded agricultural weeds and secures germination close to the soil surface [19]. To test whether this is also true for desensitized thermodynamically dormant achenes of *L. sativa* these have been imbibed in water and were exposed to a red photon fluence of 6.5 ± 0.3 mmol × m<sup>-2</sup> at 657 nm, being equivalent to 40-fold half maximal photoconversion of phytochrome B, this is saturating photoconversion. Such single exposure in 25 min induced 17.6 ± 1.9% (± SE) germination, whereas the same exposure split into five daily repeated pulses of 5 min gave 97.7 ± 0.7% germination. Dark control was 0.0+0.5% germination [31]. This result proves the strategy of surface close germination, associated with need for repeated daily light exposure, as typical of many small-seeded agricultural weeds and needs further research.

### Action spectrum for germination

Remaining problem is identity of the involved steering pigment for maximal photosensitivity of germination, because no far- or deep-red reversibility could be obtained. Therefore, an action spectrum for *L. sativa* has been elaborated, to compare with action spectra of *Arabidopsis thaliana* (Thale Cress) by Shinomura et al. [34]. They have shown that the photoirreversible VLFR of germination is triggered by photolabile phytochrome A, whereas the far-red reversible LFR is under control of the more stable phytochrome B.

**Method:** For maximally sensitized achense of *L. sativa* 20 fluence-response curves for the spectral range 300 to 800 nm were elaborated, using 6 s to 10 min exposure. Spectral transmittance of the seed-coat was measured for correction [33].

### Results

1. For germination of sensitized *L. sativa* all fluence-response curves, from ultra-violet at 300 to near infra-red at 800 nm, run nearly parallel to saturation. Fluence-response curves for *A. thaliana* at 780 nm and 800 nm run flatter and do not saturate.
2. Therefore, no far-red reversibility can be found for germination control via the VLFR of phyA.
3. Deep-red at 800 nm is a factor 200,000 or 2 × 10<sup>5</sup> less efficient than red at 666 nm.
4. So-called green safe-light at 520 nm is merely a factor 1000 less efficient than red and fully unsuited as a safe light to use in studies with the VLFR of phyA [4].

**Action spectra:** Two action spectra for 50% germination were derived from these fluence-response curves of sensitized Lettuce seed: an apparent and a corrected conversion spectrum to compare with the conversion spectrum of phytochrome A *in vitro* for the transition P<sub>r</sub> → P<sub>fr</sub> [33,35]. The corrected action spectrum is a phytochrome conversion spectrum for the photoconversion phyA<sub>r</sub> → phyA<sub>fr</sub> with decreasing efficiency below 450 nm. This corrected action spectrum does not fully coincide with the one for the VLFR of germination of *A. thaliana* [34]. Comparing the corrected action spectrum with spectra of extracted phyA shows that for 50% germination merely ≈1 of 200,000 phyA molecules has to be photoconverted to phyA<sub>fr</sub>. This means less than 40

molecules of phyA<sub>fr</sub> must be formed per cubic root meristem cell of 50 µm size for half saturated VLFR [4,33,35].

### Conclusions

1. Soil cultivation at night might be hampered as soon as photosensitized imbibed weed seeds occur in the seed-bank and are exposed at the soil surface between timely split tillage operations [20].

2. Additional far-red or deep-red exposure during tillage operations will not reduce emergence of sensitized weed seeds, because all wavelengths from 300 to 800 nm saturate the VLFR of germination [33,35].

3. It is more promising to use light-shielded tillage equipment, because photosensitivity of the seed-bank may reversibly shift over 9 orders of magnitude within 1 week [31].

**Summary and outlook:** Data on germination and emergence in the field must be considered as a function of meteorological data, to gain reliable model based predictions on photosensitivity of the soil seed-bank [36-39]. During phases of dormancy lightless tillage should be inefficient, but during phases of high photosensitivity it should be useful. Further refining of the method requires more reliable weed emergence models to gain short-term predictions on the sensitivity state of weed seeds in the soil seed-bank. Another important point: as soon as lightless tillage is used repeatedly selection of dark germinating and rooting weeds occurs [8,40].

**Strategy of cultivation for central Europe:** 1. First grubbing or harrowing in bright daylight, to photostimulate emergence of weeds. 2. Three to six weeks later, when weeds have emerged and are sufficiently developed: light-less harrowing with sowing (or planting) and rolling, to destroy emerged weeds and to minimize photostimulated germination of more weeds. 3. Application of fertilizer has to be postponed after the period of crop and weed emergence.

**What can we expect?:** 1. Seed-bank of arable weeds will be lowered. 2. Selection of dark germinating and rooting weeds is minimized. 3. Weed emergence during development of crop plants is reduced. 4. Herbicide dose and/or weeding may be lowered [8,9,13,40].

**Photocontrol of early growth:** Seedlings, emerging in a field, may suffer from extreme situations: Full sun up to 140 klx illuminance or canopy shade with high levels of far- and deep-red and merely small levels of red and green light. Young seedlings are well adapted to canopy shade exposure, showing spectral responses known as “high irradiance responses” [3,14] or “high irradiance phenomena” [4]. Action spectra for HIR have been elaborated for numerous photoreponses, and show great variability of spectral pattern. One of the most accurate action spectra is reported for inhibition of hypocotyl lengthening of dark-grown seedlings of *L. sativa*. Peaking action occurs in UV-A (370 nm), blue (450 nm), and far-red (720 nm), but nearly no effect from green to red (500 upto 700 nm; [41,42]. Action spectra of the HIR have been interpreted by means of phytochrome network models [41-46]. Light perception and signalling is by phytochrome A. Photoconversion and nuclear trafficking cycles determine response to far-red light, with newly formed phy A<sub>r</sub> or phy A<sub>fr</sub> as effector molecule [47-50]. Numerous interacting photoreceptors, molecules, and compartments, remain a challenge for successful interpretation of the variable HIR [51]. We may state: Phytochromes *in vivo*, behave like ladies, you can look for, but you can't understand.

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